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Terrestrial Expert Monitoring Group, Circumpolar Biodiversity Monitoring Program

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Executive summary

Polar environments experience some of the harshest conditions for life including extreme cold, strong winds, drought, extended darkness, high UV radiation, and short growing seasons. Arctic ecosystems harbor highly specialized lineages including endemic taxa that have adapted to these harsh conditions, and migratory species that exploit rich Arctic resources during their breeding period. Despite the remoteness of Arctic regions, ecosystems are under increasing pressure from threats within and outside northern latitudes, including contaminants, over-exploitation of endemic and migratory species, anthropogenic disturbance, resource extraction and landscape alteration, habitat loss and fragmentation, climate change, and shifting distributions of prey and pathogens. Understanding these complex dynamics is complicated even further by a lack of long-term monitoring data from across the Arctic to determine trends and develop adequate responses to the challenges facing biodiversity.

The Conservation of Arctic Flora and Fauna (CAFF), the biodiversity working group of the Arctic Council, established the Circumpolar Biodiversity Monitoring Program (CBMP) to address the need for coordinated and standardized monitoring of Arctic environments. The CBMP includes an international network of scientists, conservation organizations, government agencies, Permanent Participants Arctic community experts and leaders. Using an ecosystem-based monitoring approach which includes species, ecological functions, ecosystems, their interactions, and potential drivers, the CBMP focuses on developing and implementing long-term plans for monitoring the integrity of Arctic biomes: terrestrial, marine, freshwater, and coastal (under development) environments.

The CBMP Terrestrial Expert Monitoring Group (CBMP-TEMG) has developed the Arctic Terrestrial Biodiversity Monitoring Plan (CBMP-Terrestrial Plan/the Plan) as the framework for coordinated, long-term Arctic terrestrial biodiversity monitoring. ***The goal*** of the CBMP-Terrestrial Plan is to improve the collective ability of Arctic traditional knowledge (TK) holders, northern communities, and scientists to detect, understand and report on long-term change in Arctic terrestrial ecosystems and biodiversity. The CBMP-Terrestrial Plan aims to address these priority management questions:

1. What are the status, distribution, and conditions of terrestrial focal species, populations, communities, and landscapes/ecosystems and key processes/functions occurring in the Arctic?
2. How and where are these terrestrial focal species, populations, communities, and landscapes/ecosystems and key processes/functions changing?
3. What and how are the primary environmental and anthropogenic drivers influencing changes in biodiversity and ecosystem function?
4. Where are the areas of high ecological importance including, for example, resilient and vulnerable areas (related to the FECs) and where are drivers having the greatest impact?

The Plan includes terrestrial species and habitats in the Arctic, sub-Arctic, and high latitude alpine regions adjacent to and continuous to these environments. Four main terrestrial biotic groups were selected for systematic monitoring: (1) vegetation (including fungi); (2) invertebrates (including some arthropods with life stages in aquatic environments); (3) birds (resident and migratory); and (4) mammals (resident and migratory).

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The framework of the CBMP-Terrestrial Plan was developed collaboratively by international participants with taxonomic, scientific, traditional knowledge and community-based expertise and related stakeholders and was focused around three consensus-based workshops. Best practices in monitoring design were used to develop a strategy that is efficient, practical and allows for participation along a range of capacity and across varying ecological conditions. The Plan is structured around a set of focal ecosystem components (FECs) which are the targets of the monitoring effort, and their related attributes (characteristics). FECs and attributes were identified by (a) determining critical information needs related to biodiversity and ecosystem function, (b) creating conceptual models to understand key ecological relationships, processes and drivers and (c) evaluating current and potential capacity to conduct long-term monitoring and the relative feasibility of various approaches. A common set of core attributes emerged among the biotic groups. These were diversity, composition, phenology, demographics, spatial structure, temporal cycles, health, productivity, and ecosystem functions and processes.

Participants used the following four criteria to prioritize the FEC attributes as either essential (highest priority) or recommended: (1) ecological importance as identified through the development of conceptual ecological models; (2) Relevance to ecosystem services; (3) importance to Arctic indigenous and non-indigenous peoples and communities; and (4) importance for management and legislation needs. For each attribute, sampling parameters (measurements in the field), methods, monitoring frequency and spatial scales were identified. Methods were categorized as either basic (requiring knowledge, training or equipment that is easy to acquire) or advanced (requiring a higher level of experience, expertise or more sophisticated equipment) to allow for participation across a range of capacity of potential contributors.

The CBMP-Terrestrial Plan describes a nested, multi-scale framework to determine baseline conditions and evaluate changes with respect to the long-term integrity of Arctic ecosystems and biodiversity. Methods and strategies for monitoring range from site-based focal studies to pan-Arctic remote sensing and global modeling approaches, and incorporate data-gathering through scientific analyses, Traditional Knowledge (TK) and community-based monitoring (CBM)(see Chapters 3 and 4). The CBMP-Terrestrial Plan recommends building on robust standardized techniques that are feasible and already in use across circumpolar regions where possible, and suggests additional techniques (e.g., genetic analyses, stable isotope signature analyses, satellite-based or other technology-based tracking and telemetry systems, and remote sensing) where infrastructure and capacity exists.

The CBMP-Terrestrial Plan intends to benefit from, build on, and expand the efforts of existing networks and monitoring effort through enhanced coordination and collaboration. The Plan highlights the important role of partnering with the International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT; **http://www.eu-interact.org/**) and other Arctic monitoring stations as strong potential contributors to a coordinated, long-term approach to biodiversity monitoring. The Plan also identifies the importance of partnership with abiotic monitoring networks, biodiversity monitoring networks outside the Arctic, and other Arctic Council working groups to inform biodiversity assessments. The comprehensive 2013 Arctic Biodiversity Assessment (CAFF ABA 2013) will serve as the foundation on the status of Arctic species and ecosystems.

To facilitate the integrated monitoring efforts under the CBMP-Terrestrial Plan, CAFF will establish an international CBMP Terrestrial Steering Group (CBMP-TSG) to implement, coordinate and track progress of work stemming in response to the CBMP-Terrestrial Plan and guide activities of the national Terrestrial Expert Networks (TENs). The TENs will be responsible for implementing monitoring within their own nation as outlined in the Plan. The general implementation approach for the CBMP-Terrestrial Plan has been outlined (Chapter 8), but each country will determine management details and facilitate ongoing support, which may evolve as monitoring needs arise and capacity expands in the future. Important steps for implementation include the creation and activation of the governing structure and TENs, the establishment of data nodes, the refinement of monitoring design and selected attributes, the collection and analysis of existing monitoring data, and the establishment of coordinated monitoring, reporting, and program evaluation. Data nodes will facilitate knowledge exchange and data dissemination related to the FEC attributes using established standards for metadata and data discovery, exchange and archiving.

The CBMP TSG will report on Plan implementation. Reporting will be tailored to target audiences including decision-makers from local to international scales, Arctic communities, scientists, and managers, and their needs as per specialized formats and reporting schedules (see Chapter 7). Reporting will include scientific articles, general communications, and status and performance reports. Reporting will accumulate in the release of the *State of the Arctic* report, with the first release in 2017, the subsequent report in 2020 and continuing thereafter every five years.

Although knowledge gaps remain with respect to Arctic biodiversity and the complex linkages between species and regions within and beyond Arctic borders, establishing baseline conditions and developing coordinated monitoring is a crucial and positive step toward improved policy, mitigation and applied responses to ecosystem change. Harmonised monitoring will facilitate detection of drivers, emerging threats, and provide insight into what scale changes are occurring and the effectiveness of management responses. For biological communities, species of special concern and critical regions, such as breeding grounds and migratory stop-over sites, implementing pan-Arctic monitoring may provide invaluable insight into movement patterns, shifting distributions and information on poorly-known biodiversity and on the success of conservation strategies. Implementation of coordinated monitoring strategies can inform decision-making to promote more sustainable uses of Arctic resources and biodiversity and mitigate harmful practices in the face of climate change and increasing pressures.

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1. Introduction and background

The size and nature of Arctic ecosystems make them critically important to the biological, chemical, and physical balance of the globe. Furthermore, healthy Arctic ecosystems are of fundamental economic, cultural, and spiritual importance to Northern residents. Dramatic changes in regional climates are impacting Arctic biodiversity, affecting the resilience of some species while benefitting others, influencing the potential for human use, and in some cases, affecting the overall integrity of northern ecosystems (CAFF ABA 2013). Increasing development, transportation, and other activities may further impact Arctic biodiversity, ecosystem functions and northern communities in ways that are not yet understood. Moreover, continued rapid change in the Arctic will likely have repercussions for the ecosystems and biodiversity of the entire planet through alterations in albedo (reduced snow cover and increased heating), carbon cycling, shifting ocean currents and effects on local climates, and changes in breeding habitat for migratory species; from fish and marine mammals to terrestrial birds harvested in the North and elsewhere.

Currently, monitoring of Arctic biodiversity lacks the coordination needed to provide a comprehensive, pan-Arctic understanding of the status and trends related to key species, habitats and ecological processes and services. Enhanced coordination would improve our ability to detect important trends, link these trends to their underlying causes, assess the effects of increasing northern development, and provide critical information to support responsible decision making. Coordination of existing monitoring will not be sufficient to address all needs for information, and new monitoring will be required. Information on how the Arctic is responding to pressures such as climate change and human activity is urgently needed to allow decision makers, whether in local Arctic communities, regional or national governments, or international venues, to make timely and effective decisions regarding resource management, conservation actions and adaptive management.

In response to these critical needs, the Conservation of Arctic Flora and Fauna (CAFF)[1] working group of the Arctic Council created the Circumpolar Biodiversity Monitoring Program (CBMP). The CBMP is working with scientists, traditional knowledge (TK) holders, and local resource users from around the Arctic to harmonize and enhance long-term Arctic biodiversity monitoring efforts (Fig. 1.1). The Terrestrial Expert Monitoring Group (TEMG) is one of four CBMP Expert Monitoring Groups (EMGs) developing integrated, ecosystem-based monitoring plans for the Arctic's major biomes. Each of the groups (marine, coastal, freshwater, and terrestrial; **http://www.caff.is/about-the-cbmp**) functions as a focal point for scientists, community experts, and managers to coordinate research and monitoring activities. The primary approach during the initiation phase of the integrated, pan-Arctic biodiversity monitoring plans is to use existing data and knowledge to facilitate improved, cost-effective monitoring that can detect and provide insight into emerging trends in Arctic biodiversity. These efforts will be coordinated through the implementation of integrated, pan-Arctic biodiversity monitoring plans.

The development of the Arctic Terrestrial Biodiversity Monitoring Plan (CBMP-Terrestrial Plan) comes at a critical time. The parties of the Convention on Biological Diversity, having recognized that their 2010 goal to reduce the rate of loss of global biodiversity had failed, established new 2020 targets (Aichi Biodiversity Targets: **http://www.cbd.int/sp/targets/**) to reduce the rate of biodiversity loss by focusing efforts on the underlying causes. In most cases, the rate of loss has not been adequately measured yet (Pereira, et al. 2012). The report *Global Biodiversity Outlook 3* (SCBD 2010) highlighted the need for increased mobilization of resources for the research and monitoring of biodiversity to address this knowledge gap. At the same time, the Intergovernmental Panel on Climate Change (IPCC) has concluded that climate change related to increased greenhouse gas concentrations will result in major physical, ecological, social, and economic impacts (Pachauri and Reisinger 2007). There is broad acknowledgement that the polar regions are experiencing rapid and dramatic changes as a result of a changing climate (see Anisimov and Fitzharris 2001).

A number of Arctic Council assessments and reports have called for improved biodiversity information to support effective management of the Arctic environment. The *Arctic Climate Impact Assessment* (ACIA 2005, 2004) recommended that long-term Arctic biodiversity monitoring be expanded and enhanced in the face of a rapidly changing Arctic. A key finding of *Arctic Biodiversity Trends 2010: Selected Indicators of Change* (CAFF 2010) was that "long-term observations based on the best available traditional and scientific knowledge are required to identify changes in biodiversity, assess the implications of observed changes, and develop adaptation strategies." Similarly, the *Oil and Gas Assessment* (Skjoldal, et al. 2010) called for "…improved mapping of vulnerable species, populations and habitats in the Arctic…". The most recent *Arctic Biodiversity Assessment: Report for Policy Makers* determined "current knowledge of many Arctic species, ecosystems and their stressors is fragmentary, making detection and assessment of trends and their implications difficult for many aspects of Arctic biodiversity" (CAFF, ABA Policy 2013)

All of these recommendations highlight the pressing need to improve Arctic biodiversity monitoring to support effective management of the Arctic environment. In addition, Arctic states have commitments through various regulatory regimes and associated legislation to protect their Arctic ecosystems and the biodiversity they support. Sub-national governments, including Indigenous governments in some countries, also have mandates to ensure the maintenance of healthy Arctic ecosystems and wildlife. The CBMP-Terrestrial Plan will directly support national and sub-national needs as well as international reporting mandates while respecting monitoring investments already in place.

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[1] Acronyms and key terms used throughout the Terrestrial Plan are defined in Chapter 9 (Glossary).

1.1 Benefits of contributing to a circumpolar, coordinated effort

The CBMP-Terrestrial Plan will facilitate more powerful and cost-effective assessments of Arctic terrestrial ecosystems through the generation of and access to harmonized [i.e., integrated to the extent possible across themes and scales (see Chapter 3.5.1)], pan-Arctic data sets. This will allow for more informed, timely and effective conservation and management of the Arctic terrestrial environment. While most Arctic biodiversity monitoring networks are—and will remain—national or sub-national in scope, there is immeasurable value in establishing circumpolar connections among monitoring networks. The development of the CBMP-Terrestrial Plan is designed to facilitate these connections and harmonization amongst national and sub-national research and monitoring networks, including scientific, TK, and community-based knowledge networks, increasing their power to detect and attribute change. In addition, the increased power will come at a reduced cost, compared to the cost of multiple uncoordinated approaches allowing for these savings to be invested in filling critical gaps in our monitoring coverage. Metadata generated from the integrated monitoring approaches will provide insight on the status of Arctic biodiversity from a scientific perspective, and including awareness on the changing state of Arctic communities.

1.2 Goals and objectives

The overall goal of the CBMP Arctic Terrestrial Biodiversity Monitoring Plan (CBMP-Terrestrial Plan) is to improve the collective ability of Arctic TK holders, northern communities, and scientists to detect, understand and report on long-term change in Arctic terrestrial ecosystems and biodiversity. Through coordination and harmonization of Arctic terrestrial biodiversity monitoring we aim to generate better quality long-term data to inform decision-making. This contribution toward understanding ecosystem changes and underlying processes will facilitate adaptive management. To meet these goals, the CBMP-Terrestrial Plan establishes a framework to address the following key objectives:

- Identify key agency, industrial, community and TK management needs for terrestrial biodiversity information and key ecological relationships.
- Identify a common suite of biological focal ecosystem components (FECs), attributes, parameters and comparable methods to coordinate the monitoring of change across Arctic terrestrial ecosystems.
- Identify key abiotic **drivers**[2], relevant to terrestrial biodiversity, which should be monitored and integrated with biological parameters.
- Identify existing monitoring capacity and data that can be aggregated to establish baselines and form the backbone of a monitoring scheme.
- Identify new partners in government, industry, communities and academia that could contribute to an evolving terrestrial monitoring effort.
- Identify a sampling strategy to meet identified monitoring objectives, making efficient use of existing monitoring capacity and planning for the future.
- Identify priority gaps (taxa, spatial, and/or temporal) in coverage and opportunities to address gaps where feasible
- Identify key monitoring methodologies and ways to incorporate TK expertise and to build and extend collaborative initiatives and partnerships to identify priorities, needs, and knowledge gaps
- Facilitate communication and coordination among Arctic terrestrial biodiversity researchers and monitoring groups.

In addition, the CBMP-Terrestrial Plan has been designed to answer a number of key management questions that were identified for various biotic groups (see chapters 3 and 4).

1.3 Audience

The CBMP-Terrestrial Plan is aimed at responding to questions and information needs at the circumpolar scale, but includes a scaled approach applicable at regional or finer scales of resolution. As such, the plan is designed to provide relevant information to service decision-making at multiple scales.

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[2] **Drivers** are referred to as agents of change, those elements that are controlling or influencing the state of a system with no connotation as to positive or negative effects. **Stressors** are referred to as agents of change that cause negative effects specifically. For example, climate can be considered a driver controlling growing seasons, while climate change could be considered a stressor by forcing an ecosystem from one state to another, for example, from tundra to forest.

1.4 Integrated, ecosystem-based approach to Arctic biodiversity monitoring

The CBMP is adopting an integrated ecosystem-based approach to monitoring in its program design, organization, and operation (Fig. 1.1). The ecosystem-based approach integrates information across ecosystems, species, and their interactions, and lends itself to monitoring many aspects of an ecosystem within a geographic region. This approach considers the integrity of entire ecosystems and their interaction with other ecosystems. Although the complexity and data/analysis requirements far exceed those of the species approach, the rewards of the ecosystem-based approach are significant. It identifies important relationships, bridging ecosystems, habitats, and species and the impacts of stressors and drivers on ecological function. The resulting information contributes directly to adaptive management, enabling effective conservation, mitigation, and adaptive actions appropriate to the Arctic. Lastly, by connecting biodiversity to its supporting abiotic drivers, it will be possible to model future changes in biota as a result of anticipated changes in key drivers, thus providing decision makers with critical information to support proactive management approaches for the Arctic.

1.5 Definitions of biodiversity, Focal Ecosystem Components (FECs), attributes and parameters

The Convention on Biological Diversity defines biological diversity, often shortened to biodiversity, as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems"(SCBD 1992). Biodiversity, therefore, must be viewed at the level of the gene, the species, and the ecosystem, ranging in scope from local to regional and global systems.

In the context of Arctic biodiversity, CAFF's CBMP recognizes the integral nature of global and human processes in the Arctic ecosystem. Arctic biodiversity depends, to a large extent, on conditions outside the Arctic, due to a high proportion of migratory species and the interconnections of Earth's systems (e.g., global ocean circulation, contaminant pathways). In addition, humans and their cultural diversity are components of Arctic ecosystems, as well as beneficiaries of essential goods provided by Arctic biodiversity. Monitoring all elements of ecosystems—including species, habitats, ecosystem structure, processes, functions, and drivers to the ecosystems—is necessary to gain meaningful insight into the state of biodiversity in the Arctic and to predict what may happen in the future.

The monitoring program outlined here is based on a three-level hierarchical approach: Focal Ecosystem Components (FECs), attributes, and parameters, as exemplified in Table 1.1 below. This approach is much in line with what is used in other comparable programs, including Essential Biodiversity Variables, developed by GEO BON (Group on Earth Observations – see chapter 1.9) (Pereira, et al. 2013). FECs are critical to the functioning and resiliency of Arctic ecosystems and/or reflect the vital importance to the subsistence and economies of northern communities. The TEMG identified FECs on the basis of (a) consensus expert opinion which was developed through a conceptual ecological modeling process intended to clarify and communicate the ecological theory and critical system components and interactions supporting their selection, and (b) information needs of communities and managers/decision-makers. FEC selection followed the guidelines developed by the CBMP under its *Five-Year Implementation Plan* and *Strategy for Developing Indices and Indicators*. As much as possible, attributes describing the FECs are intended to be scalable.

FEC attributes describe various aspects or characteristics of each component. Lastly, each attribute has a number of potential parameters that are the actual metrics measured in the field. Working in concert, the hierarchical components (FECs, attributes, and parameters) build on one another; that is, individual parameters inform the status of the attributes, and in turn, the attributes collectively inform the status of the FECs (see Table 1.1).

To facilitate effective and consistent reporting, the CBMP has chosen a suite of FECs and related attributes that provide a comprehensive picture of the state of Arctic biodiversity—from species, to habitats, to ecosystem processes, to ecological services. A full description of the FEC, attribute and parameter selection process is provided in Chapter 3.

Table 1.1. Structure of the monitoring program, here exemplified with caribou/reindeer.

FEC	ATTRIBUTE	PARAMETER	FREQ.	LIKELY DRIVER	PROGRAM
Caribou/reindeer	Abundance	Number	Annually	Forage; snow	CARMA
	Demographics	Calf percentage	Annually	Forage; snow	
		Age composition			

1.6 Phases of development and implementation

To create a successful, robust monitoring program, the CBMP-Terrestrial Plan follows a phased approach for its development. These phases are not mutually exclusive.

A. Plan design

The creation of a framework to guide a long-term approach for integrated, ecosystem-based Arctic biodiversity monitoring. This Plan represents the first phase.

B. Network-building and design optimization

The successful implementation of the CBMP-Terrestrial Plan will depend entirely upon the engagement and participation of Arctic terrestrial biodiversity monitoring practitioners, stakeholders and users. Active dialogue and communication with existing and new partners will be enhanced through the initiation of Terrestrial Expert Networks (TENs). TENs will identify key long-term datasets and essential data gaps, as will mechanisms to coordinate and harmonize monitoring methods and data. Improvements to plan monitoring and design to support implementation will continue. Implementation activities will be based on this Plan, but are not included here.

C. Implementation initiation phase

Network contributors will initiate coordinated data collection. Chapter 4 describes the recommended monitoring methods and temporal sampling frequency for each priority parameter. CBMP-Terrestrial Plan implementation partners and stakeholders will be encouraged and supported, as possible, to gather and process data following the recommended sampling design and to share and integrate the data as described in Chapter 5. Digitization and sharing, using common accepted standards, and creating comprehensive metadata will be paramount to the long-term use and accurate interpretation of data. Ecological baselines building on the baseline created by the Arctic Biodiversity Assessment (ABA) will be identified.

D. Full implementation with adaptive monitoring and management

Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. With the Arctic Biodiversity Assessment as a platform (CAFF ABA 2013), the CBMP–Terrestrial Plan will implement a monitoring program where ongoing, systematic and focused assessments of the Arctic terrestrial biodiversity will be produced. As data is gathered, adaptation and tailoring of the CBMP-Terrestrial Plan components (priority FECs, attributes, methods, etc.) may be required to suit the needs of users and enhance data quality and monitoring effectiveness.

1.7 Arctic biodiversity drivers

The Arctic is currently undergoing rapid changes: cultural, political and socio-economic transitions resulting in exploitation of natural and non-renewable resources, as well as physical development, and changes in climate and pollution—both local and trans-boundary. These changes, which can interact and may accelerate in the future place increased pressure on biodiversity within the Arctic in various, often unanticipated ways.

Generally, there is a strong correlation between biodiversity and temperature, directly in the form of freezing tolerance or productivity, but also indirectly through effects of thawing of permafrost, earlier snowmelt, drought, fires, and changes in trophic interactions, invasive species pest outbreaks and disease transmission. Therefore, it is expected that future warming will have a large and widespread impact on biodiversity throughout the Arctic. For some species currently limited by the short Arctic summer, longer growing seasons may be an advantage in terms of reproduction and growth; however, for specialized Arctic flora and fauna, the combined drivers may result in mainly negative effects (Bale, et al. 2002; Descamps, et al. 2009; Gilg, et al. 2012; Ma, et al. 2011; Post, et al. 2009; Rouse, et al. 1997).

Effects may be gradual or abrupt. Gradual change is exemplified by successional processes, such as the northward movement of treelines, which will affect not only Arctic biodiversity through shifting habitats and species, but also reduce albedo (surface reflectivity), further enhancing warming of the atmosphere. Similarly, the composition and distribution of plant communities is likely to change throughout the Arctic. To date, an increase in productivity over much of the Arctic has been reported (CAFF 2010; Gensuo, et al. 2009), as well as an increase in the length of the growing season. While the number of plant species inhabiting the current Arctic may actually increase over the long-term, plants unique to the Arctic could decrease in abundance and diversity (e.g., high Arctic mosses and lichens are expected to decline). Retreat of permafrost and changing soil moisture conditions will also affect plant communities. For example, mires and alpine habitats are at risk of drying out, leading to possible losses of associated arthropod and bird fauna. For estuarine and other lowland flora and fauna, sea level rise may cause substantial habitat loss. In addition, changing conditions may result in altered habitat structure (vegetation height, density, and openness), with important implications for animal communities including nesting birds (Ballantyne and Nol 2011; Walpole, et al. 2008).

Abrupt effects are more difficult to predict. Increased risk of extreme events, such as icing and severe wind and storms, and their cascading effects will contribute to more unstable and unpredictable conditions (Mallory, et al. 2009; Pisaric et al. 2011; Vermaire, et al. 2013). An example is the changes to rodent cycles due to unstable winter conditions. This has a cascading effect on the guild of mammalian and avian predators depending on this prey (Reid, et al. 2012; Schmidt, et al. 2012b). Decreasing winter ice may limit the dispersal ability of large carnivores (e.g., polar bears) and other mammals (Durner, et al. 2011; Stirling and Derocher 2012). Indirectly, inability to disperse may be forcing the exploitation of novel prey and niche shifts by large carnivores and herbivores, which may have unpredictable long-term impacts on the predators themselves, prey species, vegetation, or food webs which may already be under stress (Descamps, et al. 2011; Mallory, et al. 2009; Smith, et al. 2010). Other unpredictable and quick changes may include large-scale outbreaks in Arctic populations not previously exposed at the same levels to pathogens and parasites from southern climates(Descamps, et al. 2011; Descamps, et al. 2009; Gaston, et al. 2002; Verocai, et al. 2012). Migratory Arctic species constitute a special case since they are not only affected by changing conditions on their Arctic breeding grounds but also by global changes on their staging and wintering grounds outside the Arctic. Arctic-breeding shorebirds are at particular risk from pressures on their intertidal habitats in their staging and wintering areas (Baker, et al. 2004).

Human use of living resources in terms of harvesting, reindeer husbandry, and small-scale farming, harvesting of roots and greens, and collection of mushrooms and berries, affect certain species and ecosystems. Patterns and intensity of use will change with ongoing cultural and technological transitions and warmer climate. Many Arctic communities are already changing their harvest strategies in response to multiple drivers. For example, as caribou/reindeer migrations change due to warmer temperatures, interest in caribou/reindeer-hunting from outside users increases, and changes in vegetation and water levels occur, Arctic hunters may have to travel further and longer to harvest caribou/reindeer (Kendrick, et al. 2005; Nancarrow and Chan 2010). Note, the terms caribou and reindeer and used interchangeably in this document.

With increasing global demands for resources, the Arctic is becoming a focal area for hydrocarbon, mineral and hydropower development. Increasing industrial development affects biodiversity directly due to physical development of infrastructures, transportation and traffic, disturbance, on-site and downstream pollution and/or, indirectly, via behavioural disturbances (via human activity in wildlife-use areas), alteration of ground surfaces including vegetation and permafrost, or by opening up access to adjacent, previously remote areas (Prowse, et al. 2009). For example, reindeer herding in Siberia is impacted by increased resource development (Forbes, et al. 2009), and in northern regions, hydrocarbon development, resource extraction, and human disturbance have been shown to affect *Rangifer* populations (Anttonen, et al. 2011; Boulanger, et al. 2012; Vistnes and Nellemann 2008). Large-scale mining proposals in Arctic Canada for metals including zinc, copper, gold, uranium, diamonds and other resources are already undergoing evaluation. Some would require both on-land infrastructure and extensive road expansion, as well as infrastructure development for shipping and waste disposal (e.g. **http://nunalogistics.com/services/bathurst.html**).

Increasing industrialization within and outside the Arctic, releases contaminants that are appearing in Arctic foodwebs and ecosystems. While some volatile compounds are released in warmer regions around the globe where they evaporate, these contaminants travel via atmospheric transport into cold regions including the Arctic where they condense and are deposited into the environment, and may enter foodwebs through bioaccumulation (e.g., organochlorines in fish and seabirds; Blais, et al. 1998; Choy, et al. 2010; Krummel, et al. 2003). In addition, metal contaminants may be transported into terrestrial Arctic ecosystems via migratory species themselves (Blais, et al. 2007; Foster, et al. 2011), and include recent inputs from increasing industrialization (e.g., mercury, cadmium, and other metals). Contaminants have been detected in species from polar bears to soil arthropods (Dietz, et al. 2009; Fisk, et al. 2005; Hargreaves, et al. 2011), and while the long-term effects of exposure are unknown in some taxa, negative effects such as eggshell thinning in endangered ivory gulls have been linked to contaminants (Miljeteig, et al. 2012).

In addition to the industrialization of the Arctic and climate change, tourism is increasing throughout the Arctic. On-shore activities from cruise ship tourists, self-funded explorers and individual-based hiking, are placing increased disturbance

Photo: Josef Hanus/Shutterstock.com

pressure on terrestrial flora and fauna in some places. Lessons from Antarctica demonstrate that, concurrent with warming temperatures and increasing traffic and tourism, the risk of colonization and establishment of non-native species can increase (Barnes, et al. 2006; Chown and Convey 2007; Chown, et al. 2008).

1.8 Traditional Knowledge

Traditional knowledge (TK) is a systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation (ICC, 2013).

Under this definition it is clear that indigenous groups have taken in observations of change within their environment and addressed concerns as they arise based on the analysis of those observations. This knowledge remained in the hands of the community members. Children are taught from the beginning of life, about the world around them through epistemology, based on a set of knowledge and trained with keen senses. For example, modern day observations often note anomalies within an environment of uniquely interlinked systems.

The TEMG supports the inclusion of TK holder expertise involvement in projects from the inception of projects to the analysis of information gained, and in building a network of experts within both science and TK. Moving forward we will work to ensure input from TK holders as well as scientists within TEMG. The employment of a participatory approach to research may further aid in the success of this goal. Information will be gathered from both sources of knowledge and analyzed together. Special TEMG task force groups (see fig. 7.2), should include scientific expertise as well as TK expertise. A participatory approach ensures that information is gathered from both sources of knowledge and most importantly that the analysis of this information is done with both sources of knowledge, or ways of thinking.

1.9 Community Based Monitoring and citizen science

Community based monitoring (CBM) and citizen science can make significant contributions to circumpolar monitoring efforts. CBM refers to a range of observation and measurement activities involving participation by community members and designed to learn about ecological and social factors affecting a community. Citizen science is the collection of observations on the natural world often conducted by non-professional community members following recommended protocols. Many types of CBM and citizen science approaches exist, such as those that aim to collect baseline data, or those designed to monitor for ongoing changes **(Danielsen, et al. 2009; Gofman 2010).**

The participation and collaboration of community members in the collection of research and monitoring data leads to a greater investment in the effort itself and a greater understanding of the results. In addition to lowering costs of monitoring and research and accessing remote areas, recruiting and training willing volunteers to use scientific monitoring techniques offers additional benefits, such as strengthening partnerships between communities and scientists, improving knowledge exchange and building community awareness. Maximizing the contributions of circumpolar peoples to the CBMP will help ensure that the program is relevant and responsive to local concerns. The CBMP-Terrestrial Plan includes varying levels of complexity for data collection methods (see Chapter 4) to engage participation in Arctic terrestrial biodiversity monitoring across a range of capacity levels. The CBMP TEMG will make use of the best available information on ecosystem and biodiversity status and change. To this end, community-based knowledge will be incorporated into CBMP TEMG analysis and reporting products.

1.10 Links and relevance to other programs and activities

A coordinated monitoring approach for Arctic terrestrial ecosystems serves a variety of mandates at several scales. The Arctic Council will be a direct beneficiary. The outputs of the CBMP-Terrestrial Plan will help populate Arctic Council assessments and identify issues that require a coordinated, pan-Arctic, or even global response. The CBMP-Terrestrial Plan will also benefit scientists directly, by improving cross-disciplinary collaboration and providing greater access to long-term and pan-Arctic data sets. This, in turn, will facilitate advanced research and publications on the mechanisms that drive environmental trends.

CBMP-Terrestrial Plan outputs will also be of direct value to national and sub-national governments and organizations charged with monitoring and reporting on the status of Arctic terrestrial ecosystems within their jurisdictions. In many Arctic countries, this responsibility is shared across a number of government agencies. Developing optimal sampling schemes and harmonized and integrated approaches to monitoring at a pan-Arctic scale will: (1) improve sub-national and national governments' ability to understand trends and the mechanisms driving these trends; (2) support planning and monitoring activities around industrial and other developments; and (3) increase the capacity of individual agencies to respond effectively. Integration with international monitoring schemes will allow monitoring programs a multiple scales of effort to contextualize observed changes.

To the greatest extent possible, information developed under the CBMP-Terrestrial Plan will be provided at the local scale to serve local decision-making. This will be achieved partly through local-scale, community-based monitoring, but also through interpolation and modeling techniques to provide information that Arctic residents can use to make effective adaptation decisions.

The successful implementation of the CBMP-Terrestrial Plan depends upon effective links to a number of biotic and abiotic monitoring programs and initiatives, including those that are concerned with anthropogenic drivers. However, critical information could also be garnered from other monitoring efforts including other national, umbrella and extra-Arctic programs. These programs can use the information generated by the CBMP-Terrestrial Plan and could provide opportunities for coordinated monitoring (e.g., shared sampling sites). Examples of related monitoring programs, assessments and initiatives are described in Chapter 4.

1.10.1 Arctic Council working groups and activities:

The CBMP-Terrestrial Plan will build on, collaborate with and inform related programs in the Arctic Council, which include:

Arctic Biodiversity Assessment (ABA)

The Arctic Biodiversity Assessment (ABA), led by the CAFF working group of the Arctic Council, is a three-phase assessment containing the best available science informed by TK on the status and trends of Arctic biodiversity and accompanying policy recommendations for biodiversity conservation. The first phase, the *Arctic Biodiversity Trends: Selected Indicators of Change* report (CAFF 2010), was based on the suite of CBMP indicators and indices. The CBMP-Terrestrial Plan will benefit from the *Arctic Biodiversity Assessment* 2013, full scientific assessment report. The ABA terrestrial chapters provide useful baseline information from which the CBMP-Terrestrial Plan can build. The CBMP-Terrestrial Plan will use the ABA as the baseline from which it will reassess the state of the Arctic's terrestrial ecosystems in regular five year intervals.

Other CAFF activities related to the terrestrial environment including the work of the CAFF Flora Group. This group will also contribute to and benefit from the CBMP-Terrestrial Plan.

Arctic Council Arctic Monitoring and Assessment Programme (AMAP) working group

The Arctic Monitoring and Assessment Programme (AMAP)'s mandate is to monitor and assess the status of the Arctic with respect to pollution and climate change issues, document status and trends, pathways and processes, and effects on ecosystems and humans, propose actions to reduce associated threats, and to produce robust assessments and products to inform policy and decision-making processes (AMAP 2013). As such, AMAP aims to create a "sustained, robust circumpolar monitoring network effective at detecting change and discerning trends over the entire Arctic Region related to a range of environmental stressors including pollutants, climate change and the interaction between them" (AMAP 2010).

The information generated by AMAP on pollutants and their impacts on Arctic flora and fauna will be an important data element in interpreting Arctic terrestrial biodiversity trends in some cases. Opportunities for monitoring efficiencies between AMAP's monitoring program and the CBMP-Terrestrial Plan should be investigated and, wherever feasible and desirable, coordinated monitoring should be implemented.

AMAP is also involved in climate assessment and led the Snow, Water, Ice and Permafrost in the Arctic (SWIPA) project. SWIPA was established by the Arctic Council in April 2008 as a follow-up to the 2004 Arctic Climate Impact Assessment, with the goal of assessing current scientific information about changes in the Arctic cryosphere, including the impacts of climate change. Of particular relevance is the assessment of snow cover and permafrost change as these are important physical elements that can influence many aspects of the Arctic terrestrial ecosystem.

Arctic Council Sustainable Development Working Group (SDWG)

The objective of the Sustainable Development Working Group (SDWG) is to protect and enhance the economies, culture, and health of the inhabitants of the Arctic in an environmentally sustainable manner. Currently, the SDWG is involved in projects in the areas of children and youth, health, telemedicine, resource management, cultural and ecological tourism, and living conditions in the Arctic. The work of SDWG—in particular, development of indicators related to human-community response to changes in biodiversity—will be useful to the CBMP-Terrestrial Plan. In turn, it is anticipated that the outputs of the Plan will directly benefit SDWG's indicator development.

Sustaining Arctic Observing Networks (SAON)

Sustaining Arctic Observing Networks (SAON) is composed of representatives of international organizations, agencies, and northern residents involved in research and operational and local observing. This Arctic Council initiative is developing recommendations on how to achieve long-term, Arctic-wide observing activities. The goal is to provide free, open, and timely access to high-quality data that will contribute to pan-Arctic and global value-added services and provide societal benefits. CAFF's CBMP is the biodiversity component of SAON. The CBMP-Terrestrial Plan will both facilitate and benefit from the development of an integrated pan-Arctic observing network.

1.10.2 Other programs

The CBMP has formed strategic collaborations with other key programs which will support the delivery of the CBMP-Terrestrial Plan.

Group on Earth Observations Biodiversity Observation Network (GEO BON)

The Group on Earth Observations Biodiversity Observation Network (GEO BON) is the biodiversity arm of the Global Earth Observations System of Systems (GEOSS). Some 100 governmental and non-governmental organizations are collaborating through GEO BON to make their biodiversity data, information, and forecasts more readily accessible to policy makers, managers, experts and other users. GEO BON is also a forum for collaboration on harmonizing monitoring programs and for the development of monitoring programs in gap regions. GEO BON is a voluntary, best-efforts partnership guided by a steering committee. The network draws on the Group on Earth Observation's work on data-sharing principles and on technical standards for making data interoperable. This global initiative is closely aligned with the CBMP, and the CBMP is the now the Arctic-BON of the global network. The CBMP's outputs, including the outputs from the CBMP-Terrestrial Plan, will feed directly into the GEO BON effort. In order to ensure outputs and sampling approaches are aligned with global biodiversity monitoring efforts under GEO BON, the CBMP- Terrestrial Plan will map its FECs to the recently published *Essential Biodiversity Variables* (Pereira, et al. 2013) to ensure complementarity (see Chapter 3 and Table 3.2). Correspondingly, pan-Arctic biodiversity monitoring will benefit from the information generated globally, providing context for the patterns and trends detected in Arctic ecosystems.

Biodiversity Indicators Partnership, including IPBES, and the Convention on Biological Diversity

The Convention on Biological Diversity's Biodiversity Indicators Partnership (BIP) is the global initiative to promote and coordinate development and delivery of biodiversity indicators in support of the CBD, Multilateral Environmental Agreements, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), national and regional governments and a range of other sectors. The BIP brings together over forty organizations working internationally on indicator development to provide the most comprehensive information on biodiversity trends. The CBMP is a partner organization and has identified a suite of high-level indicators and indices that will be used, in part, to track the Arctic's progress towards some of the Aichi 2020 Targets. The data rescued, aggregated and generated by the CBMP-Terrestrial Plan will be used to directly populate many of these indicators and thus, the CBMP-Terrestrial Plan will be a direct contributor to the global assessment of trends in biodiversity.

The Global Biodiversity Information Facility (GBIF)

The Global Biodiversity Information Facility (GBIF) was established by governments in 2001 to encourage free and open access to biodiversity data via the Internet. Through a global network of countries and organizations, GBIF promotes and facilitates the mobilization, access, discovery and use of information about the occurrence of organisms over time and across the planet, and provides a platform to standardize taxonomy

Programs and monitoring networks in other global cold regions: Antarctica and alpine regions

The Arctic is undergoing rapid change, along with other cold regions of the world including Antarctica and high alpine regions. Comparative data, monitoring capacity, infrastructure and expertise already exist focusing on these cold regions elsewhere and on bipolar settings, and valuable contributions and knowledge can be exchanged via existing networks. As an illustration, IPY projects often resulted in Antarctic, Arctic, and bipolar collaborations, and outputs are often accessible, nationally and internationally (e.g. **http://www.ipy.org/** ; even for the earliest IPY in the late 1800s: **http://www.arctic.noaa.gov/aro/ipy-1/**). The Scientific Committee on Antarctic Research (SCAR: **http://scar.org/**) and the British Antarctic Survey (BAS: **http://www.antarctica.ac.uk/**) specialize in Southern regions, but include many bipolar initiatives. For alpine egions, an international initiative for research, monitoring and assessment includes Diversitas - Global Mountain Biodiversity Assessment (**http://gmba.unibas.ch/index/index.htm**) and the Global Observation Research Initiative in Alpine Environments (GLORIA) (**http://www.gloria.ac.at/**)

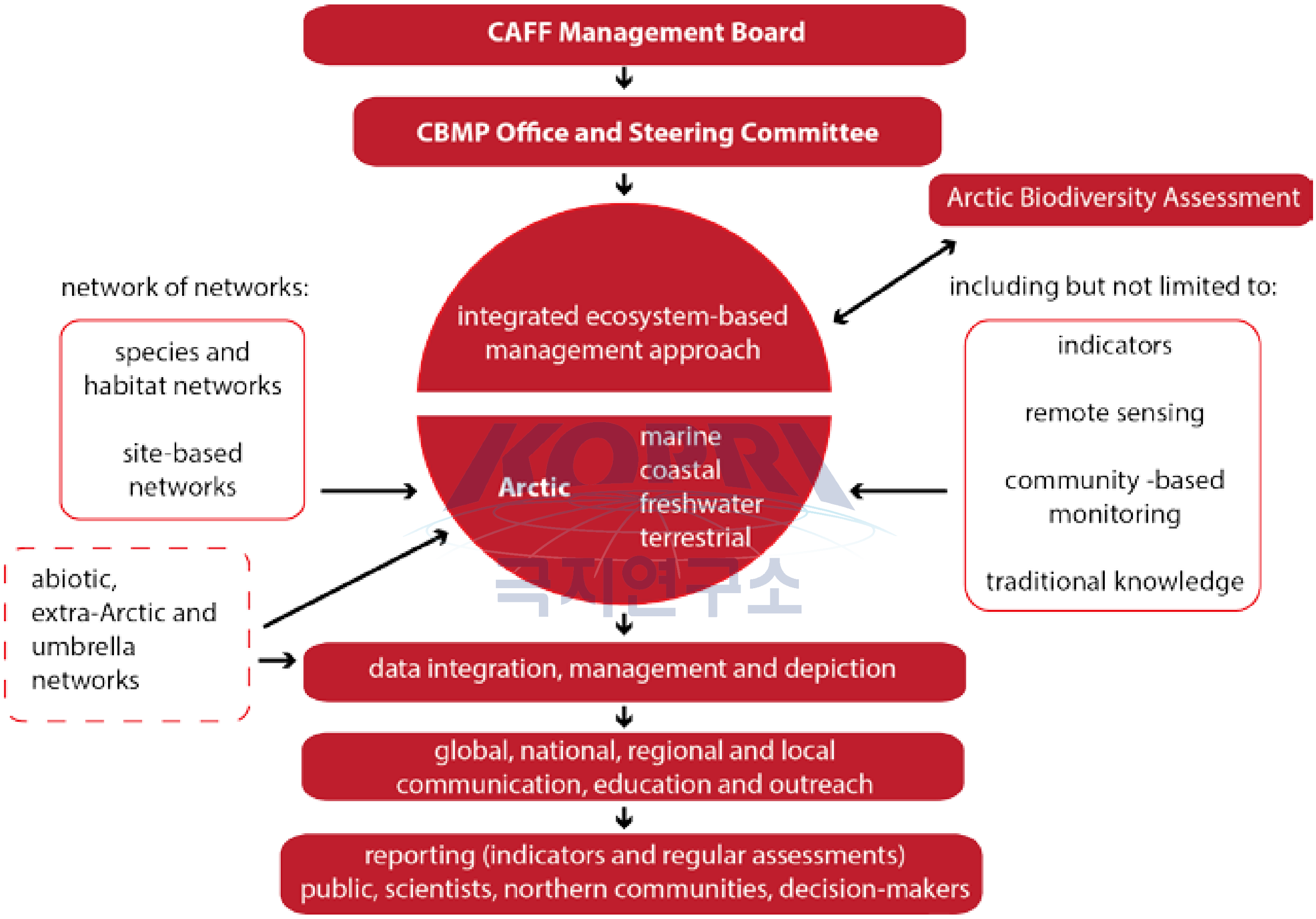


Figure 1.1 Organizational structure of the Circumpolar Biodiversity Monitoring Program (CBMP).

2. Scope and focal areas

2.1 Species and ecosystems included in CBMP-Terrestrial Plan

Since there is no strict definition of the Arctic or Arctic species, ecosystems of the Arctic-proper and species that reproduce in the Arctic-proper and/or have genuine populations in the Arctic-proper, except for species with accidental or clearly insignificant appearance within the Arctic are included in the Plan.

The CBMP-Terrestrial Plan considers all ecosystems and respective constituent organisms from the marine high-water mark, inland. The intertidal zone will be considered as part of the future *Arctic Coastal Biodiversity Monitoring Plan*. Fens and marshes are considered terrestrial while tarns, ponds, lakes and rivers are considered freshwater and are included in the *Arctic Freshwater Biodiversity Monitoring Plan* (Culp, et al. 2012).

Currently, the CBMP-Terrestrial Plan does not include comprehensive coverage of some important functional groups or ecosystem components due to limited monitoring capacity, costs, logistics, or feasibility. For example, the TEMG acknowledges the crucial role of microorganisms in ecosystem processes including nutrient cycling (e.g., bacteria), functioning as primary producers in some harsh terrestrial environments (e.g., snow algae), and influencing the population dynamics of other species (as symbionts or pathogens). However, due to current limitations, microorganisms are only included for monitoring indirectly at this time (e.g., measurements of decomposition rates and nutrient cycling), or under particular key components (e.g., monitoring health and outbreaks in some cases). Through some limited sampling that can serve as a baseline (e.g., soil samples as part of the current CBMP-Terrestrial Plan; see Chapter 4), microorganisms can be included in future surveys using DNA-based identification and quantification methods. However, when opportunities exist to include microorganisms through collaboration or future surveys and expansion of monitoring capacity, it is strongly recommended that this functional group is included. Climate change is already influencing microbe-driven ecological processes, resulting in important positive and negative implications for food webs, disease transmission, nutrient cycling, and even Arctic greenhouse gas emissions (Descamps, et al. 2011; Vincent 2010).

While the Plan focuses on biological elements and develops sampling designs for biological components only, it also identifies critical abiotic parameters which affect and drive biological change that should be monitored as part of an integrated ecosystem approach. Where those abiotic parameters are appropriately layered with biological monitoring sites and stations, they will be included in the CBMP-Terrestrial Plan. Otherwise, developing a sampling strategy for these abiotic factors is outside the scope of the current Plan. In those instances, the TEMG will rely on, and communicate and collaborate with, other relevant organizations and programs that are responsible for Arctic abiotic monitoring (see chapter 1.9 and 4.3).

2.2 Geographic boundaries and definitions

The TEMG closely follows the definitions, geographic boundaries, species and ecosystem coverage as outlined by the CAFF Arctic Biodiversity Assessment (CAFF ABA 2013) (Figure 2.1). The CBMP-Terrestrial Plan scope includes high and low Arctic consistent with the Circumpolar Arctic Vegetation Map's subzones A-E (CAVM Team 2003 and alpine sub-Arctic regions in proximity of the Arctic proper).

Arctic proper: From a geophysical point of view, the terrestrial Arctic may be defined as the land north of the Arctic Circle, where there is midnight sun in the summer and darkness in winter. But from an ecological point of view, it is more meaningful to use the name for the land north of the treeline, which generally has a mean temperature below 10-12 °C for the warmest month. With this definition, the Arctic land area comprises about 7.5 million km^2, or some 5.5% of the land surface on Earth. The Arctic may be divided into a number of subzones based on floristic types, i.e., subzones A-E on the *Circumpolar Arctic Vegetation Map* (CAVM Team 2003). Here, the division between the high Arctic and the low Arctic is most relevant, and the separation between subzones C and D on the CAVM is used (Figure 2.2).

High Arctic: The high Arctic comprises the Arctic land masses in the far north where mean July temperatures vary from 6°C in the south to only approximately 2°C in the north. Precipitation in the north is less than 50 mm per year and falls mainly as snow. The high Arctic consists of polar semi-desert vegetation in the south (cryptogam–herb, cushion plant–cryptogam, and wetland communities which do not cover all of the ground) and polar desert (cryptogam-herb communities which cover only approximately 5% of the ground) in the far north.

Low Arctic: The low Arctic is characterised by mean July temperatures between 6 and12°C, more precipitation more evenly distributed during the year, both in form of snow and rain. The low Arctic tundra has much more productive vegetation than the high Arctic, with shrub tundra, wetlands and, in the northern end, dwarf shrub–herb communities.

Sub-Arctic: The sub-Arctic is characterized by short cool summers and long cold winters and generally found at latitudes from 50° to 70°N. Alpine regions in the sub-Arctic have a similar climate and ecology to the Arctic. The sub-Arctic comprises low alpine and high alpine zones in mountainous areas closely connected to the Arctic, oceanic tundra (e.g., the Aleutian Islands) and the forest tundra. The sub-Arctic/Arctic ecotone is dynamic with evidence of treeline advance into the Arctic (Harsch et al., 2009). The sub-Arctic hosts species of significance to the Arctic tundra and serves as a potential corridor for species movement into the current Arctic tundra region due to global change. The CBMP-Terrestrial Plan coverage thus includes the sub-Arctic/Arctic interface and Arctic alpine areas of the sub-Arctic.

2.3 Vegetation and bioclimatic zones

Figure 2.2 shows the location of existing long-term monitoring sites and the major bioclimatic zones for the Arctic proper, as well as high, low and sub-Arctic regions, where ecotones between these adjacent regions and northern alpine areas may occur. The scope of the CBMP-Terrestrial Plan thus covers a range of ecosystem classifications, from cryptogram and herb barrens to low shrub tundra, and elevations (see Chapter 4; Figure 4.1). Existing monitoring programs and infrastructure (see Appendix A) span an array of these ecosystems, but a goal of the Plan particularly during the implementation phase is to identify where gaps exist to guide future monitoring.

Using the CAVM bioclimate subzones (**http://www.arcticatlas.org/maps/themes/cp/cpbz** ; table summary in **http://www.arcticatlas.org/photos/mapunits/graphicsEnlargement.php?regionCode=cp&filename=cavm_table1**), five regions are identified in the Arctic, from A to E, and from coldest to warmest, respectively.

Subzone A has a maximum average July temperature of 3 °C, is mostly barren with some lichen and moss cover, and vascular plant cover is less than 5% of the area.
Subzone B has a maximum average July temperature of 5 °C, and has some vascular plants less than 5 cm tall and covering up to 25% of total area.
Subzone C has 7 °C as the maximum average July temperature, and may include prostate dwarf shrubs reaching 15 cm; vascular plants may represent 50 % of total cover.
Subzone D has 9 °C as the maximum average July temperature; vascular plants and dwarf shrubs may reach up to 40 cm and cover may be up to 80% of total area.
Subzone E, the warmest, can reach 12 °C, include vascular plants and shrubs reaching up to 80 cm in height, and may reach 100% vegetation cover (closed canopy).

Svalbard landscape. Photo: Mark Marissink

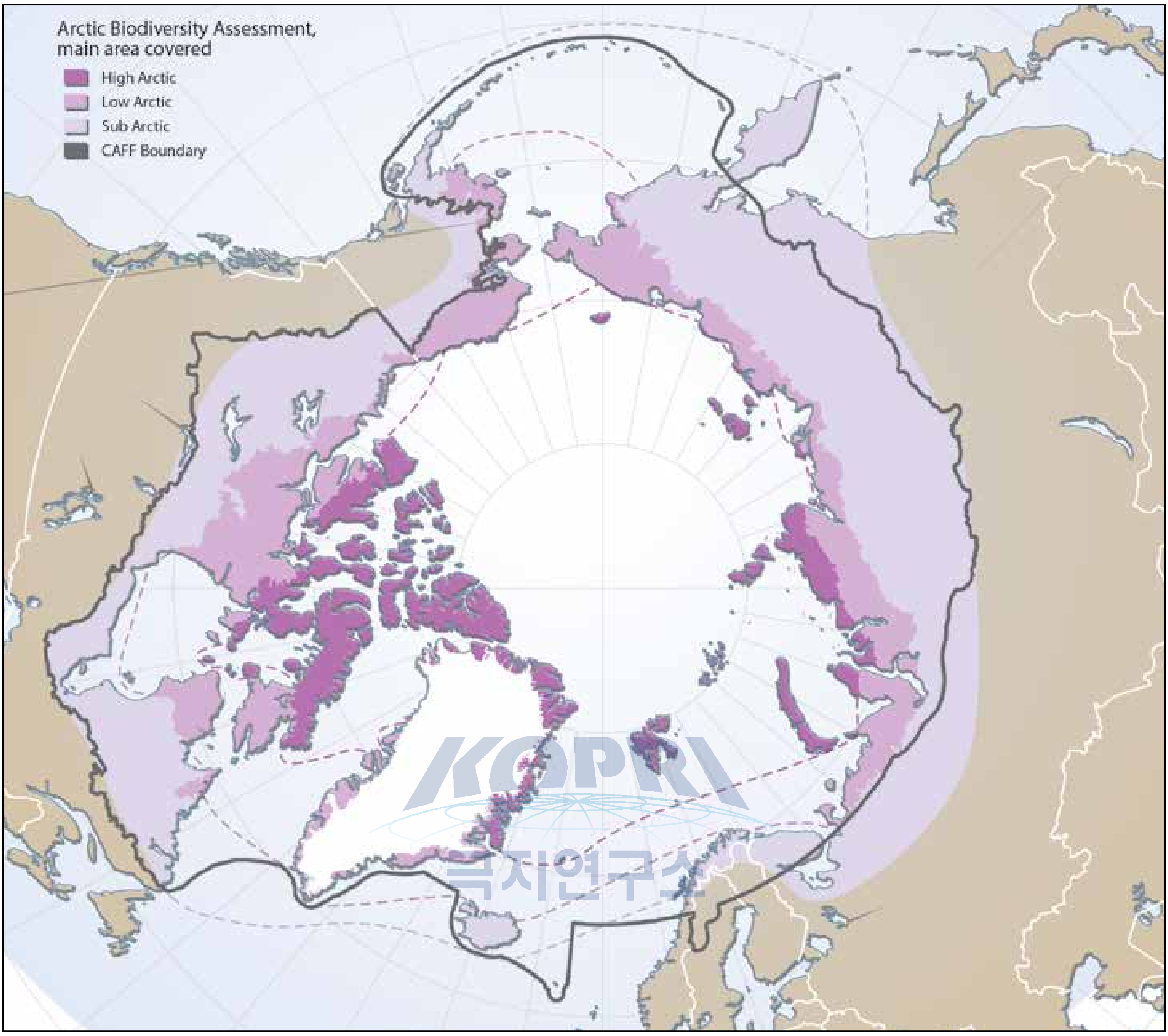


Figure 2.1 Boundaries of the geographic area covered by the Arctic Biodiversity Assessment and the terrestrial CBMP, defined by the division between high Arctic, low Arctic and sub-Arctic according to the Circumpolar Arctic Vegetation Map (CAVM Team, 2003). Mostly the Arctic proper is covered in the CBMP-Terrestrial Plan. With the inclusion of Eurasia, alpine regions in close proximity or with ecological linkages to the Arctic proper, sub-Arctic regions are also included. The sub-Arctic includes regions north of the treeline (and may extend further south in some cases, and may not be shown in detail on the map as included areas). Map modified from: Hohn and Jaakkola (2010).

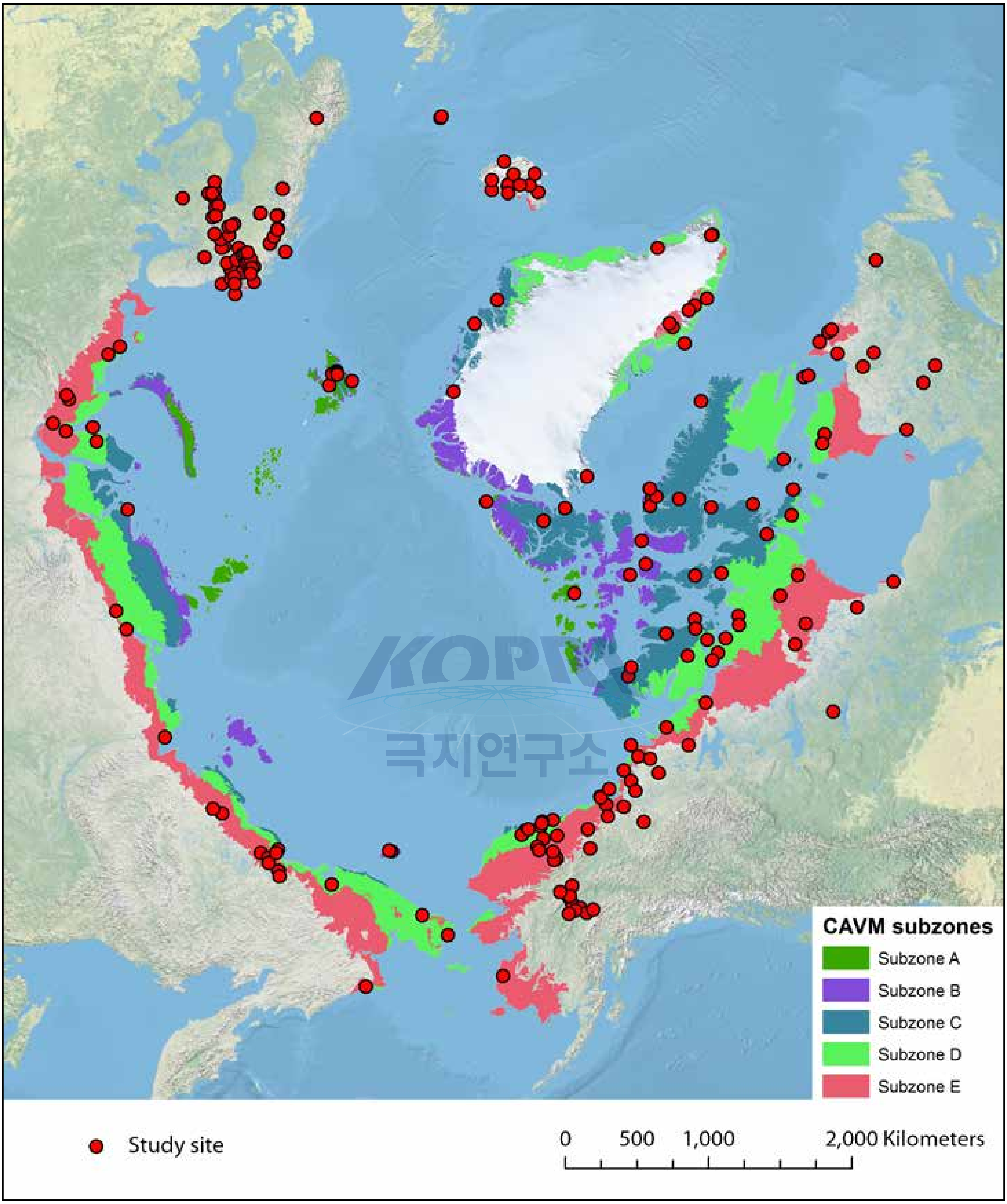


Figure 2.2 Circumpolar Arctic bioclimate subzones (CAVM Team 2003) and location of long-term monitoring sites, programs and infrastructure that can contribute to monitoring capacity as part of the CBMP-Terrestrial Plan. The map includes all biotic groups. The map shows territories within the Arctic proper, but other regions in the Arctic/sub-Arctic and alpine ecotones are included. Subzones are briefly described in the text.

3. Overview of monitoring approach, objectives, general methods, and sampling design

3.1 Overall monitoring approach

The CBMP TEMG will pursue a terrestrial biodiversity monitoring program predicated on an ecosystem-based approach, which generates a system-based understanding to better inform decision making on the conservation and management of critical Arctic terrestrial biodiversity. Focal Ecosystem Components (FECs), which are described by key biodiversity and related composition, structure, and functional attributes, captured via multiple interacting parameters at various scales, will be identified and integrated to describe and report on biodiversity and ecosystem status and trends, and to diagnose potential drivers, processes at play, and implications of those trends.

The CBMP-Terrestrial Plan is focused on the status and trends of Arctic terrestrial biodiversity FECs, but also on the ability to predict future potential changes in these FECs and to facilitate the identification of the causal mechanisms driving these trends. A solid conceptual understanding of Arctic ecosystems and clearly-articulated monitoring questions (see Chapter 3.2 and 4) are essential to shape the selection and assessment of FECs and their associated attributes and parameters. Monitoring to address the priority questions identified within the CBMP-Terrestrial Plan and detailed in Chapter 3.2 will be initially based on data from existing monitoring networks and local capacity to maximize the efficiency and likelihood of success. However, while much can be accomplished through existing networks and monitoring efforts, the CBMP-Terrestrial Plan also identifies monitoring needs which cannot be addressed through current capacities or existing efforts. Existing and new monitoring initiatives and partners will be considered at different spatial scales (from plots to landscapes, and from species to communities and/or populations) and temporal scales (from years to decades) and integrated through modeling. Figure 3.1 illustrates the global CBMP-Terrestrial Plan monitoring and data harmonization scheme.

The CBMP-Terrestrial Plan describes a balance of both (1) targeted, research-based monitoring (Lindenmayer and Likens 2010) and (2) survey-based, or surveillance, monitoring (Boutin, et al. 2009; Nichols and Williams 2006) (see commentaries on the value of both approaches: Casadevall and Fang 2008; Kell and Oliver 2004). Surveillance monitoring commonly focuses on a broad suite of ecological indicators to identify impacts of multiple drivers across a range of possible biological endpoints and ecosystem functions. Since surveillance monitoring is commonly applied at a broad scale and across multiple aspects, it is more likely to remain relevant over the long-term as ecological stresses arise and evolve (Boutin, et al. 2009) and as drivers are impacted by climate change. Surveillance monitoring best supports general status and trend estimations and will likely not address why a change is occurring, although qualitatively derived cause/effect relationships may be hypothesized based on conceptual model formulation and form the basis for future research needs.. Still, well-designed surveillance monitoring approaches are responsive to monitoring questions. Targeted, research-based monitoring, on the other hand, explores specific factors and their drivers, and is designed to address a specific set of hypotheses, usually at a finer scale of assessment than surveillance monitoring, to quantitatively build a mechanistic understanding of cause/effect relationships (Lindenmayer and Likens 2010). A challenge for the CBMP-Terrestrial Plan is to develop an analytical process that will allow for the integration of both survey-based and targeted monitoring to meet Arctic terrestrial biodiversity monitoring goals.

The CBMP-Terrestrial Plan development follows steps required to establish an effective, efficient and adaptive monitoring program (Boutin, et al. 2009; Elzinga, et al. 1998; Fancy, et al. 2009; Gross 2003; Lindenmayer and Likens 2010; Mulder, et al. 1999; Taylor, et al. 2012; Toevs, et al. 2011). The key activities are outlined in Table 3.1.

Table 3.1 Key activities of the CBMP-Terrestrial Plan development processes, timelines, and chapter references.

Activity	When completed	Plan reference
Clearly define monitoring goals and objectives.	TEMG Workshop 1, 2, & 3	Chapter 4
Compile and summarize existing information (TEMG monitoring inventory of existing capacity)	Background Paper; ongoing	Appendix A
Develop conceptual models to elucidate and communicate understanding and interrelationships of key ecological components and interactions	TEMG Workshop 1 & 2	Chapter 4
Identify and select indicators meaningful to management objectives and ecosystem priorities	TEMG Workshop 1 & 2	Chapters 3 & 4
Identify and select monitoring parameters, methods, and develop overall sampling design	TEMG Workshop 2 & 3	Chapter 3
Establish data management, analysis and reporting procedures	CBMP Data Management Strategy	Chapter 3,5,& 6
Field test; analyze data	Implementation	Chapter 3 & 7
Modify and adapt as required	Implementation	Chapter 3 & 7

3.2 Central questions to be addressed

The CBMP-Terrestrial Plan aims to address these priority management questions (see Fig. 3.4 and Ch. 4):

1. What are the status, distribution, and conditions of terrestrial focal species, populations, communities, and landscapes/ecosystems and key processes/functions occurring in the Arctic?

2. How and where are these terrestrial focal species, populations, communities, and landscapes/ecosystems and key processes/functions changing?

3. What and how are the primary environmental and anthropogenic drivers influencing changes in biodiversity and ecosystem function?

4. Where are the areas of high ecological importance including, for example, resilient and vulnerable areas (related to the FECs) and where are drivers having the greatest impact?

3.3 Development Process

3.3.1 Conceptual models for monitoring design

An integrated monitoring approach needs to reach across programs, jurisdictions, stakeholders and agencies to manage for ecosystem sustainability. One way to achieve this goal is to identify both essential management questions and critical components, processes and drivers of ecosystem sustainability through a conceptual modeling process.

A conceptual model represents a working hypothesis about key system relationships, functions and organization (Beever and Woodward 2011). Developing a monitoring program based on a structured, discussed (amongst multiple experts and/or stakeholders) and well thought-out ecosystem-based conceptual model approach can generate a comprehensive, system-based understanding that provides the foundation to identify and assess a suite of key FECs and related attributes, and priority ecosystem structures, functions, and processes (Gross 2003; Lindenmayer and Likens 2010; Taylor, et al. 2012), as well as their linkages to abiotic and biotic drivers (see Chapter 3.4.2). Conceptual ecological models for the Arctic, based on science and other expert input, are tools that can provide a "common language" to elucidate and communicate the critical components, processes and drivers of ecosystem sustainability within and across resource disciplines. Conceptual models allow for the identification and selection of priority monitoring elements that will meaningfully describe the status of many parts of the ecosystem and the likely cause of change with the least effort possible. This is especially critical when monitoring remote, difficult to access Arctic locations, where a program cannot monitor everything, everywhere, and all of the time. Once established and fully vetted, the conceptual models provide a basis for resource-use decisions predicated on maintaining or restoring ecosystem capacities through monitoring FECs, functions, processes, and their associated attributes and parameters.

Resource scientists/specialists commonly will be able to employ expert knowledge to determine the most critical components and processes essential to their field of study, which was also true for members of the TEMG. The CBMP TEMG used both ecological theory based in conceptual models (see Chapters 3.5.3 and 4) as well as needs of management, industry, and communities (see Chapter 4) to identify and rank the parameters and attributes of the FECs in the CBMP-Terrestrial Plan.

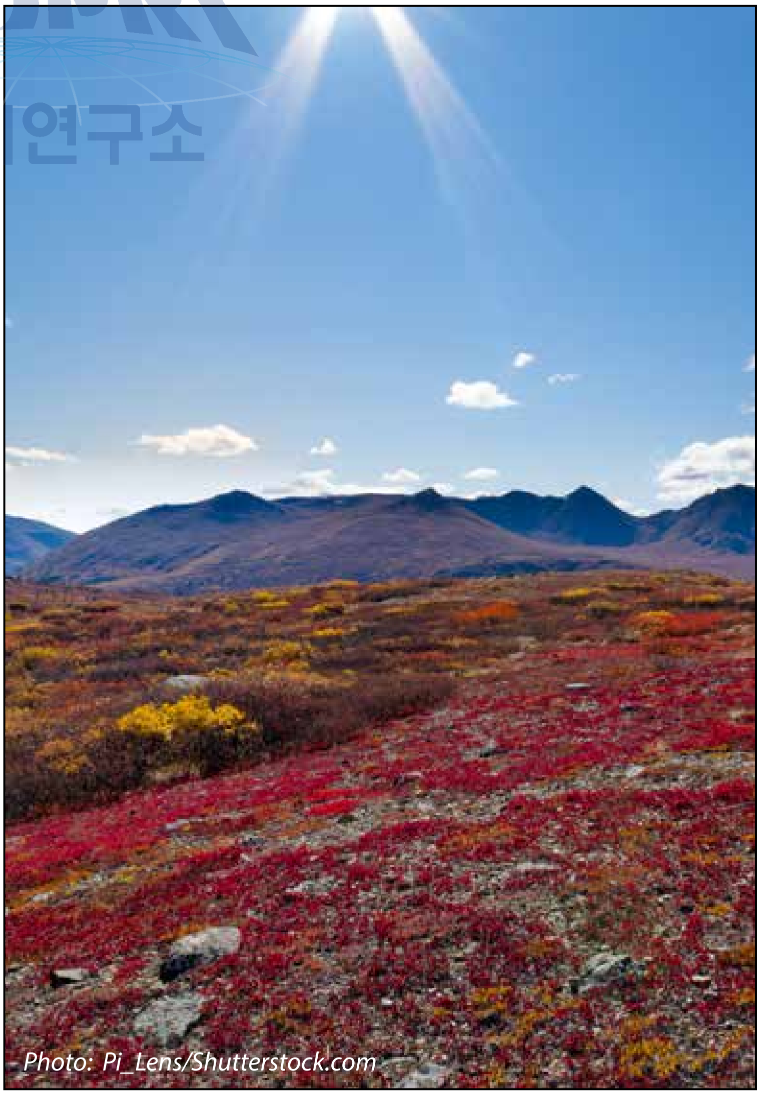


Photo: Pi_Lens/Shutterstock.com

3.3.2 Linkage to system drivers

Increasing cumulative pressures induced by, for instance, climate change and human activities are contributing to rapid changes in natural ecosystems in the Arctic and elsewhere. Hence, it is necessary to identify natural drivers and anthropogenic stressors in the terrestrial monitoring program. An appropriate balance of monitoring of ecosystem FEC attributes and system drivers must be developed to not only document change, but also to establish the causal relationships between changes in biodiversity and these pressures.

Understanding linkages between the biotic and abiotic drivers of the system and the potential FEC attributes is critical to development of a successful, efficient monitoring program. Differential driver impacts, or strength of impacts, have direct relevance on what, where and how often to monitor. Understanding what biodiversity components are likely to be affected by a given drivers(s), may prioritize the component or driver(s) for monitoring. Understanding where priority components exist, or which potential sampling strata are likely to be influenced first, or most heavily, by any given driver(s), may prioritize the sampling strata (e.g. a given ecosystem or geography of a given component) for monitoring, or call for an localized, high-density or broad, low-density sampling approach to best understand the effects. Similarly, understanding that any driver may influence a component or location first or more heavily than others, may prioritize the component for more frequent monitoring compared to other components that are likely to change more slowly through time. For these reasons, the CBMP TEMG clearly identified drivers in the development of the global conceptual model (see Fig 3.2) and biotic-group specific models. Table 4.6 in Chapter 4 illustrates the high priority drivers and how they will be monitored through the CBMP-Terrestrial Plan. Chapter 8 describes how the Plan will benefit from a network of networks approach also to integrate data from other programs focused on monitoring particular drivers of interest (see Fig. 8.1 and 8.2).

3.3.3 The CBMP TEMG conceptual model

Consensus opinion amongst TEMG members and associated experts was used to create a high-level conceptual model of the Arctic **terrestrial biome,** including key biotic groups, abiotic elements, functional relationships, and system drivers (see Figure 3.2). Conceptual models for the key biotic groups (i.e., birds, mammals, vegetation, and invertebrates) at the broadest thematic scale (see Chapter 4) were developed by consensus at two expert workshops.

The conceptual models are designed to be generic enough to be applied across the entire Arctic landscape through a process of localization, where the general conceptual model is adapted to the local food web, structural and functional relationships, local drivers, and other relevant local phenomena (see Box 4 A-D).

3.3.4 Selection of Focal Ecosystem Components (FECs), attributes and parameters

The list of potential FECs and their attributes was generated based on a combination of the conceptual models, expert opinion and management and community needs. During the first expert workshop, TEMG teams developed base conceptual models for each biotic group. In addition, TEMG teams identified key audiences for Arctic terrestrial biodiversity monitoring information, including resource managers and community members, and their needs for biodiversity information to answer key questions and manage/adapt to the environment. During the second expert workshop, these models and biodiversity information needs were refined and tables generated to identify (in list form) potential FECs, attributes and parameters (e.g. Figure 3.4).

A process based on expert opinion was then completed to rank and prioritize potential monitoring FECs and their attributes. Rankings were based on a simple sum of scores for several factors, including:

- Ecological relevance
- Relevance to ecosystem services
- Relevance to Arctic indigenous and non-indigenous peoples
- Relevance to management and legislation

Highly-ranked FECs (greater than 75% of the potential score) plus several additional FECs and FEC attributes, based on agreed management and/or community needs, were carried forward as priorities for the CBMP-Terrestrial Plan. Expert teams identified parameters to be measured in the field related to each identified attribute. In addition, the following criteria refined the parameter selection:

- sensitivity to natural or anthropogenic drivers;
- relevance to TK-based management;
- validity;
- availability and sustainability of monitoring capacity and expertise;
- relevance to targets and thresholds; and
- practicality.

A multi-scale sampling and reporting design for the priority FECs, attributes, and parameters was developed (see Chapter 4). The CBMP-Terrestrial Plan affords flexibility in the selection of locally relevant FECs which best typify biodiversity and ecosystem integrity for a given location or region. For example, the Plan proposes monitoring of large mammals as a priority FEC, and suggests specific species and attributes where appropriate, but also allows for locally relevant large mammals to be selected that better represent the ecosystems for a given location or region. In this manner, the Plan aims to balance the need for standardized data collection for assessment and reporting with requirements for the adoption and use of locally relevant attributes.

For each FEC, a series of **essential** and **recommended** attributes that should be monitored were identified. **Essential** attributes are recommended to be measured at any given monitoring location to capture a minimum set of biodiversity information relative to the FEC under study. **Recommended** attributes may be measured at some sites with additional capacity and intensity of design in order to provide more comprehensive information on the nature of the observed changes and to better understand processes driving biological change.

A set of common attributes was defined and standardised across FECs as much as possible (Figure 3.4), though the parameters, priority, temporal recurrence, scale of sampling and exact methods will vary as appropriate for the taxonomic group under study. The selected key attributes are:

- **diversity**: in species, communities, genetics, etc.,
- **abundance**: the number, density, etc.,
- **composition**: morphology, traits, general structure, etc.,
- **phenology**: timing of seasonal activities, annual cycles, etc.,
- **demographics**: age and sex structures, survival, etc.,
- **spatial structure**: distribution in space, migration, etc.,
- **temporal cycles**: stochastic ecological interactions such as predator-prey population relationships,
- **health**: disease prevalence, body condition, etc.,
- **productivity**: biomass, reproductive output, etc., and
- **ecosystem functions and processes**: nutrient cycling, etc.

Some attributes can be monitored simultaneously for particular taxonomic groups or based on particular protocols, while in some cases these must be monitored separately (see Chapter 4).

The experts also distinguished between **basic** and **advanced** protocols to facilitate selection of appropriate methods based on capacity. **Basic** protocols are simple methods that could be used by site with minimum monitoring capacity to provide scientifically robust results, and **advanced** protocols are those that require a higher level of scientific expertise and oversight for proper application.

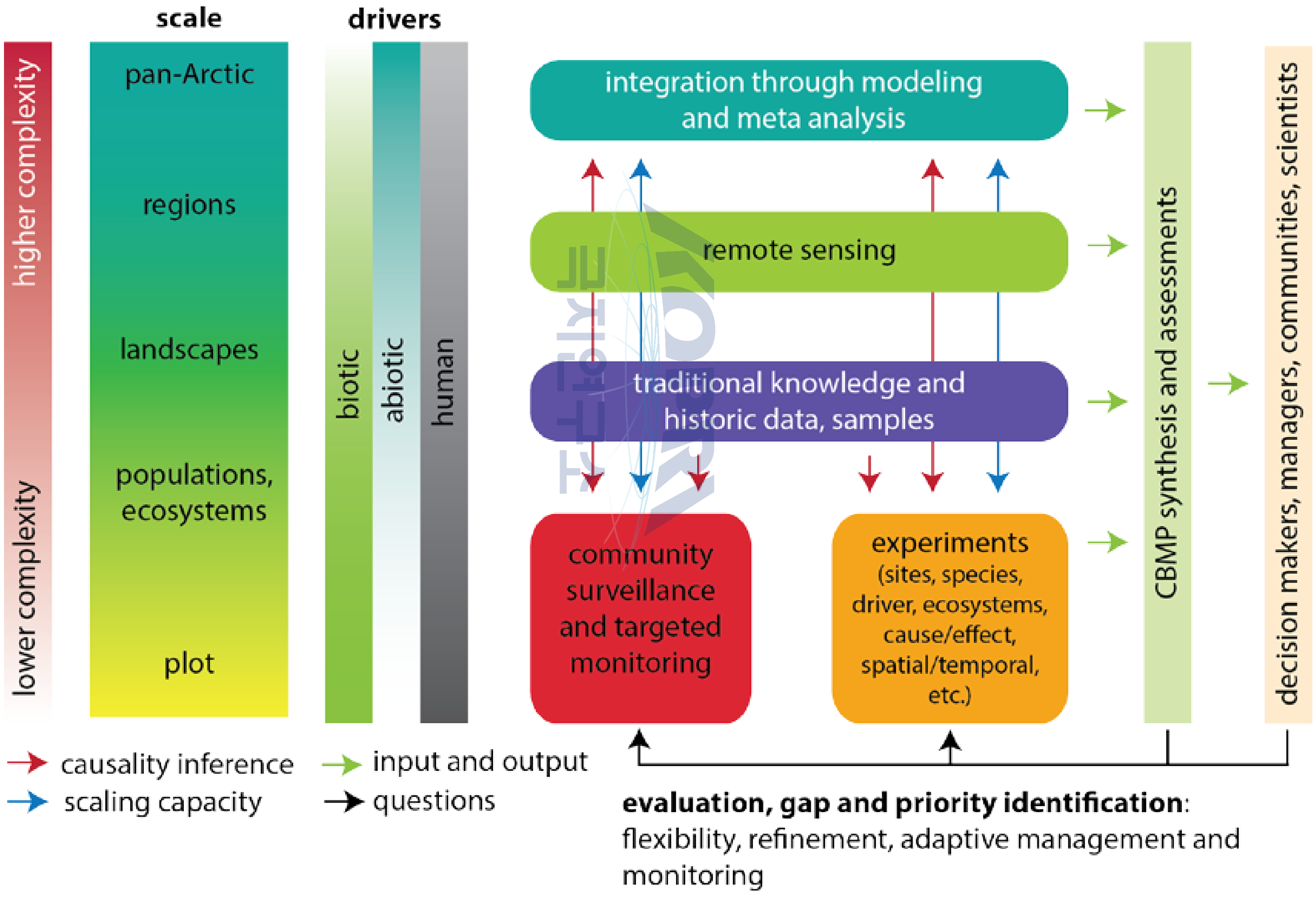
Spatial scales of sampling and monitoring for attributes and parameters are identified including; **local,** site or plot-based, **landscape**, a larger area including nearby plots or sites in the same habitat or group of habitats and transition zones, **regional**, large-scale, such as by country or biogeographic region, and **pan-Arctic** at the largest spatial scales as appropriate for the biotic group and migratory species. In addition, we propose sampling frequency intervals as appropriate and as capacity permits, i.e., **temporal recurrence**, ranging from seasonal to decadal.

The selected FECs, attributes and associated reporting indicators (see Chapter 7) align closely with the CBMP indicators (CAFF 2010; Gill and Zöckler 2008) as shown in Table 3.2. The selected FECs also map closely with Essential Biodiversity Variables (Pereira, et al. 2013) and Convention on Biological Diversity indicators (SCBD 2013). Opportunities exist during implementation to further refine the selected FECs and attributes in the Plan and to align with these indicators for global biodiversity assessment.

Table 3.2 Linkages between CBMP indicators and indices and the CBMP-Terrestrial Plan. A "√" means that the CBMP indicator is supported by the CBMP-Terrestrial Plan.

CBMP biodiversity indices and indicators	Linkage to CBMP Terrestrial-Plan
Species composition	
Arctic Species Trend Index	√
Trends in indicators of FECs	√
Trends in abundance of key species and trends in other parameters (e.g., distribution, productivity, survival body condition)	√
Arctic Red List Index	√
Change in status of threatened species	√
Trends in total species listed at risk	√
Ecosystem structure	
Arctic Trophic Level Index	√
Water Quality Index	X
Habitat extent and change in quality	
Arctic Land Cover Change Index	√
Trends in extent biomes, habitats and ecosystems	√
Arctic Habitat Fragmentation Index	√
Trends in patch size distribution of habitats	√
Extent of sea floor disturbance	X
Ecosystem function and services	
Trends in extent, frequency, intensity and distribution of natural disturbances	√
Trends in phenology	√
Trends in decomposition rates	√
Human health and well-being	
Arctic Human Well-being Index	X
Trends in availability of biodiversity of traditional food and medicine	√
Trends in use of TK in research, monitoring and management	√
Trends in incidence of pathogens and parasites in wildlife	√
Policy response	
Coverage of protected areas	X

Figure 3.1 Conceptual visualization of the Arctic terrestrial biodiversity monitoring scheme. Monitoring includes scales from plots to pan-Arctic (and beyond). Consideration of biodiversity, ecosystems and drivers, and data integration increases in complexity at larger scales (left). Monitoring efforts at various levels (middle) are integrated through modeling and meta-analyses (blue arrows). Causal linkages (red arrows) can be established through experimental work, and on the larger scale, inferred from detailed data from the smaller scale. Extra-Arctic monitoring of migratory species will further inform synthesis and assessments. Monitoring outputs (green arrows) can be extracted on all levels, and feed into the assessment and decision-making processes (right), ultimately also feeding back into the Plan monitoring scheme (black arrows) to enable flexible and adaptive implementation.



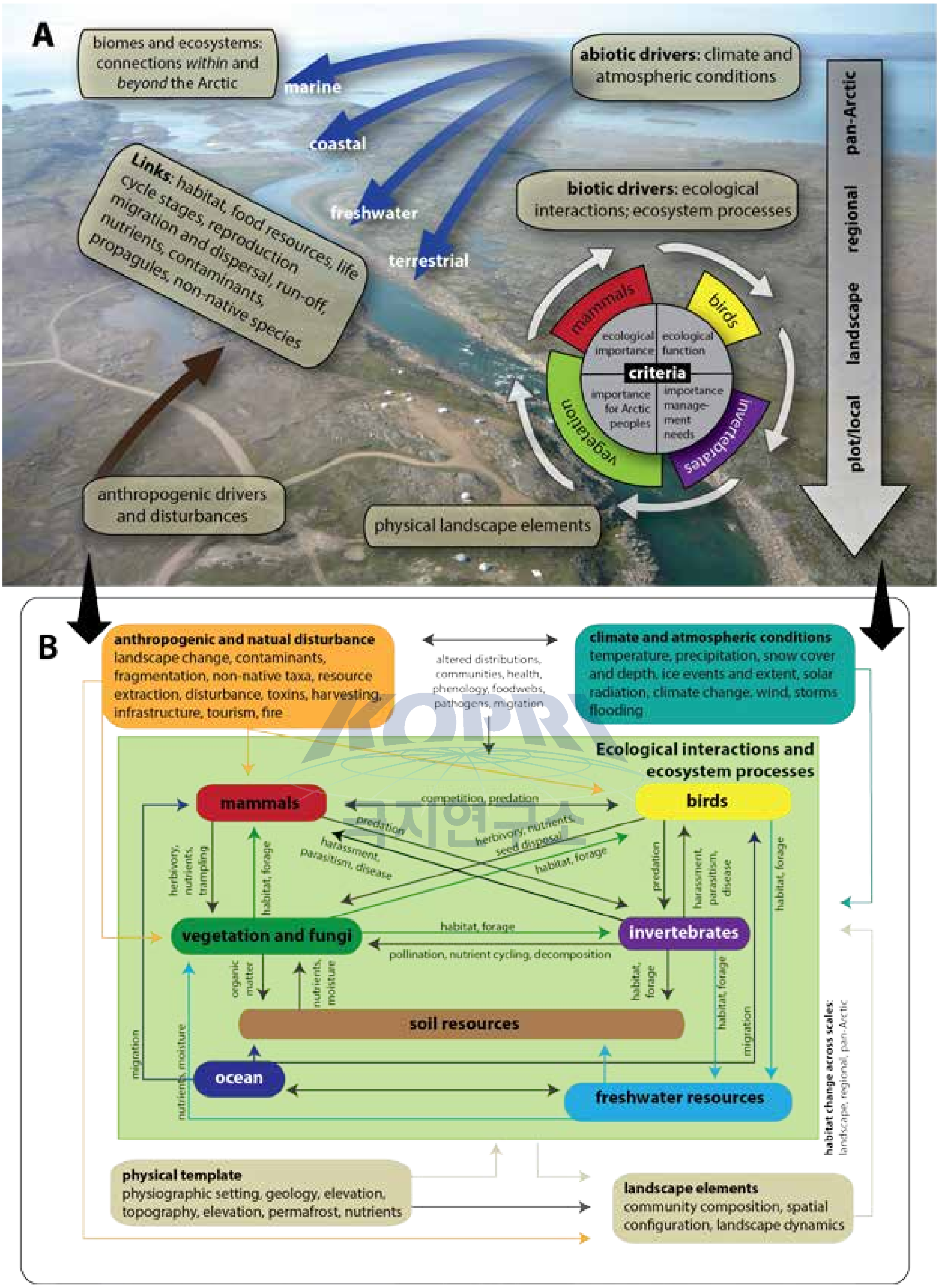


Figure 3.2 Overall conceptual model of the Arctic terrestrial biome showing key biotic and abiotic model elements and their primary interactions.

A. Overview of large-scale linkages among terrestrial, marine, freshwater, and coastal biomes, including major drivers that influence biodiversity, and the key biotic groups.

B. Example ecological interactions and ecosystem functions, drivers, and linkages among biotic groups for the terrestrial biome.

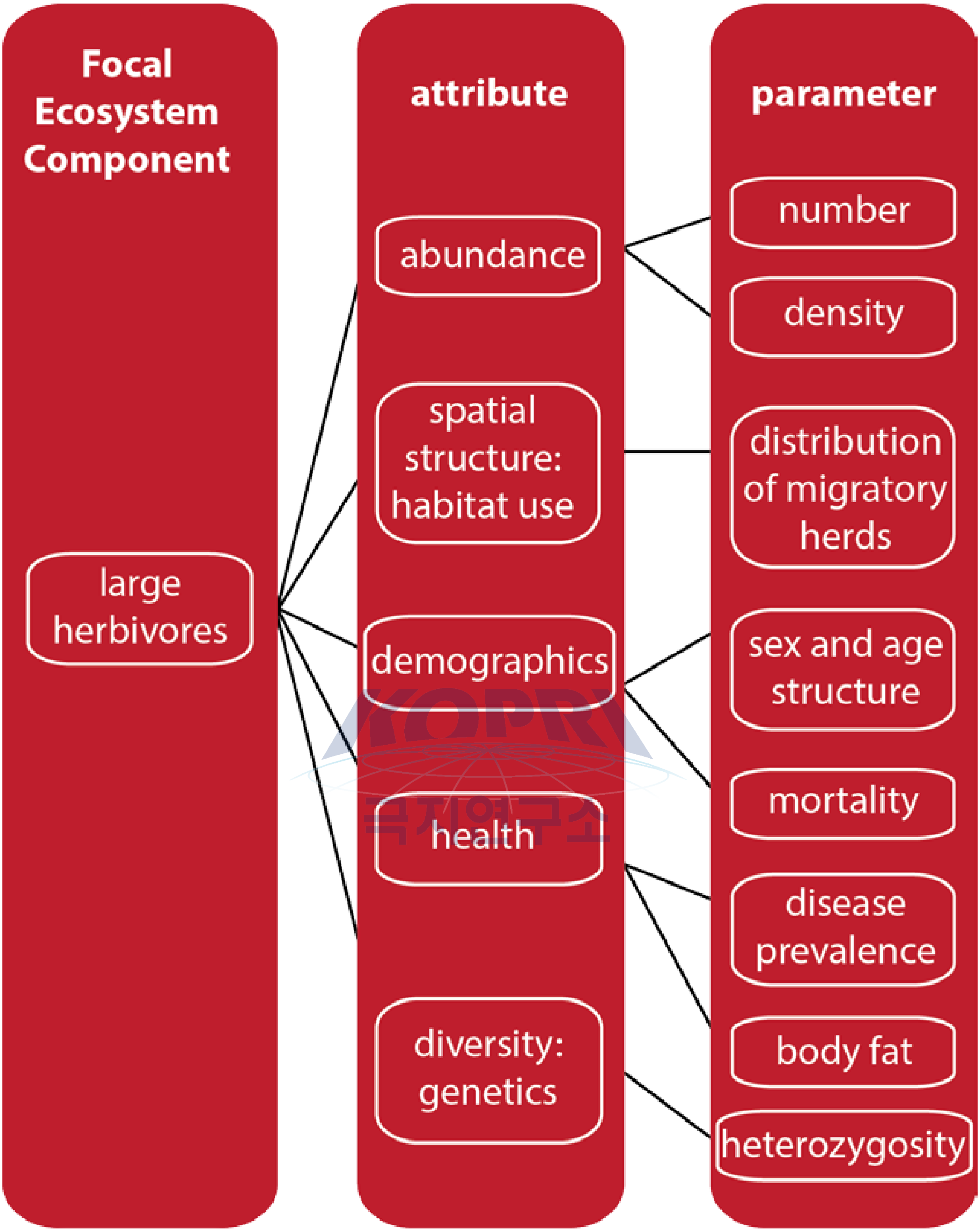


Figure 3.3 The nested structure of the TEMG monitoring scheme, here exemplified by large herbivores.

3.4 Sampling design

3.4.1 Sampling design and statistical considerations

The sampling domain for developing a cost effective experimental design for the CBMP-Terrestrial Plan includes all of the area covered by the CAVM map (2003) (Figure 2.1) as described in Chapters 1 and 2. Across the vast CAVM area, tundra ecosystems change locally (with topography, soil conditions, disturbance history, and local-scale, abiotic driving processes such as riverine or estuarine flooding and slope seepage, ground ice processes, and snow effects), across watersheds and landscapes (with aspect, elevation, exposure, snow phenology, distribution, condition and depth, hydrology, mineralogy of bedrock and soil parent material), and across the circumpolar Arctic where vegetation physiognomy (low shrub, dwarf shrub, herb) changes along climatically-defined bioclimatic zones (south to north, east to west, and with elevation). Other factors that impact tundra vegetation composition, structure and productivity include biogeographic histories, dominant bedrock, and unique interactions with drivers such as rates and kinds of herbivory, pests and diseases, and various anthropogenic effects.

Capturing all of this variability in a randomized experimental design in an attempt to answer the questions outlined in Chapter 3 is unfeasible given the vast geographic areas under consideration, remoteness, and limited resources. Given the limited number of sample locations possible due to the scale required and logistic limitations, truly representative sampling for all parameters is unrealistic. Rather, the sampling for the CBMP-Terrestrial Plan is designed to take advantage of existing resources and monitoring capacity including research stations and infrastructure, studies and programs, and mandated and regulatory monitoring conducted by many government agencies, industry, universities and research institutions, and communities; see Fig. 2.2, Appendix A and Figures A1 - A4. The CBMP-Terrestrial Plan will use results from existing monitoring platforms and stations as "example" or "index" sites to describe the status of Arctic biodiversity elements at a global scale. It is recommended that statistical rigor is employed starting *at the plot or study scale* (for data collected at index sites) with the intent to scale-up plot-level results from existing monitoring platforms and stations within Arctic ecosystems to regional or pan-Arctic scales through harmonization of local data, modeling and remote sensing techniques (Figure 3.1).

3.4.2 Stratification and representativeness

In addition to the nested spatial scales of sampling from plots to the pan-Arctic (Fig. 3.5 and 3.6), the CBMP-Terrestrial Plan will utilize an initial stratification of the circumpolar Arctic into the high-Arctic, low-Arctic, and alpine areas of the sub-Arctic. Representative monitoring across relevant ecosystem types, climate gradients and moisture regimes, and exposure to anthropogenic pressures will be sought. Vegetation based sampling, analyses, and reporting will be more specifically stratified by bioclimatic subzones as delineated by the CAVM (CAVM; Figure 2.1 and 2.2). Efforts such as the Arctic Vegetation Archive (Walker and Raynolds 2011) will further support stratification by ecosystem type. At the regional and pan-Arctic scale, data from all sampling strata and across ecosystem gradients are desired. It is clear from a preliminary assessment of long-term biodiversity monitoring capacity that some geographic and ecological areas of the Arctic will be underrepresented with this approach (Appendix A). Thus the five-year startup and implementation phase of the Plan will serve to refine the sampling design and index site identification (see Chapter 1.6). In the start-up phase, oversampling is recommended where capacity exists in order to determine required sample sizes to obtain sufficient confidence and power at a site level.

Through preliminary integration and analysis of existing data, priority gaps in sampling coverage, the required number of replicate samples, and which attributes and parameters provide the most robust and relevant data will be identified to narrow and refine the monitoring approach. Existing monitoring platforms, stations and data will be evaluated to determine representativeness for a given sampling strata, region, or biodiversity FEC and to recommend future monitoring to fill gaps and capacity to support integrated, place-based assessment of biodiversity drivers. Such post-hoc analyses will provide a reasonable estimation of ability for local, subjectively selected, Arctic monitoring platforms and stations to adequately represent biodiversity conditions and trends across the entire Arctic. As an illustration, Figure 3.6 shows how monitoring can be conducted where feasible at present and in the future, from local to pan-Arctic scales, integrating across biotic and functional groups, and starting with basic methods complemented by advanced analyses where capacity exists.

3.4.3 Limitations

Although Arctic biodiversity is low as compared to other regions of the world, the Arctic hosts a varied array of ecosystems and highly specialized and endemic species. Given this, and the large geographic extent of the circumpolar Arctic, and the climatic, geological, and geophysical variability involved, it is not realistic to fully represent all Arctic terrestrial ecosystems and ecosystem components in a biodiversity monitoring program. Even considering the full range, possible sources and coverage of monitoring data, the CBMP-Terrestrial Plan is not intended to provide fully integrated, multi-ecosystem indices on the health and/or condition of the Arctic terrestrial biome. Rather, the primary focus of the Plan is to allow for reporting on the status and trends of many key biodiversity elements within the terrestrial environment. That is, the Plan intends to use monitoring data from around the Arctic to report representative examples of the health or condition of biodiversity and/or ecosystems in the Arctic, without necessarily being able to report on the overall health and condition of the Arctic as a whole.

Nevertheless, the Plan is conceptually ecosystem-based, and wherever possible, considers integration across taxonomic and functional groups, and integration across biomes including terrestrial, freshwater, coastal and marine habitats, and considers drivers such as abiotic, biotic and anthropogenic elements. The monitoring demand of a 'full-factorial' treatment of biodiversity elements and interactions across all ecosystem types at the entire pan-Arctic scale is not practical for any one Plan.

3.5 Data collection approach

3.5.1 Harmonization and standardization of protocols and data

The CBMP-Terrestrial Plan largely focuses on harmonizing existing monitoring data, however, where opportunities for new monitoring exists, standardized monitoring approaches are suggested. Harmonization in the context of this Plan means combining data collected with different methods, either through direct integration, combining derivative products, or through modeling. The goal is to maximize the use of available data, both existing and future, while allowing flexibility to meet local monitoring needs. Before combining data from disparate sources, collection methods will have to be evaluated to determine if they are similar enough so that resultant data can be combined directly or if a derivative product will be necessary. Harmonization is aided where necessary by an approach that allows for focusing on broad taxonomic groups for analysis and reporting while providing flexibility to select different species for monitoring depending on local needs and interest.

The TEMG supports standardization of biodiversity monitoring methods, where appropriate. Standardization means to apply the same methods for data collected across the entire Arctic and is limited to new monitoring efforts rather than data monitored for decades using various methods. For new monitoring, the adoption of robust, standardized monitoring protocols will ensure the validity and consistency of the data and demonstrate to end users that results are reliable. In some cases, however, the opportunity to standardize monitoring protocols will be limited due to natural heterogeneity of desired monitored parameters among regions or the existence of long-term data sets following differing protocols. In such cases where standardization is not possible or practical, harmonization of monitoring methodologies will facilitate integration and assessment of data across regions and scales. The TEMG also supports standardization of taxonomy and robust synonymy.

During the start-up phase of implementation, methods to harmonize and/or integrate data from differing monitoring protocols, including TK, for the key parameters in the CBMP-Terrestrial Plan will be identified, and developed as required. This may involve creating strategies to calibrate data from one protocol with another and to calibrate between differing levels of study precision or resolution. Maintaining documentation for the transformation or calibration process will be essential. Where these integration methods already exist (e.g., Elmendorf, et al. 2012), and have proven to be robust and rigorous, these will be reviewed by the CBMP-Terrestrial Plan and considered for adoption.

3.5.2 Sample processing and archiving

Some CBMP-Terrestrial Plan recommended parameters will require sample processing and further analysis, including specimen sorting, taxonomic work, genomic testing or contaminant testing. Much contaminant monitoring is already coordinated under the auspices of the Arctic Council's Arctic Monitoring and Assessment Program (AMAP). Methods for sample processing should follow recommended protocols. Where required, coordinated, clear procedures for sample processing should be developed and standardized or calibrated. The procedures must describe the chain of responsibility for sample processing and maintain high standards. Where such procedures exist, they should be harmonized. Some methods for sample processing specifically related to each biotic group are described in Chapter 4.

At this time stable isotope and trace element analyses are limited under the CBMP-Terrestrial Plan. However, these methods show excellent potential to facilitate and complement future monitoring activities, and inclusion of such tools in current initiatives through collaborations is recommended where sampling and sample storage can be accommodated as a minimum.

The CBMP-Terrestrial Plan recommends that participating monitoring agencies follow standardized protocols for appropriately storing and archiving biological data collections. This will be true for all data sources including remotely sensed products, genomic data and biological samples. For example, vegetation samples may be stored in herbaria, including digital herbaria, and invertebrate samples should be sorted, preserved in ethanol, and stored in long-term cold storage, as described in Chapter 4. Appropriate DNA preservation of samples will enable future barcoding analyses. Long-term, environmental barcoding methods have potential for use in Arctic monitoring plans (e.g., next generation sequencing (Hajibabaei, et al. 2011), but in the shorter-term (i.e., 10-15 years), sorted, identified specimens are required to fill in the immense gaps in knowledge about Arctic invertebrates.

Once the methods for collecting and processing data are harmonized, the integration and analysis of existing data is recommended to inform an assessment of baseline conditions and trends to date. The data assessment tools or method will depend on the FEC, attribute and parameter of interest and the spatial scale over which the analysis is required.

3.5.3 Potential data analysis methods

Data from CBMP-Terrestrial Plan partners will be integrated where possible, or harmonized where necessary, to provide assessments of the status (and possibly trends) and natural variation in FEC attributes. Many analytical methods are possible across spatial or temporal scales. The specific method used will be selected as part of the implementation phase and tailored to the FEC, attribute, and parameters under study. Potential analytical methods include:

- Meta-analysis methods that combine results of individual studies using a statistical approach to generalize results to a broader population or area, and improve the precision and accuracy of estimates. Meta-analyses are often used in Arctic systems to study observed changes over the pan-Arctic region because of the low sample sizes of individual studies and huge geographic area under study. For examples of meta-analyses, see Dormann and Woodin 2002; Elmendorf, et al. 2012; Myers-Smith, et al. 2011; Rigét, et al. 2010; Rigét, et al. 2011;
- Multi-variate analysis, ordination methods, or Permutational Multivariate Analysis of Variance to look at changes in community structure over time;
- Analyses of taxon sampling curves for high diversity taxa, to assess completeness of sampling efforts and for estimates of species richness at various spatial or temporal scales;
- Parametric statistical analyses, such as Analysis of Variance, autoregressive models, or General Additive Models;
- Calculation of diversity indices or species trend indices;
- Remote sensing discrete classification or fractional land cover change detection (Fraser, et al. 2011; Lantz, et al. 2010; Mouat, et al. 1993); and,
- Analyses of population genetic structure and phylogeography, and novel genetic tools, where appropriate and when capacity exists, to asses dispersal patterns or changes in these patterns over time and to understand cause/effect relationships affecting biodiversity and ecosystem function and structure (See Table 3.3).

Modelling will be used where possible to harmonize data from various scales and sources and to upscale/downscale identified trends. By combining local information, including TK, with information on changes in FEC attributes and abiotic drivers, with the geographic extrapolation abilities of remote sensing, modeling will serve to extend local results to broad areas of the circumpolar Arctic where direct monitoring information is lacking. Models are also useful to predict and test potential future scenarios and will further elucidate possible changes and inform proactive adaptive management.

Table 3.3 Types of potential genetic and chemical analyses to support CBMP-Terrestrial Plan implementation.

Tools and analyses	Example applications	Reference
DNA analysis and barcoding	Population studies; species identification; presence or absence of taxa, diet analyses and food web dynamics	Darling, et al. 2007; Deagle, et al. 2007; Idaghdour, et al. 2003; Spies, et al. 2006; Thomsen, et al. 2012
Phylogeographic and phylogenetic analyses	Understanding diversification, distinguishing expanding immigrant lineages from endemic taxa, tracing the origin of individuals, following colonization routes, and tracing species invasions and epidemics	Caldera, et al. 2008; Diaz-Perez, et al. 2008; Holderegger, et al. 2003; Lindqvist, et al. 2010
Population genetics (sampling individuals within or/and among populations)	Diversity (heterozygosity, the number of alleles and their frequency), genetic structure and meta-population dynamics (sources and sinks; population age), inbreeding and/or outbreeding depression	Faria, et al. 2010; Ludwig 2006
Comparative studies of functional genes	Ability of species and populations to adapt to future change	Andersen, et al. 2009; Pörtner, et al. 2007
Biogeochemical analyses of stable isotope signatures, contaminants and trace elements	Species movements, investigating population declines, inferring diet and shifts in trophic levels, and environmental conditions including the presence of toxins (e.g. temporal diet shifts and population bottlenecks have been inferred for some avian species following DDT exposure)	Brown, et al. 2007; Chabot, et al. 2012; Choy, et al. 2010; Clegg, et al. 2003; Kristensen, et al. 2011; Krummel, et al. 2003; Nocera, et al. 2012; Pisaric, et al. 2011; Webster, et al. 2002
Behavioral focal studies	Movement, habitat use, threats to populations and their location, and the adaptive potential of populations as prey distributions shift or as food webs change	Kanai, et al. 2002; Suryan and Fischer 2010; Webster, et al. 2002; Woo, et al. 2008

3.6 Multi-scale monitoring

Data collection and analytical methods and reporting will be multi-scale and will include plot-based ground measures, remotely-sensed products, and sampling of species, populations, and communities. At the local (plot or site) scale, data will be collected on individual species, life forms, or functional guilds as appropriate, on ecological interactions and ecosystem functions, and on drivers, to the extent that capacity exists (see Box 4B). At landscape scales, the composition, structure and diversity of populations, communities, or ecosystems will be measured; and finally, at the regional or pan-Arctic scale measures will focus on landscapes and/or regions and relevant features.

Methods that detect change at scales from local to landscape and provide complementary information are essential. The various approaches can be designed as layers and combined during data collection, analysis, and/or reporting. Multi-scale integration between and among the monitoring efforts will increase the probability of detecting change, will support up- and down-scaling of identified effects, and will create a more effective monitoring scheme. CBMP TEMG aims to identify and assess trends at the appropriate scale relative to the monitoring question, but attention will be given to scales from landscape to pan-Arctic, versus site-specific reporting (see Chapter 7).

Monitoring Arctic biodiversity with ground-based sampling and a number of remote sensing platforms in an integrated manner offers an opportunity to complete a pan-Arctic assessment for a number of priority FECs. Ground-based monitoring data will be used to derive local estimates of status, trend, and condition where robust data exist. These ground data can also be used to validate remote sensing products where applicable, which can then be used to extrapolate ground-based resource estimates to broader areas (especially for vegetation characteristics) which are logistically or financially difficult to access or completely inaccessible. Combining ground sampling with remote sensing observations will provide a regional context for detailed ground measurements. Fine spatial resolution remote sensing data and ground sampling can also be combined to better interpret coarse resolution (1km) satellite data so that pan-Arctic classifications are possible.

The ecosystem-based approach encompasses a range of scales from local to circumpolar including all major functional groups represented by priority FECs (Figure 3.4 and 3.5).Targeted research-based monitoring and experimental research implemented via linkages with research collaborators and networks such as INTERACT will anchor the program, and will be designed to link measured changes in FECs, attributes, and parameters to measured changes in ecosystem drivers and processes to establish causal relationships for the changes observed. Such long-term installations can also be used to integrate the key biotic groups of the CBMP-Terrestrial Plan to understand ecological interactions and to draw functional connections among these groups and the physical environment. Co-locating monitoring measurements of FEC attributes at integrated, long-term monitoring sites is therefore highly desirable. Figure 3.7 shows a hypothetical example of a general integrated plot-based monitoring site approach. Local scale results at research stations can be combined with broader scale surveillance monitoring (wide-ranging mammals, migratory birds and remote sensing), to develop a coherent picture of Arctic biodiversity change, and an understanding of the reasons for the changes reported including the presence of drivers such as climate change, shifts in species ranges including changes in pathogens and more southern species, land use changes, and others.

The CBMP-Terrestrial Plan will maximize the use of existing monitoring investments through efficient, effective designs integrated across multiple scales by applying the following approaches:

i) establish monitoring of both **essential** and **recommended** field monitoring attributes at a core network of long-term, integrated monitoring sites including both basic and advanced protocols;

ii) for the essential attributes, establish a core set of basic field monitoring protocols to be applied as broadly as possible through engagement and collaboration with existing and potential new monitoring programs; and,

iii) conduct spatial up-scaling from local to broader geographic scales through (a) modeling, (b) meta-analyses, and (c) integration of field or high resolution spatial data with broader scale, coarser-resolution remote sensing.

To integrate across spatial scales, regions, biotic groups and datasets to facilitate monitoring and detecting trends and changes in Arctic ecosystems, the following methods will be incorporated.

i) **Targeted, research-based, cause-and-effect monitoring**

Scale of analysis: local to landscape or region. Locally derived results can be extended to broader geographic regions through integration with remote sensing (see Box 4A).

What: The CBMP-Terrestrial Plan recommends monitoring of both **essential** and **recommended** attributes at a core network of long-term, integrated monitoring stations and other sites as capacity allows. Monitoring related to all terrestrial biotic groups as well as relevant abiotic factors/physical drivers should be conducted at these stations in an integrated fashion. Monitoring will include both the core set of **basic** and **advanced** protocols that can help to elucidate cause and effect relationships. Ideally there should be three to five intensive monitoring stations within each CAVM bioclimatic subzone (Fig. 2.2; example in Fig. 3.6) to minimally capture spatial variability. Monitoring study design should include the range ecosystems, and be statistically valid with sufficient power at the site level. The design should include, for example, stratified, randomly placed long-term plots and transects as capacity allows (see Fig. 3.6 and 3.7). Not all ground stations may meet these specifications through current monitoring. Those that do can stand as reference sites as monitoring capacity expands (see Box 4A), and as existing stations re-implement their monitoring programs. This monitoring can be used to:

- understand cause and effect relationships and specific process-based monitoring questions and ecosystem interactions;
- training and validation of multi-scale remote sensing;
- contribute to status and trend surveillance; and,
- model observed changes and relationships from local to broader geographic scales

Who: Arctic researchers and Arctic research facilities and operators including participating INTERACT/SCANNET sites and other high capacity Arctic research sites and stations. Partnership with researchers in the International Study of Arctic Change **http://www.arcticchange.org/** and the International Arctic Science Committee (IASC: **http://www.iasc.info/home/iasc**) will support delivery.

Where: An inventory showing the locations of potential contributors is shown in Figure 2.2.

ii) Survey based, status and trend monitoring

Scale of analysis: Landscape/regional to pan-Arctic

What: As compared to targeted monitoring, survey-based, status and trend monitoring generally employs a smaller set of commonly less complex monitoring methods, but at a much larger number of sites and stations. Survey-based sampling should include implementation of the **essential** attributes and **basic** monitoring protocols and should be conducted by a number of collaborating partners to greatly increase the geographic range over which the CBMP-Terrestrial Plan can detect changes. Survey-based monitoring can also include co-location of monitoring across and between biotic groups, as described above and illustrated in Figures 3.6 and 3.7 (also see Figures A1 to A4). Extensive monitoring recommended by the CBMP-Terrestrial Plan includes:

- understand and describe conditions and trends across broad geographic and temporal scales, and address scale-appropriate management and monitoring questions;
- provide regional and/or global context for interpreting locally collected cause and effect monitoring;
- train and validate multi-scale remote sensing; and
- model observed changes and relationships from local to broader geographic scales.

Who: Current and potential Arctic monitoring contributors including governments at various scales, industry partners, parks and protected areas, academia, protected area monitoring practitioners, and communities including community based monitoring projects and networks such as *eBird*, wildlife observing, phenology networks and checklists.

Where: Use remote sensing to understand representativeness of all sample locations within each stratum. Compare these sites/facilities and their geographic and thematic distributions and propose new sample locations to fill critical gaps in relation to bioclimatic subzone/strata and national boundaries.

iii) Mid to low resolution remote-sensing for modelling, and status and trend sampling

Scale of analysis: Regional to pan-Arctic.

What: Monitoring Arctic biota and drivers with a number of remote sensing platforms collected at a variety of spatial and temporal scales in an integrated manner in conjunction with ground-based sampling offers an opportunity to expand the results of ground based sampling to the pan-Arctic area (see Figure B1 and Tables B1 to B3). Using these data, functional relationships between abiotic drivers and biotic response measures developed at experimental sites can be interpolated to broader areas using the range of available remote sensing platforms. Fine spatial resolution remote sensing data and ground sampling can also be combined to better interpret coarse resolution (1 km) satellite data so that pan-Arctic classifications are possible. Remote sensing derived information on weather, climate, sea ice, and the coastal marine environment can support terrestrial biodiversity monitoring modeling activities (Appendix B). Remote sensing technologies continue to rapidly evolve and the CBMP-Terrestrial Plan aims to take advantage of these emerging technologies when possible and where appropriate.

Who: Current and potential Arctic vegetation monitoring contributors with appropriate expertise in modelling, remote sensing and scaling techniques. This may involve teams of sub-national, national and international remote sensing specialists and academic researchers working together to develop analyses that support different jurisdictions and taken together can represent the whole Arctic area.

Where*:* Remote sensing and modelling approaches can be applied across the entire circumpolar Arctic, or sampled using stratified random approaches.

Photo: Natalia Davidovich/Shutterstock.com

3.7 Establishing reference conditions (baselines)

3.7.1 Approach to establishing baseline conditions

Points of reference against which the status of populations, species, or ecosystems can be compared are required to assess change and condition in a meaningful way. Baselines provide a starting point for analysis of change (Dunster and Dunster 1996). The baselines for trend analysis are parameter-specific.

Nielsen et al. (2007) identify four potential sources for establishing baselines or reference points: (1) protected areas or other spatial benchmarks (i.e., comparisons of areas unaffected by a given driver, such as a control site, to areas affected by the driver); (2) time-zero (arbitrary date or level); (3) desired goals or targets (management goals); and (4) modeled reference conditions using empirical estimates.

The Arctic is impacted by some drivers affecting the entire region including climate change and contaminants, for which a spatial baseline or "control" cannot be fully derived. Other drivers, such as anthropogenic footprint, are spatially differentiated so that reference sites can be used to assess changes between impacted and non-impacted sites.

In the absence of global management goals or targets for Arctic biodiversity, focal ecosystem attributes and detailed empirical data on historical biodiversity trends from which modeled reference conditions could be derived, the CBMP TEMG is recommending baseline conditions be established using a combination of (1) current and historical data analyzed over time to establish a range of historical variation (for as many years of historical data that are available) and (2) benchmark or reference sites, as appropriate for a given attribute and time zero approaches where historical baselines cannot be derived. Protected areas and appropriately situated field stations conducting integrative monitoring (e.g., SCANNET/INTERACT sites) could act as suitable spatial reference sites. The TEMG recommends seeking out and integrating the best available historical and current data as the basis for reporting FEC attribute changes, and hence, changes in biodiversity and ecosystem integrity into the future.

Assessing the range of variation needs to be at the appropriate ecological scale. For example, for cyclical populations, the CBMP-Terrestrial Plan may assess both the population amplitudes and the cycle periods.

3.7.2 Sources of baseline information

During the start-up phase, temporal and spatial information of selected parameters will identify baseline conditions ascribed to a particular point in time or space and describe a parameter's range of historical variation. Sources for this historical information will include TK and existing long-term monitoring data. Audio recordings from TK holders, which describe changes over a period of time, can be a useful source of information for time-zero analysis. Initiatives such as the International Polar Year "Back to the Future" research project **http://www.btf.utep.edu/**) are particularly helpful for establishing long-term trends and natural variation. Satellite imagery and aerial photography provide a rich and extensive source of historical information. Satellite imagery for most of the circumpolar Arctic can be compiled to establish baselines dating back to the 1970s or 1980s and aerial photography is available for some Arctic locations dating back to the 1950s and earlier. An Arctic Vegetation Archive (Walker and Raynolds 2011) will be a helpful tool for assessing the baseline of Arctic vegetation communities. Museum records, inventory data and published literature will also assist in building the historical ecological conditions or baselines. Potential sources of baselines in archives, libraries, sources of grey literature and maps, electronic records, museum collections, and herbaria, and even living biological collections (zoological parks and aquaria, conservatories and botanical gardens) continues to grow rapidly (Casas-Marce, et al. 2010; Thomsen, et al. 2009; Tsangaras and Greenwood 2012; Vo, et al. 2011). Identification and digitization of historic datasets will likely be required to assist in establishing baselines. Where this has been done, access and coordination of historical datasets would follow.

Natural archives in sediment are particularly valuable baselines, and in some cases are the only baselines for some species or regions, and can be sampled later in time. These archives have the advantage that data and samples can be simultaneously obtained for contemporary and historic times. Sediment cores can serve as repositories of pollen and microfossils, DNA, and contaminants that can help infer changes in surrounding ecosystems and climate through time. Microfossil identification (e.g., Jørgensen, et al. 2012) and new advances in DNA barcoding and stable isotope chemistry can complement focal studies and monitoring where capacity exists.

Establishing baselines from these and other sources should include an assessment of the reliability of the underlying data. Further, establishing baselines from existing data may not be possible for all taxa, notably those which are data-deficient (e.g., terrestrial invertebrates). Several years of data collection following implementation of the CBMP-Terrestrial Plan may be required to identify preliminary spatial and temporal.

Box 3A: Genetic tools for monitoring programs, focal studies, and for obtaining baselines.

Ancient DNA methodology and advances in wildlife forensics and genomics have been invaluable in studies of populations even when species have migrated out of an area, are rare or difficult to study, or are sensitive to direct disturbance. Through improvements in technology in laboratory equipment (e.g. , next-generation sequencing technologies) and computing (e.g., computation-intensive analyses and data storage), and through the continued optimization of sample-collection, preservation, extraction, and screening methods, hair, feathers, egg fragments, carcasses, skins, and fecal samples can be used for studies of species. For example, even short fragments may be useful for species identification and clarifying systematics (e.g., DNA barcoding and environmental sequencing) (Allcock, et al. 2011; Spies, et al. 2006; Thomsen, et al. 2012), and for inferring the presence or origin of taxa in historic samples (Lee and Prys-Jones 2008; Lindqvist, et al. 2010; Martin-Gonzalez, et al. 2009). Novel cryptic species and their status as endemics or representatives of cosmopolitan taxa have been uncovered by complementing other morphology-based taxonomic or lab culturing approaches (D'Elia, et al. 2008; Darling, et al. 2007; Friesen, et al. 1996; Kreier, et al. 2010; Vecchione, et al. 2009). Genetic studies can support behavioural studies of reproduction (Ibarguchi, et al. 2004; Lunn, et al. 2000), and even of the future reproductive potential of species through dormant egg or seed banks (Gómez and Carvalho 2000). Genetic approaches continue to be costly, but the availability of freely-accessible bioinformatics databases such as the Barcode of Life Database **(http://www.barcodinglife.com/)**, GenBank **(http://www.ncbi.nlm.nih.gov/genbank/)**, and the European Bioinformatics Institute **(http://www.ebi.ac.uk/Databases/)**, provide outstanding resources to facilitate low-cost but high-quality and high-impact research and understanding of historical distribution and diversity of species.

3.8 Establishing thresholds of concern

In order to establish ecologically relevant thresholds of concern, one must understand how resilient a system is and where the system's ecological tipping points reside. Ecological tipping points are locations along a gradient of change where a small change in external conditions can result in a drastic change in the structure and composition of a system (Groffman, et al. 2006). Such changes are often abrupt and may be irreversible. In some cases, multiple stable steady states exist and systems may fluctuate between the two states without loss in ecosystem function. Changes between states may be driven by both anthropogenic and natural disturbance (Van der Wal 2006). Change in ecosystems is natural, but the pace, magnitude and cumulative impact of biodiversity drivers may push ecosystems beyond normal system variation.

Tipping points are scale-dependent. For example, the minimum number of individuals to maintain a viable population of a particular species is a biological tipping point. It is possible that a species could go locally or regionally extinct, without loss of overall ecosystem function and structure, if other species can perform a similar function or if other system compensation mechanisms exist. In the Arctic, there is little functional redundancy in avian and mammalian biota, so the likelihood of other species assuming similar functional roles of a vulnerable species is reduced. This may render Arctic systems more vulnerable to drastic ecosystem shifts.

Tipping points are difficult to identify, because ecological relationships are often non-linear and characterized by uncertainty. Some Arctic vegetation communities, for example, are resistant to change and it may not be possible to detect ecosystem level responses until after a threshold is crossed (Hudson and Henry 2010). An additional complication for determining tipping points is that many populations of species and species relationships follow a cyclical pattern of ,for example, interactions of weather factors, the abundance of the forage available, and the density of predator species (e.g., lemmings). Establishing the range of variation for ecosystems, their communities, and other key components is essential to identify and understand biologically relevant tipping points, and subsequently, to derive biologically relevant thresholds of management concern. Determining range of variation necessarily involves analysis of long-term information.

Thresholds can also be assigned based on management goals or targets. These targets may be made based on best available scientific knowledge for the appropriate management of a given ecosystem, as well as the values and trade-offs considered by ecosystem managers and society. Common goals and targets for Arctic biodiversity have not yet been well-defined.

The CBMP TEMG implementation plan will strive to understand the historical range of variation for each FEC-attribute parameter. For some parameters, sufficient information may already exist, while for others, establishing this variation will necessarily involve the collection of data over a period of years; particularly through focused monitoring at the integrative research monitoring sites (see Chapter 4). Where biological thresholds are unknown, statistical thresholds may be identified as interim thresholds until sufficient data is collected to understand variability. Ecosystems are subject to a range of local pressures and drivers which may have a cumulative impact on biologically identified thresholds. A clear understanding of the range of historical variation will allow managers to identify, as best as possible, biological and ecological thresholds in their particular context and assist Arctic managers and communities with evidence-based decision-making.

MANAGEMENT QUESTIONS TO GUIDE MONITORING

1. What are the statuses, trends, distributions, conditions and thresholds (if known) of terrestrial ecosystems, biodiversity, and key processes / functions in the Arctic?
2. How and where are these ecosystems, biodiversity and processes / functions changing?
3. What and how are the primary environmental and anthropogenic drivers influencing changes in biodiversity and ecosystem function?
4. Where are the regions of high ecological importance including resilient and vulnerable areas and where are drivers having the greatest impact?

FOCAL ECOSYSTEM COMPONENTS

Invertebrates, Vegetation, Birds, Mammals

ATTRIBUTES: Essential and Recommended

Priority, parameters and protocols selected depend on biotic group

- ***Diversity***: taxonomy, species presence/absence, genetic diversity & heterozygosity, community composition, rare and non-native species.
- ***Abundance***: number, density, percent cover, population size, etc.
- ***Composition***: canopy structure, morphology, ecological traits, etc.
- ***Phenology***: timing - breeding, migration, moulting, flowering, emergence
- ***Demographics***: sex ratios, age structure, longevity, birth rates, behaviour, population viability, population genetics
- ***Spatial structure***: distribution - landscape effects, clumping, social groups, migration patterns, connectivity, fragmentation, genetic structure
- ***Temporal cycles***: prey-predator cycles, seed-production and fire, etc.
- ***Health***: parasite loads, pathogens, mass and size, body condition, contaminants
- ***Productivity***: Biomass, NDVI , reproductive output, nutrient content, etc.
- ***Ecosystem functions and processes***: nutrient-cycling, decomposition, pollination

DATA COLLECTION

Surveillance and hypothesis-driven monitoring, community-based monitoring, experiments, traditional knowledge, focal studies

SAMPLING: Basic to Advanced

Parameters, methods, frequency and priority depend on biotic group and feasibility

SCALES: Local, Landscape, Regional, Pan-Arctic

Site-based: Surveys, sampling, measurements

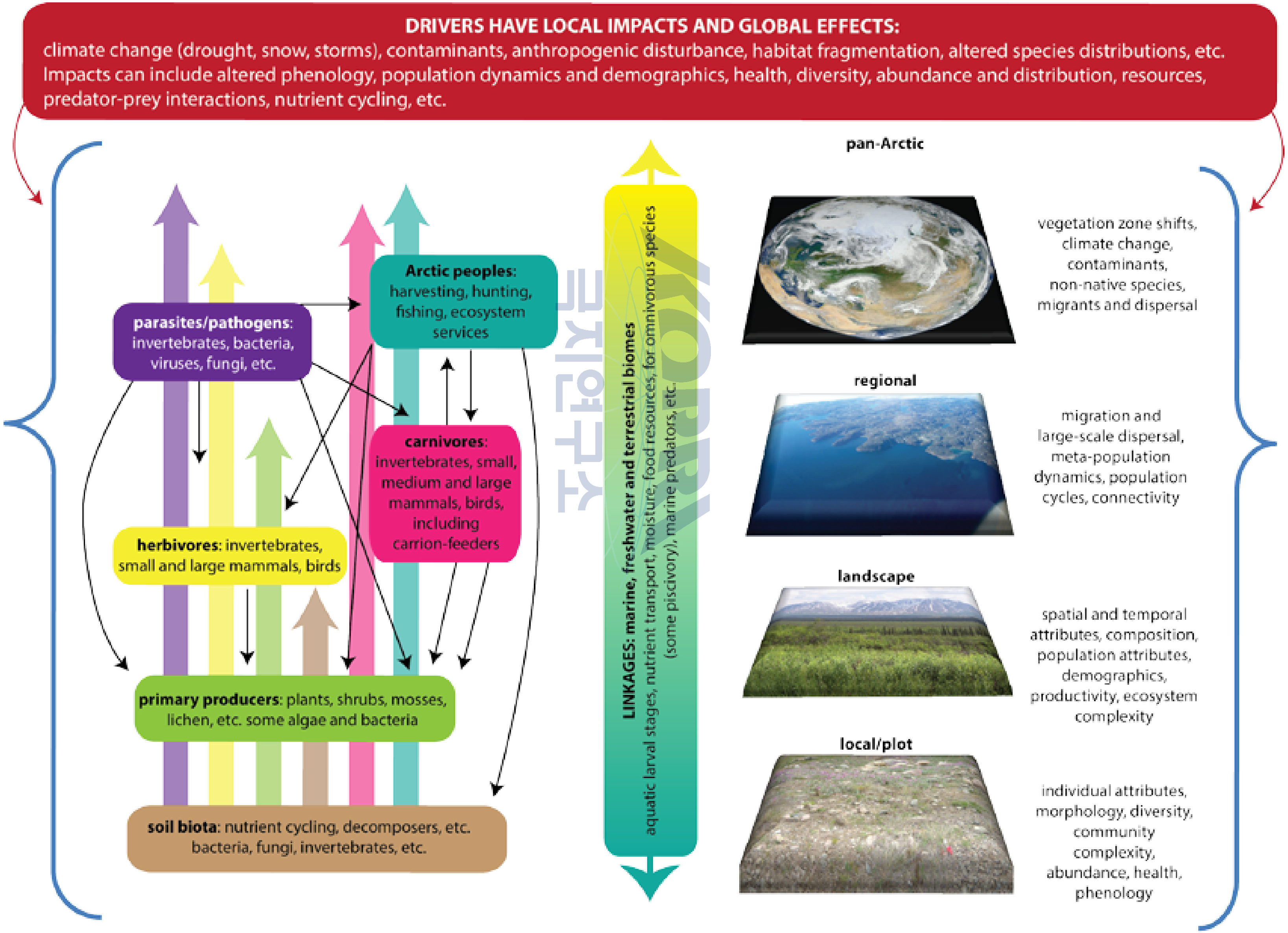
Large scales: remote-sensing, modelling, meta-analyses; may link to regions beyond Arctic

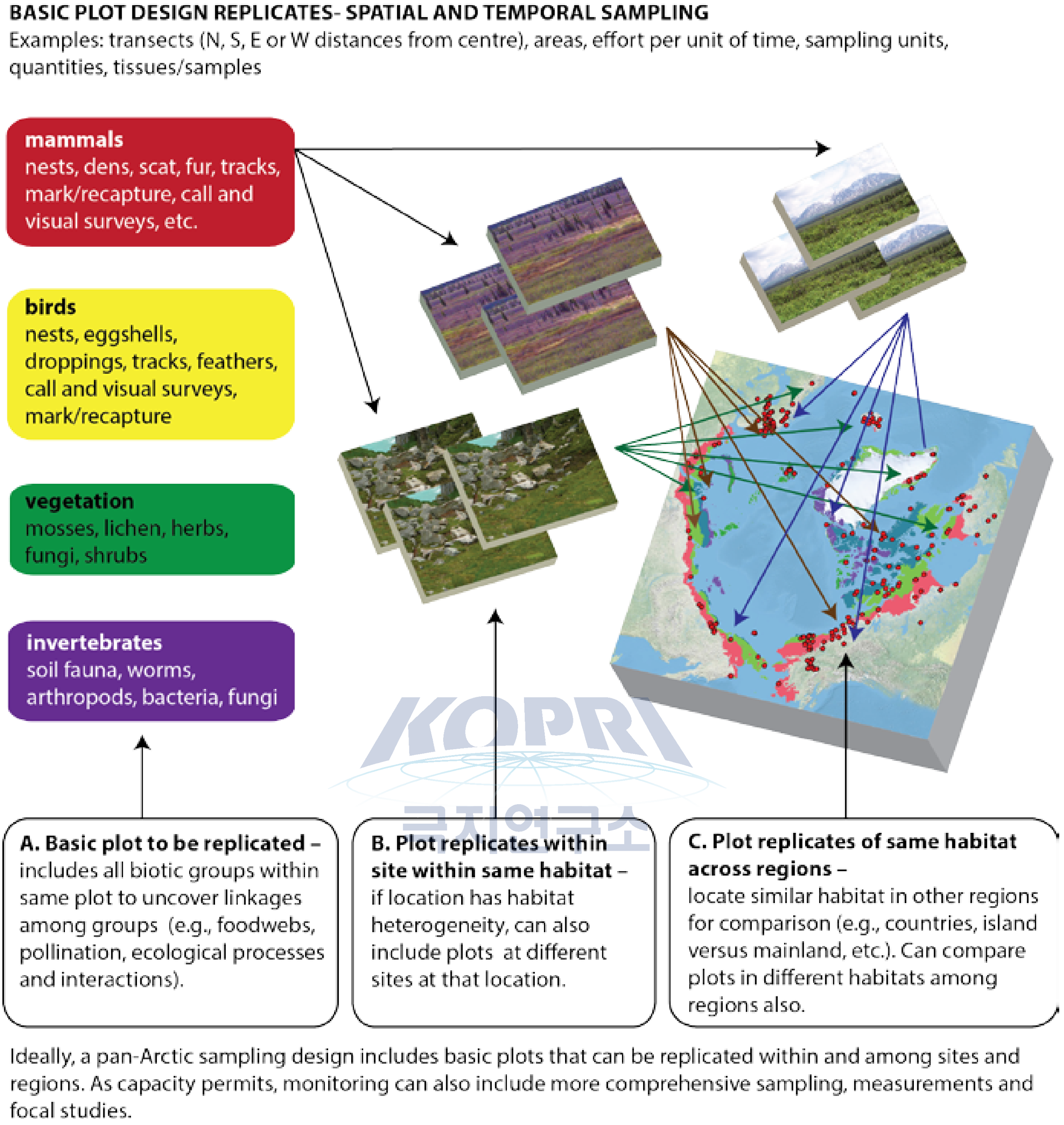
TEMPORAL RECURRENCE FOR SAMPLING AND MONITORING

Monthly to decadal sampling

Figure 3.4 Overview of management questions, FECs, attributes, and monitoring approach for terrestrial biodiversity in the Arctic.

Figure 3.5 Conceptual model of Arctic communities, terrestrial functional groups, foodwebs, ecological interactions and ecosystem processes operating from local to pan-Arctic scales. Abiotic, biotic and anthropogenic drivers can influence biotic groups and their attributes directly or indirectly at these spatial scales. Small black arrows indicate trophic or ecological interactions among functional groups; large coloured arrows indicate the approximate spatial scales relevant for biotic groups. Terrestrial habitats are linked to freshwater and marine biomes through the exchange of nutrients, the completion of life stages of organisms, and the transport of migrants and contaminants





BASIC PLOT DESIGN REPLICATES- SPATIAL AND TEMPORAL SAMPLING

Examples: transects (N, S, E or W distances from centre), areas, effort per unit of time, sampling units, quantities, tissues/samples

mammals
nests, dens, scat, fur, tracks, mark/recapture, call and visual surveys, etc.

birds
nests, eggshells, droppings, tracks, feathers, call and visual surveys, mark/recapture

vegetation
mosses, lichen, herbs, fungi, shrubs

invertebrates
soil fauna, worms, arthropods, bacteria, fungi

A. Basic plot to be replicated – includes all biotic groups within same plot to uncover linkages among groups (e.g., foodwebs, pollination, ecological processes and interactions).

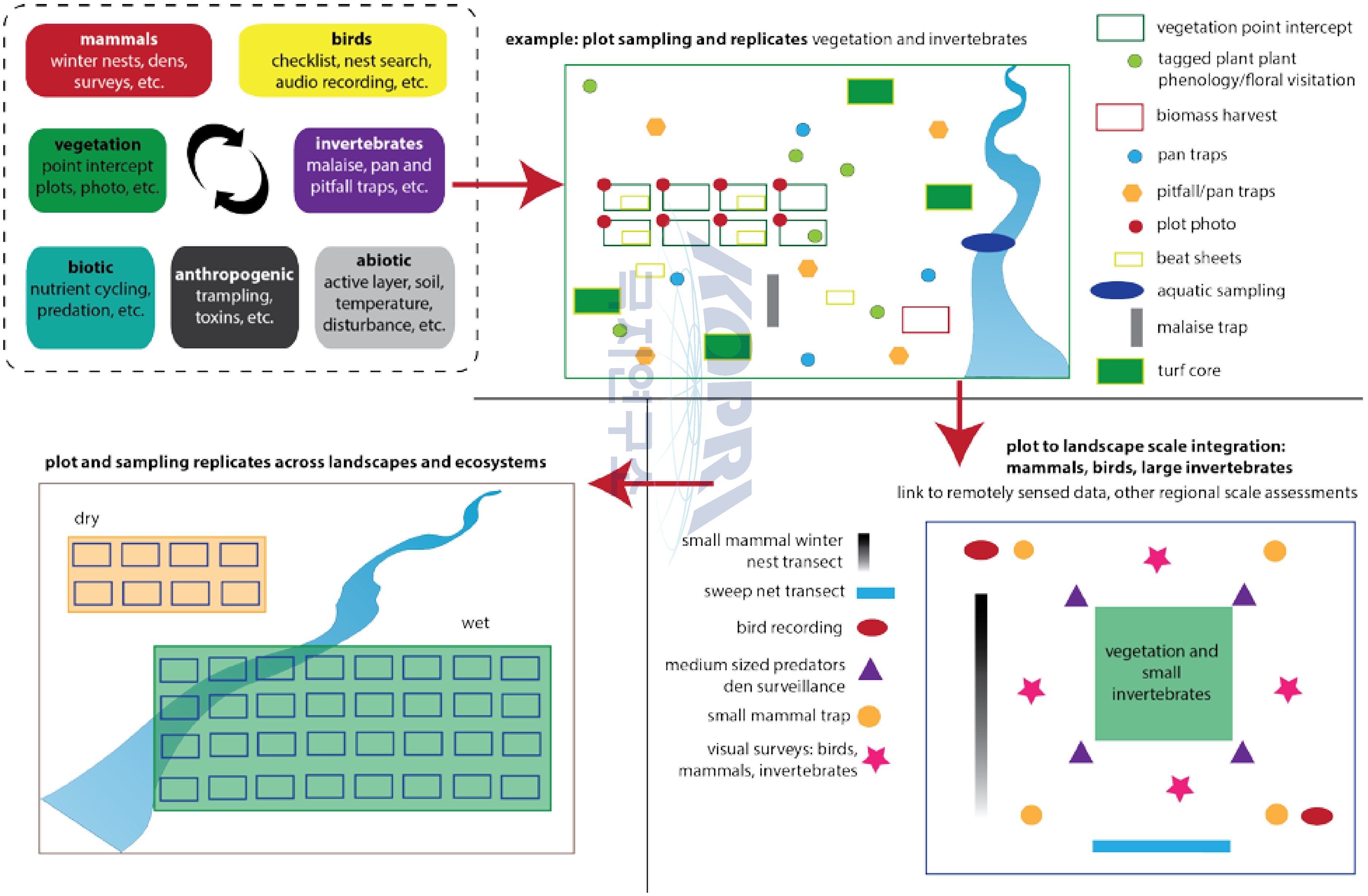
B. Plot replicates within site within same habitat – if location has habitat heterogeneity, can also include plots at different sites at that location.

C. Plot replicates of same habitat across regions – locate similar habitat in other regions for comparison (e.g., countries, island versus mainland, etc.). Can compare plots in different habitats among regions also.

Ideally, a pan-Arctic sampling design includes basic plots that can be replicated within and among sites and regions. As capacity permits, monitoring can also include more comprehensive sampling, measurements and focal studies.

Figure 3.6 Illustration of a basic, integrated, plot-based, replicated sampling design that can be implemented where capacity exists and in future monitoring efforts. The use of standardized protocols within plots facilitates data integration and analyses, and incorporating nested surveys and sampling across biotic groups within sites facilitates detecting trends in ecosystem function and ecological interactions.

Figure 3.7 Hypothetical example of plot-based ecosystem sampling and data collection for vegetation, invertebrates, birds and mammals, environmental conditions, drivers and interactions (top left). At each site sampling and data collection can be conducted following established protocols to enable repeated measurements for monitoring (e.g., top right: vegetation and small invertebrates; bottom right: larger invertebrates, mammals and birds). Bottom left: sampling replicates can be established from plots to ecosystems, from local to pan-Arctic scales.



4. Data collection and methods

4.1 Sampling metadata and site data

Sampling metadata

Metadata collected at each site should be consistent with metadata collection standards. Metadata is essential for users to understand how the data can be used and manipulated and to determine the accuracy and validity of the monitoring initiative. Best practices in the documentation of data collection procedures should be followed. Methodology used must be explicit in monitoring metadata, along with any alterations to the methodology. The metadata must clearly describe the datasets and all relevant information about the monitoring conducted including methods used, monitoring location and date, monitors and their skill level, etc. Along with the data suggested in the tables in the following biotic group sections in Chapter 4 and the site establishment data, the following metadata should be recorded with each monitoring event:

- Date of monitoring event, time of day
- Location name
- Site latitude and longitude
- Size of monitoring location
- Name(s) of monitors
- Experience/capacity of monitors (e.g., taxonomic expertise)
- Weather (temperature, humidity, precipitation)
- Observable physical and natural disturbance (evidence of grazing)

Site data

Plot level information should be collected when establishing a monitoring site and recollected at each site visit when relevant and possible. This includes:

- Climate data
- Description of topographic setting
- Elevation
- Aspect
- Slope angle at plot locations
- Proximity to ocean, snow or glaciers
- Local hydrology (proximity to streams, rivers, lakes and ocean)
- Snow depth
- Geology and soil description including
    - Parent material
    - Substrate lithology
    - Depth and homogeneity of soils across the study area
    - Depth of permafrost, depth of active layer, organic matter depth decomposition
    - Soil total carbon and nitrogen content (if possible)
    - Patterned ground type
    - Soil class
    - Soil pH
    - Soil temperatur
- Disturbance and land-use, proximity to roads/human settlements
- Dominant vegetation
- Plot digital photographs, following standardized procedures

4.2 Focal Ecosystem Components (FECs)

Invertebrates, vegetation, birds and mammals, the biotic groups selected for monitoring under the CBMP-Terrestrial Plan, represent all the major functional groups and trophic levels in Arctic terrestrial ecosystems; nutrient-cycling biota, decomposers, primary producers, herbivores, carnivores, carrion-feeders and parasites/pathogens (Figure 3.5).

4.2.1 Background on key biotic groups

4.2.1.1 Invertebrates

Arctic invertebrates exhibit high diversity (Danks 1981) are biologically intriguing (Strathdee and Bale 1998), and there is an increased recognition that arthropods play key ecological roles in northern systems. Invertebrates pollinate plants (Kevan 1972), are tightly linked to the decomposition process in the Arctic (Coulson, et al. 2000), are pests of wildlife (Hughes, et al. 2009), and are prey to highly valued vertebrates (McKinnon, et al. 2012b; Tulp and Schekkerman 2008). In a broader food-web context, there is growing evidence about the important role of arthropods in the north (Hodkinson and Coulson 2004; Legagneux, et al. 2012). Research is revealing how shifts in global temperatures are influencing arthropod populations and thus other species, including affecting wildlife as parasites (Hughes, et al. 2009), creating shifts in the biomass of vertebrate prey (Tulp and Schekkerman 2008), changing parasitic wasp assemblages (Fernandez-Triana, et al. 2011) and shifting the sexual dimorphism of spiders (Høye, et al. 2009). It is essential that these effects do not go unnoticed, and that additional research, including long-term monitoring, be completed on key species in northern systems including invertebrates – a topic that remains as critical today as when Callaghan et al. (1992) and Danks (1992) discussed it 20 years ago. Invertebrate life cycles are directly influenced by abiotic factors such as temperature and snow regimes and invertebrates are relatively short lived. As a result, invertebrates are anticipated to respond early to changing climactic conditions (Hodkinson and Jackson, 2005).

For the purposes of this report, the focus is on invertebrates that occur in terrestrial environments, although some taxa have aquatic larval stages. Of these, the benthic invertebrates are largely covered by the CBMP- Freshwater Plan (Culp, et al. 2012), although the Terrestrial Plan covers some aspects of biting flies (i.e., some families of Diptera) with a slightly different focus. Overall, this Plan focuses on the ecological functions of aboveground arthropods, i.e., insects and spiders, and soil living invertebrates, e.g., microarthropods, enchytraeids and earthworms. Key chemical and physical life-sustaining functions occur in the soil such as nitrification, decomposition, and humification (moisture and nutrient retention), support vegetation and all higher trophic levels (Figure 4.2). Nematodes may be important in speeding nutrient-cycling in Arctic soils (M. Laidlaw and P. Grogan, unpublished), and while they are recognised as important indicators of soil ecosystems elsewhere, their identification remains extremely challenging (Chen, et al. 2010a; Yeates 2003) and thus are not a group of focus in the current Plan. DNA barcoding in conjunction with taxonomic studies may become an invaluable tool in future monitoring efforts, and sample archives may be useful to provide baselines of soil ecosystem conditions.

4.2.1.2 Vegetation

The CBMP-Terrestrial Plan includes monitoring and reporting on the status and trend in Arctic vegetation as fundamental objectives. There are over 2000 vascular plant species, 1750 lichen species and 900 byrophytes (mosses, liverworts) known in the Arctic distributed across 21 floristic provinces within five bioclimatic subzones (CAFF ABA 2013; CAVM Team 2003). There is a strong increase in species richness from 102 species in the high Arctic subzone A to 2180 species in the southernmost low Arctic subzone E (see Fig 2.2 and 4.1) (CAFF-ABA Group 2013).

Vegetation is a critical component of Arctic ecosystems. Plants, as primary producers, produce essential resources to support other Arctic species. In turn, the structure and composition of Arctic vegetation that makes up these habitat attributes is largely determined by the direct and indirect influences of key biotic and abiotic drivers and soil biodiversity. Soil fungal communities, including mycorrhizal, also play critical roles in vegetation establishment and success, and affects community structure and function. The key abiotic drivers affecting vegetation change in the Arctic are climate (temperature, length of growing season, precipitation, etc.), cloud cover, solar radiation, site characteristics (soils, permafrost, soil moisture, topography etc.), hydrology and natural disturbance (fire and landslides, etc.). Anthropogenic disturbances and land use including infrastructure, waste, contamination and pollution, and nutrient enrichment also affect vegetation at various scales. In some areas of the Arctic, grazing and trampling from domesticated reindeer, overabundant waterfowl, and travel and tourism are also considerable stressors. While over 100 non-native species have been found in the Arctic, no species is yet considered invasive, though there is threat that some may become invasive with a changing climate (CAFF ABA 2013). Climate and climate-mediated impacts are by far the most serious drivers to Arctic vegetation (CAFF ABA 2013).

Impacts of these drivers and large scale processes in the Arctic may be expressed through alterations in vegetation phenology and species interactions, species ranges, community composition and relative dominance, and productivity. Temperature increases in the north are expected to result in generally higher productivity and northward range expansions for certain vegetation species, and narrowing of ecological niches for others (Prowse, et al. 2009, Callaghan et al, 2004). Flora community composition and distribution changes consistent with warming have been noted by Arctic community members (Downing and Cuerrier, 2011). Studies using plot and satellite imagery have shown increases in vegetation productivity in the Canadian Arctic since the early to mid-1980s (Ahern 2008; Bhatt, et al. 2010; Elmendorf, et al. 2012; Epstein, et al. 2012; Hudson and Henry 2010; Jia, et al. 2009; Pouliot, et al. 2009). Some changes in community composition and relative dominance of plant species have already been observed, with most assessments demonstrating an increase in shrub abundance (Elmendorf, et al. 2012; Hudson and Henry 2009; Myers-Smith, et al. 2011; Sturm, et al. 2001) and decrease in bryophytes (Elmendorf et al. 2012). Meta-analysis of plot based passive warming experiments has demonstrated increased shrubbiness and graminoid cover, and decreased cover of mosses and lichens with increasing air temperature (Walker, et al. 2006). Shrub area and size gradually decrease with increasing latitude indicating the shrub ecotone will be sensitive to continued warming (Lantz, et al. 2010). Some Arctic vegetation communities are resistant to change and it may not be possible to detect ecosystem level responses after a threshold has been crossed (Hudson and Henry 2010). Changes in the plant community composition and structure may impact physical processes and ecological services including the provision of food and habitat, carbon sequestration, soil insulation and permafrost maintenance, nutrient inputs, soil structure and aeration, terrain stability, and water and nutrient availability, evapotranspiration, and absorption/reflection of solar radiation, among others (Epstein, et al. 2004; Lantz, et al. 2010; McGuire, et al. 2006; Myers-Smith, et al. 2011; Tape, et al. 2006) .

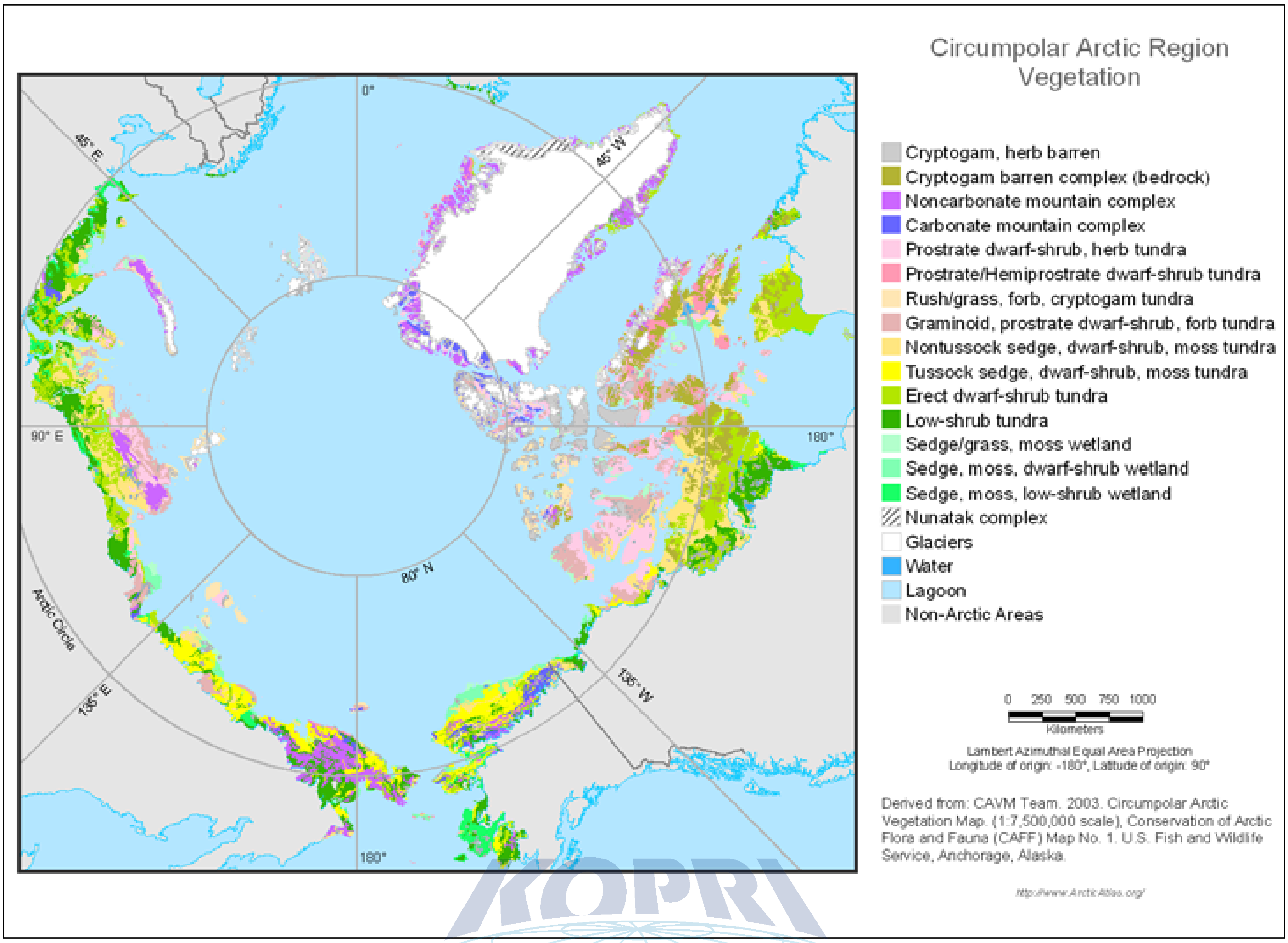


Figure 4.1 Circumpolar Arctic Vegetation Map (CAVM Team 2003). (Modified from: © 2008 Alaska Geobotany Center, Institute of Arctic Biology University of Alaska Fairbanks; CCA-NC-SA License. **http://www.arcticatlas.org/maps/themes/cp/cpvg**). The map shows territories within the Arctic proper, but adjacent ecosystems in the Arctic/sub-arctic and alpine ecotones are included.

4.2.1.3 Birds

The goal for avian monitoring is to track and report on changes in bird abundance, productivity, and distribution in relation to biotic and abiotic drivers, and to monitor, interpret, and report on how these changes may affect other functional groups in the ecosystem. The ecosystem approach will enable spatial and temporal integration of monitoring results to establish, measure, and report on causative interrelationships among drivers, changes in avian populations, and changes reported from other components included in the vegetation, mammal and arthropod monitoring sections (see Box 4B). Thus a solid scientific approach is proposed as part of the Plan, including design (and adaptation of existing capacity), investigation through monitoring and focal studies, and interpretation of trends, interrelationships, and ultimately the patterns and causes of change in Arctic ecosystems and biodiversity.

Arctic birds constitute a special case with regard to monitoring populations and causes of change. Firstly, with few exceptions, Arctic-breeding birds are long-distance migrants, mere visitors to a feeding resource made available by the short summer. Causes of change in population sizes are often due to factors outside the Arctic, such as hunting, development, habitat changes in wintering and staging areas, pollution and disturbance. However, Arctic-breeding species are subject to pressures in their polar region as well, including climate change. Secondly, many species have a patchy, but wide breeding distribution; hence, it is difficult to capture many populations with a site-based approach, particularly given that the CBMP-Terrestrial Plan will be based primarily on the existing station networks.

These characteristics result in great challenges to population monitoring, but also great potential advantages. Species breeding at very low density in the Arctic, such as shorebirds, may aggregate in vast groups on their wintering grounds in temperate or tropical areas, where they can be counted more effectively to track overall changes in population size rather than trying to track small changes in highly variable local breeding densities. Species of particular significance for human communities in the Arctic and elsewhere, such as important harvestable species like ducks and geese, may be already very well monitored because of their cultural values. Long-term data, as well as information on factors regulating and limiting those populations, and their demographics may exist. For example, annual survival rates can be derived from capture-mark-recapture studies of duck, goose and swan populations, and assessments of annual production of young based on age categories of individuals shot by hunters through "wing surveys" or "tail surveys" (see Table in Box 4C). For non-migrant species, population size and change will have to be assessed through sampling approaches at some stage during the year. Climate change may not only affect the overall size of populations, but also their distributions, as the climate template that shapes their habitat and food resources shifts in time and space. It is therefore important to combine flyway population monitoring with breeding avian community composition studies, an objective that can also be achieved through sampling on the breeding grounds.

Not all avian species can be covered in a circumpolar monitoring program at all stages of their life cycle, so the challenge is to achieve coverage of as many species as possible in relation to reporting on parameters that will answer specific management questions in the future. This should be done in a representative, but pragmatic and cost-effective way. Fortunately, there are many ongoing monitoring mechanisms in existence, and with some planning, data can be integrated or trends can be analyzed to take advantage of such available programs. For other bird groups, such as birds of prey, carnivores, piscivores and passerines, data-collection is less systematic, and monitoring experts need to assess the best methods of deriving annual indices of their numbers and how to track changes in their abundance over time (see Box 4D). This is especially important for the status of those bird species that provide insight into ecosystem process or the functioning of such processes.

Some species, including key avian predators, have long been monitored as indicators of the Arctic environment and long-term data series already exist, allowing for multi-decade comparisons of breeding density, reproductive success/productivity, timing of breeding (all affected by climate change). These data are often also coupled with other parameters such as pollutant loads or habitat and prey characteristics and change.

4.2.1.4 Mammals

Mammal species in the Arctic are a variety of sizes, occupy various trophic positions and assume a variety of life strategies. While many of the Arctic species reside in the same area year-round (e.g., lemmings), some species are either true migratory species (e.g., caribou/reindeer) or roam over vast areas (e.g., wolf). Unlike Arctic birds, Arctic mammal species are generally widely distributed year-round and therefore cannot be censused at aggregation areas, except in some cases. Arctic mammals in general constitute important components of the Arctic terrestrial ecosystem, and for instance some species of small mammals play a key role in the vertebrate predator-prey dynamics (Schmidt et al. 2012).Some species, such as the caribou/reindeer, are hunted by local people, and their abundance and demographics are therefore often monitored by local communities. Population monitoring of Arctic mammal species therefore includes an array of methodologies and approaches. The goal for the mammal monitoring is to track and report observed changes in mammal abundance, productivity, and distribution, and to monitor the likely biotic and abiotic drivers of change. While the outlined mammal monitoring initiates from existing monitoring efforts, a number of additional essential and recommended monitoring protocols are presented to act as guidelines for the improvement of mammal monitoring across the Arctic.

4.2.2 Arthropods and invertebrates sampling approach and monitoring

4.2.2.1 Invertebrate management questions

The overarching management questions for Arctic terrestrial biodiversity summarised in Figure 3.4 have been adapted as appropriate for each biotic group. For invertebrates, the questions are:

- What is the status (abundance, diversity) of functionally important terrestrial invertebrate taxa occurring in the Arctic?
- What are the main trends in the status of these taxa (i.e., changes in the diversity, distribution, abundance) and relevant ecological functions? Where and how are these changing, within and across years?
- What are the key drivers behind the trends in key invertebrate taxa and associated ecological function?
- What are the status and trends of invertebrate species of special interest, including invasive and introduced species, occurring in the Arctic?

4.2.2.2 Invertebrate conceptual models

Invertebrate sampling is developed from the perspective of key ecosystem processes (see Fig. 3.2) in the Arctic. For invertebrates the following processes are highlighted as being highly relevant: decomposition and nutrient cycling, herbivory, invertebrates as prey for birds, pollination and blood-feeding (e.g., biting flies). There are complex food-webs embedded within each of these processes as illustrated by Figure 4.2 for soil-based food webs.

Other processes are also important (see Fig. 3.2), but not included in detail in this monitoring report. For example, parasitic wasps play a key role in Arctic systems, as one type of top-down control on various arthropods (e.g., spiders (Bowden and Buddle, In press); and caterpillars (Klemola, et al. 2010)). Wasps will, however, be collected as part of the required plan and can be stored long-term and made available for scientists in the future. Monitoring of parasitic arthropods of large and small mammals, such as bot and warble flies, blood-feeding lice and ticks, has also been excluded. Although these taxa and processes are important in the Arctic (e.g., see Hughes, et al. 2009) it is anticipated that some aspects of mammal health will be monitored as part of the mammal monitoring plan (see section 4.2.5), and that parasites of mammals could be partially captured under mammal monitoring.

The decomposer ecosystem of the soil has a trophic structure spanning a broad range of taxonomic groups including microorganisms, mites, hexapoda and earthworms. The food web holds microbial feeders, detritivores and predators also characterized as primary and secondary decomposers, as they may form detritus food-chains with a few links before being eaten by a predator (see Fig. 4.2). Although monitoring capacity is limited at this time for these important microbes, we suggest requiring the monitoring of the mesofauna with collembolans at the species level, as this group hitherto is the most feasible concerning availability of expertise and equipment (Bispo, et al. 2009). The vertical distribution and corresponding contrasting life-forms guarantees capturing environmental changes.

4.2.2.3 Invertebrate monitoring design principles and components

Given the limited coverage of monitoring programs for invertebrates, it is very difficult to prioritize locations and habitats for future monitoring. Instead, the inclusion of invertebrate monitoring with other monitoring efforts as a required sampling 'module' is suggested. In other words, whenever vegetation, bird, or mammal monitoring occurs, so should invertebrate sampling. We also suggest that all active research stations in the Arctic consider adding a monitoring program for invertebrates. After invertebrate monitoring has been initiated at a pan-Arctic scale, it will be possible to prioritize for additional key locations and habitats. At a local scale, terrestrial invertebrate monitoring should ideally be done at more than one location, and more than one habitat, with plant communities and moisture gradients as key considerations in selecting habitats.

The monitoring can be approached with different levels of detail, and the capacity of individual monitoring programs depends on personnel, funding and infrastructure. Given these constraints, we have considered a subset of all possible attributes for each function as being required, meaning they should be part of any monitoring programs (seeTable 4.1). However, it is recognized that some monitoring programs may not be able to complete all required monitoring of invertebrates, and thus should pick and choose (i.e., from Table 4.1) the key attribute given logistical or financial constraints and/or if more specific management questions are a focus for a given monitoring location.

4.2.2.3.1 Invertebrate FECs and functional groups

Blood-feeding invertebrates

Flies are among the most commonly encountered animals in the Arctic, and biting flies (Diptera; several groups) are notorious for their blood-feeding behaviours. All Arctic biting flies have aquatic larval stages but occupy terrestrial habitat as adults, and include black flies (Simuliidae), mosquitoes (Culicidae), 'deer flies' or 'moose flies' (Tabanidae), and others. Adult females blood-feed for the successful development of their eggs, and hence are nuisance pests and can introduce pathogens and parasites. Biting flies also play critical roles in pollination, especially in northern systems (Kevan 1972). Biting flies are a primary reason for the initiation of the Northern Insect Survey (Freeman 1949) and are among the most well-known of the northern insects. Furthermore, biting fly harassment of wildlife may be increasing, and with additional compounded effects of climate change, may further increase negative impacts on populations (Gaston, et al. 2002). For these reasons, they must be part of an Arctic monitoring plan.

Pollinators

The codependence of flowering plants and their invertebrate pollinators requires that both biotic groups be included in integrated monitoring efforts and that attributes such as spatial structure (distributions), diversity, abundance, and phenology be considered as much as possible. In the Arctic, groups such as Hymenoptera, and Diptera may be the most important and feasible to monitor (Buddle 2013). Because of the familiarity of many species (e.g., bumble bees) and as some protocols can be adapted for ease of use (e.g., observing flower visitation rates) community-based monitoring can be an invaluable component of programs.

Prey species for vertebrates

Many arthropods and invertebrates are exploited by birds and small mammals, and in the Arctic, monitoring is proposed for spiders (Araneae), some flies (Tipulidae) and for Lepidoptera, for feasibility. For many migratory avian breeders, one major driver of their extensive journeys is to exploit the rich sources of invertebrate prey that emerge in time to coincide with the high energy demands of reproduction and for feeding offspring. Climate change may be causing drought conditions in some tundra regions, which over time may affect aquatic larval stages of insect prey. The shifting phenology of prey and predators, and mismatched reproductive periods, could impact avian populations and other predators of invertebrates (Bolduc, et al. 2013).

Decomposers and nutrient-cyclers

Soil and tundra meso- and micro-fauna perform critical ecosystem functions including breaking down larger organic particles and facilitating decomposition, facilitating the movement of energy and nutrients along foodwebs from microbes to small prey, burrowing and creating air spaces in soil that benefit vegetation and other species, and serving as predators, fungivores, detritivores, and prey. Monitoring can be practical for at least some groups, and where possible, samples of other species should be archived so that these can be analysed as capacity permits in the future (Buddle 2013). Under the current Plan, soil invertebrates that should be monitored include soil mesofauna (springtails, mites, and Enchytraeids), fungi, earthworms, and microfauna and microorganisms (some requiring DNA-based analyses).

Herbivores

As many arthropod taxa are phytophagous (Leptidoptera, Aphidae, Coleooptera, Acari, etc.), herbivores are dependent and influence their host plants and thus vegetation in the Arctic. They are expected to respond quickly to changes in vegetation and monitoring programs should include them are they could signal important changes in ecosystems (Hodkinson and Bird 1998). However, selecting key taxa for inclusion is challenging as taxonomic capacity for some groups is virtually non-existent, whereas other taxa are known well, especially in their adult forms (e.g., butterflies).

4.2.2.3.2 Invertebrate attributes, sampling protocols and design

Invertebrate abundance and diversity varies from year to year in the Arctic (Bolduc, et al. 2013), and a single season of monitoring will not provide answers to the management questions. It is therefore recommended that the frequency of monitoring be done on a yearly basis until yearly variation is tracked for several seasons. Once the natural range of variation is tracked, it may be possible to move into a five-year cycle of monitoring. Additional specifics about methods can be found in the included references. When multiple traps are required per site (e.g., pan or pitfall traps), it is recommended that at least 10 traps be used per habitat. Addition of a preservative is required to allow for subsequent DNA extraction. Duration of trapping depends on specific methods. If possible, taxon sampling curves (see Buddle et al. 2005) should be used to assess whether sampling has been sufficient in reference to number of taxa collected, and in reference to sampling effort (e.g., whether 10 or more traps would be required). As for other biotic groups, species of special interest can be monitored indirectly through these protocols, including non-native species and species of conservation concern.

The **essential** set of protocols is considered as covering a 'minimum set' of attributes, but we advocate for a larger set of **recommended** attributes to be collected if logistically possible and/or if specific management or research questions trigger the need for additional invertebrate data. This strategy includes broader taxonomic coverage, but more notably, phenology and abundance or density estimates of many taxa. In many cases, the additional data collection involves expanding the taxonomic scope and/or timing of sampling. Critical thresholds and ecological tipping points may not be detected with sampling that only completes the essential protocols.

1) Blood-feeding insects

- **Attribute: Diversity** (species richness) — ***Essential***
  - Metric: species richness per sampling location - taxonomic resolution - species; DNA Barcoding (COI barcode, or additional barcodes)
  - Methods: larval and pupal Simuliidae and Culicidae collected by hand from lotic and lentic waters, respectively. Minimum of six streams/rivers and six ponds/pools required. Emphasis should be on sampling as many different habitats and microhabitats as possible. For simuliids, these include streams of various sizes and velocity, pond outlets, and flows that originate from groundwater or ice melt. Substrate from which larvae and pupae should be sampled includes trailing grasses, rocks, and submerged twigs. For culicids, standing water of various sizes and with different types of emergent vegetation should be sampled, including small pools in hummocky terrain or in rock crevices. For aquatic sampling, minimum of 30 minutes per habitat (e.g., individual river or pond). When sampling culicids from exceptionally small bodies of water (e.g., water-filled depressions in hummocky terrain), then 30 minutes should be devoted to collecting larvae and pupae from multiple pools in a particular area. All specimens should be fixed in 95% ethanol to facilitate DNA barcoding. Adults of simuliids and culicids, and those of other families (e.g., Tabanidae) can be collected opportunistically using a sweep-net or aspirator, or will be collected in malaise traps as part of other protocols (see below).
    (References: Adler, et al. 2004; Silver 2008)

- **Attribute: Abundance— Recommended**
  - **Abundance of** blood-feeding insects (e.g., mosquitoes) can be estimated with standardized sweep-net samples taken around the collector's bodies; index is relative number of biting flies.

2) Pollination

- **Attribute: Diversity** (species richness) — ***Essential***
  - Metric: flower (or inflorescence) visitation per hour, recorded by plant species; taxonomic diversity per visitation period, number of pollinators per pan trap; COI barcodes (or other barcodes); taxonomic resolution: dependent on expertise for Diptera, but species is required for Apoidea (i.e., including the families Megachilidae, Colletidae, Halictidae, Andrenidae and Apidae)

  - Methods: flower visitation rates; flower visitation should be done with dominant flowering plants, standardize by time per plant, or by area depending on habitat structure. Standardize grids of yellow, white and blue pan traps (minimum 10 traps, placed > 10 m apart), or vane traps (blue/yellow), opportunistic sweep-net collections with floral hosts recorded when possible.

(References: Dafni, et al. 2005; Elberling and Olesen 1999; Stephen and Rao 2005)

- **Attribute: Ecosystem functions and processes** (pollination success) — ***Essential***
  - Metric: grains per stigma; % fruit set; % fruit yield
  - Methods: Pollination success can be measured indirectly by comparative studies of fruit set and fruit yield, requiring repeated visits to plants, i.e., done separately for different target species of plants. A more direct measure is pollen grains per stigma. This is done by comparative studies of plant stigma, with aid of field microscope. This requires repeated visits to the same plants.

- **Attribute: Spatial structure** (distribution) — ***Recommended***
  - Opportunistic sampling of key pollinators can be done through community-based monitoring efforts, with a focus on Apidae. Bumble bees are readily sampled with a sweep-net. It is also straightforward, and simple to establish grids of pan traps (yellow/white/blue) and/or vane traps.

(References: Dafni, et al. 2005; Stephen and Rao 2005)

3) Prey availability for vertebrates

- **Attributes: Abundance, productivity and phenology** (relative abundance / biomass and phenology) — ***Essential***
  - Metric: number or weight of arthropods per trap per day (phenology is the abundance or biomass data, over time); taxonomic resolution: family-level.
  - Methods: For ground-dwelling arthropods, standardized grids of pan or pitfall traps, minimum of 10 traps per habitat, established as soon as possible after snowmelt until the end of the active snow-free season. For flying arthropods (e.g., Diptera), one standard malaise trap per habitat, sampled for the same time period as pan and pitfall traps. Note: modified trap types are possible (e.g., combined pan trap with malaise head, and horizontal screening); specimens preserved for later DNA extraction.

- **Attributes: Abundance** (relative abundance)**, spatial structure** (distribution), **diversity** (species richness)— ***Recommended***
  - Additional laboratory work required

(References: Bolduc, et al. 2013; Ernst and Buddle (In press); Karlsson, et al. 2005; Salmela 2011)

4) Decomposition and nutrient cycling

- **Attributes: Diversity** (species richness) **abundance, and distribution** — ***Essential***
  Species richness and density estimates are collected at the same time, and together allow for assessment of community diversity.
  - Metric: abundance of dominant taxa per m^2 at specific depths, result in measure of community diversity per location; taxonomic resolution: species-level for Collembola, higher levels for Acari, Enchytraeidae, and other taxa. Preservation for future DNA extraction to obtain some species-level responses.
  - Methods: Soil and turf cores, taken on site, returned to the laboratory for extraction, with validated extraction apparatus (i.e., Berlese funnels or MacFadyen high gradient extractors, O'Connor's Funnel for wet extraction). For each habitat, minimum of 10 samples per sample location recommended to provide a mean population density m^{-2} with variability estimate, 95% confidence limits. Minimum stratum is the top A-horizon.

- ***Attributes:* Ecosystem functions and processes** (% mass loss, NPK levels) — ***Recommended***
  - Broader taxonomic approach by including a selection of more than one of the main taxonomic groups. Taxonomic resolution should be species, when possible. Measures of ecosystem functions and processes in terms of decomposition rate (litter-bag, native foliage); inorganic nutrient levels in soil.

(References: Aastrup, et al. 2009; ISO 2006)

5) Herbivory

- **Attribute: Diversity** (species richness) — ***Essential***
  - Metric: number of species of herbivores, per plant, or per area sampled. Taxonomic resolution: family-level, but stored for DNA extraction or further taxonomic research.
  - Method: timed visual surveys for dominant taxa of herbivores including but not restricted to Lepidoptera Hymenoptera larvae, Hemiptera. Timed surveys done on dominant vegetation; timed beat-sheet samples for woody vegetation (done for dominant plant type/species, repeated per habitat).

(References: Mjaaseth, et al. 2005; Raimondo, et al. 2004)

- **Attribute: Ecosystem functions and processes** (herbivory) — ***Essential***
  - Metric: plant damage (as per cent or category) expressed on a per plant basis, separated by damage type (e.g., skeletonize, mine, gall).
  - Methods: dominant plant type selected and recorded, minimum of five leaves per plant, five plants per vegetation type (or: selective plant parts for gall counts). Randomly select leaves/shoots for examination, record damage per leaf or use categorical class as necessary; repeated for dominant vegetation type per habitat.

(References: Roininen, et al. 2002; Rossiter, et al. 1988)

4.2.2.3.3 Invertebrate sample processing, archiving, and other protocols (DNA barcoding)

Any invertebrate monitoring program requires a short and long-term plan for specimens. In the short-term, bulk samples should be sorted minimally to Order (or lowest taxonomic level whenever possible) as soon as possible after collecting. Samples should be data-based (with metadata) immediately and residues put into ethanol for long-term cold-storage so that DNA can be preserved and later extracted for DNA barcoding analyses (e.g., see application in Mutanen, et al. 2012).

4.2.2.4 Existing capacity to deliver the CBMP-Terrestrial Plan and potential contributors to the invertebrate monitoring scheme

Monitoring of terrestrial invertebrates is rare in the Arctic (Appendix A, Figure A1), with the exception of Zackenberg (East Greenland), Nuuk (West Greenland), Svalbard (Norway) and some recent efforts to monitor arthropod biomass in North America (Bolduc, et al. 2013). There are other regional models of arthropod monitoring in other parts of the world (e.g., Alberta Biodiversity Monitoring Institute, **http://www.abmi.ca/abmi/home/home.jsp**) and these and other protocols (Buddle 2013) can be used as models in the development of an Arctic monitoring program.

There are also some important areas in which arthropod research occurs (Figure A1), but presently these areas do not have long-term monitoring in place. Existing monitoring programs are often based on specific research projects, or monitoring for specific and focused research questions (e.g., biomass sampling in Bylot, Nunavut, for assessment of prey availability for shorebirds (Bolduc, et al. 2013). Greenland monitoring is an exception, as methods at these sites include broad taxonomic coverage, diversity, abundance, phenology, and many ecosystem processes both biotic and abiotic (e.g., see Box 4B and **http://www.zackenberg.dk/**).

The CBMP recognizes the potential of engaging local communities, schools, amateur entomologists and other interested peoples in a 'citizen scientist' approach to monitoring aspects of invertebrates. For example, date(s) of first appearance of butterflies or biting flies, range extensions of native species, and species introductions could be tracked. On model could be something akin to the "e-butterfly" online resource (**http://ebutterfly.ca/**), the Svalbard insect resource SPIDER (**http://svalbardinsects.net**), or a 'bug-guide' (**http://bugguide.net/**) with a northern focus.

Landscape to pan-Arctic scales: aquatic-terrestrial life cycles; pathogens; prey populations and climate change

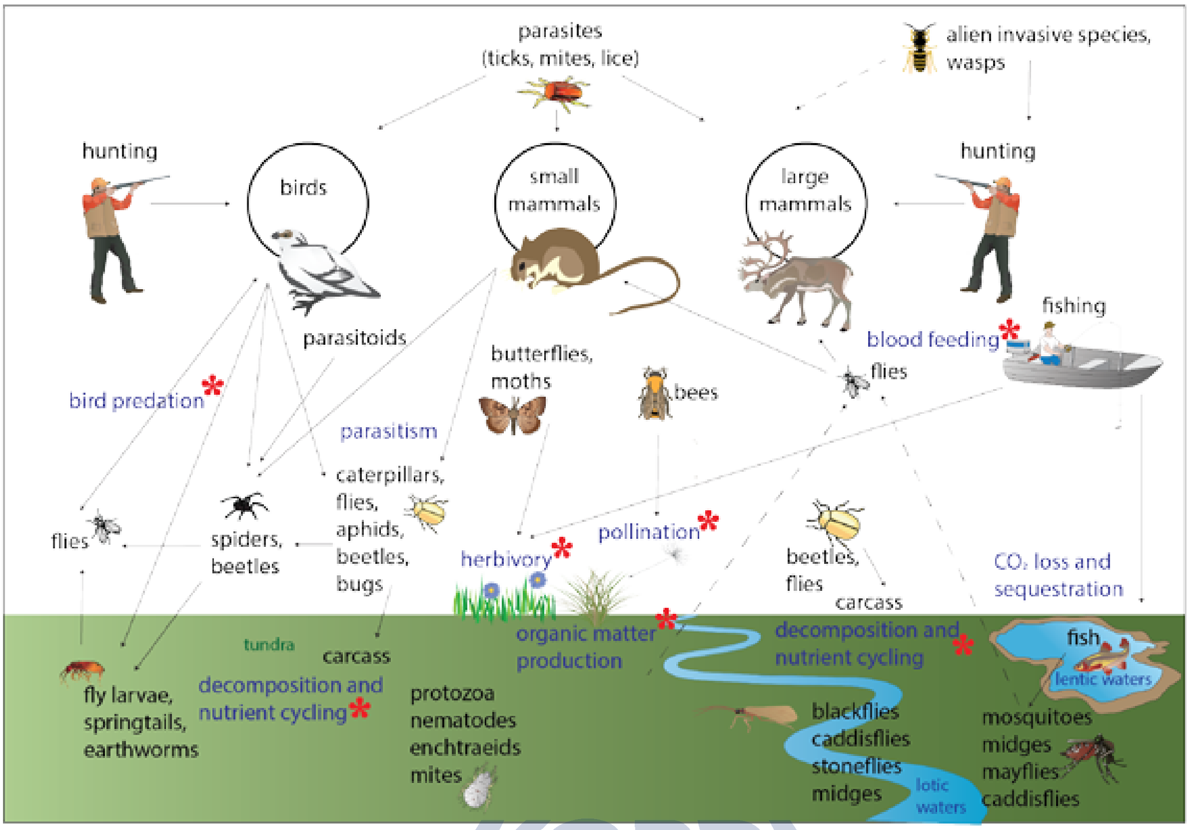
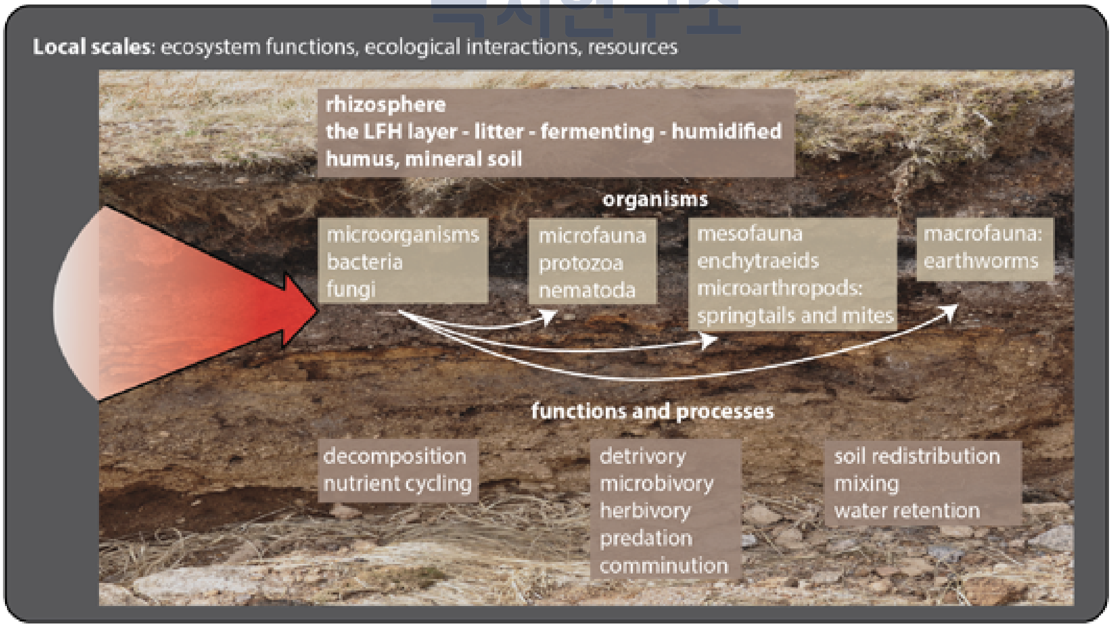


Diagram of the main ecological processes that are facilitated by and/or associated wtih Arctic invertebrates. Processes are identified by blue text and key processes from a monitoring perspective are indicated by a red asterisk (*). Interactions among invertebrates and other organisms are depicted by arrows. A solid arrow indicates a direct connection between groups (i.e., predation). A dotted line indicates movement of organisms (e.g., as part of their life cycle. Only dominant taxa are represented.

Local scales: ecosystem functions, ecological interactions, resources



Drivers: abiotic (e.g., climate, physical terrain); biotic (e.g., vegetation diversity, organic matter nutrients); and anthropogenic (e.g., pollution, trampling)

Figure. 4.2 The Arctic terrestrial invertebrates monitoring conceptual model showing ecosystem functions, ecological interactions, and examples of drivers. The top panel shows from local to large spatial scales and the bottom panel shows a model of the soil ecosystem (local or plot scale).

Table 4.1 List **of FECs for terrestrial arthropods** (FECs: major biodiversity elements), their attributes (compositional, structural, and functional aspects), monitoring priority of attributes, parameters of attributes (individual measures/methods to quantify attributes), geographic scale, method (monitoring technical approach or reference to methods), protocol complexity (basic or advanced) and temporal recurrence (how frequently monitoring should be conducted).

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
BLOOD-FEEDING: Diptera (e.g., Culicidae, Simuliidae, Ceratopogonidae, Tabanidae)	Diversity	Essential	Species richness (estimates) local	Local	Larvae collections in aquatic habitats, sweep net samples for adults; sweep net samples around ungulates	Basic / Advanced (for taxonomy)	Annually at first; 3-5 years afterwards	Knowledge of the entire community is important; invertebrates such as biting flies are important for wildlife and humans, as disease vectors, etc. Community monitoring could be used to collect data on species richness.
	Abundance	Recommended	Relative abundance, terrestrial and aquatic, via sweep sample / in ponds / densities	Local	Examples: # per unit effort (time, or number of sweeps), density per unit area/ volume; baited traps; for aquatic, may need special nets	Basic / Advanced (for taxonomy)	Annually at first; 3-5 years afterwards	Difficult to get accurate estimates of density, although a relative activity index may be possible. Abundance of these species could act as a driver for large mammals.
	Spatial structure	Recommended	Species presence/ absence	Regional/ pan-Arctic?	Same as above & historical collections (i.e., previously collected material)	Basic / Advanced (for taxonomy)	Annually first; 3-5 years afterwards	Understanding range expansions of these species could be important in some locations.
	Phenology	Recommended	Date of first emergence, seasonal activity	Local	Same as above, plus TK (local, community)	Basic	Annually first; 3-5 years afterwards	Important but requires full season monitoring which may not be possible
	Demographics	Recommended	Body condition, life stage; sexes	Local	Analyses of sample sets; identification of sexes and stages	Basic / Advanced (for taxonomy)	Varies by group: As req. (min. 5 years)	Perhaps in the future blood samples could be analyzed (DNA barcodes)

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
POLLINATION: Hymenoptera (e.g. Colletidae, Andrenidae, Halictidae, Megachilidae, Apidae), Diptera (many families)	Diversity	Essential	Species richness (estimates)	Local	Flower visitation observations, sweep nets, passive sampling, i.e., collections in standardized yellow / white / blue pan traps (grids of traps), vane traps	Basic / Advanced (for taxonomy)	3-5 yrs as a minimum; annually if possible	Bees are important in Arctic systems, and taxonomically well-known but standardized techniques that are quick/efficient are lacking.
	Abundance	Recommended	Relative number per sweep transect, or flower surveys	Local	# visitations per unit time; number of specimens per sweep, net transect, or timed sweep-net surveys	Basic / Advanced (for taxonomy)	Annually	Difficult to standardize 'relative abundance' in monitoring program
	Spatial structure	Essential	Presence / Absence	Local to pan-Arctic	Same as above, plus other published literature, historical collections and consultation with experts	Basic / Advanced (for taxonomy)	Annually	Some pollinator species (e.g. Apidae) could be monitored via community efforts.
	Phenology	Recommended	Seasonal activity patterns	Local	Traditional/ community knowledge	Advanced	Annually	Potentially important but not feasible without specialist and intense monitoring all season
	Ecosystem functions and processes: pollination success, fruit-set, and yield	Essential	Fruit set and seeds	Local	Some focal surveys required; traditional/ community knowledge	Basic and Advanced	3-5 years as a minimum; annually if possible	This process is facilitated by arthropods, but is not a direct measure of pollinator species; this attribute is a driver for plant fitness.

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
FOOD PREY FOR VERTEBRATES (esp. birds): Araneae, Diptera (e.g., Tipulidae), Lepidoptera	Diversity	Recommended	Species richness (estimates) - local level	Local	Standard grids of pan and/or pitfall traps	Basic (some taxonomy required)	Annually first; 3-5 years afterwards	Spiders as top predators and as easily sampled taxa should be a priority
	Abundance and productivity	Essential	Relative number per trap	Local	As above; can conduct standardized area sampling to achieve density estimates also (labour intensive)	Basic / Advanced	Annually if possible where bird studies are conducted; 3-5 years as minimum	Possible if standard protocols can be used. This is a key driver for insectivorous birds.
	Spatial structure	Recommended	Presence / Absence	Regional, pan-Arcti	As above, but include consultation with experts, historical collections	Basic / Advanced	Annually first; 3-5 years afterwards	See above
	Phenology	Essential	Seasonal activity patterns	Local	Same passive sampling approach but done over entire active season, from snowmelt until snow arrival; possible community / local knowledge?)	Basic (some taxonomy required)	Annually if possible where bird studies are conducted; 3-5 years as minimum,-	Potentially important (e.g., for vertebrate feeding), but requires season-long monitoring plan
	Health and productivity	Recommended (wolf spiders)	Body condition index, body size index, clutch size (wolf spiders)	Local	Wolf spiders only: body size index; clutch size of females, parasitism rates	Basic / Advanced	Annually first; 3-5 years afterwards	Simple to conduct for some taxa, e.g., wolf spiders

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
DECOMPOERS and NUTRIENT CYCLING: Soil Mesofauna (Collembola, Acari Enchytraids), Detrivores s.l. (Fungivores, Bacterivores, Saprophages), macroinvertebrates (e.g., earthworms), microfauna, microorganisms	Diversity	Essential	Species richness (estimates) - local	Local	Soil and turf cores, taken on site, returned to laboratory for extraction (i.e., Berlese funnels or MacFadyen high gradient extractors, O'Connor's funnel for wet extraction)	Basic / Advanced	Annual	Sampling can be conducted over a short time should that be all that logistics allow. Collembolans are feasible to include concerning taxonomy. A trait-based (light-weight pseudotaxonomy short-cut) approach may be proposed in the future. Enchytraids and mites are difficult to identify. DNA barcoding will provide a solution to this obstacle and deliver presence/absence data (CBOL program). It is also possible to use higher level taxonomy instead of species to increase feasibility.
	Abundance	Essential	Density estimates i.e., number per standard soil core	Local	Numbers calculated per sq. m at a specified depth	Basic / Advanced	Annual	Abundance data (i.e., density) are collected with the same protocols as used for determining species richness; straight-forward.

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
DECOMPOERS and NUTRIENT CYCLING: Soil Mesofauna (Collembola, Acari Enchytraids), Detrivores s.l. (Fungivores, Bacterivores, Saprophages), macroinvertebrates (e.g., earthworms), microfauna, microorganisms	Spatial structure	Essential	Presence/ absence	Local/ regional/ pan-Arctic	All collembolan life-forms (~4 types, representing the vertical stratification from epi-phytic to true soil-dwelling). The horizontal distribution is not included in environmental surveys, except for variance estimates between samples collected in a random but stratified manner. [Same species and target species/groups. Consult historical collections/ experts]	Basic / Advanced	Annually first; 3-5 years afterwards	For some taxa, getting presence/ absence is possible and high priority, given high feasibility (i.e. taking soil cores); DNA barcoding will facilitate this in the future
	Demographics and phenology	Recommended	Phenology, voltinism, population growth rate	Local	Repeated sampling	Basic / Advanced	Monthly	
	Ecosystem functions and processes: Nutrient levels	Recommended	NPK	Local	Sampling nitrogen, phosphate, potassium: chemical analyses	Advanced	As required	These nutrients are a result of invertebrate activity within the soil/ tundra.
	Ecosystem functions and processes: Decomposition	Recommended	% mass loss	Local	Standard litter-bags used to assess % mass loss over time as a measure for decomposition rate	Basic / Advanced	As required	These nutrients are a result of invertebrate activity within the soil/ tundra.

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
HERBIVORES (Lepidoptera, Symphyta, Aphidae, Hempitera, Coleoptera, Acari)	Diversity	Essential	Species richness (estimates) - local	Local	Opportunistic collection of adults and/or standardized sweep samples/ systematic surveys of plants for larvae	Basic (some taxonomy required)	Annually first; 3-5 years afterwards	Given the popularity of butterflies, and ease of identification, local estimates of species could be worthwhile
	Abundance	Recommended	Relative number per sweep transect; visual surveys, number per beat-sheets (density)	Local	Opportunistic collection of adults; standardized sweep samples; standardized beat-sheet sample / systematic surveys of plants for larvae	Advanced	Annually	Difficult to achieve by non-specialist
	Spatial structure	Essential	Presence / Absence	Local/ regional/ pan-Arctic	Same, but also using expert knowledge, e-databases (e.g., e-butterfly), community/ local knowledge	Basic / Advanced	Annually first; 3-5 years afterwards	Feasible and important (e.g., range expansions)
	Ecosystem functions and processes: herbivory	Essential	Plant damage	Local	% leaf area lost, index of leaf damage, leaf miner damage	Basic	Annually	This is an indirect measure of insect feeding, Time consuming; may be difficult to achieve.
	Health	Recommended	Body size, pupal mass	Local	Weight of caterpillars, pupal cases	Basic	Annually first; 3-5 years afterwards	
	Phenology	Recommended	Seasonal activity patterns	Local	Timing of first appearance, local/ TK, season-long sampling	Basic	Annually	Requires season-long monitoring, which is time consuming and difficult, but potentially of high priority to monitor outbreaks
	Demographics and temporal cycles	Recommended	Population estimates (cycles), larvae/ adult dynamics	Local	See methods above for abundance	Basic	Annually	May be high priority if damage is significant

4.2.3 Vegetation sampling approach and monitoring

4.2.3.1 Vegetation management questions

Development of the CBMP-Terrestrial Plan is guided by the broad set of priority management questions/issues presented in Chapter 3 (see Figure 3.4), and a conceptual understanding of key vegetation attributes (see Figure 4.3). Specific examples of vegetation composition, structure, function and drivers were also selected through the conceptual modeling process. Priority management questions that guided the vegetation monitoring scheme are:

1. What are the status and trends of vegetation species and communities with respect to diversity, abundance, productivity, distribution and composition?
   a. What is the pattern of native plant species richness across the landscape?
   b. What are the status, trends and extent of plant species of conservation concern?
   c. How are soil fungal (mycorrhiza and decomposers) composition and relative abundance changing and what is the impact on soil ecosystem function, structure and stability?
   d. How are edible plant species and communities changing? (e.g., quality and availability, location, and type)
   e. How is habitat and forage for focal mammals and birds changing?
2. How and where are the major changes occurring?
   a. How is vegetation changing along major physiognomic ecotones, e.g., treeline, shrubline?
   b. How and where are the productivity, local abundance and distribution of Arctic shrubs changing and how is this affecting ecosystem function and biodiversity?
   c. How are the composition, structure, distribution and extent of landscapes changing?
3. What are the drivers influencing changes in vegetation and what changes are occurring?
   a. Where, and how abundant, are non-native plant species and how are they changing?
   b. How do large scale climatic patterns interact with biotic drivers to influence the plant FECs?
   c. What is the relative importance of land use/anthropogenic pressures on vegetation change?
4. Where are the vegetated regions of priority importance, such as locations of high vulnerability, resilience, habitat and conservation value, and what changes are occurring in those areas?

4.2.3.2 Vegetation conceptual model

The vegetation conceptual model (see Figure 4.3) was developed by the vegetation expert teams as described in Chapter 3. The model illustrates the scaled conceptualization of vegetation from species and life form diversity operating at local scales, to changes in communities and focal species operating at landscape scales, to changes in vegetation types or landscapes operating at regional scales, to changes in regions operating at the scale of the entire Arctic. The model also describes key ecosystem functions and services provided by vegetation, influential system drivers, and example between-system interactions.

4.2.3.3 Vegetation monitoring design principles and components

Vegetation monitoring at long-term sites should be established to enable spatial and temporal integration of monitoring results so that causative relationships among abiotic and biotic components can be established, measured and reported. These relationships may also help inform changes reported from other types of mammal, bird and arthropod monitoring. The vegetation FECs and attributes were deliberately selected to generate data that could be used to answer a number of different monitoring questions. For instance, point-intercept (Bean and Henry 2003; Jonasson 1988; Molau and Mølgaard 1996) data on vegetation community composition and abundance of different life forms can be used to generate information on productivity, species distributions, diversity and changing dominance (Elmendorf, et al. 2012), among other attributes. In addition, the vegetation monitoring approach employs a scaled assessment from local to pan-Arctic following the strategy described in more detail in Chapter 3. Plot scale monitoring from field studies and high resolution imagery, combined with geographically broad sampling of a less rigorous set of parameters conducted by partners and medium and coarse resolution remote sensing will be used to track changes across the Arctic. Co-location of vegetation monitoring with arthropod, avian and mammalian monitoring is suggested to support integrated assessment of ecological dynamics and change. It is recommended to engage taxonomic experts in verifying plot species, but ongoing-monitoring could be at a coarser taxonomic resolution, such as life forms, where required to enhance the power and accuracy of trend monitoring by non-specialists (Hudson and Ouimet 2011). Specific sampling design strategies for Arctic vegetation will be determined in the implementation phase and make use of existing investments in Arctic research and monitoring as much as possible.

Monitoring of abiotic drivers which affect vegetation is described in more detail in section 4.3. Monitoring of some biotic drivers affecting vegetation (e.g., competition, invasive species and parasitism) will be handled by monitoring the vegetation itself (see Table 4.3). Monitoring of pollination and herbivory is addressed in the arthropod section. Data to understand relationships from other biotic drivers will also be gathered following methods described in the bird and mammal monitoring sections.

As described in section 3.7, our approach recommends statistical rigor at the scale of a local study design. There are ongoing well designed Arctic vegetation research and monitoring programs and initiatives from which instruction on sampling design, such as plot site selection and layout can be derived. Several of the programs include recommendations on the number of required replicates to achieve the desired power in results at a plot scale (Hudson and Ouimet 2011), and detailed description of monitoring methods including handbooks and data collection templates. These programs include the International Tundra Experiment (Molau and Mølgaard 1996), CANTTEX (Bean and Henry 2003; Bean, et al. 2003); PPS Arctic (Hofgaard and Rees 2008); Zackenberg BioBasis (Schmidt, et al. 2012a), Nuuk Biobasis (Aastrup, et al. 2009); ArcticWOLVES (Jefferies, et al. 2008); Arctic Long Term Ecological Research Station (Arctic Long Term Ecological Research Site 2003). Further, the CBMP-Terrestrial Plan will draw on established and emerging remote sensing sampling design approaches utilized at landscape, regional and pan-Arctic changes, as described in Table 4.3 (and see Tables B1 to B3). These include methodologies to assess land cover change (e.g., Fraser, et al. 2011), length of growing season, productivity (e.g., Beck and Goetz 2011; Epstein, et al. 2012), etc.

4.2.3.3.1 Vegetation FECs and functional groups

The vegetation FECs include both vascular and non-vascular plants. The CBMP-Terrestrial Plan identifies the vegetation life forms listed below as FECs for monitoring at a variety of scales using techniques designed to answer a number of different monitoring questions. These life forms include trees, shrubs, forbs, graminoids, mosses, and lichens, (Chapin et al. 1996; Toolik-Arctic Geobotanical Atlas, 2012) and described in Table 4.2. It is also recommended to monitor fungi, including microfungi, in conjunction with the plant species where capacity allows. In addition, the CBMP-Terrestrial Plan specifically identifies food species, which are important contributors to the diet of Arctic peoples, rare, and non-native species as FECs. The monitoring of vegetation as habitat and forage for mammals, birds, and arthropods will be addressed through employing the same set of attributes and parameters addressed under all vegetation species.

Table 4.2 Arctic vegetation life forms.

Life Form	Description
Tree	Single woody stem, tall (greater than snow depth). (e.g., *Picea glauca Picea mariana,* and *Larix laricina Populus balsamifera, P. tremuloides, Betula papyrifera)*
Deciduous shrub	Multiple-stemmed woody plants, generally > 60cm, leaves not persistent in winter. (e.g., *Salix* sp, *Alnus viridis, Betula glandulosa)*
Evergreen shrub	Multiple-stemmed woody plant with persistent green leaves, often members of the Ericaceae family. (e.g., *V. vitis-idaea, Ledum* sp., *Empetrum nigrum, Harrimanella* sp.)
Forb	Broad-leaved herbaceous plants, mostly dicots, non-woody, annual or perennial (e.g., *Rubus chamaemorus)*
Graminoid	Grass-like herbaceous plants with leaves mostly very narrow or linear in outline. Includes grasses, rushes and sedges.
Moss	Small, soft plants growing in mats or clumps, includes peat moss (e.g., *Sphagnum* sp.).
Lichen	Low-growing fungus-like organisms, not forming leafy stems like moss, often in continuous mats or crusts (e.g., *Cladonia* sp.)

Food species (special interest)

In some Arctic communities food insecurity remains a challenge. Locally harvested species, including plants, are an important and healthy part of the diet of Arctic peoples. For example, at some points in the year, almost half (48%) of the population of the Nunavik region in Canada participates in berry collecting at least once a month (Furgal, et al. 2012). Vegetation species collected in the Arctic include berry species such as *Vaccinium vitis-idea* (known as cranberry, ligonberry, partridgeberry, kinminak, etc.), *Rubus chamoemorus* (Akpik, bakeapple, salmonberry), *Vaccinium uliginosum* (blueberry, Kigutangirnaq, Kegotangenak) and *Empetrum nigrum* (blackberry, Paurngaq). Other plants and roots are harvested for tea or as vegetables. It is unclear how plants used for food will react to changing climate conditions, or the impact that this may have on the diet of Arctic peoples (Nancarrow and Chan 2010), which may include longer and warming growing seasons, but also regional dryness and the effects of shading from increased shrub cover (Lévesque, et al. 2012).

Species of special concern (special interest)

Several Arctic plant species are rare and/or endemic and have a very local distribution. Some of them are at threat from human activities. Many of these species will be included in a comprehensive "red" list of rare and endangered Arctic plants, based on IUCN classifications, in development through the CAFF Flora Group. These species will be targets for monitoring. Other species may be deemed special interest because they are regionally rare or of particular interest to the community and could be targeted with a finer scale monitoring program.

Non-native species (special interest)

Non-native and invasive species is one of the future risks for Artic biodiversity, particularly in combination with the effects of climate change (CAFF, ABA 2013). Terrestrial non-native species may spread into the Arctic through accidental or intentional transportation or through expansion of their ranges. Monitoring around anticipated ports or corridors of introduction, such as roads, or along species range edges is recommended.

4.2.3.3.2 Vegetation attributes, sampling protocols and design

Based on the FECs that were selected, **essential** and **recommended** attributes and monitoring parameters were developed through the TEMG workshop process (Table 4.3). The proposed protocols typically can be applied to answer a number of monitoring questions, yet can also generate standardized information that can be integrated for addressing broader scale questions. Depending on the FECs, the priority of the following attributes may vary:

1) Most vegetation groups

- **Attribute: Diversity** (species richness, alpha/beta/gamma diversity, community composition) — ***Essential***
- **Attribute: abundance** (percent cover, density, number of plants/units, etc.) — ***Essential***
- **Attribute: composition** (vertical and horizontal structure of plant species; morphology, canopy structure, etc.) ***Essential***
- **Attribute: spatial structure** (distribution of communities, total area by community, clumping, fragmentation, connectivity, location) — ***Essential***
- **Attribute: productivity** (biomass, photography, remote sensing) — ***Essential***
- **Attribute: phenology** (timing of growth, flowering, senescence) — ***Essential***

2) Species of special concern

- **Attribute: abundance** (population size, numbers, presence/absence) — ***Essential***
- **Attribute: spatial structure** (location) — ***Essential***
- **Attribute: spatial structure** (distribution pattern, total area of community, fragmentation, connectivity) — ***Recommended***
- **Attribute: diversity and demographics** (genetic and neutral diversity; population genetics - migration estimates and gene flow, effective population size, etc.) — ***Recommended***
- **Attribute: demographics** (population viability; meta-population dynamics) — ***Recommended***
- **Attribute: health** (disease/pathogen prevalence, percent of affected individuals and populations, etc.) — ***Recommended***

3) Non-native species

- **Attributes: abundance and spatial structure** (presence/absence of species, population sizes, location, cover) — ***Essential***
- **Attribute: composition** (vertical and horizontal structure of plant species; morphology, canopy structure, etc.) — ***Essential***
- **Attribute: health and demographics** (prevalence of pathogen/disease, percent of affected plants in population, population viability) — ***Recommended***
- **Attribute: diversity** (genetic diversity: gene flow, directionality of colonization, migration rate, etc.) — ***Recommended***
- **Attribute: phenology** (timing of growth, flowering, senescence) — ***Recommended***

4) Food species

- **Attribute: phenology** (timing of growth, flowering, senescence) — ***Essential***
- **Attributes: productivity and biomass** (as for most plants above; nutrient content) — ***Essential and Recommended*** (see Table 4.3)
- **Attribute: health** (prevalence of pathogen/disease, percent of affected plants in population) — ***Recommended***

4.2.3.3.3 Vegetation specimen processing, archiving, and DNA barcoding

Plot photographs must be taken and accurately labeled and archived so that plot data is associated with the photo. Collection of representative plot vegetation species specimens, also known as vouchers, when first establishing a plot is recommended where capacity to process and store the monitoring specimen is available. When capacity is not available, collection of vouchers for unknown species is recommended to facilitate identification. At a minimum, high resolution digital photographs of the species in question should be taken. To preserve the integrity of the plot, voucher collection should occur outside the plot. Careful study of specimens under a dissecting microscope is often required to properly identify an unknown species. To document a rare plant species, voucher specimen could be collected provided the local rare plant population has more than 100 individuals and the specimen will be donated to a Herbarium. Plot establishment data should be shared and integrated into national and international efforts to establish an international database of vegetation plots to support research and decision-making, such as the Arctic Vegetation Archive (CAFF 2013).

Voucher specimen collections should follow best practices and standardized procedures for collecting, pressing, rapidly drying, storage and shipping, identification, mounting, and archiving. Voucher specimens should be deposited with an appropriate herbarium, such as at a museum or university, where it will be mounted and archived. For both specimen photographs and voucher samples, it is essential to ensure the specimen are appropriately labeled with key information which should include name of the plant, location of collection/monitoring event, habitat, associated species collector, collection number, collection date, and the name of the person who identified the plant. Specimen identification should be verified by an expert, as needed. These records are then available for future reference or DNA analysis, as required. Standardized procedures for preparation of vegetation samples for DNA analysis are available (Saarela 2011). The samples can be integrated into international efforts to develop a DNA database for polar regions (**International Barcode of Life Project**, 2011; **Polar Barcode of Life**, 2010).

Standardized taxonomies should be used for species identification. The TEMG recommends using the *Annotated Checklist of the Panarctic Flora –Vascular Plants* (Elven 2011 [onwards]) for describing taxonomies, in conjunction with available volumes of the *Flora of North America* series, the *Pan-Arctic Checklist of Lichens and Lichenicolous Fungi* (Kristinsson et al., 2010) and the *Panarctic Moss Checklist* (in progress). A project is currently underway to develop a new *Arctic Flora of Canada and Alaska* (Gillespie, et al. 2012 [onwards]), which will eventually serve as the standard reference for Arctic plant taxonomy in the region. The proposed CAFF Arctic Red List species could serve as the basis for identification of rare species (CAFF, in press). Further, the CAFF Flora Group has recommended development of a standardized set of protocols for monitoring Red Listed plants throughout the Arctic (Gillespie, et al. 2012).

DNA analysis of fungi from soil samples at the vegetation plots

Collection of soil samples for DNA analysis is essential for tracking changes in soil fungal (mycorrhiza and decomposers) composition and relative abundance. Collection of the soil samples for DNA analysis for fungi should be conducted at the same time as the vegetation is sampled. The analysis will identify and be used to assess the abundance of fungal taxa, hence also measure species richness and species composition. The functional properties of the fungi, hence effects on ecosystem processes, may be possible to infer from linking identified soil fungi to documented life forms, such as different mycorrhizal forms, saprotrophytic and parasitic fungi (e.g. Kubartová, et al. 2012). The sampling may be coordinated with the collection of soil cores taken for DNA barcoding of soil animals (4.5.2 and 4.5.3). Sampling should follow best practice and standardized protocols for sampling, processing and analysis of fungal DNA, procedures that quickly are developed and improved (Lindahl, et al. 2013). For each site, 10 soil cores are recommended to provide a measure of the more abundant species and their frequencies (each with 50 ml soil, minimum sampling is the A-horizon, preferably down to 5 cm) and directly in the field conserved by being put into 70% ethanol or CTAB, allowing for long-term storage without breakdown of DNA at storage above zero degrees, or if possible frozen (Timling, et al. 2012). Fungal DNA barcoding will be accomplished using high throughput sequencing approaches with fungal-specific rDNA primers (Ihrmark, et al. 2012; Lindahl, et al. 2013). Even though environmental barcoding will not presently enable all taxa to be taxonomically identified, all distinguished DNA sequences, irrespective of whether they have been identified or not, will enable monitoring in space and time. Initially unidentified sequences can be grouped phylogenetically and over time will be identified and can be made available (International Barcode of Life Project 2011; Polar Barcode of Life 2010) or used in other research.

4.2.3.4 Existing capacity to deliver the CBMP-Terrestrial Plan and potential contributors to the vegetation monitoring scheme

A partial list of networks that could contribute to the CBMP-Terrestrial Plan vegetation component is described in Table 4.3. In addition, monitoring undertaken by industry and consulting firms, parks and protected areas, governments, academia, non-governmental organizations, community groups, and Arctic community members, including TK holders will contribute to the monitoring program. Appendix A Figure A2 shows representative locations for long-term plot-based vegetation monitoring programs identified to date. Other types of contributions that can facilitate and complement long-term monitoring already exist through programs that use remote sensing (see Appendix B). Data obtained through such programs can provide invaluable information on land cover, climate, and how the landscape is changing, and will be indispensable to complement and extend the coverage of data collection through monitoring as proposed in the CBMP-Terrestrial Plan for vegetation and other biotic groups.

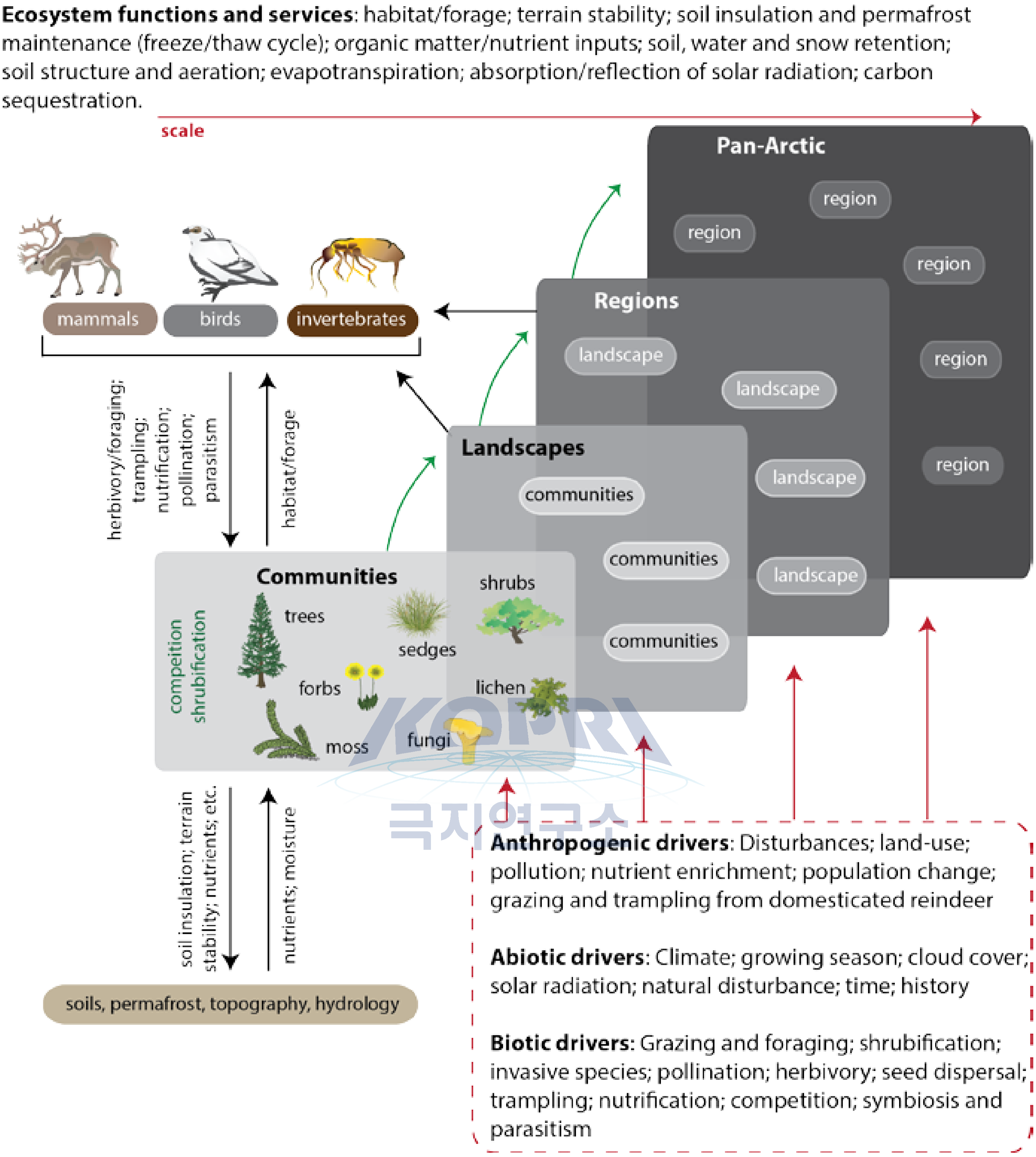
Box 4A From local scale monitoring to the circumpolar Arctic – An example for the Vegetation Biomass Indicator.

A key premise of the CBMP-Terrestrial Plan design is that the results of local scale, question-based monitoring can be projected broadly across the Arctic, through the development of remote-sensing based models that extrapolate causative relationships derived locally to a wide area using a similar, driver-indicator relationship. Vegetation biomass is one attribute in the CBMP-Terrestrial Plan that may be increasing both locally (Gauthier, et al. 2011a; Gauthier, et al. 2011b; Hudson and Henry 2010), and across broad areas of the Arctic tundra (CAFF 2010; Gensuo, et al. 2009). Vegetation biomass has also been used to predict the quality of habitat factors such as caribou/reindeer forage during the post-calving period (Chen, et al. 2009b), and thus links to other CBMP-Terrestrial Plan components.

Vegetation biomass is often calculated using estimations from point-intercept methods (Bråthen and Hagberg 2004) or measured in quadrats of known area, through destructive sampling of above- and below-ground plant components (species or species group), field-weighed to estimate total fresh weights of all components, and developing fresh weight-dry weight relationships from sub-samples dried in a field laboratory (Bean, et al. 2003; Jefferies, et al. 2008). Sample sites are selected to be relatively uniform in vegetation composition and structure and vegetation dry weight/m2 is estimated. Sampling is repeated to account for spatial variability within a site, and estimates are linked to the imagery through regression analysis with the different radiometric bands and indices in the imagery, often scaling through high resolution to lower scales of resolution for broader coverage. Sampling is generally conducted across the range of tundra ecosystems (e.g., tall shrub, low shrub-herb, dwarf shrub herb, herb, herb-moss lichen, and rock-lichen) to account for variability in vegetation biomass across a tundra landscape, and to facilitate scaling-up from the destructive ground sampling to high, medium and low resolution satellite imagery.

The CBMP-Terrestrial Plan proposes that biomass sampling occurs concurrently in areas where abiotic drivers such as soil and air temperatures, wind, depth-of-thaw, nutrient availability and snow conditions are monitored. Causative relationships are interpreted between biomass change and these drivers. Recent work has shown that vegetation biomass change varies across the landscape, and is greatest in moist or seepage-affected tundra ecosystems where soil moisture and nutrients are sufficient to support the increased productivity made possible by increasing summer warmth (Elmendorf, et al. 2012). Models would be parameterized for each ecosystem (or ecosystem groups) with similar driving ecosystem processes and vegetation biomass production. Remote sensing models predicting changes in vegetation biomass could be developed that use the same causative drivers and relationships identified in the local scale modeling, and then applied widely using the imagery. Model prediction can be refined using non-destructive, photographic methods (Chen, et al. 2009a; Chen, et al. 2010b).

Correlating localized ground observations to remote sensing and other regional data can achieve broad coverage; a critical consideration in the vast and remote Arctic. Options for interpolation to remote sensing imagery include a broad census of the circumpolar Arctic, imagery transects along climatic gradients, or imagery tiles sampled according to a stratified random design. Reliable models can be extrapolated in time as well as space. Future conditions of vegetation biomass, or other vegetation/landscape indicators (vegetation functional groups, active layers, and caribou/reindeer forage production (e.g. Doiron, et al. 2013)) can be predicted for a range of climate scenarios; a very useful tool for anticipating change and supporting proactive management decision making.



Ecosystem functions and services: habitat/forage; terrain stability; soil insulation and permafrost maintenance (freeze/thaw cycle); organic matter/nutrient inputs; soil, water and snow retention; soil structure and aeration; evapotranspiration; absorption/reflection of solar radiation; carbon sequestration.

Anthropogenic drivers: Disturbances; land-use; pollution; nutrient enrichment; population change; grazing and trampling from domesticated reindeer

Abiotic drivers: Climate; growing season; cloud cover; solar radiation; natural disturbance; time; history

Biotic drivers: Grazing and foraging; shrubification; invasive species; pollination; herbivory; seed dispersal; trampling; nutrification; competition; symbiosis and parasitism

Figure 4.3 The Arctic vegetation monitoring conceptual model showing key drivers, attributes and geographic scales of biodiversity.

Table 4.3 A list of existing networks and programs which could potentially contribute to the implementation of the CBMP-Terrestrial Plan. The list is not-exhaustive.

Network	**Focal Biotic group**
The Network of Arctic field stations (SCANNET/INTERACT) and other seasonal or permanently manned research and monitoring installations	All
The ArcticWOLVES **http://www.cen.ulaval.ca/arcticwolves/index.html**	All
CircumArctic Rangifer Monitoring and Assessment Network (CARMA) **http://www.caff.is/carma**	Rangifers
International Tundra and Taiga Experiment (ITEX) network **http://www.geog.ubc.ca/itex/**	Vegetation
"Present day processes, Past changes, and Spatiotemporal variability of biotic, abiotic and socio-environmental conditions and resource components along and across the Arctic delimitation zone" (PPS Arctic network) **http://ppsarctic.nina.no/**	Vegetation
Global Observation Research Initiative in Alpine Environments (GLORIA) **http://www.gloria.ac.at/?a=7**	Vegetation
International Waterbird Census (IWC) **http://www.wetlands.org/Whatwedo/Biodiversitywaterbirds/InternationalWaterbirdCensusIWC/tabid/773/Default.aspx**	Birds
International Breeding Conditions Survey on Arctic Birds (ABBCS)	Birds
The Arctic Shorebird Demographics Network Breeding Protocol (**http://www.manomet.org/arctic-shorebird-demographics-network**)	Birds
Arctic Program for Regional and International Shorebird Monitoring (Arctic PRISM) **http://www.ec.gc.ca/reom-mbs/default.asp?lang=En&n=FC881C1B-1**)	Birds
International Shorebird Surveys (ISS) **http://www.pwrc.usgs.gov/iss/iss.html**	Birds
Australasian Wader Studies Group (AWSG) **http://www.awsg.org.au/**	Birds
U. S. Fish and Wildlife Service and Canadian Wildlife Service Waterfowl and Breeding Bird surveys **http://www.fws.gov/migratorybirds/NewsPublicationsReports.html; http://ec.gc.ca/rcom-mbhr/default.asp?lang=En&n=762C28AB-1**)	Birds
Birdlife International **http://www.birdlife.org/**	Birds
The Ornithological Council **http://www.nmnh.si.edu/BIRDNET/orncounc/index.html**	Birds
Breeding Bird Survey (BBS) **https://www.pwrc.usgs.gov/bbs/**	Birds
Christmas Bird Count **http://birds.audubon.org/christmas-bird-count**	Birds
Northwest Territories/Nunavut Bird Checklist Survey **http://www.ec.gc.ca/reom-mbs/default.asp?lang=En&n=60E48D07-1**	Birds
Circumarctic Active Layer Monitoring (CALM) Network	Abiotic
Arctic Palaeoclimate and its Extremes (APEX) **http://www.apex.geo.su.se/**	Drivers

Table 4.4 List of FECs for vegetation (FECs: major biodiversity elements), their attributes (compositional, structural, and functional aspects), monitoring priority of attributes, parameters of attributes (individual measures/methods to quantify attributes), geographic scale, method (monitoring technical approach or reference to methods), protocol complexity (basic or advanced) and temporal recurrence (how frequently monitoring should be conducted).

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE
All plants (Species, life form groups and associations/ communities). Includes monitoring of forage species.	Diversity, composition and abundance	Essential	Percent cover by life form or species	Local	Point intercept/line point intercept	Basic	2 years
			Canopy gap	Local	Line intercept	Basic	2 years
			Alpha Diversity	Local	Plot species list	Basic	2 years
				Local	DNA soil sampling	Advanced	2 years
				Local	Plot photograph	Basic	2 years
			Height of representative life forms	Local	Mean of 5 representative plants	Basic	2 years
			Beta/gamma diversity	Regional/ pan-Arctic	Low resolution remote sensing: MODIS	Basic	Annual
				Landscape/ regional	Med resolution remote sensing: Landsat	Basic	10 years
				Landscape	High resolution remote sensing (e.g., Quickbird)	Advanced	As required

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE
All plants (Species, life form groups and associations/communities). Includes monitoring of forage species	Diversity and spatial structure	Essential	Pattern: fragmentation/ connectivity	Landscape/ regional	Remote sensing	Basic	5 years
			Area: total area by community	Landscape/ regional	Remote sensing	Basic	5 years
			Distribution of communities	Landscape/ regional	Remote sensing	Basic	5 years
	Productivity	Essential	NDVI/ fPAR/ LAI/ EVI	Landscape/ regional	Remote sensing	Basic	Annual
			Aboveground Biomass	Local	Point intercept estimation; photo digital photograph classification (non-destructive); clip plots (destructive)	Advanced	2 years
			Total biomass	Local	Harvest and root clipping (destructive)	Advanced	2 years
			Biomass	Landscape/ regional	Remote sensing	Advanced	Annual
				Local	TK: Harvest observations related to food abundance	Basic	As required
				Local	Tree ring and shrub ring samples	Basic	5 years
	Phenology	Essential	Date of leaf-out (species)	Local (plot)	Direct observation	Basic	Annual
			Date of green-up/ senescence/ length of growing season	Regional/Pan-Arctic	Remote sensing	Advanced	Annual
			Date of flowering (species)	Local (plot)	Direct observation	Basic	Annual
			Date of senescence (species)	Local (plot)	Direct observation	Basic	Annual
			Amount of plant reproductive parts and newly emerged vegetative parts	Local	Direct observation	Advanced	Annual
			Date of senescence (species)	Local	TK: Morphological observation	Advanced	Annual

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE
Rare species, species of concern	Abundance	Essential	Presence/ absence; number of individuals /population size	Local	Direct count observations	Basic	10 year
	Diversity genetic, neutral:	Recommended	Gene flow, effective population size, migration rate and directionality, population growth rates, bottlenecks; evolutionary potential	Regional	DNA analysis	Advanced	As required
	Abundance	Recommended	How many populations, locations (meta-populations)	Landscape	Direct observation	Basic	As required
			Abundance of individuals within a populations over time	Local	Direct observation	Basic	As required
	Health	Recommended	Presence/ absence of population with condition (disease, parasites, insects)	Local	Direct observation	Basic	As required
			% of population with condition	Local	Direct observation	Basic	As required
			Community observed changes in plant health	Local	Direct observation	Basic	As required
	Spatial structure	Recommended	Pattern: fragmentation/ connectivity	Landscape	Direct observation	Basic	5 years
			Area: total area by community	Landscape	Direct observation	Basic	5 years
			Distribution of communities	Landscape	Direct observation	Basic	5 years
Non-native species	Abundance	Essential	Presence / absence	Local	Direct Count observations	Basic	As required
			Population sixe	Local	Direct Count observation	Basic	As required
	Spatial Strucutre	Essential	Extent	Landscape	Remote sensing	Basic	As required

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE
Food Species	Productivity Quality	Essential	Species Mix	Local	TK; direct observation	Basic	Annual
			Size distribution	Local (plot)	TK; direct observation	Basic	As required
		Recommended	Palatabilty; secondary compounds	Local	Phyto-chemical analysis (Laboratory analysis)	Advanced	As required
	Productivity	Recommended	Berry abundance, wight and ripeness	Local	Berry collection drying and observation	Basic	As required
	Phenology	Essential	Date of leaf out	Local (plot)	Direct observation	Basic	Annual
			Date of flowering	Local (plot)	Direct observation	Basic	Annual
			Date of senescene	Local (plot)	Direct observation	Basic	Annual
	Health	Recommended	Presence/absence of species with condition (disease, parasites, insects)	Local	Direct observation	Basic	As required
			% of pop with condition	Local	Direct observation	Basic	As required
			Community observed changes in plant health	Local	Dorect observation	Basic	As required

4.2.4 Birds sampling approach and monitoring

The CBMP-Terrestrial Plan has adapted priority management questions to address the needs and challenges for monitoring avian populations. For many birds, their annual distribution extends beyond Arctic boundaries. In addition, some constitute important game species harvested by Arctic peoples and communities elsewhere. The primary objectives of monitoring thus include:

1. locating the best available information and sources of annual data that would enable assessment of trends in flyway population sizes;
2. estimating current sizes of Arctic bird populations;
3. obtaining information on long-term changes in annual survival and productivity;
4. conducting focal site-based integrated ecosystem monitoring for Arctic keystone species (incorporating drivers that may influence avian abundance and breeding success);
5. coordinating and standardising data collection and collation for monitoring, detecting and understanding changes in population sizes and distributions, and to infer causation;
6. developing a future monitoring framework to capture data on overall population sizes for as many Arctic flyway populations as possible;
7. integrating monitoring of avian populations with those drivers that may affect birds within and beyond the Arctic in monitoring efforts; and
8. to provide informed knowledge to management agencies for successful avian conservation.

Based on these objectives and to address the challenges of monitoring and conserving avian populations, the following management questions have been adapted for Arctic birds.

4.2.4.1 Avian management questions

The key general management questions guiding Arctic terrestrial biodiversity monitoring (Figure 3.4) have been adapted for avian populations and comprise a two-tier approach, from the standpoint of requirements under existing international conventions and national legislation (usually in relation to single species), and with respect to monitoring the health and diversity of terrestrial ecosystems. However questions related to birds can also be connected to specific conservation issues. In this case, more tailored monitoring follows. Where wild bird populations function in the human food supply chain, there is a need to secure a long-term sustainable harvest, as well as fulfill information needs related to reporting required under international (or national) obligations such as the Ramsar Convention, Convention on Biological Diversity (CBD), Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA), Convention on Migratory Species (CMS), the *Migratory Birds Act*, etc., as well as reporting on national and internationally red-listed species (partly related to international obligations). The CBMP-Terrestrial Plan therefore identifies the following Arctic avian management questions:

A. Questions focused on species

1. What are the status (abundance, richness, diversity survival and productivity), trends and distributions of Arctic avian species at the population flyway level?
    a. Within a global and flyway perspective (conventions like CBD and Ramsar)?
    b. Within a regional/national perspective (legislation)?
    c. Given the status, how many birds can be harvested (informing local managers, communities, etc.)?
2. To what extent are existing annual and long-term data available that can serve to answer these questions?
3. Where and how are populations and communities changing?
4. Where and how are drivers influencing changes in species (particularly species of focal interest)?
5. Are protected site networks living up to their intended criteria for conservation?

B. Questions for ecosystem-based monitoring approaches

1. What are the trends in avian population at the local/site-based ecosystem level and how do these relate to global/flyway population level changes?

2. What and how are the primary drivers (biotic, abiotic and anthropogenic) influencing avian diversity and ecosystem function (within and beyond the Arctic) and how are these changing?(Encompassed in coordinated and integrated monitoring of other key biotic and abiotic attributes)
    a. What are the implications of changes in drivers for birds and other species (phenology, structure, productivity, abundance, and breeding success)?
    b. For bird species of concern or that are declining, what are the factors affecting phenology, distribution and abundance?
    c. What can we do about negative trends (including related to food security)?

The two approaches are interlinked; for example, demographic parameters such as breeding success collected in the wintering quarters can be related to changes in snow conditions in key breeding areas, detected by a combination of local snow coverage measurements and remotely sensed data.

4.2.4.2 Avian conceptual model

The avian conceptual model is provided in Figure 4.4. Birds, as keystone consumers in Arctic ecosystems, are highly affected by the processes and drivers (biotic, abiotic and anthropogenic) that affect their food base. For example, in common with mammalian herbivores, grazing herbivores (primarily geese) are greatly influenced by spring conditions, the length of growing season, and the climate template for graminoid production upon which they depend for energy and nutrition (Boyd and Fox 2008; Davies and Cooke 1983; Dickey, et al. 2008; Fox and Gitay 1991; Madsen, et al. 2011). Likewise, the birds that consume the flush of invertebrates during the short summer season (such as grouse, waders and passerines) are also affected by climatic factors that shape the abundance of such organisms (Bolduc, et al. 2013). However, these same species are also affected by top-down control, for instance through the influence of raptors and mammalian carnivores, which may shift between alternative prey in response to differential prey availability or other factors (Giroux, et al. 2012; Legagneux, et al. 2012; Rockwell, et al. 2011; Smith, et al. 2010; Summers 1986).

Human exploitation of populations, both within and outside the Arctic, may also have a major effect on population trajectories. Furthermore, for many of the long distant migrant species, the major factors affecting the abundance of avian species may operate outside the part of the annual cycle when the birds are present in Arctic regions. For this reason, it is essential that in considering the functional significance of specific avian species, monitoring of avian attributes is closely integrated into those of other relevant taxa. Hence, if expansions in geese are causing cascade effects on vegetation, such as snow geese grubbing of Hudson Bay lowlands (Abraham, et al. 2005; Jefferies, et al. 2006), as a keystone avian species, it is vital that the botanical monitoring is closely integrated with that of the geese (e.g., see Box 4C). Likewise if a species monitoring protocol is designed around reflecting changes in key variables, such as snowy owl abundance, Arctic foxes and lemmings (Giroux, et al. 2012; Legagneux, et al. 2012; Roth 2002; Schmidt, et al. 2012b), it is essential that these elements are integrated into a cohesive monitoring program that includes all facets of the functional ecosystem components.

4.2.4.3 Avian monitoring design principles and components

A wide variety of methods have been used for bird monitoring across the Arctic. Sometimes different methods are used to monitor the same parameters in the same functional groups due to regional differences in bird biology (e.g., density and behaviour), resources and expertise available, and specific monitoring goals and needs. Methods vary in accuracy and precision as well as in implementation costs, and it may be difficult to suggest a single unified method to monitor an attribute, because of logistic or other limitations, or because some methods may be less feasible or useful to implement in frameworks of TK observations and/or citizen science, or based on region-specific management needs. However, standardizing protocols during the implementation phase of monitoring is strongly encouraged whenever possible, and analyses of trends can still be performed when methods vary across groups and regions. A major advantage in avian monitoring is the broad interest in the study of bird populations and the wealth of data that are available regardless of the variety of methods employed; invaluable opportunities thus exist to integrate such data from sources ranging from community-based surveys to focal research studies.

Any strategy to monitor avian populations must recognise logistic limitations and prioritise accordingly. Hence, monitoring effort should be concentrated on species with (i) keystone functions in Arctic ecosystems, (ii) indicator species of particular value because of correlations with specific variables (e.g., snowy owl, rough-legged buzzard, and pomarine skua/jaeger or long-tailed skua in relation to lemming cycles), (iii) rare, threatened or rapidly declining species, (iv) species of cultural or exploitative value to human communities (e.g., hunted species), (v) flyway populations for which there are legal obligations (national or international) to monitor, and (iv) non-native species. TK is most relevant to include in this regard since knowledge holders quickly will be able to assess potential changes within the environment. For instance, assessments can be conducted on unusual species spotted in new areas or reporting can be included on locally-observed declines on harvested or non-harvested populations

Table 4.4 includes a list of FECs for terrestrial birds. The table also describes attributes, their monitoring priority, recommended frequency and scales of sampling, and references to methods and protocols. As described previously, two categories of methods (**basic** or **advanced**) were defined to address an issue of differences in resources and expertise available at different monitoring localities. Basic methods form a core of monitoring schemes. The data collected using basic methods are sufficiently accurate and precise to provide scientifically robust answers to management questions. Advanced methods can be implemented at a portion of sites where basic methods are being employed, and where time, labour and technical resources allow for the collection of additional information. This information can be used to further enhance precision of basic methods and to answer additional questions that can aid interpretation of casual relationships in monitoring data.

4.2.4.3.1 Avian FECs and functional groups

To identify key interactions at an ecosystem level and among other biotic groups, birds are monitored under the CBMP-Terrestrial Plan as part of functional groups (more comprehensive) rather than taxonomically. The bird fauna of the Arctic terrestrial ecosystem can be divided into four major FECs as follows:

- Insectivores (shorebirds/waders, passerines)
- Carnivores (diurnal birds of prey, owls, skuas/jaegers, ravens)
- Herbivores (geese, swans, ptarmigan)
- Omnivores (piscivores[3], cranes, ducks)

These functional groups are widely distributed throughout the Arctic, inhabiting most regions with the exception of the northernmost polar desert ecosystems. In spite of similarity in ecosystem functions, each of the four groups includes taxonomically distinct bird species, which differ in many aspects of their biology, representing specific challenges when developing unified monitoring methods even for a single FEC. Typical bird densities in the Arctic are lower over vast areas of suitable habitat compared with many temperate and tropical ecosystems which represents another challenge for their effective monitoring.

The CBMP-Terrestrial Plan specifically does not cover seabirds and sea ducks, which are covered in the CBMP's *Arctic Marine Biodiversity Monitoring Plan*. Some overlap may occur between the CBMP-Terrestrial Plan and the CBMP's *Arctic Freshwater Biodiversity Monitoring Plan*. The CBMP-Freshwater Plan includes all birds that can have an effect to the freshwater ecosystem on a site-based level including divers and grebes, which will not be considered under the CBMP-Terrestrial Plan.

1. Insectivores
The functional group of insectivores in the Arctic includes most species of shorebirds also known as waders (suborder Charadrii) and most species of passerines (order Passeriformes). The term "insectivores" is to a certain extent inappropriate, because these birds also consume many other invertebrates on the breeding areas and, particularly, on non-breeding grounds, many passerines consume a diet of seeds. Insectivores constitute the dominant component of avian fauna in the terrestrial part of Arctic, both in terms of numbers of species and of their population densities, although none of the species in this FEC attain large body size. Insectivores play a role in the ecosystem as consumers of invertebrates and as a prey (including adult birds, eggs and chicks) for mammalian and avian predators. Because of their dependence upon invertebrates as a primary food source, insectivores are subject to the impacts of adverse weather conditions, which greatly affect their food availability.

Several larger species of shorebirds are harvested, but generally insectivores are less subject to hunting or other forms of exploitation by humans both in the Arctic and on non-breeding grounds compared in contrast to herbivores and omnivores. During recent decades, large population declines have been observed in Nearctic and Palearctic shorebird populations, and some species have become critically endangered (IUCN 2012 [onward]; Wetlands International 2012). The reasons for these more or less well documented declines are not known, but habitat loss and change, as well as other anthropogenic impacts in the temperate and tropical non-breeding areas are suspected to contribute (e.g., Baker, et al. 2004).
Many species of insectivores are inconspicuous incubators with the result that assessment of their densities on the breeding grounds using nest searches can be challenging and labour-intensive. At the same time, the complex mating systems of many shorebird species do not permit inference about nest or bird abundance based on territory mapping alone, even if a species exhibits territorial behaviour during the breeding period. The challenges of making effective breeding density assessment of shorebirds stimulated development of double-sampling techniques for density estimation.

All avian species in this FEC are migratory, allowing assessment of population sizes and demographic parameters for several species of shorebirds on the non-breeding grounds. For passerines, information is sparser and estimating population size and annual breeding success can be far more challenging.

2. Carnivores
The functional group of Arctic avian carnivores includes diurnal birds of prey (families Accipitridae and Falconidae), true owls (Strigidae), skuas/jaegers (Stercorariidae) and ravens (Corvidae). Carnivores play a role in the ecosystem as top predators and may be a regulating factor of other functional groups of birds and small mammals. Population cycles of lemmings and voles have a strong impact on the local abundance and reproduction of most avian predators, which may in turn radically affect predation rates on alternative prey, making these important components in Arctic food webs.

However, the degree of specialization of predatory birds on small mammals varies, with snowy owl, pomarine skua/jaeger, and long-tailed skua/jaeger showing strong responses to fluctuations in small mammal abundance (see Box 4B). Several species aggressively protect their nests from other predators, a behaviour which is exploited by some species of Arctic geese to gain protection from mammalian predators. Generally, there is no systematic harvest of avian carnivores, although they can locally suffer from occasional

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[3] Piscivores are included here as *omnivores* because this group represents relatively few species which overlap to some extent with CBMP's *Arctic Freshwater Biodiversity Monitoring Plan*, but which do not constitute a major group of their own in the terrestrial environment.

catching/shooting, disturbance by humans and falconry. A few species have shown recent range expansion and/or population increase while others may have recently declined (IUCN 2012 [onward]), but generally information about trends is very scarce.

Many species are conspicuous during the breeding season which makes assessment of their local population size relatively straightforward based upon mapping of territorial pairs and nest searches. However, breeding densities are much lower compared with other functional groups, which require surveys conducted across much larger areas. In addition, some avian predators may be difficult to locate as their populations fluctuate widely in response to prey cycles (small mammals). Most species are migratory but their wide dispersal throughout vast winter ranges do not always allow for the use of bird counts on the non-breeding grounds for assessment of population numbers.

The two circumpolar raptors, the peregrine falcon (migrant) and gyrfalcon (resident), have been continuously monitored in terrestrial study areas across the tundra regions of Alaska, Canada/Nunavut, Greenland, Arctic parts of Scandinavia and Russia from the 1980s or earlier. Most of these studies follow similar basic sampling protocols (plus more advanced, site-specific add-ons) and could be coordinated into a circumpolar terrestrial avian predator monitoring scheme of breeding density, reproductive success/productivity, timing of breeding and pollutant loads, etc. The many study areas also offer opportunities for comparing different sub-populations for identification of variable climate effects and extremes on the basic parameters (for instance, very different effects recorded from Nunavut and Greenland).

3. Herbivores

The herbivore functional group in the Arctic includes geese and swans (Anatidae) and ptarmigan (Tetraoninae). These medium to large-sized birds have diverse roles in the ecosystem as they can have a major grazing impact on habitats, make a substantial contribution to nutrient cycling, and provide a prey base to support populations of mammalian and avian predators. Breeding efforts of some herbivores are often limited by abiotic conditions early in the season.

There is large-scale harvest of many herbivore species both in the Arctic and on non-breeding grounds. This is undoubtedly the most important group of birds for maintaining traditional livelihoods of people living in the Arctic. Apart from hunting, egg harvesting by humans can have locally strong impacts on the reproductive output of breeding populations. During recent decades, several species have shown large increases in abundance, some apparently due to improved feeding conditions and protection on the non-breeding grounds. In several areas, goose densities have apparently exceeded the local capacity of the ecosystem, leading to local habitat degradation. However, there are also populations with known declining trends and are therefore of conservation concern (IUCN 2012 [onward]; Wetlands International 2012).

Some species (e.g., swans) are highly conspicuous, which allows their efficient census on the breeding grounds using ground or aerial surveys. Several species of geese nest in colonies where breeding effort and demographic parameters can be efficiently assessed. Geese and swans are long-distant migrants, while ptarmigans undertake relatively short-distant seasonal movements, mostly within Arctic areas. Population size and certain demographic parameters of most species of geese and swans are already assessed on the non-breeding grounds.

4. Omnivores

The functional group of omnivores includes divers/loons (Gavidae) cranes (Gruidae) and ducks (Anatidae). With the exception of the divers that are specialist piscivores (and therefore primarily affect freshwater systems), these taxonomic groups of birds are less specialized in their ecosystem functions compared with the previous three FECs and accordingly play a less distinct role in the ecosystem. Generally, omnivores play a similar role in the ecosystem to that of insectivores and herbivores as consumers of invertebrates and plants. While cranes occasionally function also as top predators they do not show the dependence on fluctuations in animal prey abundance that typifies several carnivores. Ducks, similar to insectivores and herbivores, also play a role as prey for mammalian and avian predators. Some seabirds (for example, auks, Alcidae, gulls, Laridae, and terns Sternidae) are included in the CBMP-Marine Plan, and some species can be considered omnivores and are also part of the terrestrial biome, but they have not been included as key FECs based on the criteria of the CBMP-Marine Plan (Gill, et al. 2011) or the Terrestrial Plan (Fig. 3.2).

Some general estimates of overall population sizes and trends for species are available (IUCN 2012 [onward]; Wetlands International 2012) in addition to some estimates at local sites. Sandhill cranes are subject to a regulated harvest in the Nearctic. Ducks are being hunted in the Arctic and on non-breeding grounds, and are similar to herbivores as an important hunting resource. The population of sandhill cranes is currently increasing and they are known to be expanding their range in the Russian Arctic. Siberian cranes continue to be critically endangered, and threats continue at stop-over and wintering sites (Kanai, et al. 2002). During recent decades several species of ducks have shown decreases in their abundance, while others have shown long-term increases in overall population size (IUCN 2012 [onward]; Wetlands International 2012).

Omnivores are medium to large size birds which permit an assessment of numbers through counts on the breeding grounds using ground or aerial surveys. All species are migratory. Populations of cranes and ducks can be also assessed on migration and wintering grounds.

4.2.4.3.2 Avian attributes, sampling protocols and design

For all four FECs, seven common attributes have been selected for monitoring. The parameters to be monitored, the drivers of change as well as methods and scale are largely the same for all functional groups, with some variations (see Table 4.3).
For all functional groups, the attributes and their overall priority are the following:

- **Attribute: Abundance** — ***Essential***
  From an overall monitoring perspective, the key attribute is abundance from which trends in population sizes can be inferred; for Arctic resident species, this has to be done on the Arctic breeding grounds based on networks of monitoring sites, while for migratory species, a combination of breeding bird monitoring and surveys outside the Arctic can be applied, dependent on the population in question. For a wide range of species, the most efficient way to monitor trends in population size is by standardized surveys on the staging or wintering grounds, in some cases supplemented by surveys of birds on passage at migration hotspot areas.

- **Attribute: Spatial structure** (distribution) — ***Essential***
  Birds are expected to rapidly shift breeding ranges northward with ongoing climate change. Due to fragmentary coverage in terms of site-based station networks, it will be difficult to quantify the rate of change over wide areas. The terrestrial station network can be used to provide data on detailed rates of settlement and ecosystem consequences. Monitoring under the CBMP-Terrestrial Plan can be complemented through the use and linkage to software such as eBird, geo-referenced information for recording distribution changes which will be applicable for a citizen science approach as well as for expeditions visiting remote areas; standards for recording will have to be developed.

- **Attributes: Demography** (survival and Productivity) — ***Essential***
  Monitoring changes in demographic parameters is important to assess causes behind observed population trends in order to provide the basis for management actions. Such monitoring can directly feed into inferences about the impacts of harvest on huntable populations. At local scales, data on breeding output can be monitored in terms of nest success rates, and at population levels, by standardized counts of the proportion of juveniles in the observed flocks on migration or staging or even on the winter quarters. Age structure (and some survival rates) can be derived from harvest data and wing surveys (e.g., geese), through observations and focal studies, or preferably through mark capture-recapture studies which are, however, often costly in terms of man-power and effort. Demography studies in birds and mammals often capture data related to reproduction also (categories of 'productivity' as defined for other biotic groups; see Fig 3.4).

- **Attribute: Phenology** — ***Essential***
  Changes in avian time budgets, schedules, and annual cycles can be informative about changing abiotic and biotic drivers including shifts in climate (temperature, precipitation and snow melt), food resources, habitat quality, predator pressure, pathogens, and drivers operating at stop-over and wintering sites. Mismatches between environmental cues, hormones and physiology, reproduction and peak food availability (e.g., insect emergence, vegetation productivity, etc.) or climate can have devastating consequences on populations (Durant, et al. 2007; Gilman, et al. 2010; Mallory, et al. 2010; McKinnon, et al. 2012a; Miller-Rushing, et al. 2010; Van der Putten, et al. 2004), particularly as climate change may result in earlier growing seasons. Timing of breeding, moulting, and migration can be assessed through population surveys, site-based observations, focal studies, radar (Alerstam, et al. 2001; Hedenström, et al. 2009), and through data integration from observatories outside the Arctic. The effect of changes in timing on demography and fitness needs close integration with other measured attributes.

- **Attribute: Diversity** (community structure) — ***Recommended***
  Monitoring the composition and diversity of bird communities can give a first indication of ecosystem structure and habitat quality; for example, the density, abundance and composition of the predatory bird guild will reflect rodent cycle persistence. If collected in a standard way over a variety of climatic gradients and habitats, the composition of communities can indicate general effects of climate change. In the CBMP-Terrestrial Plan context it is regarded as a supplement to species-specific monitoring as well as providing a regular measure of local biological diversity and insights into changing trophic relationships. Community structure can be monitored indirectly from essential attributes such as abundance and demography; where feasible it can be monitored directly also.

- **Attribute: Health** (pathogen prevalence) — ***Recommended***
  With climate change, zoonoses are expected to become more prevalent in Arctic birds which may affect the health of populations; in some species, the combined effects of climate change, zoonoses and contaminant load may aggravate the impacts. Furthermore, since most species are migratory, birds may increasingly be a pathway for the transmission of vectors to Arctic ecosystem and human populations (see Chapter 1). Prevalence and impacts of zoonoses can be investigated at field stations or specific studies with programs for capturing birds for ringing.

- **Attribute: Health** (body condition) — ***Recommended***
  Body condition is a measure of the fitness of an organism at a given time and state. Monitoring trends in body condition of birds in a standardized way can provide useful information that can be related to the health of a population and can be linked to changes in the environment. Monitoring of body condition can be carried out at field stations or part of specific studies where standardized capture of birds or field observations of body condition indexes are performed, but may require intensive studies to provide reliable information.

- **Attribute: Diversity** (genetics) — ***Recommended***
  Low genetic diversity may result from several processes including population bottlenecks or metapopulation dynamics that reduce the level of diversity and result in reduced ability to survive/reproduce at the population level. Genetic diversity information may provide relevant insights about the demographics of a population and contributes to the definition of population or management units, and hence to flyway population definitions as well.

- **Attribute: Temporal cycles** (predator-prey interactions) — ***Recommended***
  For avian carnivores that are highly dependent on prey species that undergo stochastic population growth and declines (population cycles with periodic crashes), such as snowy owls that feed on lemmings, data obtained from measuring attributes such as abundance, health, demographics, and others for both the avian carnivores and for prey populations can provide insight into causes of population declines or altered ecological interactions. Obtaining data on temporal cycles would require concomitant analyses of prey and predators where such data can be collected, ideally from the same regions over long periods of time to understand natural variation and cycles.

As for other biotic groups, species of special interest can be monitored indirectly through these protocols, including non-native species and species of conservation concern.

4.2.4.3.3 Avian sample processing, archiving, and other protocols

As for other biotic groups, the planned and opportunistic collection of tissues (blood, carcasses, feathers, eggshells, and droppings) is recommended whenever possible and where permits can be obtained. Such samples can be invaluable in focal studies of species but also for detecting change (see Chapters 1.7.4 and 3.5.3), serving as genetic baselines (e.g., assessments of genetic diversity, management units, flyway populations, inferring systematics, detecting shifting distributions of species and hybridization, etc.) and as chemical baselines (e.g., for monitoring changing contaminant levels, detecting diet shifts by trophic level, and identifying the general locations of wintering grounds). Since birds are consumers and may feed at high trophic levels, avian species are sensitive to environmental changes, and to contaminants (Hargreaves, et al. 2010, 2011; Miljeteig, et al. 2012). Analyses of stable isotope signatures are revealing new ways of monitoring Arctic ecosystem health indirectly through avian studies. For example, many terrestrial Arctic species which were previously considered to be capital breeders (using endogenous body reserves that were accumulated outside the short Arctic breeding period for reproduction) are now thought to rely heavily on resources within the Arctic breeding grounds as income breeders (Gauthier, et al. 2003; Klaassen, et al. 2001). Thus, the status and reproductive success of bird populations can serve to inform on the state of prey and ecosystems within the Arctic per se. In addition, as climate change drives shifts in species distributions, sampling bird populations for the presence of new pathogens in the Arctic, or comparing immunogenetic profiles among populations to investigate their capacity to recover from outbreaks in conjunction with other stresses, will likely increase in importance (e.g., Descamps, et al. 2011; Descamps, et al. 2012). Careful archiving and storage of tissues that can serve as baselines is recommended even when capacity for conducting more intensive studies is currently limited, as such samples may help understand change that may be more subtle and difficult to detect over shorter time or geographic scales (see Table 3.3).

4.2.4.4 Existing capacity to deliver the CBMP-Terrestrial Plan and potential contributors to the avian monitoring scheme

Figure A3 includes mapped sites of intensive bird monitoring in the Arctic and illustrates existing capacity. In the interests of efficiency and effectiveness, it is essential to recognise the activities of many existing mechanisms that already collate monitoring data relating to birds that breed in the Arctic. Chapter 1.9 lists several key monitoring networks and programs that can contribute toward the implementation of the avian monitoring plan. Some of these sources of information are vital cornerstones to any future CBMP construction, since many of these already deliver the results of monitoring data or analysis of such data at the flyway population levels. Pre-eminent amongst these is the Wetlands International Waterbird Monitoring Programme (**http://www.wetlands.org/Whatwedo/tabid/55/Default.aspx**), which globally monitors all waterbird populations and provides a three year reporting cycle of population sizes, trends and the reliability of the census data. The Arctic Birds Breeding Conditions Survey (ABBCS: **http://www.arcticbirds.net/**) is a joint venture of the International Wader Study Group and Wetlands International's Goose and Swan Specialist Groups, and collates annual information on environmental conditions on the breeding grounds of Arctic nesting birds.

For data on changes in abundance of non-waterbird avian species, a number of regional schemes exist that monitoring winter bird abundance on the winter quarters, such as the Christmas Bird Count and Breeding Bird Surveys in Canada and the U. S., which generate annual abundance indices for species not otherwise covered by annual surveys (**http://birds.audubon.org/data-research**).

Monitoring on non-breeding grounds beyond Arctic regions

For many migratory species that breed in the Arctic, particularly those travelling thousands of kilometers and crossing several international jurisdictions (e.g., many with wintering grounds in southern continents), monitoring within breeding grounds only provides information on a fraction of the yearly cycle of these species. Some species are presently well covered by aerial sampling on the breeding grounds to assess the precise abundance of nesting birds to generate an annual index of abundance (e.g., **http://www.flyways.us/status-of-waterfowl/population-estimates/2012-total-breeding-duck-population-estimates**). However, for the majority of terrestrial birds in the Arctic, this is difficult, expensive or simply not possible. Identifying factors that may influence reproduction and survival, recruitment, and changing abundance and distributions, must include monitoring during migration and overwintering outside the Arctic. Conducting surveys on the non-breeding areas when birds are far more aggregated may be easier than on Arctic breeding grounds, and may facilitate estimating total population counts with some degree of certainty and accuracy (e.g., Greenland white-fronted geese; Fox, et al. 2010a) or annual indices which provide a robust measurement of annual changes in population size (e.g., Gilissen, et al. 2002). Information on the reproductive success of entire flyway populations may also be available from existing monitoring programs on the winter quarters as well (especially relating to species such as geese; e.g., Fox, et al. 2010a). Several of the most threatened Arctic breeding species are also the subject of detailed monitoring programs outside the Arctic breeding areas (e.g., spoon-billed Sandpiper: **http://www.saving-spoon-billed-sandpiper.com/**).

Fortunately, data on many additional species are collected systematically and/or opportunistically as part of existing research efforts, international networks and citizen science initiatives (see also Chapter 1). Opportunities exist for knowledge exchange through additional groups already working throughout the Americas, their partners, and their research and community outreach tools (e.g. MANOMET: **http://www.manomet.org/**; Western Hemisphere Shorebird Network: **http://www.whsrn.org**; Cornell Laboratory of Ornithology, **http://www.birds.cornell.edu**, and their tools such as eBird: **http://ebird.org**; and Bird Studies Canada: **http://www.bsc-eoc.org/**). At a global scale, smaller focal networks include partners conducting research or monitoring at least including some migratory Arctic species (e.g., Global Raptor Information Network: **http://www.globalraptors.org**). Additional information to track avian populations outside their breeding grounds may be obtained through bird observatories (e.g., migrants) and banding offices (e.g., the Bird Banding Laboratory: **http://www.bsc-eoc.org/**; EURING: **http://www.euring.org/index.html**).

Changes in breeding distribution may constitute a particularly challenging area for monitoring; the prediction is that many species will be expected to shift their distributions northwards and those that already breed at the northern edge of their continents will have nowhere to go. However, it is difficult to study this through a network of dispersed monitoring stations with sufficient statistical power to demonstrate effects. For this reason, it is necessary to promote other innovations to generate extensive data, for example by encouraging collation of casual visiting species lists and vagrants, including through a centralised collation of citizen science observations (for example though eBird; **http://ebird.org/content/ebird/**). Large scale research based studies could use spatial modelling approaches to predict species distributions based on biotic and abiotic envelopes, using remote sensing and other data layers, reliant on field surveys to validate model predictions.

Monitoring species within and outside the Arctic can be facilitated by incorporating data derived from technology-based tools that can complement observations and site-based studies. Recent advances in satellite tracking technology and data loggers have facilitated the collection of information including the location and type of activity of individuals (e.g., accelerometers, temperature and pressure recorders), and coupled with remote sensing (see Appendix B), such tools can provide valuable data on natural history and distributions of species that are difficult to follow or of special concern (e.g., Kanai, et al. 2002; Therrien, et al. 2011). In addition, improved protocols and a growing body of knowledge to enable comparative studies of genetics, trace elements and stable isotope signatures are expanding our knowledge on diet and trophic levels, population connectivity, migratory routes, contaminant levels and sources, and the conservation status of species (see Chapters 1 and 6). These technology-based tools can greatly extend our potential for monitoring species within and outside the Arctic, complementing censuses and focal studies on the wintering grounds and stop-over sites, and for providing insight into some of the emerging threats to Arctic breeders.

Box 4B Site-based bird monitoring at Zackenberg Field station – Part of a bigger picture.

Zackenberg Research Station is located in the high Arctic at Zackenberg in Northeast Greenland (74°30′ N, 21°00′ W; **http://www.zackenberg.dk/**). The Station is an ecosystem research and monitoring facility owned by the Government of Greenland and operated by Aarhus University in Denmark. The long-term monitoring program Zackenberg Basic was initiated in 1995 with the objective to provide long time-series of data on a high Arctic ecosystem. This has been accomplished through monitoring of selected biological and physical parameters. Biobasis, the biodiversity component of the Zackenberg field station monitoring program (**http://www.zackenberg.dk/monitoring/biobasis/**), includes 35 elements of terrestrial plant, arthropod, bird and mammal dynamics in Zackenbergdalen and adjacent valleys (Schmidt, et al. 2012a).

The aim is to have a monitoring program that is *simple, comprehensive and standardized*. Currently, the station and program are facilitating data acquisition on typical high Arctic plant and animal populations and their interactions that can be expected to be sensitive to inter-annual variation, and to long-term changes in the local ecosystem (Schmidt, et al. 2012b; Schmidt, et al. 2012c).

Monitoring birds at Zackenberg

Zackenberg's bird monitoring program places emphasis on *populations, phenology, reproduction and predation*. Annually during June and July, the bird populations, their breeding phenology, and their hatching success are monitored in a 15.8 km2 census area. In mid-June, the main effort is directed towards coverage of the potential breeding populations, while the work in late June and July concentrates on searching for nests and broods in order to monitor nesting success and breeding phenology. In total, about 400 territorial pairs are found within the census area, with waders (shorebirds) being the most numerous group (protocols available online: Schmidt, et al. 2012a).

Monitoring birds: Part of a bigger picture

Six species of waders breed with an average of 260-300 pairs in the Zackenberg bird census area. Their inter-annual variability in population density together with timing of reproduction and breeding success have now been monitored for more than 15 years. Studies have uncovered that early spring food availability is the most important determinant in the timing of egg-laying, followed by snow-cover in years with less than average snow-free land in early June (Meltofte, et al. 2007a; Meltofte, et al. 2007b). The data series show that clutch size from 1998-2005 decreased during June–July and the total length of the laying period has shortened in years where there has been late snowmelt. This means that the chances for re-laying in case of failure were limited in such years. The data indicates reduced breeding success in seasons of late breeding.

Waders are not the only species monitored at Zackenberg. Changes have also been observed in highly specialized lemming predators including some non-avian carnivores, the snowy owl and stoat (see Fig. 4.5c). Regional observations extending over a decade until 2010 (Schmidt, et al. 2012b) indicated that following a lemming cycle collapse, snowy owl fledgling production declined by 98% and a severe local population decline of stoats occurred. The less specialized long-tailed skua/jaeger and the generalist Arctic fox were more loosely coupled to the lemming dynamics, but suffered decreased reproductive success.

The disruption of lemming population cycles in northeast Greenland has already affected the tundra ecosystem, demonstrated by reduced reproductive performance and declining populations of high Arctic predators. If the lemming populations remain at the same non-cyclic, low-density state as during the last decade, the result will probably be population extinctions of endemic predators and further impoverishment of these Arctic communities.

Ultimately, disruption of predator-prey dynamics and extinctions may cause cascading impacts on the entire tundra food web and have unknown consequences, and demonstrate that the nature of such trophic cascades is contingent on the health of tundra ecosystems. Improving the ability to predict the impacts of climate change on vulnerable Arctic ecosystems will require enhanced and coordinated spatial replication of long-term monitoring programs, like Biobasis in Zackenberg (Schmidt, et al. 2012a).

Box 4C Goose target-oriented monitoring. Results from breeding/staging/wintering regions contribute to overall assessment of status and trends

Abundance and trends: In the case of Arctic nesting geese, because of their cultural and economic importance as major hunted species and recent interactions with agriculture, there has been a long term interest in monitoring the size and conservation status of different flyway populations. This information is centrally collated and provided on a three year reporting cycle for all waterbird populations by Wetlands International; the last tabulation is available on the web (Wetlands International 2012). This synthesis (see Table Box 4C) is achieved through inventory work on the wintering areas, which gives rise to an annual index and a flyway population estimate in the case of the North American populations (U.S. Fish and Wildlife Service 2012), periodic assessments of Eurasian continental populations, and in exceptional cases, total counts also (Fox, et al. 2010a; Fox, et al. 2010b; Fox and Glahder 2010).

Distribution: Many of the inventory schemes generate data on local wintering density, presence/absence, and in rarer cases habitat utilization also, for most flyway populations on the wintering grounds and staging areas. Information is less forthcoming from the breeding areas, where there may be infrequent extensive aerial surveys (e.g., Fox and Glahder 2010; Malecki, et al. 2000).

Demography: Age specific survival rates are available for some populations (e.g., Fox 2003) even to the extent of understanding the effects of density on emigration/immigration rates (Marchi, et al. 2010). Breeding success is regularly sampled on an annual basis and published for many flyway populations (Fox, et al. 2010a; Fox, et al. 2010b; U.S. Fish & Wildlife Service 2010).

Community structure, health and body condition: Attributes under these subjects are important but of lower priority and data availability varies greatly among flyways. Generally, little is collected or collated on community structure because species typically breed in low densities over large areas of the Arctic, although such information is available in areas where nesting density is high (e.g., Yukon-Kuskokwim Delta Alaska). Health is often screened periodically, typically checking for blood, feather and faecal parasites, but data are rarely collated or centrally reported (Hoye, et al. 2011). Most capture programs (such as those associated with capture-mark-recapture studies of population dynamics) take measurements of mass at capture which can be related to linear body measurements to generate indices for fat content and to factors affecting fitness (Madsen and Riget 2007).

Jaeger. Photo: Photo Incredible Arctic/Shutterstock.com

Table Box 4c Example showing the conservation status of the entire set of circumpolar flyway populations of the greater white-fronted goose *Anser albifrons*. Results of respective monitoring schemes from around the different breeding, staging and wintering regions contribute to the overall assessment of abundance and trends (literature resources provided where appropriate).

English and scientific name	Subspecies and Population	Breeding range	Wintering, or core non-breeding range	Europe	Asia	North America	Population estimate	Trend	Literature sources	Notes
Greater white-fronted goose *Anser albifrons*	***albifrons,*** Baltic - North Sea	European Arctic Russia & NW Siberia	NW Europe	X	X		1,000,000	Stable	(Gilissen, et al. 2002; Koffijberg 2005?; Wetlands International Specialist Groups)	Increases in 1990s leveled off in 2000s, as indicated by lower breeding success of birds wintering in W Europe.
	albifrons, Pannonic	European Arctic Russia & NW Siberia	Central Europe	X	X		10,000-40,000	Declining	(Madsen, et al. 1999)	
	albifrons, Pontic/Anatolian	European Arctic Russia & NW Siberia	SE Europe, Turkey	X	X		350,000-700,000	Stable	(Madsen, et al. 1999)	
	albifrons, Caspian, Iran, Iraq (non-bre.)	European Arctic Russia & NW Siberia	Caspian, Iran, Iraq	X	X		15,000	Declining	(Perennou, et al. 1994; Scott and Rose 1996)	
Greenland white-fronted goose	***flavirostris***	W Greenland	Ireland, Scotland, Wales	X		X	27,000	Declining	(Fox and Francis 2004)	Numbers peaked at 35,500 in late 1990s, declined to <27,000 by 2002 . Production of young in 2003 remained below that necessary to maintain a stable population. Population estimated at 24,000 in spring 2005.

English and scientific name	Subspecies and Population	Breeding range	Wintering, or core non-breeding range	Europe	Asia	North America	Population estimate	Trend	Literature sources	Notes
	frontalis, E Asia	E Siberia	East Asia		X		150,000-200,000	Declining	(Gerasimov and Gerasimov 2003; Kondratyev 1995; Li and Mundkur 2004)	144,917 recorded by AWC in 1999. 40,000 migrate through the Kamchatka Peninsula in spring
	frontalis**,** Pacific	Yukon-Kuskokwim Delta, Alaska	Central Valley, California			X	443,900	Incomplete	(U.S. Fish & Wildlife Service 2005)	
	frontalis**,** Mid-Continent	C & NW Alaska across Arctic Canada to Foxe Basin	Louisiana, Texas & Mexico			X	644,300	Stable	(U.S. Fish & Wildlife Service 2001, 2005)	
Tule white-fronted goose	***gambelli***	Alaskan Taiga	California, USA			X	5,100	Incomplete	(Callaghan and Green 1993; Orthmeyer, et al. 2002)	
	elgasi	SW Alaska	San Clemente Valley, California			X	5,000 - 10,000	Unknown	(AOU 1983 [onward]; Clements 2007 [onwards]; Wetlands International 2012)	Recently described; recognized by AOU (1998) and Clements (2000); see online updates.

Box 4D Lapland bunting - Fluctuations of local density and breading success can be linked to trophic relationships

Abundance and trends: Compared to Arctic nesting geese, data are lacking on the abundance and trends of Lapland bunting (or Lapland longspur, *Calcarius lapponicus*) populations. This represents the other end of the spectrum with regard to tracking abundance, distribution and diversity of Arctic breeding birds. The species has a circumpolar Arctic and sub-Arctic breeding distribution and winters in the temperate zones of Japan, Korea, China, central Eurasia and the North Sea coasts, and across continental North America. Little is known about changes in subpopulation abundance and distribution around the globe on breeding, staging or wintering areas.

Because buntings are not perceived to have equal cultural or economic importance to other species that are harvested and despite extraordinarily large populations and ubiquity throughout the Arctic, limited information about species abundance is available, but is estimated to include approximately 150 million individuals (**http://rmbo.org/pif_db/laped/PED4.aspx**). The Lapland bunting is a keystone species because of its relation to vegetation stratigraphy, its abundance reflecting the height, nature and extent of willow scrub, and because of its dependence on the phenology and abundance of invertebrate prey and the effects that buntings have on prey and predator populations (avian and mammalian carnivores). The relationship between breeding, staging and wintering areas is poorly known, and few assessments of long term changes in annual winter distribution and abundance have been conducted. The North American continental population is estimated to be 70 million (**http://rmbo.org/pif_db/laped/PED4.aspx**), but the population trends are not well known. Some winter surveys based on the Christmas Bird Count in the U. S. suggest declines, but the large mid-continent wintering concentrations show no change. The species can aggregate in enormous flocks which roam in search of food making censuses extremely challenging.

The Lapland bunting thus represents a species which presents challenges for developing global or flyway monitoring programs that can deliver a simple status report on the instantaneous conservation status for the species as a whole. However, conducting regular monitoring to obtain key abundance measures may be possible at a series of sites where sufficiently high breeding densities exist and monitors with expertise are available. Monitoring can help to generate a useful time series to examine fluctuations in local density and breeding success, and investigate links to trophic relationships, and biotic and abiotic factors affecting the populations at local scales.

Distribution: Almost nothing is known about changes in density and distribution on the breeding areas, apart from results from local studies, which suggest retractions in the southern parts of the range in Hudson Bay, Canada and parts of Finland, balanced by expansion in Kola Peninsula in Russia (Hussell and Montgomerie 2002). However, to design a data collection protocol for such an abundant and widespread species is challenging, since data would need to be collated from a very large number of sites over many years before the study would have sufficient statistical power needed to detect changes in abundance at large spatial scales. In contrast, long time-series data to track local changes in density, together with collations of species lists and casual records over many years and across many sites may enlighten long term changes, and would therefore merit monitoring actions across many different Arctic regions. As above, this long-term monitoring would illuminate the relationship of the species with its local environment and help separate any short term noise, driven by food supply or weather, from long term signals such astrends in local population development.

Demography: Annual adult survival rates (estimated at 43-45%) and breeding success at egg, nest and fledging stages are available for very few populations (Hussell and Montgomerie 2002). Although obtaining good measures of survival and reproduction parameters from intensive monitoring effort may be insufficient to generate population models to track changes in abundance, there is great value in collecting such data on a regular basis at sites where the species is common, and possibilities for large samples sizes offers very exciting monitoring opportunities to link annual reproductive success to local environmental conditions to gain deeper insight into factors affecting breeding. It is known from studies that late snow and prey availability affects the timing of breeding and reproductive success (e.g., Fox, et al. 1987), so gaining a deeper understanding of these types of processes from regular monitoring would greatly contribute to our ability to understand factors affecting the distribution and abundance of this species throughout the Arctic.

Community structure, health and body condition: These attributes are currently of lower priority until serious declines in abundance signal the need for further investigation. The species is common throughout the Arctic wherever the habitat is suitable, and so its disappearance would be evident from key areas, and would likely have ecosystem consequences, both as a consumer of arthropods and prey to generalist predators such as Arctic foxes but also of specialist predators, such as peregrine falcons, where declines could have local consequences. For some other species, disease, parasite infestations and observations of body mass changes throughout the annual cycle are being documented (see Chapter 1), but data are currently lacking for buntings. Such data however can contribute in the future to a robust monitoring program for this species. Investigating health and body condition in response to a specific hypothesis, such as where a local breeding population is showing adverse change, (e.g., in relation to changes in breeding phenology and potential mismatches between timing of insect emergence and brood rearing; Bolduc, et al. 2013; McKinnon, et al. 2012b) may be more cost effective than using precious monitoring resources to gather regular data that is not likely to be used.

Figure 4.4 The Arctic terrestrial birds monitoring conceptual model showing FEC examples, interactions among other biotic groups, and some key drivers and attributes operating at local to pan-Arctic scales and beyond

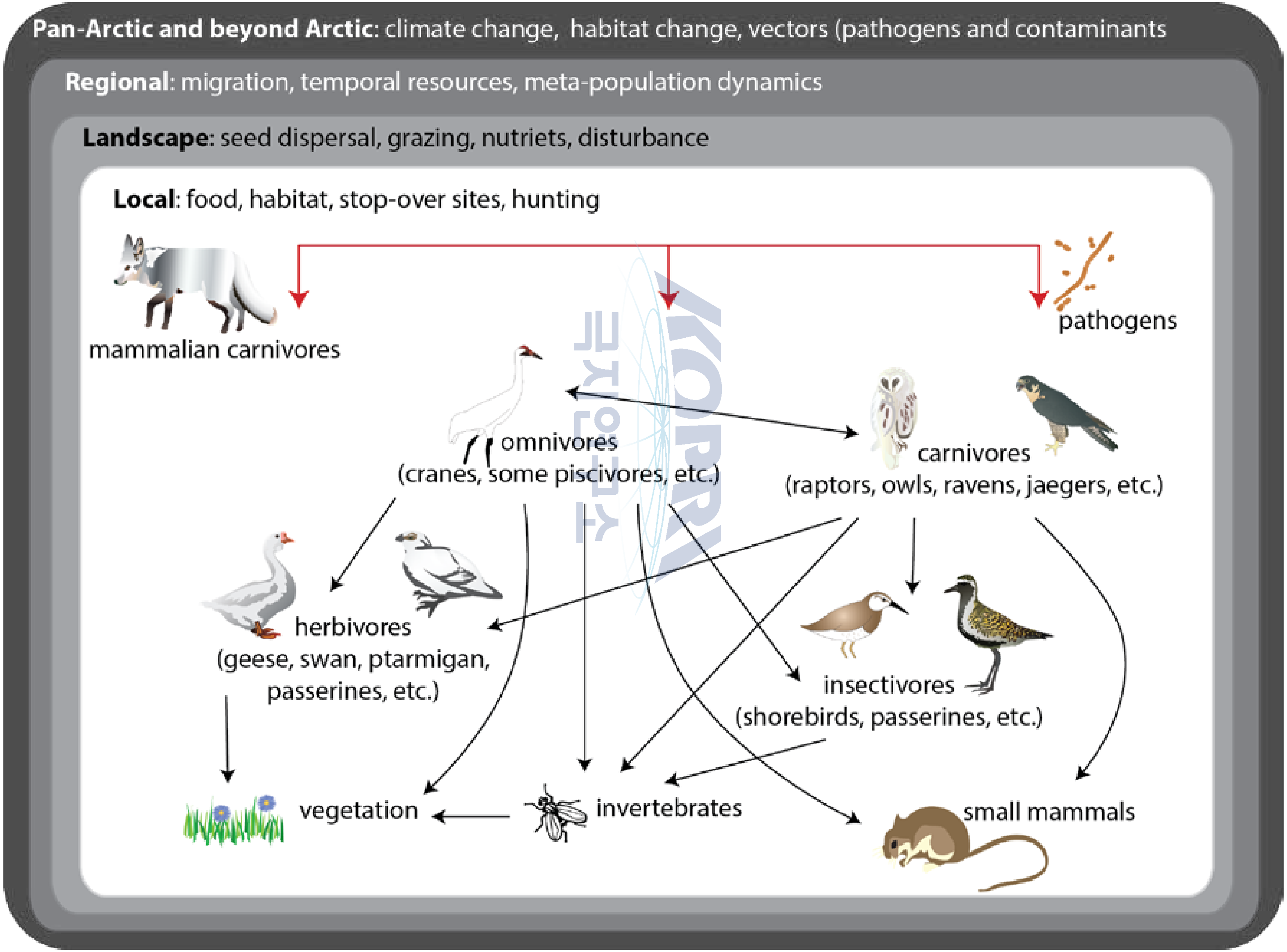


Table 4.5 List of FECs for terrestrial birds (FECs: major biodiversity elements), their attributes (compositional, structural, and functional aspects), monitoring priority of attributes, parameters of attributes (individual measures/methods to quantify attributes), geographic scale, method (monitoring technical approach or reference to methods), protocol complexity (basic or advanced) and temporal recurrence (how frequently monitoring should be conducted)

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Herbivores (geese, swan, ptarmigan)	Abundance	Essential	Population size, number, habitat selection	1) local - global 2) regional 3) regional - global 4) local	1) various aerial and ground surveys 2) non-breeding census 3) banding (capture-mark-recapture) 4) citizen science and TK	Basic and Advanced	1) annual 2) annual 3) annual 4) continuous	Must be included; ptarmigan may be poorly covered by these methods
	Spatial structure	Essential	Local density; presence/absence, habitat selection, migration patterns	1) local - global 2) regional 3) regional -global 4) local	1) Various aerial and ground surveys 2) non-breeding census 3) banding (capture -mark-recapture 4) citizen science (TK)	Basic and Advanced	1) annual 2) annual 3) annual 4) continuous	Must be included
	Demographics, productivity and phenology	Essential	Propensity; clutch size; brood size; age ratio; nest success; age specific survival; genetic diversity; breeding behavior; phenology	1) regional to global 2) regional to global 3) local 4) local	1) banding (Capture-Mark-Recapture) 2) hunter collected: wing surveys (see Glossary); 3) site-specific studies 4) egg collectors	Basic and Advanced	1) annual 2) annual 3) annual 4) annual	Demography feeds directly into population size and is of high priority. Often, it is the only measurable attribute at the flyway scale.

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Herbovores(geese, swan, ptarmigan)	Diversity and composition	Recommended	Diversity index, habitat selection	See rows above	See rows above	Advanced	See rows above	Relative abundance of all species within defined area. Lower priority but data can be obtained from population abundance parameters.
	Diversity, spatial structure and health	Recommended	Heterozygosity and genetic diversity: stable isotope chemistry and trace elements	Local to global	Sample tissues can be collected opportunistically or as part of planned surveys (e.g., carcasses, hunted birds, feathers, eggshells, blood samples, etc.)	Basic and Advanced	As required; minimum every 3 years	See Chapters 3 and 4
	Health	Recommended	Prevalence of pathogens, parasites, contaminants (and trace elements)	1) local 2) regional to global 3) local - global	1) specific projects 2) citizen science 3) opportunistic or targeted samplings as needed	Advanced	1) as required 2) annual 3) as required	Under some circumstances, this may become imperative requiring policy changes (i.e., H5N1 outbreak)
	Health: Body condition	Recommended	Diet, fat index, feeding rate	1) local 2) regional to global 3) local-global	1) specific projects 2) citizen science 3) opportunistic or targeted samplings as needed	Advanced	1) as required 2) annual 3) as required	Could be considered an aspect of health

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Insectivores (shorebirds, passerines)	Abundance	Essential	Population size, numbers, habitat selection	1) regional (North America) 2) reagional/ global 3) regional (North America) 4) global 5) local 6) local	1) Arctic PRISM: shorebirds 2) non breeding surveys: flyway 3) CBC passerines; BBS 4) Arctic - breeding Birds Conditions Survey 5) single - species surveys 6) local knowledge (TK)	Basic and Advanced	1) every 15 - 20 years; 2) annual 3) annual 4) annual 5) annual 6) continuous	Must be included; statistically valid.
	Spatial structure: distribution	Essential	Local density; presence/ abscence, habitad selection, migration patterns	1) regional / global 2) local 3) see above 4) regional - global	1) citizen science (eBird, TK, BBS) 2) research station 3) see row above except CBC 4) banding and tracking studies (refers to migration pattern)	Basic and advanced	Various (annual to continuous)	Must be included. Data should be gathered through population abundance parameters on a long-term standardized basis.
	Demographics, productivity and phenology	Essential	propensity; clutch size; brood size; age ratio; nest success; age specific survival, genetic diversity, breeding behavior, phenology	1) regional/global 2) global 3) local 4) regional/global 5)regional/global	1) ASDN 2) ABBCS; 3) Specific projects 4) citizen science (incl. TK 5) non-breeding ground surveys (CBC, MAPS, juvenile ratios)	Basic and advanced	1) annual 2) annual 3) as required 4) continuous 5) annual	Demography feeds directly into population size and is of high priority. Often, it is the only measurable attribute at the flyway scale.

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Insectivores (shorebirds, passerines)	Diversity and composition	Recommended	Community structure, Diversity index, habitat selection	See rows above	See rows above	Advanced	As required; annual if possible	Relative abundance of all species within defined area.
	Diversity, spatial structure and health	Recommended	Heterozygosity and genetic diversity: stable isotope chemistry and trace elements	Local to global	Sample tissues can be collected opportunistically or has part of planned surveys (e.g. carcasses, hunted birds, feathers, eggshells, blood samples, etc.)	Basic and advanced	As required; minimum every 3 years	See text: ch. 4 and Ch. 3
	Health	Recommended	Prevalence of pathogens, parasites, contaminants	1) local 2) regional 3) regional - global 4) local - global	1) specific projects 2) ASDN projects 3) citizen science 4) opportunistic or targeted samplings as needed	Advanced	1) as required 2) annual 3) continuous 4) as required	Under some circumstances, this may become imperative, requiring policy changes (i.e.. H5N1 outbreak).
	Health: Body condition	Recommended	Diet, fat index, feeding rate	1) regional 2) local 3) regional - global	1) ASDN 2) specific projects 3) citizen science (harvest information)	Advanced	1) annual 2) as required 3) annual	Could be considered an aspect of health. However if the bird is in hand low cost monitoring contributing to long-term perspective.

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Carnivores (raptors, skuas/jaegers, ravens and owls)	Abundance	Essential	Population size; numbers, habitat selection	1) regional 2) regional 3) regional 5) global	1) boat surveys (raptors) 2) aerial surveys (skuas/jaegers, owls, some falcons) 3) ground migration surveys (raptors); 4) ArcticWOLVES Observatories Network	Basic and Advanced	1) annual 2) annual 3) annual 4) annual	Must be included. Limited harvest in various places in some countries.
	Spatial structure	Essential	Local density; presence/absence, habitat selection, migration patterns	1) regional 2) regional 3) regional 4) global 5) regional	1) boat surveys (raptors) 2) aerial surveys (skuas/jaegers; owls, some falcons) 3) ground migration surveys (raptors) 4) ArcticWOLVES Observatories Network 5) citizen science (eBird, TK)	Basic and Advanced	1) annuall 2) annual 3) annual 4) annual 5) annual	Must be included
	Demographics, productivity and phenelogy	Essential	propensity; clutch size; brood size; age ratio; nest success; age specific survival, genetic diversity, breeding behavior, phenology	1) global 2) regional 3) local	1) ArcticWOLVES Observatories Network 2) citizen science (Cornell, TK) 3) site specific study	Basic and Advanced	1-3) annual	Demography feeds directly into population size and is high priority. Often it is the only measurable attribute at the flyway scale

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Carnivores (raptors, skuas/jaegers, ravens and owls)	Diversity and composition	Recommended	Diversity index, habitat selection	See rows above	See rows above	Advanced	As required annual if possible	Relative abundance of all species within defined area. Low priority but data will be gathered through population abundance parameters.
	Diversity, spatial structure and health	Recommended	Heterozygosity and genetic diversity; stable isotope chemistry and trace elements	Local to global	Sample tissues can be collected opportunistically or as part of planned surveys (e.g., carcasses, hunted birds, feathers, eggshells, blood samples, etc.)	Basic and Advanced	As required minimum every 3 years	See Chapters 3 and 4
	Health	Recommended	Prevalence of pathogens, parasites, contaminants	1) regional 2) local	1) citizen science (Cornell TK) 2) site specific study	Advanced	1-2) annual	Under some circumstances, this may become imperative requiring policy changes (i.e., H5N1 outbreak). Elevated relevance because of the high trophic level.
	Health: Body condition	Recommended	Body condition: Diet, fat index, feeding rate	1) regional 2) local	1) citizen science (Cornell; TK) 2) site specific study	Advanced	1-2) Annual	Could be considered an aspect of health
	Temporal cycles	Recommended	Derived from abundance, health, demographics, productivity and from data on prey species	1) regional 2) local	1) citizen science (Cornell; TK) 2) site specific study	Basic and Advanced	Annual	

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Omnivores (ducks, cranes)	Abundance	Essential	Population size; numbers, habitat selection	1) local - global 2) regional 3) regional - global 4) local	1) various aerial and ground surveys 2) non-breeding census 3) banding (Capture-Mark-Recapture) 4) citizen science (TK)	Basic and Advanced	1) annual 2) annual 3) annual 4) continuous	Must be included
	Spatial structure	Essential	Local density; presence/absence, habitat selection, migration patterns	1) local - global 2) regional; 3) regional - global 4) local	1) various aerial and ground surveys 2) non-breeding census 3) banding (Capture-Mark-Recapture) 4) citizen science (TK)	Basic and Advanced	1) annual 2) annual 3) annual 4) continuous	Must be included
	Demographics, productivity and phenology	Essential	propensity; clutch size; brood size; age ratio; nest success; age specific survival, genetic diversity, breeding behavior; phenology	1-2) regional to global 3) local; 4) local	1) banding (Capture-Mark-Recapture) 2) wing surveys 3) site specific studies 4) egg collectors	Basic and Advanced	1-4) annual;	Demography feeds directly into population size and is a high priority. Often it is the only measurable attribute at the flyway scale
	Diversity	Recommended	Community structure, diversity index, habitat selection	See rows above	See rows above	Advanced	As required annual if possible	Relative abundance of all species within defined area. Low priority but data will be gathered through population abundance parameters.

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Omnivores (ducks, cranes)	Diversity, spatial structure and health	Recommended	Heterozygosity and genetic diversity, genetic diversity stable isotope chemistry and trace elements	Local to global	Sample tissues can be collected opportunistically or as part of planned surveys (e.g. carcasses, hunted birds, feathers, eggshells, blood samples, etc.)	Basic and Advanced	As required minimum every 3 years	See Chapters 3 and 4
	Health	Recommended	Prevalence pathogens, parasites, contaminants	1) local 2) regional to global 3) local - global	1) site-specific projects; 2) citizen science 3) opportunistic or targeted samplings as needed	Advanced	1) as required 2) annual 3) as required	This could under certain circumstances (i.e.. H5N1 outbreak) quickly elevate to high and may result in legislation.
	Health: Body condition	Recommended	Diet, fat index, feeding rate	1) local 2) regional to global 3) local - global	1) site-specific projects 2) citizen science; 3) opportunistic or targeted samplings as needed	Advanced	1) as required 2) annual 3) as required	Could be considered an aspect of health
Piscivores (loons, merganser abd grebes)	Abundance	Essential	Population size; numbers, habitat selection	1) local - global 2) regional 3) local	1) various aerial and ground surveys 2) non-breeding surveys 3) Citizen science (TK)	Basic and Advanced	1) annual 2) annual 3) continuous	Must be included; grebes may not be represented in a defined Arctic region.
	Spatial structure	Essential	Local density; presence/ abscense, habitat selection, migration patterns	1) local - global 2) regional 3) local	1) various aerial and ground surveys 2) non-breeding surveys 3) Citizen science (TK)	Basic and advanced	1) annual 2) annual; 3) coninuous	Must be included

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE	COMMENTS
Piscivores (loons, merganser abd grebes)	Demographics, productivity and phenology	Essential	propensity; clutch size; brood size; age ratio; nest success; age specific survival, genetic diversity, breeding behavior; phenology	1) local 2) local 3) regional	1) site-specific studies 2) egg collectors; 3) aerial surveys for propensity	Basic and Advanced	1-3) annual	Demography feeds directly into population size and is high priority. Often it is the only measurable attribute at the flyway scale
	Diversity and composition	Recommended	Diversity index, habitat selection	See rows above	See rows above	Advanced	As required; annual if possible	Relative abundance of all species within defined area. Lower priority but data can be obtained from population abundance parameters.
	Diversity, spatial structure and health	Recommended	Heterozygosity and genetic diversity; genetic diversity, stable isotope chemistry and trace elements	Local to global	Sample tissues can be collected opportunistically or as part of planned surveys (e.g. carcasses, hunted birds, feathers, eggshells, blood samples, etc.)	Basic and Advanced	As required; minimum every 3 years	See Chapters 3 and 4
	Health	Recommended	Prevalence pathogens, parasites, contaminants	1-3) local	1) site-specific studies; 2) citizen science; 3) opportunistic or targeted samplings as needed	Advanced	1) annual 2) annual 3) as required	Under some circumstances, this may become imperative, requiring policy changes (i.e., H5N1 outbreak). Elevated relevance because of the high trophic level.
	Health	Recommended	Diet, fat index, feeding rate	1-3) local	1) site-specific studies 2) citizen science 3) opportunistic or targeted samplings as needed	Advanced	1) annual 2) annual 3) as required	Could be considered an aspect of health.

4.2.5 Mammals sampling approach and monitoring

4.2.5.1 Mammal management questions

Many of the core management questions relevant for mammals are related to understanding the interactions in the ecosystem, and hence understanding the key attributes such as abundance, demographics and health, as well as the impact of drivers is important. Other management questions for mammals are related to specific conservation issues, such as securing sustainable hunting or meeting the international requirements for reporting on biodiversity issues (e.g., in connection with the Convention on Biological Diversity). Some migratory mammals may spend part of their annual cycle just beyond Arctic borders and in transition zones (ecotones), creating challenges for monitoring as populations may be affected by additional drivers in those regions.

The mammal FEC species have been selected because they act as indicators for other species or processes, are rare, threatened or rapidly declining, are exploited by man, and/or are invasive.

Specifically, the overall management questions related to mammals are:

1. What are the status and trends of the relevant mammal populations (i.e., FECs) in the Arctic?
2. Where in the Arctic are the populations changing?
3. What and how do the primary biotic, abiotic and anthropogenic drivers influence the various FECs, and hence, influence mammal diversity and ecosystem function?
   Where are the most important regions for FECs (including calving grounds, migratory corridors, major hunting/grazing/foraging areas, etc.), how are these changing, and what drivers have an impact?
4. What characteristics make some regions important? Identifying the habitat attributes of the most important regions is critical, because habitat use can change under different conditions.
5. What is the total area and location of these important regions? (e.g., quantifying the amount and location of all areas containing habitat attributes similar to the current most important regions of seasonal range use). How much suitable habitat is available and where might shifts in future range use occur?

4.2.5.2 Mammal conceptual model

Mammals are affected by processes that affect their food base. Grazing herbivores may be affected by, for example, the start of the growing season, which is influenced by the climate (bottom-up). The same species may be influenced/controlled by predator species (top-down). Also, the anthropogenic influence on, for example, caribou/reindeer may have a major impact at a population level. Therefore it is sometimes necessary to monitor not only the species in question but also other relevant taxa. These interactions around a key species are projected in a food web or a conceptual model. The mammal conceptual model (see Fig. 4.5A) was developed by the mammal expert team and it illustrates the conceptualization of the six functional mammal groups operating at a pan-Arctic scale. The three most important functional groups are the **large herbivores**, the **medium-sized predators** and the **small herbivores.** Not all functional groups are present in several geographically distinct areas. Therefore, two localized conceptual models with only some of the functional groups included (Fig. 4.5B and 4.5C) have been illustrated. The models help to illustrate other taxonomic groups that may interact with mammals, such as birds and vegetation groups.

4.2.5.3 Mammal monitoring design principles and components

The classification of mammals into the six FEC groups described below is based upon the theory that different-sized mammals interact differently with other ecosystem components, i.e., occupy different positions in the food web. Thus, one can outline a conceptual model where the interactions between the mammal FECs (and those with other FECs) are visualized as a food web (Figs. 4.5A-C). Arctic terrestrial ecosystems have relatively few mammalian species and hence only a few foodweb links. The following FECs are considered and are described in more detail in the following section.

- Large herbivores (caribou/reindeer, muskox, moose)
- Medium-sized herbivores/omnivores (hares, ground squirrels)
- Small herbivores (lemmings, voles)
- Large predators (wolves, bears)
- Medium-sized predators (wolverine, lynx, foxes)
- Small predators (small mustelids, shrews)

As shown in Figs. 4.5A-C there are some FECs that occupy more central spaces in the conceptual model, than others. For instance, small herbivores play an important role, as they interact with a comparatively high number of other FECs. However, how many and which of the mammal FECs that are present in any given geographical region varies across the Arctic. Therefore, localized conceptual models are outlined in Figs. 4.5B and 4.5C (and section 4.2.5.2).

Not all the mammal functional groups are represented across the whole pan-Arctic area and this is even more evident when it comes to the individual species within each functional group. Thus, identifying which FEC to monitor will depend largely on geography and, hence, local conditions. Nevertheless, it is possible to highlight three of the functional groups which play a major role in the ecosystem and a pan-Arctic (or near pan-Arctic) distribution: ***large and small herbivores*** and ***medium-sized predators.*** Consequently, these three functional groups are considered most important to monitor from a pan-Arctic perspective. However, when feasible, one should also endeavour to monitor the other functional groups. Metadata and abiotic data should be gathered at each monitoring location where feasible.

Table 4.5 summarizes the minimum recommended key parameters and attributes to monitor for each FEC. Recommended types of methods are included. Where there are existing detailed protocols, such as the CARMA program, these should be used as guidelines.

4.2.5.3.1 Mammal FECs and functional groups

Large herbivores

The large herbivore functional group in the Arctic proper includes caribou/reindeer (*Rangifer tarandus*) and muskox (*Ovibos moschatus*), while snow sheep (*Ovis nivicola*) and Dall's sheep (*Ovis dalli*) are regarded as marginally Arctic species. In alpine ecosystems the moose (*Alces alces*) is also included. This group is widely distributed across the Arctic. The large sized herbivores are long-lived (more than 10 years) and produce normally only one young every year or every other year. The large herbivores are important in many parts of the Arctic, both as consumers but also as prey (including carcasses) for the large and medium-sized predators. Caribou/reindeer in particular have especially strong linkages to human communities in the Arctic.

Medium-sized herbivores/omnivores

The medium-sized herbivore functional group in the Arctic includes three hare species: Arctic hare (*Lepus arcticus*), snowshoe hare (*Lepus americanus*) and mountain hare (*Lepus timidus*) as well as the Arctic ground squirrel (*Spermophilus parryii*). Hares are widely distributed across the Arctic while the ground squirrel is found in mainland North America and Russia. Medium-sized herbivores have a lifespan of approximately four to five years, and may reproduce once a year with litters of varying size. Medium-sized herbivores function as prey for mainly medium-sized predators.

Small herbivores

The small herbivore functional group in the Arctic includes species of lemmings (*Dicrostonyx sp.* and *Lemmus sp.*) and voles (*Microtus sp.* and *Myodes sp.*). This group is widely distributed across the Arctic, and is the key prey for a wide spectrum of both avian and mammalian predators. Lemmings and voles are short-lived, but can reproduce fast, producing large litters per year. The population dynamics of voles and lemmings is often characterised by large inter-annual fluctuations. The Arctic ground squirrel (*Spermophilus parryi*) is a true hibernating species, and this sets it somewhat apart from the other small herbivores.

Large predators

The large predator functional group in the Arctic proper only includes the grey wolf (*Canis lupus*), the brown bear (*Ursus arctos*) and the American black bear (*Ursus americanus*). The group is distributed across most of the Arctic. However, no species of large predators are found in Iceland, on Svalbard or in most of Greenland. Only northeast Greenland currently hosts wolves. While population densities are generally low, large predators are long-lived, and while the wolf may reproduce every year, the brown bear reproduces only every two to three years. Polar bear (*Ursus maritimus*), is also an important predator on land, and is considered under the CBMP-Marine Plan.

Medium-sized predators

The medium-sized predator functional group in the Arctic proper consists of wolverine (*Gulo gulo*), and Arctic fox (*Vulpes lagopus*), though Eurasian lynx (*Lynx lynx*), Canada lynx (*Lynx canadensis*) and red fox (*Vulpes vulpes*) can be regarded as marginally Arctic species. The group is truly circumpolar in its distribution; especially so for the Arctic fox. Similar to the large predators, population densities are generally low, especially in the high Arctic. Medium-sized predators are of varying longevity, may reproduce every year, with varying litter sizes. The litter size of the Arctic fox in particular is linked to the availability of voles and lemmings.

Small predators

The small predator functional group in the Arctic proper consists of stoat/weasel/ermine (*Mustela erminea*), least weasel (*Mustela nivalis*) and the shrew (*Sorex sp.)*. Small mustelids are distributed across the Arctic, and with generally low densities, and are short-lived, - reproducing frequently depending on the availability of vole and lemming prey. Shrews are the only insectivorous mammal predator that has colonized Arctic habitats. There are no shrew species in the high Arctic and they are most diverse in Siberia and Alaska (CAFF ABA 2013). The shrew has a high metabolism and small body size and so is likely affected by food availability and thermal cover in winter.

4.2.5.3.2 Mammal attributes, sampling protocols and design

For each mammal FEC, a number of attributes have been identified (see section 4.1.7 below). The sampling protocol includes a number of **essential** and **recommended** attributes that should be monitored in the mammal program. For each of the attributes, a number of parameters have also been identified.

The attributes are summarized below:

- **Attribute: Abundance — *Essential***
  Knowing the abundance of a given species is essential for overall monitoring as this attribute allows for the evaluation of status and trends of a given species/group of species. Depending on the species, the most efficient tool to monitor population abundance is through standardized censuses/counts in well-defined areas of interest.

- **Attribute: Spatial structure** (distribution and spatial use) **— *Recommended; essential*** for ***Rangifer***
  Since most mammal monitoring in the Arctic is based on permanent field stations, the spatial coverage is inherently fragmented. It is therefore hard to assess changes in the spatial distribution of most mammal species. Knowledge of the spatial distribution is therefore only recommended for all species with the exception of migratory caribou/reindeer populations, where it is essential. Changes in spatial use by migratory populations may be expected in a changing Arctic.

- **Attribute: Demographics — *Essential*** *and* ***recommended***
  Changes in abundance are likely to be caused by changes in the demographics of given species, i.e., attributable to changes in age structure, fecundity, mortality etc. Knowledge of population demographics is therefore regarded as essential for large and medium sized herbivores and large predators. For the small herbivores and predators, which have the ability to reproduce at a high rate, and for medium-sized predators, information on demographics is only recommended.

- **Attribute: Health — *Essential***
  Both changes in abundance and demographics may ultimately be attributable to changes in the health of individuals in a population. Knowledge on the prevalence of zoonoses and diseases, level of contaminants and general body condition is possible at field stations or with designated projects.

- **Attribute: Diversity** (genetics) **— *Recommended***
  Low genetic diversity may result from population bottlenecks or metapopulation dynamics that reduce the level of diversity thus resulting in reduced ability to survive at the population level. Genetic diversity information may provide relevant information about the demographics of a population also, breeding success, and population connectivity.

- **Attribute: Phenology — *Essential***
  As for other biotic groups, changing climatic conditions may have impacts on vegetation, prey species, and even hormones and physiology (through environmental cues). Monitoring temporal patterns related to breeding, hibernation, migration, and the availability of resources (e.g., grazing habitat) is possible as part of focal studies and site-based monitoring, telemetry, and indirectly through remote sensing (e.g., to reveal patterns in vegetation productivity). This attribute can be monitored in conjunction with demographics, abundance, spatial use and/or health in some cases.

- **Attribute: Temporal cycles** (predator-prey interactions) **— *Recommended***
  For carnivores that are highly dependent on prey species, particularly small mammals that undergo inter-annual changes in abundance (cyclic population growth and decline), data obtained from measuring attributes such as abundance, health, demographics, and others for both the carnivores and for prey species can provide insight into causes of population declines or altered ecological interactions. Obtaining data on temporal cycles would require concomitant analyses of prey and predators where such data can be collected, ideally from the same regions over long periods of time to understand natural variation and cycles and to detect change.

As for other biotic groups, species of special interest can be monitored indirectly through these protocols, including non-native species and species of conservation concern.

4.2.5.3.3 Mammal sample processing, archiving, and other protocols

As described above for avian monitoring (see Chapter 4.2.4.3.3), tissues that can serve as baselines and can be collected in the field as part of other studies (e.g., capture-mark-recapture; focal studies, etc.), via non-invasive methods (e.g., using wildlife forensic protocols for carcasses, fecal samples, hair, and others), and from harvested species. Genetics, studies of trace elements and contaminants, and stable isotope analyses, are powerful tools that can complement focal and experimental studies, surveys and behavioural observations (see Chapters 1.7.4 and 4.2.4.3.3 and Table 3.3).

4.2.5.4 Existing capacity to deliver the CBMP-Terrestrial Plan and potential contributors to the mammal monitoring scheme

Ongoing mammal monitoring in the Arctic is highly fragmented, and only caribou/reindeer populations are monitored across the pan-Arctic following standardized protocols through the Circum Arctic Rangifer Monitoring and Assessment Network (CARMA). For remaining mammal species, some countries have well-developed monitoring programs for some species or groups of species. However, the vast majority of mammal species in the Arctic are currently either not sufficiently monitored or the ongoing monitoring is not sufficiently coordinated to allow for a pan-Arctic assessment of status and trends. Moreover, there are only a few examples of mammal species being monitored in an ecosystem framework.

Through existing programs and infrastructure the capacity exists to implement monitoring strategies to increase Arctic mammal monitoring (see Appendix A). In addition, opportunities exist for knowledge exchange through existing expert groups and initiatives through academic (several universities that also have research stations), community and government groups (for example, in North America, Alaska Department of Fish and Game: **http://www.adfg.alaska.gov/**; Canadian territorial governments: **http://env.gov.nu.ca/**, **http://www.env.gov.yk.ca/** and **http://www.enr.gov.nt.ca/_live/pages/wpPages/home.aspx**).

Generally, mammal monitoring in the Arctic is conducted at permanent field stations/sites. The aim of the CBMP-Terrestrial Plan is therefore to utilize an existing network of field stations in the Arctic, for example the INTERACT project (**http://www.eu-interact.org/**), to improve coordinated monitoring within the CBMP-Terrestrial Plan. Also, this will allow the monitoring program to be truly ecosystem-based, as implemented at Zackenberg in northeast Greenland.

Arctic fox at dinner. Photo: Susan Morse

Figure 4.5A The Arctic terrestrial mammals conceptual model for monitoring showing FECs, interactions with other biotic groups, and examples of drivers and attributes that are relevant at various spatial scales

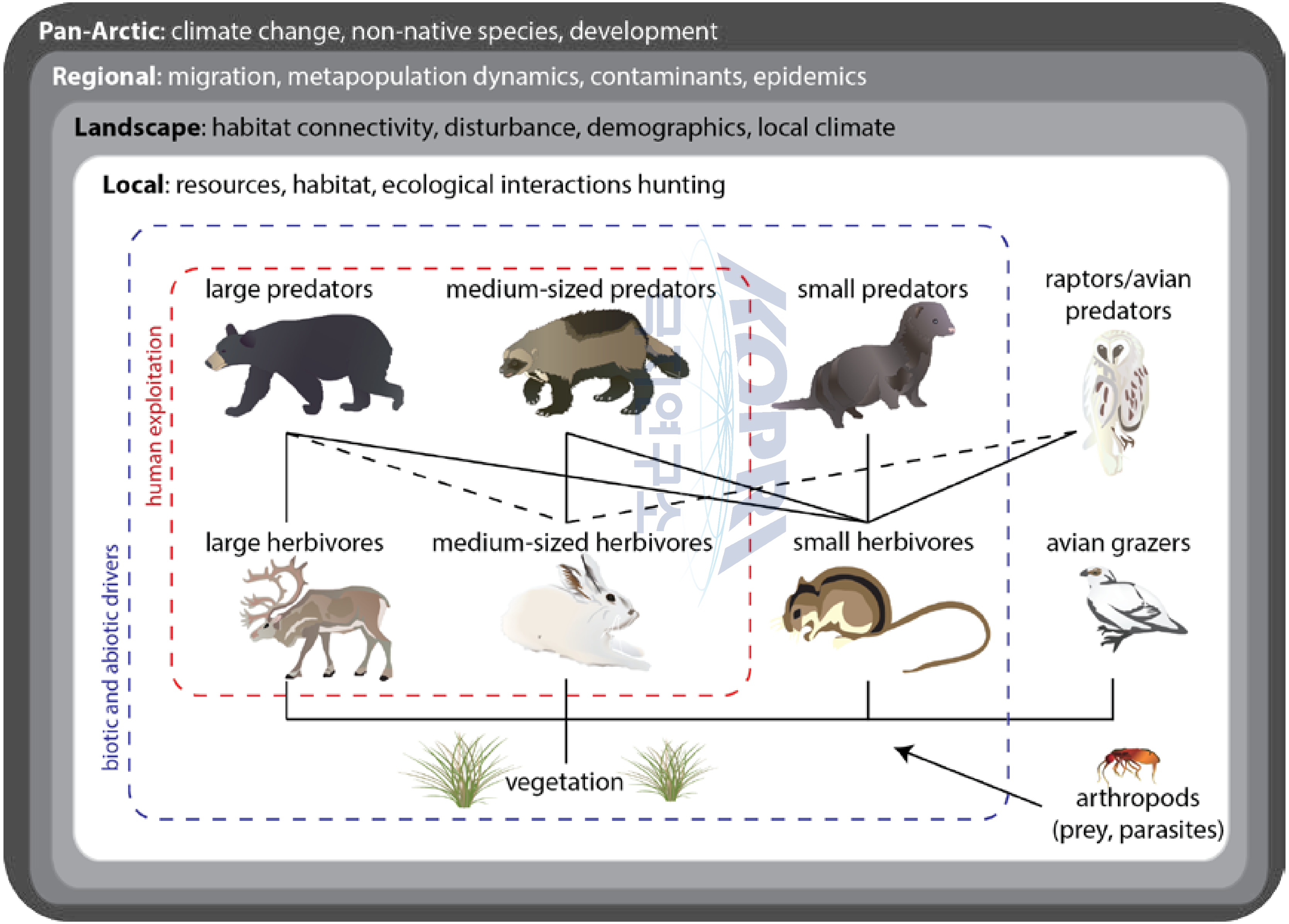


Figure 4.5B Conceptual model for Arctic terrestrial mammals monitoring on Svalbard.

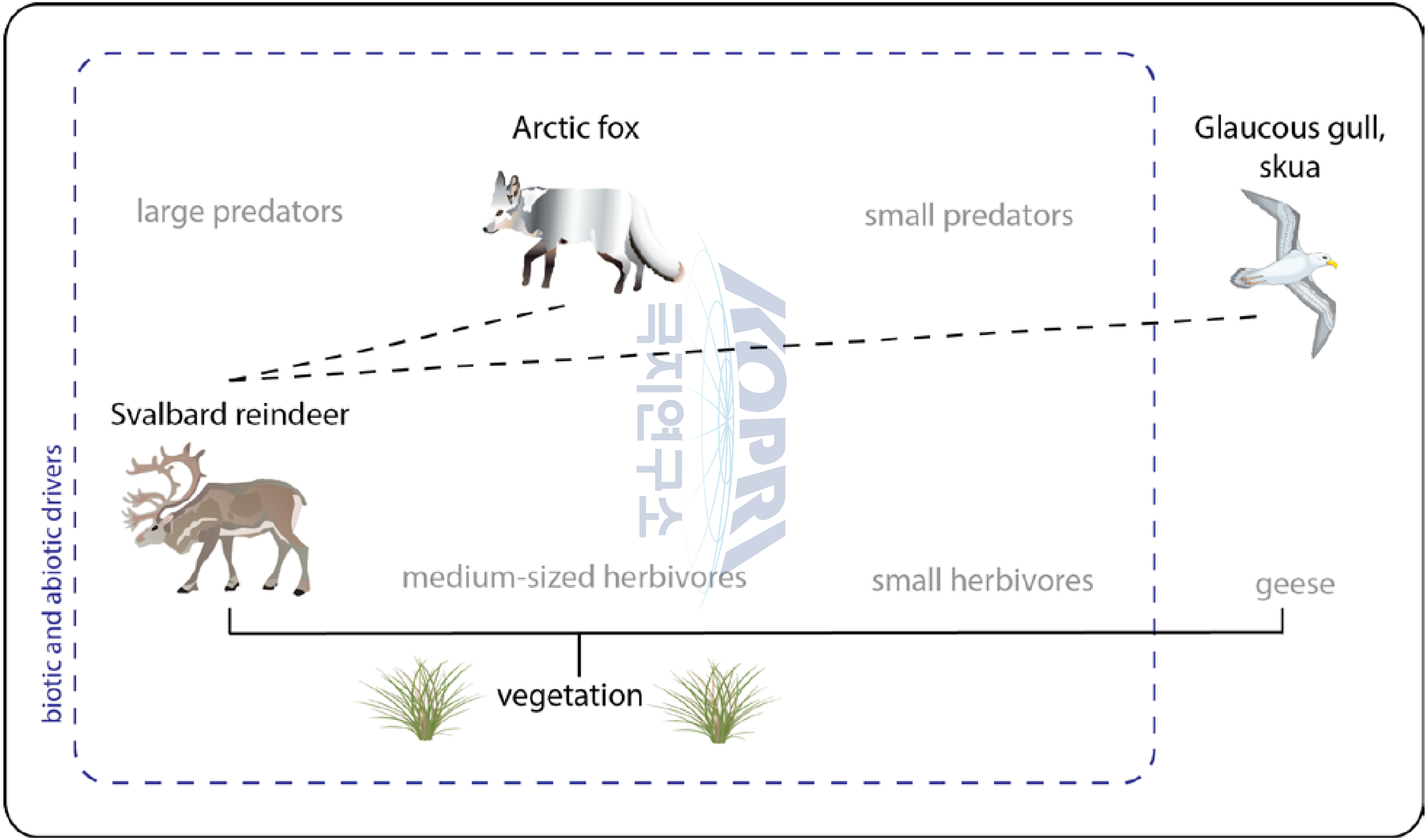


Figure 4.5C Conceptual model for Arctic terrestrial mammals monitoring on Zackenberg.

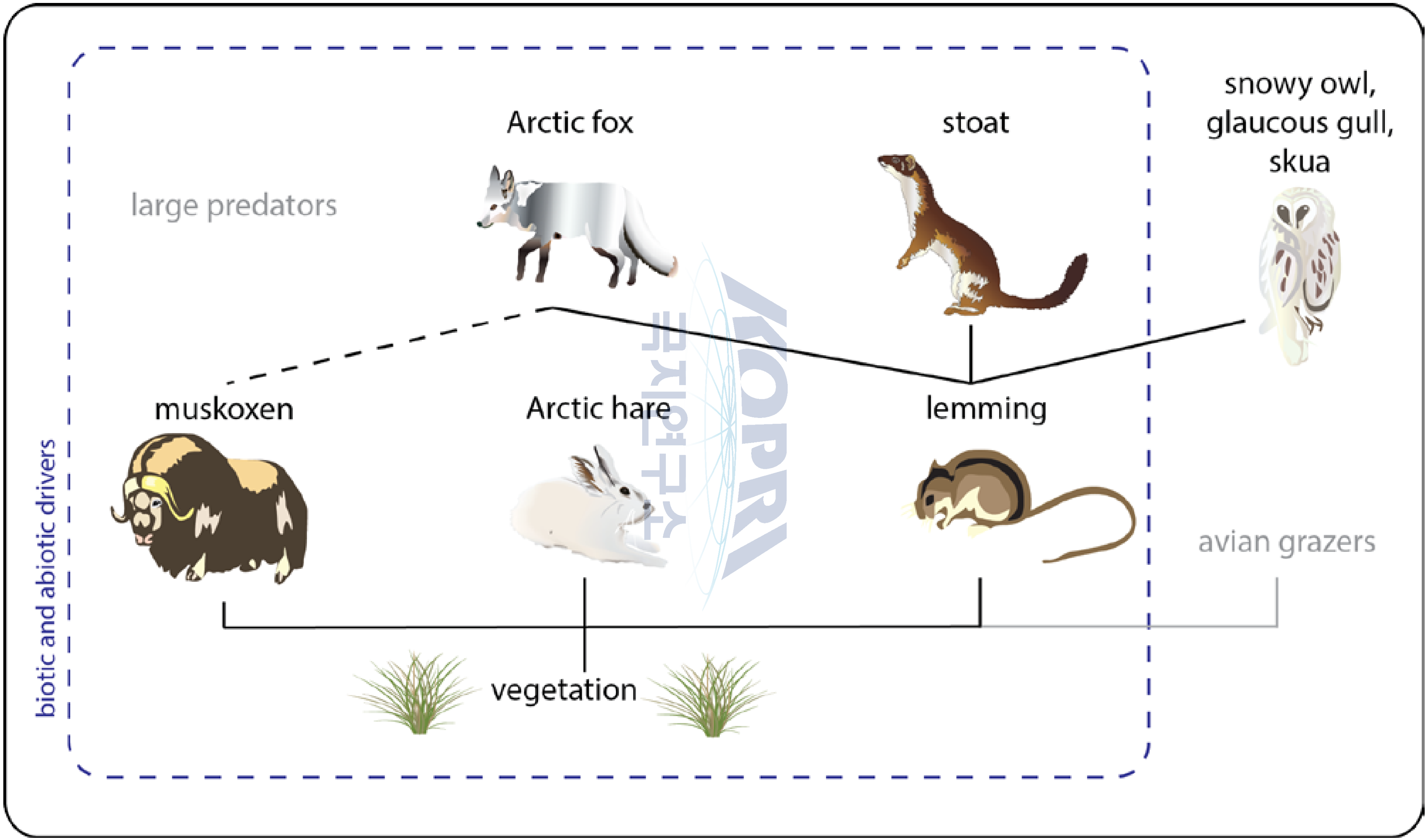


Table 4.6 List of FECs for terrestrial mammals (FECs: major biodiversity elements), their attributes (compositional, structural, and functional aspects), monitoring priority of attributes, parameters of attributes (individual measures/methods to quantify attributes), geographic scale, method (monitoring technical approach or reference to methods), protocol complexity (basic or advanced) and temporal recurrence (how frequently monitoring should be conducted). Where there are existing detailed protocols, such as the CircumArctic Rangifer Monitoring and Assessment Network (CARMA http://caff.is/about-carmahttp://caff.is/about-carma), these should be used as guidelines. Methods that are particularly recommended are in italics

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD/ REFERENCE	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE (Minimum)	COMMENTS
LARGE HERBIVORES (caribou/reindeer, muskox, moose)	Abundance	Essential	Number, density	Local/ regional	*Aerial/land-based surveys*, cue counts	Basic	3 years	
	Demographics	Essential	Age structure, mortality, fecundity	Local/ regional	*Aerial/land-based surveys*, telemetry, cue counts	Basic	3 years	
	Spatial structure	Essential	Distribution of migratory herds	Local/ regional	*Telemetry; aerial/ land-based surveys*, harvest records, tissue samples	Basic/ advanced	3 to 5 years	Monitoring of seasonal changes in spatial structure may be needed for e.g. migratory species
	Health	Essential	Pathogen prevalence and intensity, body condition, contaminants	Local/ regional	*Harvest records, tissue samples*, fecal analysis; bone length; some animal collections	Basic/ advanced	Annually	Monitoring parasites (e.g., botflies or other groups can be considered where capacity exists)
	Diversity: genetic	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	*DNA analysis*	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	*Telemetry; surveys*	Basic	Annually	
Medium sized herbivores (hares)	Abundance	Essential	Number, density	Local/ regional	*Land based surveys*, cue counts	Basic	Annually	
	Demographics	Essential	Age structure, mortality, fecundity	Local/ regonal	Land based surveys, harvest records, tissue samples	Basic	3 to 5 years	
	Spatial structure	Recommended	Temporal distribution	Local/ regional	Land based surveys, telementary, cue counts	Basic	3 to 5 years	

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD/ REFERENCE	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE (Minimum)	COMMENTS
Medium sized herbivores (hares)	Health	Essential	Prevalence	Local/ regional	*Harvest records, tissue samples*, fecal analysis	Basic/ advanced	3 to 5 years	
	Diversity: genetics	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	*DNA analysis*	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	*Telemetry; surveys*	Basic	Annually	
Small herbivores (lemmings, voles)	Abundance	Essential	Number, density	Local	Land-based surveys, cue counts	Basic	Annually	
	Demographics	Recommended	Age structure, mortality, fecundity	Local	Land-based surveys, telemetry, cue counts	Basic	Annually	
	Spatial structure	Recommended	Temporal distribution	Local	Live/ snap trapping	Basic	3 to 5 years	
	Health	Essential	Prevalence	Local	Tissue samples	Advanced	3 to 5 years	
	Diversity: genetics	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	DNA analysis	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	Telemetry; surveys	Basic	Annually	
Large predators (brown bear, grey wolf)	Abundance	Essential	Number density	Regional	*Cue count*, aerial/land-based surveys	Basic	3 years	
	Demographics	Essential	Age structure, mortality, fecunity	Regional	*DNA analysis*, den surveilance	Advanced	3 years	

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD/ REFERENCE	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE (Minimum)	COMMENTS
Large predators (brown bear, grey wolf)	Spatial structure	Recommended	Temporal distribution	Regional	*Telemetry*	Basic*	3 to 5 years	* Methods are not difficult but require specialized technology (can be expensive)
	Health	Essential	Prevalence	Local/ regional	*Harvest records, tissue samples*, fecal analysis	Basic/ advanced	3 to 5 years	
	Diversity: genetics	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	*DNA analysis*	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	*Telemetry; surveys*	Basic	Annually	
MEDIUM SIZED-PREDATORS (wolverine, Eurasian lynx, Canada lynx, red fox, Arctic fox)	Abundance	Essential	Number, density	Local/ regional	Den surveillance	Basic	Annually	
	Demographics	Recommended	Age structure, mortality, fecundity	Local/ regional	Den surveillance	Basic	Annually	
	Spatial structure	Recommended	Temporal distribution	Regional	Telemetry	Basic*	3 to 5 years	* Methods are not difficult but require specialized technology (can be expensive)
	Health	Essential	Prevalence	Local/ regional	*Harvest records, tissue samples*, fecal analysis	Basic/ advanced	3 to 5 years	
	Diversity: genetics	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	*DNA analysis*	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	*Telemetry; surveys*	Basic	Annually	

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD/ REFERENCE	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE (Minimum)	COMMENTS
Small predators (mustelids)	Abundance	Essential	Number, density	Local	*Cue counts*, land-based surveys	Basic	Annually	
	Demographics	Recommended	Age structure, mortality, fecundity	Local	*DNA analysis*, live trapping	Basic/ advanced	Annually	
	Spatial structure	Recommended	Temporal distribution	Local	*Telemetry*	Basic/ advanced	3 to 5 years	
	Health	Essential	Prevalence	Local	*Tissue samples*, fecal analysis	Advanced	3 to 5 years	
	Diversity: genetics	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	*DNA analysis*	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	*Telemetry; surveys*	Basic	Annually	

4.3 Drivers

Monitoring of all drivers is outside the scope of the CBMP-Terrestrial Plan. However, information on drivers is important to the interpretation and analysis of biodiversity information. The CBMP-Terrestrial Plan supports the collection of site-level abiotic data to facilitate cause-effect monitoring as described in section 4.1. Further, we aim to partner with relevant networks to exchange data on drivers to support integrated assessment of Arctic change. Finally, relevant information on drivers will be derived from remote sensing platforms where possible (see Appendix B). Table 4.6 illustrates the high priority drivers and how they will be monitored through the CBMP-Terrestrial Plan. The following landscape and regional-level information is required to effectively interpret biodiversity information. This information should be derived from existing or new remote sensing products.

Table 4.7 Monitoring high priority drivers as outlined in the CBMP-Terrestrial Plan and recommended additional drivers for monitoring as capacity permits (or where data exist from other networks)

TYPE OF DRIVER	HOW DRIVER WILL BE MONITORED
ABIOTIC DRIVERS (may be influenced by anthropogenic influences)	
Climate: Length of growing season	Phenology monitoring (Chapter 4: vegetation); remote sensing
Climate: temperature air and soil	Collection of site data (Chapter 4); linkage with other networks
Climate: precipitation (rain/snow, snow cover duration and extent, icing events)	Collection of site data (Chapter 4); remote sensing; linkage with other networks
Site characteristics (soils, permafrost, soil moisture, topography)	Collection of site data (Chapter 4); remote sensing; linkage with other networks
Hydrology	Collection of site data (Chapter 4); remote sensing; linkage with CBMP-Freshwater Plan
Other recommended abiotic drivers: cloud cover; solar radiation; treelines; storms; and wind. Climate change (rates of change) can be monitored indirectly from climate data	
BIOTIC DRIVERS (may be influenced by abiotic and anthropogenic drivers)	
Competition from southern species and other interspecies processes	Species/community monitoring (Chapter 4)
Invasive and non-native species	Species/community monitoring (Chapter 4)
· Shrubification	Species/community monitoring (Chapter 4)
· Grazing/foraging	Species/community monitoring (Chapter 4)
· Pollination	Species/community monitoring (Chapter 4: arthropods)
· Pathogens and parasites	Species/community monitoring (Chapter 4: mammals, birds)
· Habitat quality (connectivity, natural disturbance, nesting/breeding habitat, water resources)	Collection of site data and species/community monitoring (Chapter 4); remote sensing; for water resources see CBMP - Freshwater Plan
Other recommended biotic drivers: health of soil biota (rates of nutrient cycling, decomposition); and drivers as required for species of special interest (e.g., affecting reproductive effort, rates of herbivory, etc.). Changing species distributions due to climate change can be monitored indirectly through data-collection on species diversity, abundance and other from ecological data as above (see Chapter 4)	
ANTHROPOGENIC DRIVERS	
· Harvesting, hunting, trapping, fishing (fish prey important for terrestrial species)	TK, CBM, data available from other networks (e.g., governments, migratory bird data from other regions, etc.)
· Anthropogenic disturbance (noise, trampling, increased visitors and traffic)	Land use monitoring (Chapter 4: vegetation); remote sensing; collection of site data; data from other networks
· Land use and habitat conversion within Arctic (including fragmentation, infrastructure, resource extraction, roads)	Land use monitoring (Chapter 4: vegetation); other drivers outside study scope: remote sensing; collection of site data; data from other networks
· Habitat conversion outside Arctic	Outside study scope; linkage with other networks
· Contaminants and pollution	Outside study scope; other networks (e.g., AMAP)
Other recommended anthropogenic drivers: Nutrification and enrichment (chemical analyses, vegetation C stock, CANTTEX manual); domestication; tourism (disturbance, non-native species movement)	

5. Data management framework

5.1 Data management objectives for the CBMP

The CBMP's task to improve biodiversity trend reporting in a timely and compelling manner so as to enable effective policy responses is directly linked to improvements in data management. Currently, data management is gaining more attention within the biodiversity monitoring field. However, despite recent advances, biodiversity data formats and accessibility vary widely across the Arctic's data providers. Indeed securing basic metadata remains the priority before anything else. As such, it remains challenging to access, aggregate and depict the immense, widely-distributed and diverse amount of Arctic terrestrial biodiversity data. A related challenge is to integrate and correlate this information with other relevant data (e.g., physical, chemical, etc.) to better understand the possible causes driving biodiversity trends at various scales (regional to global). It is also critical to deliver this information in effective and flexible reporting formats to facilitate decision-making at a variety of scales. Meeting these challenges will significantly improve policy and management decisions through better and timelier access to current, accurate, and integrated information on biodiversity trends and their underlying causes at multiple scales.

With limited resources, CAFF's CBMP data management objectives are focused on the "art of the possible"—developing data-management systems that facilitate improved discovery and access to existing and current biodiversity data and integration of these data among disciplines. These objectives will also focus on maintaining data holders' ownership and control of the data once accessibility has been established. The CBMP has created the Arctic Biodiversity Data Service (ABDS **www.abds.is**), a publicly accessible, efficient, and transparent platform for collecting and disseminating information on the status and trends in Arctic biodiversity. The primary approach remains creating linkages to data where it already resides. However, in instances where this is too onerous, CAFF can provide alternative data management structures to host the data for partners until data providers have the capacity to host their own datasets.

Each country remains responsible for supporting foundational data management (e.g., quality assurance and quality control of data and compilation and formatting of existing national datasets) and providing data from their individual monitoring networks (i.e., the data holders). On the other hand, the CBMP will focus on accessing and integrating those datasets across countries and networks, as well as promoting a common, standardized data-management approach among the countries. For this approach to be successful, it is imperative that appropriate Arctic international, national and sub-national datasets are identified (metadatabases) and made available via interoperable linkages to the CBMP where appropriate.

In some cases, especially for the higher trophic levels, biodiversity data and relevant abiotic data layers are already available and are being integrated into the ABDS (**www.abds.is**). However, the task of aggregating, managing, and integrating data for the lower trophic levels is arduous, and it may be some time before such information can be accessed readily via the ABDS. The establishment of national Terrestrial Expert Networks (TEN) as defined in Section 8.1, and support from each nation and CAFF's data manager will facilitate this process through the adoption of common data and metadata standards.

The following sections provide an overview of the data management framework to be used for managing the outputs of the CBMP-Terrestrial Plan. Such a framework is essential to ensure effective, consistent and long-term management of the data resulting from coordinated monitoring activities.

5.2 Purpose of data management

Effective and efficient data management is fundamental to the success of the CBMP and its monitoring plans. A measure of success will be the ability to effectively connect individual partners, networks, and indicator-development efforts into a coordinated data management effort that facilitates data access and effectively communicates Arctic biodiversity status and trends to a wide range of audiences and stakeholders. Executed correctly, data management can fulfill the following functions:

- *Quality assurance:* ensures that the source data sets and indicator development methodologies are optimal and that data integrity is maintained throughout processing;
- *Consistency:* encourages the use of common standards and consistent reference frames and base data sets across parameters and networks;
- *Efficiency:* reduces duplication by sharing data, methodologies, analysis and experience;
- *Sustainability:* ensures archiving capability and ongoing indicator production;
- *Enhanced communications:* produces and distributes information through integrated web-based services, making indicator methodologies accessible and providing source metadata;
- *Improved linkages:* ensures complementarities between various networks and partnerships and with other related international initiatives, other indicator processes (national, regional, and global) and global assessment processes (e.g., the Global Biodiversity Outlook and Millennium Ecosystem Assessment); and
- *Enhanced credibility:* provides transparency with respect to methodologies, data sets and processes.

Implementation of the CBMP-Terrestrial Plan will rely on participation from many partners. An efficient and user-friendly metadata and data management system will facilitate this collaboration, providing multiple benefits as outlined above.

It will offer unique opportunities for monitoring networks to exchange data, draw comparisons between data sets and correlate biodiversity data with data derived from other networks using a common, web-based platform. A roadmap for data management, the CBMP Data Management Strategy (C. Zöckler, 2010; unpublished), has been developed to guide the management and access of metadata and data among the CBMP networks.

5.3 Coordinated data management and access

New, web-based data management tools and new interoperability standards and techniques have provided an opportunity for innovative approaches for the data management and integration that is critical for a complex, international initiative such as the CBMP.

CAFF's CBMP is developing the Arctic Biodiversity Data Service (ABDS **www.abds.is**), an online, interoperable and circumpolar data management system that will access, integrate, analyze and display biodiversity information for scientists, practitioners, managers, policy makers and others working to understand, conserve and manage the Arctic's wildlife and ecosystems.. The ABDS represents a distributed data management structure where data holders and publishers retain ownership, control, and responsibility for their data. Such a system will provide access to immediate and remotely distributed information on the location of Arctic biological resources, population sizes, trends, and other attributes, including relevant abiotic information. As well as providing a point for Arctic biodiversity information, the data portal will provide a simple approach for experts to share information through the web and allows for the integration and analysis of multiple data sets.

The ABDS calls for the establishment of a series of data nodes. Data nodes provide countries and disciplines the ability to organize themselves the best way they see fit. The CAFF data manager will interact with the nodes to ensure interoperability and data aggregation and will provide overall maintenance and management of the resulting pan-Arctic aggregated data in the most efficient way possible (whether nationally, by discipline, via ABDS.is or via existing data nodes).

Once nodes are established and data secured, information can be aggregated at an organization of the national TEN's choosing. The TEN leads will have overall password-controlled administrative privileges to view, maintain and edit the datasets. Each expert within a discipline group will have access to enter and maintain their own data. Each TEN will be responsible for defining and implementing the analytical approaches to generating the indicators. The CBMP will work with each TEN to establish analytical outputs tailor-made for the data collected and housed at the data node.

Users (e.g., scientists, decision-makers, and the public) will have access to the data outputs via the ABDS. Users will be able to perform set analyses (defined by each TEN) on ABDS, which will immediately access the most current data at the data node and display the output of the queried analysis. Much of the initial work in the implementation phase of the CBMP-Terrestrial Plan will involve aggregating existing data sets to create pan-Arctic data layers. The life cycle of the data, from collection to presentation, is shown in Fig. 5.1.

The ABDS will be flexible, freely accessible or password driven as appropriate and customizable to serve a diversity of clients (see Fig.5.2). The public will have access to broad indicators and general information on Arctic biodiversity data trends. National and sub-national governments as well as the national TENs will have the opportunity to customize the ABDS for their own purposes (e.g., display only the geographic scope of relevance to them). Both governments and TENs will have the authority to choose which data layers are publicly available. In addition, they will have a password-controlled domain to allow the inclusion of other data layers that are not publically accessible (e.g., unpublished data or draft reports).

This model of operation allows for user involvement at a variety of stages and can accommodate a large number of participants. The aim is to facilitate complete access to the collective knowledge, analysis and presentation tools available from the many participants and stakeholders both within and outside the Arctic community.

The ABDS will serve two purposes for the CBMP. First, it will provide access to geo-referenced information from within partner networks, as well as providing a common platform with multiple entry points for controlled data access, integration, harmonization and delivery. Secondly, it will enable a wide range of user groups to explore trends, synthesize data and produce reports with relative ease. The ABDS will generate indicators representing status and trend analyses, which in turn will be reported by the CBMP through a variety of means. These could include web-based reports and status and trends reports at multi-year intervals.

Development of this distributed system will necessitate the adoption and use of existing and widely accepted standards for data storage and query protocols, along with high quality and standardized metadata and web servers (spatial and tabular). The metadata will be housed on an existing meta-database system (Polar Data Catalogue **http://www.polardata.ca/whitesnow/**) allowing for simple and efficient access to a large and constantly updated, web-based, searchable, geo-referenced metadata system. The Arctic terrestrial monitoring datasets identified as core to the implementation of the Terrestrial Plan will be entered into this meta-database.

Geo-referencing will be critical to the successful integration of disparate data sets. Resolving the different spatial recording schemes used between the various data nodes and data holders—as well as the ranges of data volumes and bandwidth—will be challenges to overcome. Techniques will be devised to convert data into a standard format for integration. These technical issues will be addressed during the implementation phase.

5.4 Data storage, policy and standards

A decentralized data storage system is proposed for the ABDS because it offers a solution to concerns over data ownership and copyright. Through this system, the storage, responsibility for and ownership of the data will always remain with the data collector, publisher and/or holder. Although the data are decentralized, access to and depiction of the data is unified, allowing for multiple integrations for the user.

The CBMP encourages data providers to comply with the Conservation Commons (**http://conserveonline.org/workspaces/commons/**) and IPY Data Policy (**http://ipy.org**) on the delivery of free biodiversity data to the public, and equivalent legislation in the European Union for spatial information, such as the INSPIRE Directive (**http://inspire.jrc.ec.europa.eu/**). The ABDS will allow for organized and restricted access to data where necessary. Compliance with accepted data policies and provision of data to the ABDS system will result in password access being provided to the data layers found on the ABDS. This incentive-driven approach should encourage scientists and others to contribute their data as it will result in their access to other data layers relevant to them. Depending on the project and publication circumstances, the CBMP suggests a delay of no more than two years before information is released to the public, according to data type and project history.

In order for the various networks involved in implementing the CBMP-Terrestrial Plan to collaborate, input, and share data and metadata, common data and metadata standards should be followed. Freely available software allows users to apply these metadata conveniently and post them online with the clearinghouses (e.g., Polar Data Catalogue: **http://www.polardata.ca/**). Because data that lack details about their origin, methods, dates, collector names, and so on (metadata) can be virtually undiscoverable and unusable, both data and their metadata are crucial requirements and thus requested by funding agencies and the data initiatives cited here. The CBMP will encourage access to interoperable metadata nodes or storage at CBMP's main metadata node (at the Polar Data Catalogue) as the first step in enhancing access and coordination of Arctic data.

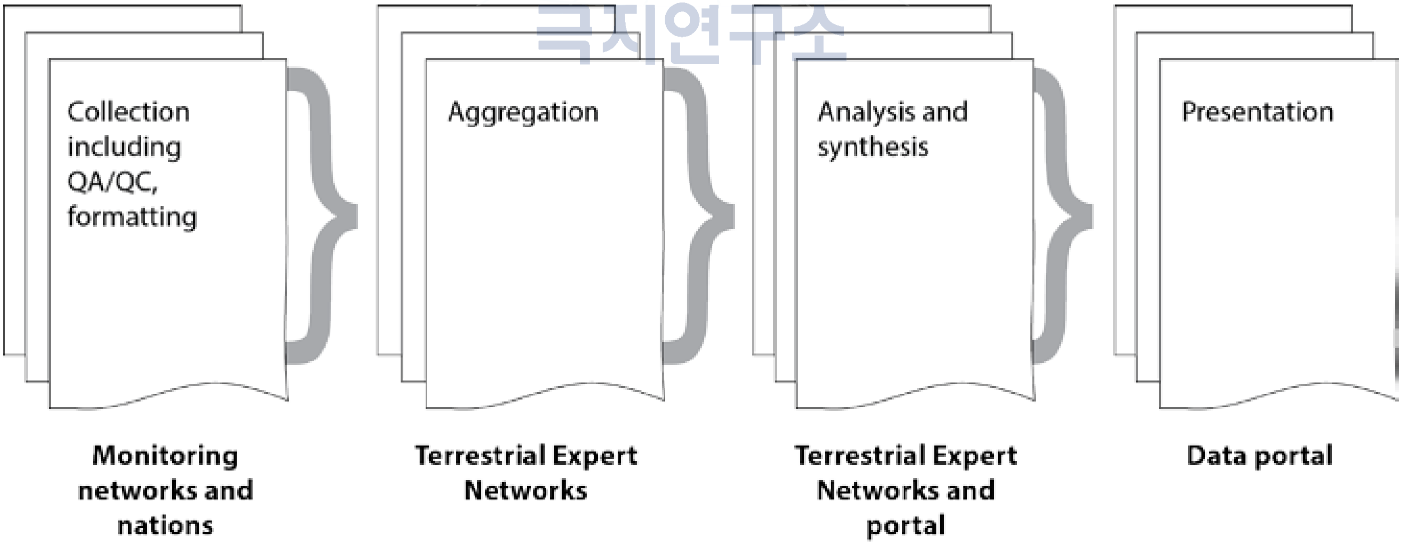


Figure 5.1 A simplified overview of the steps involved in accessing, integrating, analyzing and presenting biodiversity information via the ABDS and an indication of the responsibilities at each step.

Figure 5.2 Illustration depicting the ABDS concept and how data providers, portals and clients can utilize the system to improve biodiversity information for decision-making. The distributed network approach provides the greatest value by emphasizing linkages with existing data providers rather than establishing a whole new monitoring system in the Arctic.

6. Reporting and communication

This chapter outlines the methods by which output activities related to the CBMP-Terrestrial Plan will be reported. These reports will include results of the data collection (both existing and new data), as well as information on the creation, development and assessment of aspects of a coordinated monitoring plan. The audiences for this information range from international, national and regional policy and decision makers to local community residents, and as such, several types of reporting and timelines will be necessary. An initial *State of Arctic Terrestrial Biodiversity* report (to be completed in 2017) will provide a follow-up and expanded assessment of the state of terrestrial ecosystems in the Arctic using the Arctic Biodiversity Assessment's terrestrial ecosystems and related chapters (CAFF ABA 2013) as a baseline. These assessments will be conducted every five years to allow for an ongoing review of expected changes in Arctic terrestrial ecosystems with a specific focus on facilitating appropriate policy responses that can reverse, mitigate and/or adapt to these changes. Regular assessment reports will evaluate changes beyond the baseline conditions established in the Arctic Biodiversity Assessment. On a more frequent basis, results of data aggregation at the pan-Arctic and regional scales will be published in scientific literature and other products will be derived from this (e.g., ongoing assessments, etc.). Finally the outputs will as much as possible be targeted and coordinated with international processes, for instance related to the Aichi 2020 targets and the IPBES reporting structure and timelines.

6.1 Audiences

Table 6.1 lists the target audiences to be addressed by each type of reporting (for more details on target audiences, see the CAFF Communications Plan at **http://caff.is/images/Meeting_Docs/Board_meetings/CommsPlan_CAFF_Sept2011.pdf**). Regular, peer-reviewed reports on scientific results and program performance will be made to the Arctic Council and national and regional authorities that deal with biodiversity and/or land management issues to support programs, policies and decision-making. Program results are also relevant to local community residents across the Arctic, the scientific community (e.g., through scientific publications), non-government and other international organizations, other partners and collaborators. Furthermore, information on the status and trends in biodiversity of Arctic terrestrial ecosystems is anticipated to be contributed to international forums and processes (e.g. National reporting for the Convention of Biological Diversity, Convention on Migratory Species, etc.).

6.2 Reporting results

Table 6.1 lists the types of outputs, including reports and reporting formats that will be used to summarize activities related to the CBMP-Terrestrial Plan for each audience.

6.2.1 The *State of Arctic Terrestrial Biodiversity* report

The first *State of Arctic Terrestrial Biodiversity* report is targeted for production in 2017, four years after the release of the Arctic Biodiversity Assessment full scientific report (CAFF ABA 2013). The ABA will provide the fundamental baseline in relation to described trends but also other historical data will be used, where data permits. Overall the *State of Arctic Terrestrial Biodiversity* report will describe:

1. the baseline conditions for chosen FEC attributes and spatial comparisons, where possible, within and among the different Arctic terrestrial subzones;

2. temporal changes that have occurred since the baseline periods, in addition to historical trends, where data permits; and,

3. differences that have occurred spatially within and between terrestrial subzones.

The results (e.g., trends, spatial differences and changes in variability) will be described and interpreted, to the extent possible, both statistically and from a biophysical perspective. The results will be presented as distribution maps and graphs showing spatial and temporal trends for FECs and monitoring areas. It will be important to discuss the statistical significance, spatial representativeness, and confidence levels of the results.

Subsequent targeted reports are planned in 2020 and then every five years, and will include an analysis of how changes in biodiversity may be linked to human stressors.

6.2.2 Program review

Internal review and independent external review will be used to evaluate and adjust the monitoring program periodically. Internal review will occur in 2017, 2020 and subsequently every five years, and will involve the evaluation of chosen parameters and attributes, sampling methods, data management and analysis and reporting. The results of this review will be used to update the CBMP-Terrestrial Plan and make any necessary adjustments to the outlined methodology. It is anticipated that in the start-up phase the aggregation of existing data will help better inform the optimal sampling frequencies and intensities needed and the essential variables needed to allow for effective detection in change for terrestrial ecosystem components and services. Every 10 years beginning in 2020, there will be an additional independent external review of the program. The review process, although intended to assess the performance of the program and identify any shortcomings, should be conservative to provide statistically sound long-term measurements and would ideally add rather than remove aspects of the program.

6.2.3 Scientific publications

Scientific publications will be used to share the results of the status reports with the scientific community. Additional scientific publications are also expected to follow from the status assessments and may be specific to a particular FEC or sampling region, or may be multidisciplinary and/or multiregional in scope. These articles are intended to address the links between changes to the biotic and abiotic FECs and possible driving mechanisms at a broader or more detailed scale than may be possible with the status reports.

6.2.4 Performance reports and work plans

Performance reports and work plans will be submitted to the Arctic Council through CAFF-CBMP on an annual basis. The performance reports will detail the steps that have been made to implement the Terrestrial Plan in the previous year, and will outline the progress in managing the program. The work plans will outline the work that is anticipated to be completed during the following year, the budget and deliverables. This process will begin with the submission of a work plan in 2013 following the publication of the CBMP-Terrestrial Plan.

6.2.5 Summaries and other communications material

Summaries and non-technical communication material will be prepared for local community residents, partners and collaborators and non-scientific audiences to make the results of the status assessments and updates accessible to the interested public. These can include: presentations, workshop materials, website, newsletters, posters, brochures, films, story-pitching to media, press kits and more. The CBMP will also use its existing communications network and media (e.g., newsletter, media releases, websites, social media, etc.) to provide regular information on progress and results to these audiences.

6.2.6 Assessment and reporting of FEC attributes

Selected FEC attributes (see Chapter 4) will be assessed and reported on the ABDS (see Chapter 5) every second year starting in 2015 with a pilot effort.

Atigun Ridge. Photo: Martha Reynolds

Table 6.1 Overview of the type of reports that will be associated with the CBMP-Terrestrial Plan and the target audience for each report type.

	Primary target audience	Arctic Council	National and regional authorities	Local communities	Scientific community	Other international organizations	Partners and collaborators	NGOs and the public	Timing/ Frequency
Type of report	*State of Arctic Terrestrial Biodiversity* report, including status reports	X	X	X	X	X	X	X	2017, 2020 (update), and subsequently every five years
	Status of selected FEC Attributes	X	X	X	X	X	X	X	Bi-annually, starting with first examples in 2015
	Review of attribute performance, revision of parameters, new techniques, sampling approaches, data management approach, analysis and reporting	X			X		X		2017, 2020 (update), and subsequently every five years
	Scientific output as scientific publications, either by discipline or multidisciplinary, by Arctic Terrestrial subzone and across the Arctic				X	X	X		Ongoing, starting in 2014
	Performance reports and work plans	X	X						Annually, starting with a work plan in 2013
	Various summaries and other communications material	X	X	X	X	X	X	X	Ongoing, beginning in 2014

7. Implementation and administration

7.1 Governing structure

Implementation of the CBMP-Terrestrial Plan requires a governing structure and process for program review that will ensure this monitoring effort is relatively simple, cost-effective and addresses the monitoring objectives and questions posed in Chapters 1, 3 and 4. In addition to international bodies of the Arctic Council, other groups involved in the implementation of the CBMP-Terrestrial Plan will include national, sub-national and local jurisdictions across the Arctic (and even outside the Arctic) that already undertake terrestrial biodiversity monitoring. The implementation and review structure described below incorporates the CBMP's network-of-networks approach (see Fig. 7.1) and aims to provide value-added information on the state of Arctic terrestrial ecosystems and the biodiversity they support that is useful for global (e.g., Convention on Biological Diversity), national, sub-national and other reporting needs (see Fig. 7.2). Ultimately, it will be the responsibility of each Arctic country to implement the CBMP-Terrestrial Plan in order for the program to succeed.

CAFF will establish a CBMP Terrestrial Steering Group (CBMP-TSG) to implement, coordinate and track progress of work undertaken in response to the CBMP-Terrestrial Plan, and to oversee the activity of the eight national Terrestrial Expert Networks (TENs) (see Fig. 7.2). Composition of the CBMP-TSG will include one representative and an alternate from each Arctic nation (i.e., Canada, Denmark-Greenland-Faroes, Finland, Iceland, Norway, Russia, Sweden and the United States of America). The CBMP-TSG will be directed by co-leads drawn from these Arctic nation representatives. Permanent Participants will collaborate depending on their capacity and interest, and are invited to appoint members to the CBMP-TSG. Other relevant Arctic Council working groups (e.g., AMAP) may appoint one member each to the CBMP-TSG.

Each national CBMP-TSG representative will be responsible for:

1. facilitating implementation of the monitoring plan within their own nation;
2. building strong and ongoing connections with the relevant agencies, institutes and experts within their countries by coordinating and providing direction to their national TEN members;
3. gathering information and reporting on the implementation status of the plan within their respective nation to the CBMP-TSG; and
4. contributing to reporting to the CBMP and CAFF.

As a group, the CBMP-TSG will be responsible for setting the overall course of the evolving monitoring program, providing ongoing program oversight and adjusting the implementation approach as necessary. The CBMP-TSG will be responsible for reporting on the status of the CBMP-Terrestrial Plan to CAFF and the CBMP Office. A number of value-added services will be provided to the CBMP-TSG by the CBMP Office and CAFF International Secretariat. These services include the establishment of a common web portal and web-based data nodes, communication products and other reporting tools.

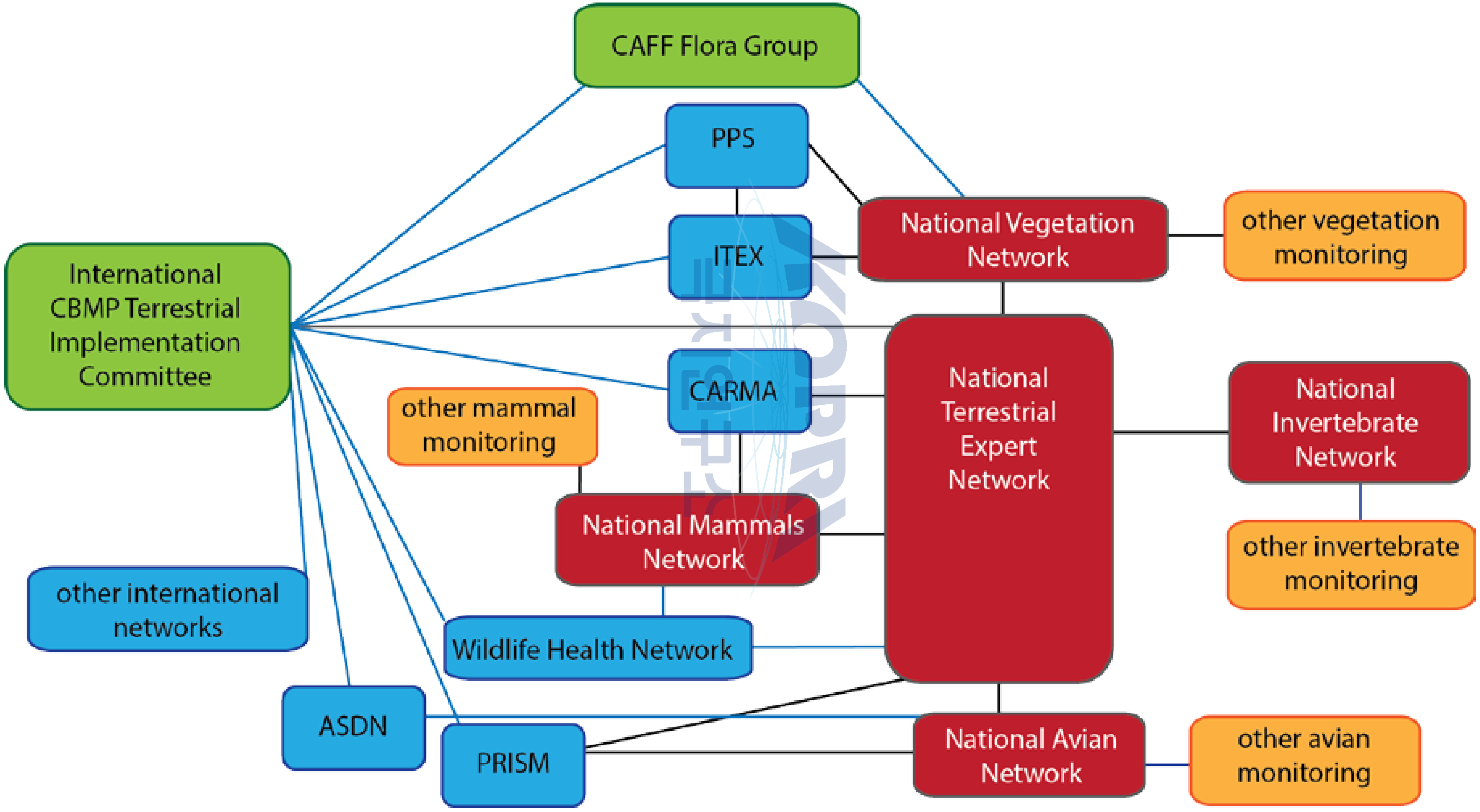
It is the responsibility of each country representative to the CBMP-TSG to identify national experts (both scientific and TK) to be included in their TEN. Each national TEN will include the expertise required to assess the status and trends of the FECs and attributes identified in Chapter 3 and should be representative of the main institutions (government and/or non-government) responsible for Arctic terrestrial biodiversity monitoring in that particular country.

In addition, TEN members will be responsible for:

1. dentifying, aggregating, analyzing, and reporting on existing datasets to contribute to FEC attribute assessments; and
2. suggesting adjustments to the parameters, attributes and sampling schemes if needed.

Each member country will benefit from the formation of its TEN as network activities will contribute to domestic reporting mandates and needs and improved coordination of domestic monitoring leading to cost-efficiencies and more powerful monitoring. The CBMP-TSG may facilitate coordination and cooperation among the various TENs as needed.

Figure 7.1 The network of networks approach for implementing the CBMP-Terrestrial Plan, including from national to international levels (national expert networks in red; other groups in orange; international groups in blue; CBMP and CAFF in green).



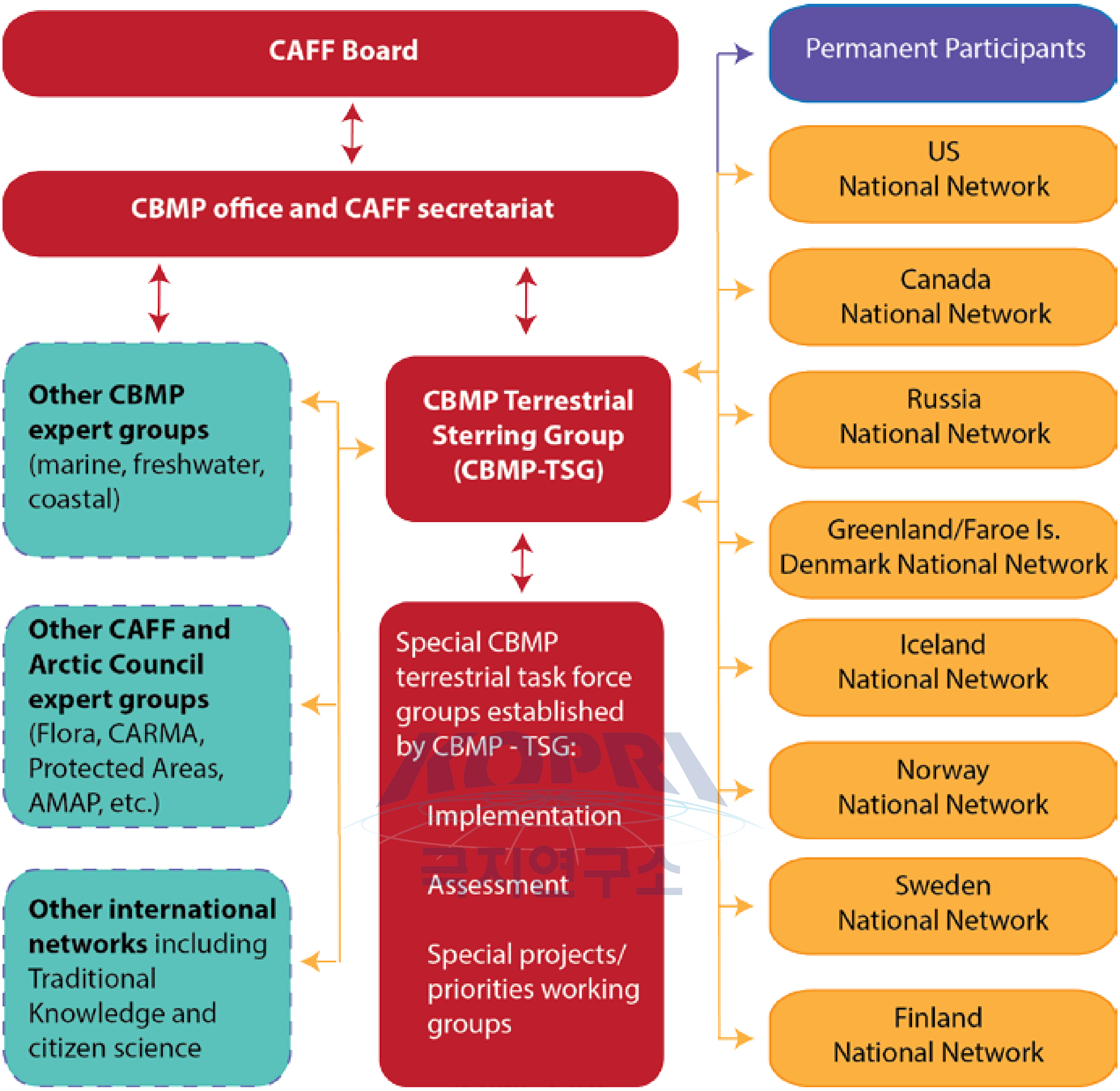


Figure 7.2 Governing structure for the implementation and ongoing operation of the CBMP-Terrestrial Plan. National Terrestrial Expert Networks include and/or work closely with Arctic Nation co-leads and representatives, TK holders, community experts and biodiversity expert groups (national and international members). TENs communicate with the CBMP Terrestrial Steering Group, which in turn organizes and coordinates reporting to the CBMP Office and CAFF Board. The Terrestrial TSG communicates with participant nations, other scientific, technical and community networks (e.g., Figure 7.1), other CBMP biome expert groups, and other CAFF and Arctic Council bodies and special task forces.

7.2 Program review

The CBMP-TSG will initiate an internal review of the program beginning in 2017. A second review will take place in 2020 and will be followed by regular internal reviews every five years to align with the production of *State of the Arctic Terrestrial Biodiversity* reports. The internal review will assess progress towards the completion of program objectives (see Table 7.1), with the goal of assessing attribute performance, determining if additional parameters, techniques or sampling approaches are needed to improve the program or if some parameters or attributes should be dropped due to lack of sampling power, and evaluating the approach to data management. The review will determine if progress has been made in terms of answering questions related to the status and trends of Arctic terrestrial ecosystems and the biodiversity they support. In addition, an external review of these aspects of the program is recommended every 10 years with the first external assessment anticipated for 2020. Changes recommended by either internal or external reviews should be implemented with caution to ensure that recommended changes to the CBMP-Terrestrial Plan do not compromise data integrity. Besides the formal reviews scheduled every five years, the CBMP-TSG should ensure that yearly milestones are met and that concerns identified during the year are addressed in a timely fashion.

Table 7.1 Program objectives and performance measures of the CBMP-Terrestrial Plan to be assessed every five years beginning in 2017.

Objective	Performance Measure(s)
Identify an essential set of attributes for terrestrial ecosystems that are suited for measurement and implementation on a circumpolar level.	Common attributes in use in three or more countries by 2016.
Identify abiotic parameters that are relevant to terrestrial biodiversity and require ongoing monitoring.	Relevant abiotic networks identified, and linkages made between CBMP-Terrestrial Plan needs and abiotic data (2013-2016).
Identify harmonized or standardized protocols and optimal sampling strategies for Terrestrial Plan monitoring.	Arctic-based monitoring networks adopt sampling approaches (2013-2016).
Identify and organize existing research and operational monitoring capacity and information (scientific, community-based and TK).	Identify monitoring groups and accumulate available data for use in reports on the state of Arctic terrestrial biodiversity (2013-2016).
Establish and promote effective communication and linkages among Arctic terrestrial researchers and monitoring groups.	Utilization of ABDS for CBMP-TSG reporting and communication outputs (2013-2016).
Address priority gaps in monitoring coverage (elemental, spatial and temporal).	Identification of priority data and sampling gaps and solutions to broaden monitoring coverage (2016).
Respond to identified scientific and TK science questions and user needs.	Indicators developed and reported in *State of Arctic Terrestrial Biodiversity* report (2017).

7.3 Implementation schedule and budget

Table 7.2 lists the major milestones involved with the implementation of the CBMP-Terrestrial Plan. The CBMP-TSG should use these as guidelines for outlining their annual work plans. These milestones include the initial publishing of the Terrestrial Plan, the activation of the governing structure and establishment of the data nodes, the collection and analysis of existing monitoring data and establishment of coordinated monitoring, production of reports, and program review. A number of activities and deliverables are associated with each milestone, and the start year for each activity or first year in which the deliverable will be produced is indicated to provide a timeline for this implementation plan.

The budget for the implementation of the CBMP-Terrestrial Plan reflects the estimated costs for pan-Arctic coordination of the monitoring and assessment of the status and trends in Arctic terrestrial biodiversity (see Table 7.3). These estimates do not include current and planned expenditures by each country to conduct their own Arctic terrestrial biodiversity monitoring or to conduct foundational data management. Similarly, costs for coordinating and holding in-country meetings with TEN members have not been included because of the large differences in cost anticipated among the countries. For an annual average investment of $5-10K USD per country in 2013 and $85-155K USD per country per year in 2014-2016, the value and output of current national monitoring efforts can be greatly increased through a more coordinated, pan-Arctic approach. The budget for 2017 and beyond will be developed at a later date when activities and deliverables for ongoing assessment have been established. Even with an improved, harmonized approach, critical gaps in our monitoring coverage will still remain and new resources will be needed to address these gaps. Also, it is critical to acknowledge the ongoing need to sustain the monitoring and foundational data management activities that the CBMP-Terrestrial Plan aims to harmonize.

Table 7.2 Implementation schedule for the CBMP-Terrestrial Plan, including activities, deliverables and start year for each milestone associated with the implementation. These activities will form the foundation of the annual work plans of the CBMP-TSG.

Milestone	Activities and deliverables	Start year
1. Plan published	a. Final plan endorsed by CAFF Board and published	2013
	b. Executive Summary report published (if needed)	2013
2. Governing structure activated	a. CBMP-TSG established	2013
	b. National TENs established	2014
3. Data management	a. Data nodes and hosts, web-entry and data standards established for each national TEN	2014/ 2015
	b. Nodes linked to ABDS and web portal analysis tools developed	2015
	c. Metadata added to Polar Data Catalogue	2013
4. FEC attributes (indicator) development	a. Existing data sets identified and aggregated	2014/15
	b. Existing data sets analyzed to establish indicator baselines	2015
	c. FEC attributes updated based on performance reports (annually)	2016
5. Establish coordinated monitoring in each country	a. Recommended monitoring protocol manuals developed Arctic terrestrial biodiversity monitoring networks	2014
	b. Monitoring stations selected within each country	2015
	c. Arctic-based monitoring networks adopt parameters and sampling approaches	2016
6. Reporting and communication	a. Annual performance reports and work plans	2014
	b. Targeted *State of the Arctic Terrestrial Biodiversity* report (initial assessment of contemporary and historical data)	2017
	c. *State of the Arctic Terrestrial Biodiversity* reports (update - incorporating new monitoring data) – four years after initial report (to align with Marine and Freshwater Steering Groups) and subsequently every five years	2020
	d. Selected FEC attribute status reports – every two years (on ABDS). A pilot report will be presented in 2015.	2015
	e. Scientific publications (ongoing)	2014
	f. General communications	2013
7. Program review	a. Review of parameters, sampling approaches, data management approach, analysis and reporting (second review four years after initial review and subsequently every five years)	2017
	b. External independent review of parameters, sampling approaches, data management approach, analysis, and reporting (nine years after initial report and subsequently every 10 years)	2020

Table 7.3 The operating budget for the implementation of the CBMP-Terrestrial Plan outlining estimated costs for the activities and deliverables and the responsibility for each cost. Note: the costs outlined in the table are focused on new efforts to harmonize terrestrial biodiversity monitoring, data management and reporting. They do not include the actual ongoing monitoring costs and foundational data management that will be incurred by each country.

Milestone	Activities and deliverables	Total cost (USD)	Cost details	Responsibility
1. Governing and operational structure activated	a. 2013 Inaugural meeting of CBMP-TSG b. Annual meeting of CBMP-TSG	50K (10 people at 5K each) plus 5K venue costs per year	Meeting costs (travel support for CBMP-TSG members and venue costs) and conference call costs	Arctic nations for travel support for their members. Lead TSG country for venue costs.
2. Data management structures established	a. Data nodes and hosts, web-entry interfaces, and data standards established	2014: 50K (data node establishment) 2014 onwards: 10K per year (data node management)	Web-entry interface and web-based databases and nodes and data entry manuals established	CAFF Secretariat/ CBMP Office
	b. Data nodes linked to ABDS and analytical tools developed	2014 onwards: 20K (web portal maintenance)	ABDS linked to data nodes via XML, and canned analysis tools developed	CAFF Secretariat / CBMP Office
	c. Metadata added to Polar Data Catalogue	2013 onwards: 0K (in-kind support from PDC and CAFF Data Manager)	Metadata entry by University of Laval and CAFF Data Manager free of charge	CAFF Secretariat/ CBMP Office
3. Indicator development	a. Identification of existing data sets and historical data, collection of metadata, and spatial assessment of data coverage for national report	2014: 20-60K per country	Costs for one person for two to six months per country (depending on country).	Arctic nations
	b. Aggregation of existing data, national and regional dataset compilations, QA/ QC, data agreements, and formatting (to be done concurrently with 3a)	2014-2015: 20-60K per year per country	Costs will vary depending on state of national datasets. Costs for one person for two to six months per year per country (depending on country).	Arctic nations
	c. Analysis of FEC attribute baseline status for each nation, summarized in national report	2015-2016: 20-60K per year per country	Costs for one person for two to six months per year per country (depending on country).	Arctic nations
	d. Dataset compilations archived	Minimal cost (10K). CAFF Data manager staff time.	All datasets compiled and used to be archived at CAFF Secretariat.	CAFF Secretariat
	e. Accumulation of links to national/ regional protocols, identification of intercalibration needs, and definition of attribute comparison limits	2014-2015: 30K	Costs for one person for three months.	CBMP-TSG

Milestone	Activities and deliverables	Total cost (USD)	Cost details	Responsibility
4. Reporting and communications	a. Annual performance reports and work plans	*Cost to be determined:* per year starting in 2014	Layout and digital publication	CBMP-TSG and CAFF Secretariat
	b. Compilation of national reports to create *State of Arctic Terrestrial Biodiversity* report	50K (10 people at 5K each) plus 5K venue costs per year	Meeting costs (travel support for CBMP-TSG members and venue costs) and conference call costs	Arctic nations for travel support. Lead TSG country for venue costs.
	c. General communications materials	*Cost to be determined:* per year starting in 2014	Layout and digital publication; website design; translation	CBMP-TSG and CAFF Secretariat
5. Program Review and adjustments	a. Review of parameters and sampling approaches.	0K – costs reflected above.		CBMP-TSG
	b. Independent review of data management approach, analysis and reporting using performance measures	30K every ten years starting in 2016	Contract independent review of monitoring program	CBMP Office
TOTALS		2013: 5-10K per country 2014-2016: 60-130K per year per country 2014-2016: 50-70K per year CAFF/ CBMP		

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9. Glossary

Term	Description	Reference or resource
advanced protocols	Monitoring protocols that consist of methodology requiring comprehensive scientific expertise and oversight for proper application	
Aichi Biodiversity Targets	Strategic plan goals to promote, protect, and enhance biodiversity by 2020; CBD	**http://www.cbd.int/sp/targets/**
albedo	surface reflectivity; fraction of solar radiation that is reflected back into space	
ABA	Arctic Biodiversity Assessment	**http://caff.is/aba**
ABBCS	Arctic Birds Breeding Condition Survey	**http://www.arcticbirds.net/**
AMAP	Arctic Monitoring and Assessment Program, Arctic Council	**http://www.amap.no/**
AOU	American Ornithologists' Union	**http://www.aou.org/**
APECS	Association of Polar Early Career Scientists	**http://www.apecs.is/**
APEX	Arctic Palaeoclimate and its Extremes	**http://www.apex.geo.su.se/**
Arctic	Land north of the Arctic Circle (approx. 66° 33′ N); ecologically, the land north of treeline at present corresponding to the 10°C (50°F) July isotherm	
Arctic WOLVES	Arctic Wildlife Observatories Linking Vulnerable Ecosystems	**http://www.cen.ulaval.ca/arcticwolves/en_intro.htm**
attributes	Characteristics of FECs selected as priority descriptors of the state of the FEC itself but also of broader ecosystem function and integrity	
basic protocols	Monitoring protocols that consist of simplified methodology that can be used at sites with minimum monitoring capacity	
BBS	Breeding Bird Survey	**https://www.pwrc.usgs.gov/bbs/about/**
biodiversity	the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD)	**CBD (http://www.cbd.int/)**
BIP	Biodiversity Indicators Partnership	**http://www.bipindicators.net/**
biotic group	Set of organisms that share some characteristics (e.g. taxonomy, habitat, functional groups, communities, etc.). In the CBMP-Terrestrial Plan, these are Vegetation, Birds, Mammals, and Invertebrates.	
black-listed species	Non-native species that are invasive or harmful in the introduced region (e.g. term used in Norway and other countries, but other terms have not been standardised in other countries); compare with Red List species (IUCN)	
CAFF	Conservation of Arctic Flora and Fauna Working Group of the Arctic Council	**http://www.caff.is/**

Term	Description	Reference or resource
CALM	Circumarctic Active Layer Monitoring Network	**http://www.udel.edu/Geography/calm/about/program.html**
CANNTEX	Canadian Tundra and Taiga Experiment; a network of scientists and sites across the Canadian North (and see ITEX)	**http://www.taiga.net/canttex/index.html**
CARMA	Circumarctic Rangifer Monitoring and Assessment Network	**http://caff.is/carma**
CAVM	Circumpolar Arctic Vegetation Map	**(CAVM Team 2003; Christensen, et al. 2011) http://www.geobotany.uaf.edu/cavm/**
CBC	Christmas Bird Count, Audubon Society	**http://birds.audubon.org/christmas-bird-count**
CBD	Convention on Biological Diversity	**http://www.cbd.int/**
CBM	See Community-based monitoring	
CBMP	Circumpolar Biodiversity Monitoring Program; created by the CAFF Working group of the Arctic Council	**http://www.caff.is/monitoring**
ABDS	CBMP's Data Portal system (www.abds.is)	**http://www.abds.is**
CBMP-Terrestrial Plan	Arctic Terrestrial Monitoring Plan; created by the TEMG	
CBMP-TSG	Circumpolar Biodiversity Monitoring Program - Terrestrial Steering Group	
CEMG	Coastal Expert Monitoring Group (see EMG)	
CMR	Capture-Mark-Recapture. A general group of ecological methods based on the initial capture of individuals which are tagged and the subsequent re-trapping of the same or a portion of the original captured individuals	
COI Barcode	DNA Barcoding: fragment of the cytochrome oxidase c I gene that is sequenced systematically and is useful for species identification in many taxonomic groups (additional markers may be needed in groups such as plants)	**http://www.barcodeoflife.org/content/about/what-dna-barcoding**
conceptual model	A set of working hypotheses about ecosystem organization, function, and key system inter-relationships, commonly formalized in a graphical depiction	**(Beever and Woodward 2011)**
community-based monitoring	Observation and measurement activities involving participation by community members; activities are designed to learn about ecological and social factors affecting a community	
critical component	Elements considered to play a crucial role in a system and that would lead to detrimental changes if these ceased to exist; elements which may be considered as priorities for long-term monitoring.	

Term	Description	Reference or resource
DEM	Digital Elevation Model	
DNA barcoding	System of protocols and databases of biodiversity taxonomy and identification based on standardised sequences of DNA	**http://www.barcodeoflife.org/**
driver	An ecological biotic or abiotic component that causes a change in an organism, population, habitat, ecosystem, or other element of the landscape (see *stressor*)	
eBird	Online avian abundance and distribution checklist based on reporting by volunteers and professionals (citizen science).	**http://ebird.org/content/ebird/**
ecosystemic	Related to the environment	
ecological tipping points	Points along a gradient of change where a small change in external conditions can result in a drastic change in the structure and composition of a system	**(Groffman, et al. 2006)**
EMG	Expert Monitoring Group (see CBMP); one of four groups of collaborating scientists, managers, and community members with expertise in Terrestrial (TEMG), Marine (MEMG), Coastal (CEMG) and Freshwater (FEMG) environments.	
essential attribute	Attributes of FECs that must be measured at any given monitoring site to capture a minimum set of biodiversity information for the FEC under study; considered critical	
Focal Ecosystem Components (FECs)	The high-level targets of the terrestrial monitoring effort that are considered critical to the functioning and resiliency of Arctic ecosystems and are representative of biodiversity	
FEMG	Freshwater Expert Monitoring Group (see EMG)	
function	Ecosystem function; the ecological role performed by a species or functional group (e.g. nutrient cycling, herbivory, etc.)	
GBIF	Global Biodiversity Information Facility (and Data Portal)	**http://www.gbif.org/**
GEO BON	Group on Earth Observations Biodiversity Observation Network	**http://www.earthobservations.org/geobon.shtml**
GLORIA	Global Observation Research Initiative in Alpine Environments	**http://www.gloria.ac.at/**
gray literature (or grey literature)	Manuscripts and articles that may be unpublished and typically do not undergo the same peer-review process as journal articles; material may consist of reports, technical papers, white papers, etc.	
high Arctic	Northern region of the Arctic particularly including the island in the north; ecologically, the area consisting of polar semidesert to desert where mean July temperatures range from 6° to 2° C	

Term	Description	Reference or resource
historic monitoring	Relevant monitoring previously conducted which could be incorporated into the monitoring scheme	
impacts	Effects of environmental degradation (DPSIR framework)	**http://www.grida.no/graphicslib/detail/dpsir-framework-for-state-of-environment-reporting_379f**
indicator	A measure or metric based on verifiable data that conveys information about more than itself	**http://www.bipindicators.net/LinkClick.aspx?fileticket=brn%2FLxDzLio%3D&tabid=157**
INTERACT	International Network for Terrestrial Research and Monitoring in the Arctic	**http://www.eu-interact.org/**
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services	**http://www.ipbes.net/**
IPCC	Intergovernmental Panel on Climate Change	**http://www.ipcc.ch/**
IPY	International Polar Year	**http://www.ipy.org/ (NOTE: domain name and site may be down temporarily)**
ITEX	International Tundra and Taiga Experiment	**http://www.geog.ubc.ca/itex/**
IUCN	International Union for Conservation of Nature and Natural Resources	**http://www.iucnredlist.org/**
landscape	A geographic area including its properties of physical terrain, land cover, water bodies, climate, land use patterns, and other characteristics	
life forms, vegetation	Type of vegetation related to ecosystem function (e.g., trees, shrubs, forbs, graminoids, bryophytes, fungi, lichens, bare ground, etc.)	
low Arctic	Southern region of the Arctic; ecologically, area with higher diversity in vegetation where mean July temperatures range from 6° to 12° C	
management, wildlife or ecosystem	Decision-making and applied ecology to preserve and enable sustainable use of wildlife populations in a manner that strikes a balance between the needs of those populations and the needs of people	
MEMG	Marine Expert Monitoring Group (see EMG)	
mire	Boggy habitat	
MODIS	Moderate Resolution Imaging Spectroradiometer; satellite-borne imaging instrument that gathers data on the Earth's surface	**http://modis.gsfc.nasa.gov/**
NDVI	MODIS Normalized Difference Vegetation Index; satellite-based data collected on land cover changes that can be used to monitor vegetation growth conditions, climate, and land use.	**http://glcf.umd.edu/data/ndvi/**
PAME	Protection of the Arctic Marine Environment	**http://www.pame.is/**

Term	Description	Reference or resource
parameter	Traits, items, or values that are measured in the field and that are used to describe FEC attributes	
PPS Arctic	Norwegian IPY program of circumpolar treelines research: 'Present day processes, Past changes, and Spatiotemporal variability of biotic, abiotic and socio-environmental conditions and resource components along and across the Arctic delimitation zone'	**http://ppsarctic.nina.no/**
pressures	Stresses that human activities place on the environment (DPSIR framework)	**http://www.grida.no/graphicslib/detail/dpsir-framework-for-state-of-environment-reporting_379f**
PRISM	Program for Regional and International Shorebird Monitoring	
range of temporal variation	Temporal and spatial distribution of ecological processes and structures prior to European settlement of North America	**(Wong and Iverson 2004)**
recommended attribute	Attributes that can be measured at some sites when additional capacity and/or expertise is available to capture information on the processes driving biological change	
red List of species (IUCN)	Framework for the classification of taxa according to their extinction risk and including species with near threatened to extinct status	**http://www.iucnredlist.org/**
redundancy	Ecologically, when a species or group of species can perform the equivalent ecosystem function of another species or group of species	
region	Spatial area demarcated by political borders (territorial or settlements), socioeconomic categories, geology, watersheds, or biogeography	
resilience	Amount of disturbance that ecosystem can withstand without changing key processes and structures (alternative stable states); time needed to return to a stable state	**(Holling 1973)**
responses	Responses by society to the environmental situation (DPSIR framework)	**http://www.grida.no/graphicslib/detail/dpsir-framework-for-state-of-environment-reporting_379f**
SAON	Sustaining Arctic Observing Network	**http://www.arcticobserving.org/**
SCANNET	Circumarctic network of terrestrial field bases; see INTERACT	**http://www.scannet.nu/ (*NOTE*: main site may be experiencing problems); http://faro-arctic.org/fileadmin/Resources/DMU/GEM/faro/2010_SCANNET_Rasch.pdf**
SDWG	Sustainable Development Working Group, Arctic Council	**http://portal.sdwg.org/**
stressor	Driver (e.g. an agent, force or external factor) that exerts *detrimental* pressure on an ecosystem, community, biotic group, organism, or on natural ecological processes or ecosystem functions (see *driver*)	

Term	Description	Reference or resource
sub-Arctic	Ecotone between timberline (taiga) and treeline (tundra) with connections to the Arctic via alpine zones, coastal tundra, and forest tundra	
SWIPA	Snow, Water, Ice, Permafrost in the Arctic assessment (produced by AMAP)	**http://amap.no/swipa/**
Traditional Knowledge TEK/TK	Traditional Knowledge: knowledge and values which have been acquired through experience, observation, from the land or from spiritual teachings and taught through generations. Traditional ecological knowledge: cumulative body of knowledge about people and organisms in relation to their environment, and that has been acquired through experience and taught through generations (and see Traditional Knowledge as broader term)	
TEMG	Terrestrial Expert Monitoring Group (see EMG)	
TEN	Terrestrial Expert Networks (established by country for coordinating metadata accessibility; CAFF)	
Terrestrial Plan	Circumpolar Biodiversity Monitoring Plan for terrestrial biodiversity	
threshold	The ecological tipping point of an ecosystem; point where abrupt change in a quality, property or phenomenon, or where small changes in a driver, produce large responses	
timberline	The altitudinal or latitudinal boundary or transition zone that delineates the ecological conditions of climate (especially temperature, precipitation, and wind) beyond which forests no longer form a closed canopy ecosystem (and see treeline)	
tipping point	See Threshold	
treeline (or tree line)	The altitudinal or latitudinal boundary or transition zone that delineates the ecological limit beyond which trees can no longer grow due to harsh climatic conditions, especially temperature, precipitation, and wind (and see timberline)	
TSG	Terrestrial Steering Group	
vegetation	Comprehensive term referring to land cover components including all plants and their growth forms, and fungi.	
wing surveys (or tail surveys)	Harvested bird species provide opportunities to estimate the numbers and species, age and sex composition of the harvest. Hunters participating in surveys submit one wing and/or the tail of bird that they shoot during the hunting season; programs run by governments in collaboration with experts identify the tissues to gather demographic and abundance data.	Examples: http://www.flyways.us/surveys-and-monitoring/hunter-surveys/parts-collection-surveys https://www.ec.gc.ca/reom-mbs/default.asp?lang=En&n=CFB6F561-1

10. Appendices

A. Appendix: Metadata and sampling coverage maps by biotic group

i. Introduction and description

Inventories of existing long-term monitoring programs related to terrestrial diversity were compiled to illustrate existing capacity to monitor Arctic terrestrial biodiversity as part of the CBMP-Terrestrial Plan. Monitoring programs were considered long-term if they were running for 10 years or longer or had the intention to run for longer than 10 years. The inventories were based on the best available knowledge and may not be exhaustive. The inventories will be integrated into the Polar Data Catalogue (**http://www.polardata.ca/whitesnow/**) and linked with the Arctic Biodiversity Data Service (**http://www.abds.is/**) and improved as more information becomes available. Metadata is provided on the biotic groups under study, the regions covered, and the general purpose of the monitoring programs.

ii. Maps, coverage and bioclimate subzones

Maps were created based on the geographic coordinates of long-term monitoring programs and infrastructure (e.g., research stations), or based on a representative centroid or point for programs spanning large regions, such as programs with multiple sites or programs covering a wide range. Maps were created to indicate monitoring capacity by biotic group (e.g., vegetation, birds, mammals, arthropods and others). The CAVM vegetation and bioclimatic subzones (CAVM Team 2003) have been included to illustrate the coverage and representativeness of monitoring efforts by subzone for the biotic groups (see Chapter 2).

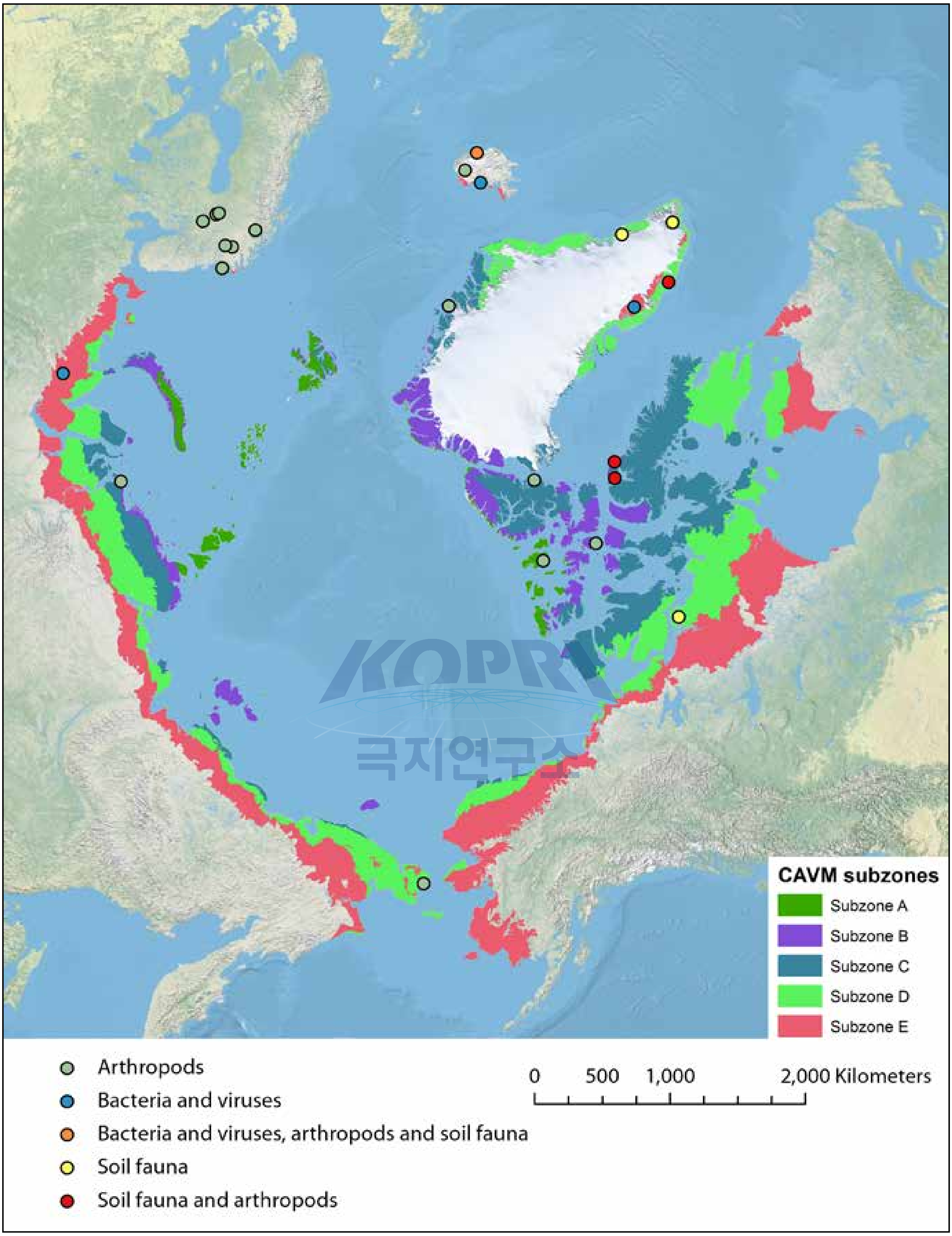

Figure A1 Location of long-term invertebrate and microbe monitoring sites and programs.

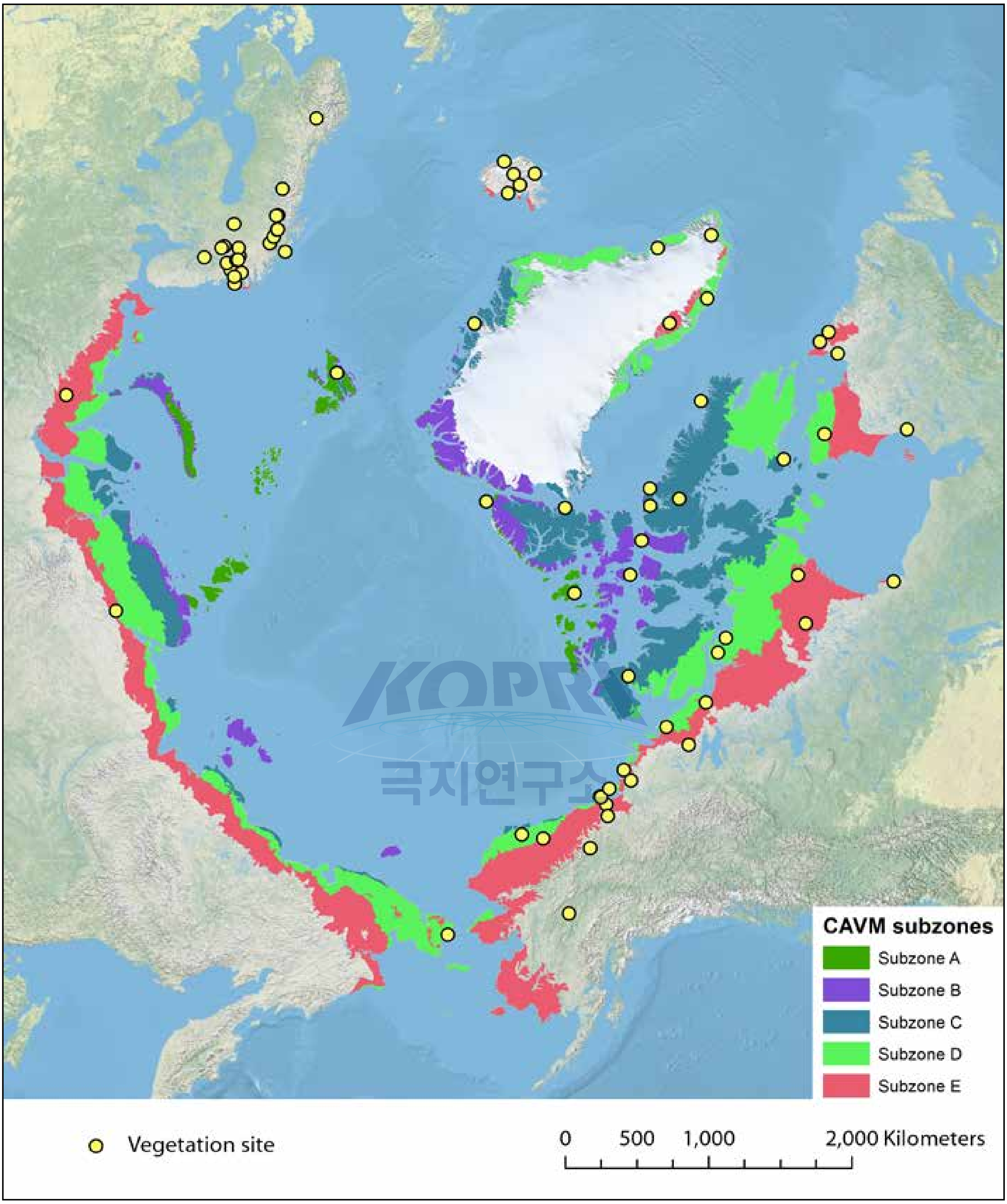

Figure A2 Location of long-term vegetation (including fungi, non-vascular and vascular plants) monitoring sites and programs.

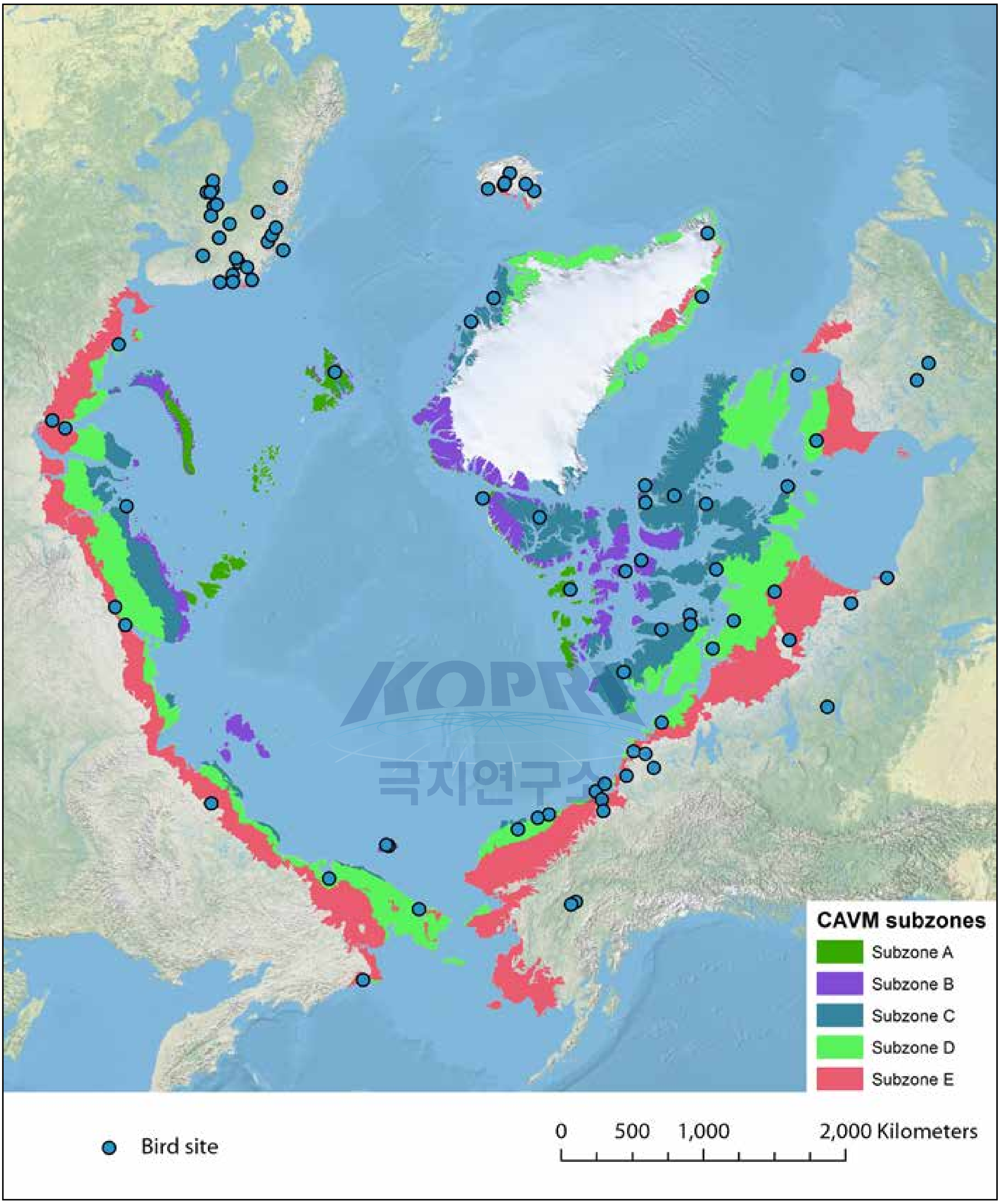

Figure A3 Location of long-term bird monitoring sites and programs.

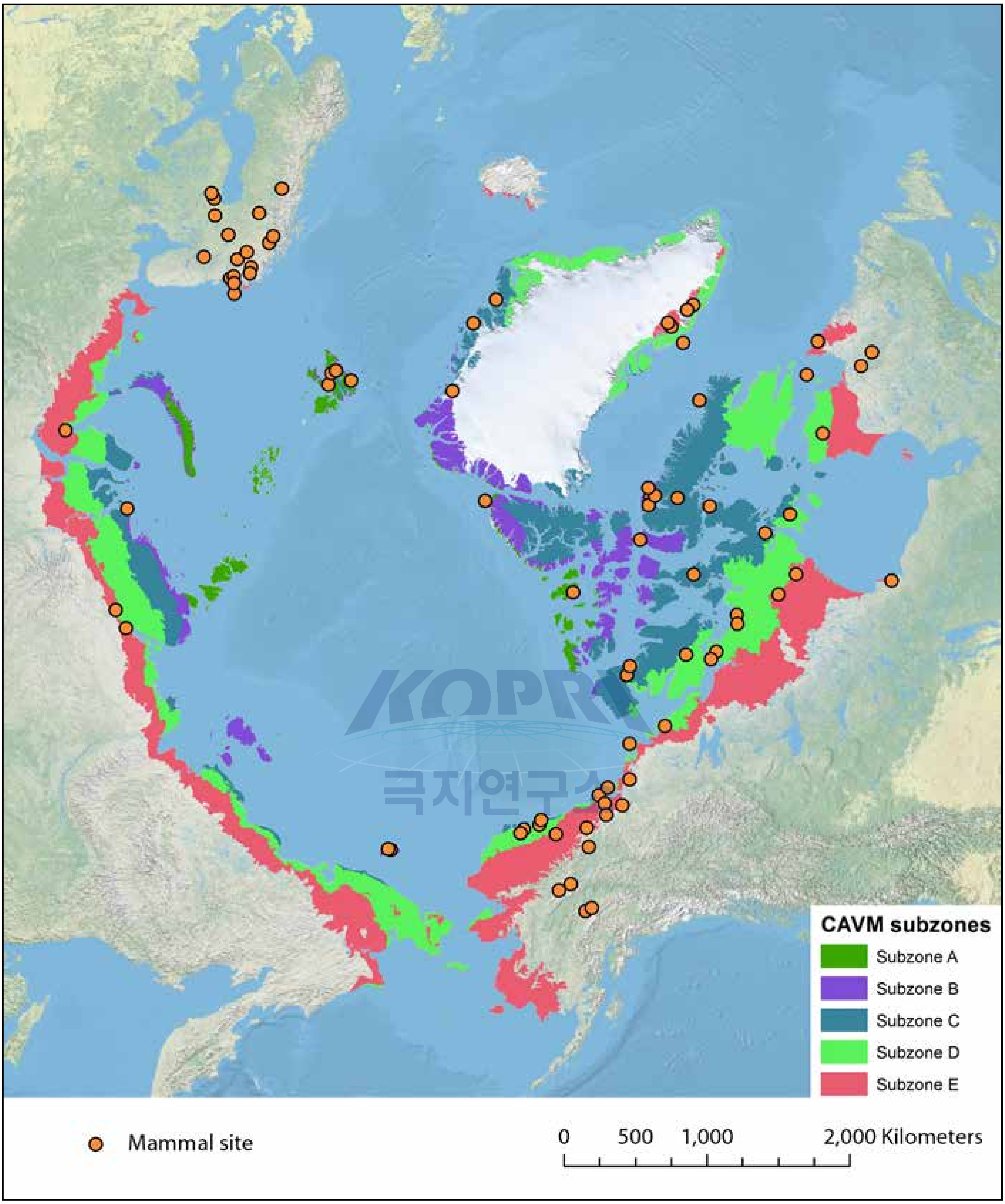

Figure A4 Location of long-term mammal monitoring sites and programs.

B. Appendix: What can be monitored with satellite data in the Arctic?

i. Remote sensing

Remote sensing is a tool that can support an integrated Arctic terrestrial biodiversity monitoring program. Remote sensing observations can provide information at a variety of scales (centimetres to kilometres). Synoptic satellite spatial and temporal information as presented in Table B1 can be generated. Presented on the table are both biotic and abiotic parameters, hence remote sensing provides useful information on both indicators and drivers. Remote sensing observations can also support modeling efforts, particularly those that are geospatially based. Ground based observation can be used to truth remote sensing data which can then be used to classify areas of the Arctic which are inaccessible. Fine spatial resolution remote sensing data combined with on-the-ground-sampling can also be combined to better interpret coarse resolution (1 kilometre) satellite data so that Arctic-wide classifications are possible. Combining the ground sampling with remote sensing observations provide insight into how to put detailed ground measurements into a regional context. Remote sensing technologies are also rapidly evolving; Lidar-generated topography and vegetation-height data are one example. Monitoring activities should take advantage of these emerging technologies when budgets can support such new technology-based projects.

Remote sensing supports the measurement of biodiversity parameters such as vegetation type, indices (NDVI, EVI, and others), phenology (start, end, duration of growing season-SOS, EOS, and DOS), and leaf area index (LAI), as well as providing important information on abiotic drivers such as temperature, cloud cover, snow cover, soil moisture, active layer, land cover, anthropogenic change, hydrology, fire burn areas, and freeze /thaw cycles (see Table B1). Remote-sensing-derived information on weather, climate, sea ice and the coastal marine environment are also useful driver information to support the terrestrial biodiversity monitoring activities that include models.

Table B2 presents a recommended series of satellite systems that can support long-term monitoring in the Arctic. Presented in the table by satellite system is the organization, sensor type, resolution on the ground, spatial and temporal coverage, data type, and derived products per system. These satellite systems were selected based on the following criteria: (1) polar orbit, (2) 10 year duration or longer, (3) electro-optical, and active/passive microwave, and (4) data available at little or no cost. Generation of the time series products identified in Tables B1 and B2 would be an invaluable set of observations to support the overall monitoring effort. Some of the derived satellite products identified in the table are partially completed; however, a comprehensive time-series of the entire pan-Arctic in a user friendly Arctic map projection does not exist. A number of time-series investigations using these satellite systems have been performed, but are incomplete from a time and space perspective. However, if available in a common database, these would be very valuable to terrestrial monitoring efforts.

A series of gaps in the satellite derived products (Table B2) have been identified. These include:

1) 1980 –present seasonally integrated NDVI using POES data,

2) Landsat derived pan-Arctic land cover for 1980, 1990, 2000, and 2010, with separate hydrology layers,

3) The suite of MODIS-derived products in polar user-friendly projection formats,

4) MODIS and AVHRR derived fire occurrence maps 2002-present,

5) Annual and inter-annual surface temperature maps 1980-present for the pan-Arctic, and

6) Annual maximum snow cover map for the Arctic 2003-present (from MODIS).

The gaps identified above should be rectified as an early step in the implementation of terrestrial monitoring activities. In addition to the six recommended time series generations based on the gap analysis, the synthetic aperture radar (SAR) ERS-1/2 should be utilized to classify shallow/deep (frozen/some liquid water at maximum freeze) for 1992, 2000, and 2010 to provide information on lake depth change and freeze/thaw history.

Before and after photography whether collected on the ground, air or from space can also be a very important tool to quantify change. The Back to the Future concept has documented significant changes in vegetative state over a few decades.

In addition to the satellite based synoptic pan-Arctic time series derived products identified above, remote sensing data of varying platforms (ground, air and space) spatial resolution and sensor types (electro-optic, infrared and microwave) will be used to support the recommended on-the-ground observations summarized in the vegetation sampling strategy tables presented in Chapter 4 (Table 4.3). The multiple roles of remote sensing in supporting the CBMP-Terrestrial Plan should be noted as they provide information at different scales and time periods on biotic and abiotic indicators and drivers.

Table B1 Ecosystem changes, components, and drivers that can be monitored using remote sensing at various spatial and temporal scales.

Climate	Ground and sea temperature Snow cover Sea ice extent Aerosols/emissions
Land	Digital Elevation Maps (DEM) Soil moisture Active layer/permafrost Vegetation type (land cover) Vegetation indices (NDVI, EVI, and many others) Vegetation phenology (start/end/duration of growing season [SOS, EOS, DOS]) Snow cover Albedo Fire/burned area Leaf Area Index (LAI)
Hydrology	Lake extent and relative depth Fluvial (gravel bars, channel locations)
Coastal erosion (time series)	Requires fine resolution data (1-2 m)
Freeze/thaw cycle	Lakes Active layer Ice break-up Snow cover
Anthropogenic	Oil and gas development (ice roads, pipelines, drill pads, etc.) Infrastructure/development
Ocean	Surface wind speeds Wave height Ocean current dynamic height method Wavelength and direction Ocean frontal boundaries Ocean temperature Color (chl, doc, sm) Oil spills and surfactants
Sea Ice	Sea ice concentration Sea ice dynamics Ice type (age) Detailed ice movement and rheology Leads Marginal ice zone (MIZ) Land fast ice Ice edge Ice free-board

Table B2 Satellite systems that have potential for supporting long-term monitoring over ranges of temporal and spatial scales. Some of the derived products here are partially completed, and efforts will be made to address gaps as described in the CBMP-Terrestrial Plan.

Satellite System	Organization	Sensor Type	Spatial Resolution	Spatial Coverage	Temporal Coverage	Data Type	Derived Products	Remarks
Polar Orbiting Platform (POES)	USA-NOAA	Visible and infrared (AVHRR)	1 km	All pan-Arctic daily	1978-present	Visible and infrared images	Surface Temp NDVI Clouds	1978-TIROS-N under re-calibration
ERS-1/2 Envisat Radarsat-1	European Space Agency Canadian Space Agency	SAR	25 m	100 km swaths all pan-Arctic over time	1991-present	Radar backscatter images	Frozen/non-frozen lakes Active layer Ice cover	Radarsat-2 can provide continuity but costly
DMSP	USA-DOD	AVHRR and passive microwave	1 km 25 km	All pan-Arctic daily	1960s-present	Visible and thermal imagery and microwave brightness temp	Sea ice type Sea ice cover Surface time Clouds Snow cover	Best source of long-term ice coverage 1979-present SMMR-SMMI
Landsat	USA-USGS	Visible and infrared	30-100 m	165 km frames all pan-Arctic over time	1973-present	Visible and infrared images	Land cover Hydrology Snow cover Ice cover	Landsat 7 has data gaps at scene edges, Landsat 5 current limited data collects over U.S. only
MODIS (Aqua and Terra)	USA-NASA	Visible and infrared	250 m-1 km	Entire earth every 1-2 days	2002-present	Visible and infrared images	Ocean ice, time, and productivity Enhanced Vegetation Index (EVI) Fire events Snow cover Surface temp. Cloud cover	Potential for generating a comprehensive suite of pan-Arctic observations

ii. Satellite imaging of pan-Arctic research stations

Table B3 and Figure B1 address the imaging requirements of satellites to map the suite of pan-Arctic research stations. Represented on the figure are the locations of the pan-Arctic research stations, the Arctic Circle, the CAFF boundary, and the different footprints (coverage) of Landsat, MODIS, and AVHRR for the region. The map of long-term pan-Arctic research stations and satellite swath widths (footprints) provides the information needed to determine approximately how many satellite scenes of a given sensor are needed to cover all of the stations. For example, Landsat provides data at a fine spatial resolution (~30 m) but at the cost of a small satellite footprint (185 km). Each AVHRR scene covers a large geographic area but the spatial resolution is coarse (~1 km). MODIS has irregular shaped satellite footprints at the poles due to the use of a sinusoidal projection, but several research stations are covered in one image scene in many areas. In terms of spatial resolution, MODIS data is provided at 250 m–1 km depending on the portion of the electromagnetic spectrum (i.e., satellite band) utilized.

Table B3 summarizes the satellite sensor, spatial resolution, footprint or swath width, temporal revisit time, and number of scenes necessary to image each station one time. For example to image each station once a year for 10 years with Landsat would require 330 images.

Table B3 Number of satellite scenes required to image the suite of Pan-Arctic research stations.

Satellite sensor	Spatial resolution	Footprint size	Temporal revisit	# of satellite scenes needed to cover all pan-Arctic research stations
Landsat	30 m	185 km	16 Days	~33
MODIS - Aqua and Terra	250 m– km	1,000 – 1,500 km	Daily	~16
AVHRR	1 km	2,500 km	Daily	~8

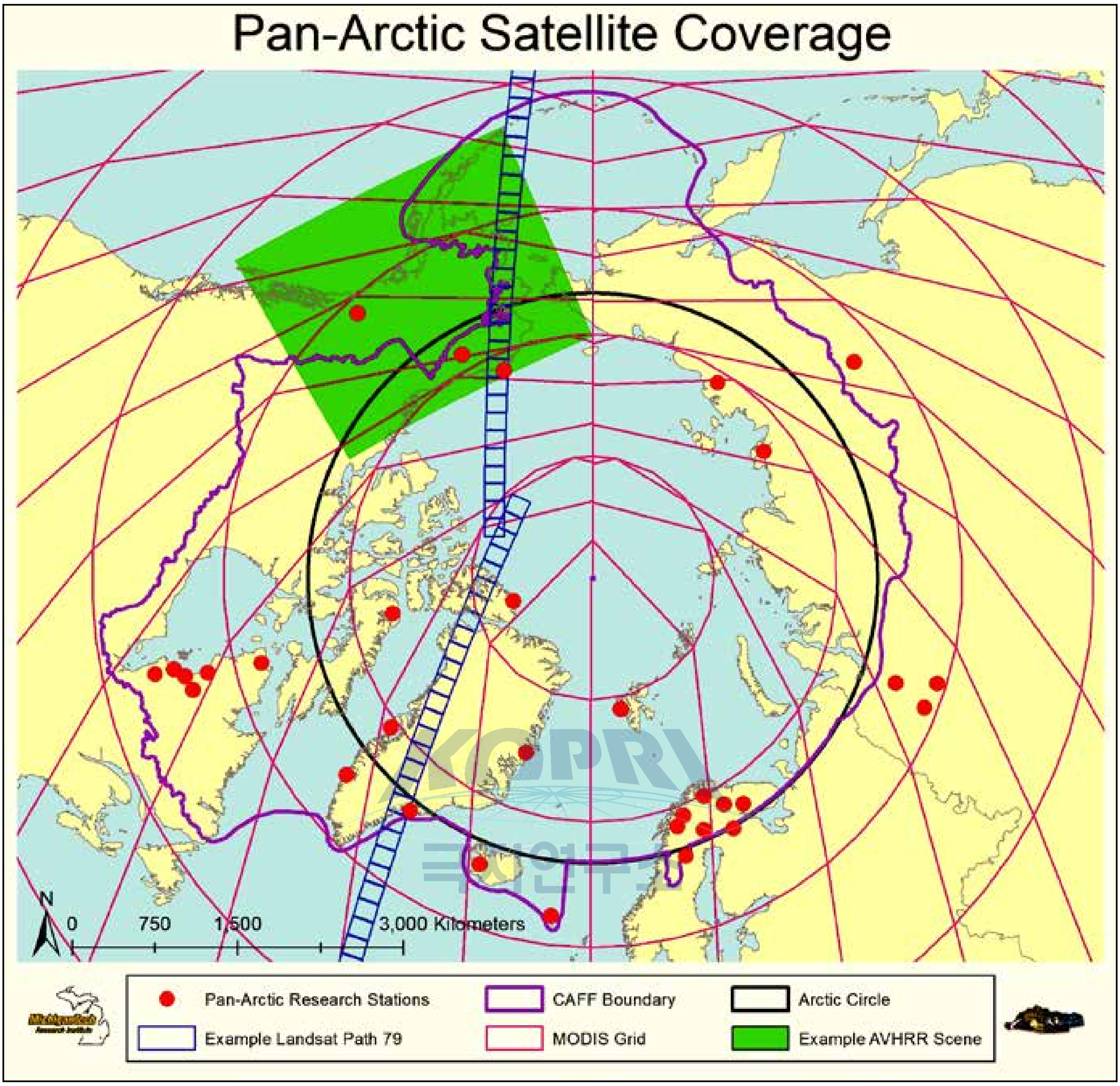

Figure B1 Pan-Arctic satellite coverage. Locations of pan-Arctic research stations (red dots), the Arctic Circle (black line), the CAFF boundary (purple line) along with the different footprints of Landsat (blue boxes), MODIS (red lines), and AVHRR (green box) for the region

C. Appendix: Workshop participants

i. Workshop 1 (October 11-13, 2011, Hvalsø, Denmark) - Designing the CBMP Terrestrial Plan

Anna Maria Fosaa	Faroese Museum of Natural History, Faroe Islands
Anne Brunk	Indigenous Peoples Secretariat, Denmark
Bård Øyvind Solberg	Norwegian Institute for Nature Research (NINA), Norway
Bob Shuchman	Michigan Tech Research Institute, USA
Bud Cribley	U.S. Bureau of Land Management, USA
Carl Markon	U.S. Geological Survey, USA
Cheryl Rosa	U.S. Arctic Research Commission, USA
Christian Bay	Aarhus University, Denmark
Christine Cuyler	Greenland Institute of Natural Resources
Dagmar Hagen	Norwegian Institute for Nature Research (NINA), Norway
Donald McLennan	Parks Canada
Donald Walker	University of Alaska, Fairbanks, USA
Elisa Pääkkö	Metshallitus Natural Heritage Services, Finland
Hans Gardfjell	Swedish University of Agricultural Sciences (SLU), Sweden
Hans Meltofte	Aarhus University, Denmark
Inge Thaulow	Ministry of Housing, Nature and the Environment, Government of Greenland
Jason J. Taylor	U.S. Bureau of Land Management, USA
Jesper Madsen	Aarhus University, Denmark
John Payne	North Slope Science Initiative, USA
Josephine Nymand	Greenland Institute of Natural Resources
Katarzyna Biala	European Environment Agency
Kristine Bakke	Westergaard Norwegian Institute for Nature Research (NINA), Norway
Lawrence Hislop	UNEP GRID Arendal
Mads Forchammer	Aarhus University, Denmark
Marlene Doyle	Science & Technology, Environment Canada
Michael Svoboda	CBMP Office, Environment Canada
Mikala Klint	Danish Environmental Protection Agency, Denmark
Mike Gill	CBMP Office, Environment Canada
Mikhail Soloviev	Moscow State University, Dept. of Vertebrate Zoology, Russia
Mora Aronsson	Swedish Species Information Centre (SLU), Sweden
Morten Skovgaard	Ministry of Energy and Climate, Denmark
Niels Martin Schmidt	Aarhus University, Denmark
Peter Aastrup	Aarhus University, Denmark
Rolf Anker Ims	University of Tromsø, Norway
Starri Heidmarsson	Icelandic Institute of Natural History, Iceland
Tatiana Minaeva	Wetlands International
Tom Barry	CAFF International Secretariat, Iceland
Tom Christensen	Aarhus University, Denmark
Tony Fox	Aarhus University, Denmark
Ulla-Maija Liukko	Finnish Environment Institute, Finland
Wenche Eide	Swedish Species Information Centre (SLU), Sweden

ii. Workshop 2 (May 15-17, 2012, Anchorage, Alaska, U.S.) - Designing an integrated Arctic terrestrial biodiversity monitoring plan

Elmer Topp-Jorgensen	Aarhus University, Denmark
Niels Martin Schmidt	Aarhus University, Denmark
Tom Christensen	Aarhus University, Denmark
Tony Fox	Aarhus University, Denmark
Maryann Smith	Aleut International Association
Don Russell	CircumArctic Rangifer Monitoring Network
Marlene Doyle	Science & Technology, Environment Canada
Michael Svoboda	CBMP Office, Environment Canada
Mike Gill	CBMP Office, Environment Canada
Katarzyna Biala	European Environment Agency
Christine Cuyler	Greenland Institute of Natural Resources
Josephine Nymand	Greenland Institute of Natural Resources
Starri Heiðmarsson	Icelandic Institute of Natural History
Carolina Behe	Inuit Circumpolar Council Alaska
Christopher Buddle	McGill University, Canada
Robert Shuchman	Michigan Tech Research Institute, USA
Mikhail Solovyev	Moscow State University, Russia
Robert Winfree	National Park Service, USA
Denny Lassuy	North Slope Science Initiative, USA
John Payne	North Slope Science Initiative, USA
Morten Wedege	Norwegian Directorate for Nature Management
Dagmar Hagen	Norwegian Institute for Nature Research
Kristine Bakke Westergaard	Norwegian Institute for Nature Research
Donald McLennan	Parks Canada Agency
Mora Aronsson	Swedish Species Information Centre
Jason J. Taylor	U.S. Department of the Interior - Bureau of Land Management
Cheryl Rosa	United States Arctic Research Commission (USARC)
Catherine Moncrieff	Yukon River Drainage Fisheries Association
Representatives	APECS (Association of Polar Early Career Scientists)

iii. Workshop 3 (September 10-12, 2012, Akureyri, Iceland) - Development and writing of the Arctic Terrestrial Biodiversity Monitoring Plan

Niels Martin Schmidt	Aarhus University, Denmark
Jesper Madsen	Aarhus University, Denmark
Tom Christensen	Aarhus University, Denmark
Paul Henning Krogh	Aarhus University, Denmark
Donald McLennan	Aboriginal Affairs and Northern Development Canada
Tom Barry	CAFF International Secretariat, Iceland
Michael Svoboda	CBMP Office, Environment Canada
Mike Gill	CBMP Office, Environment Canada
Hallur Gunnarsson	CAFF International Secretariat, Iceland
Marlene Doyle	Science and Technology, Environment Canada
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Christopher Buddle	McGill University, Canada
Elisa Pääkkö	Metshallitus Natural Heritage Services, Finland
Robert Shuchman	Michigan Tech Research Institute, USA
Mikhail Soloviev	Moscow State University, Dept. of Vertebrate Zoology, Russia
John Payne	North Slope Science Initiative, USA
Morten Wedege	Norwegian Directorate for Nature Management (NINA); Norway
Mora Aronsson	Swedish Species Information Centre/SLU, Sweden
Cheryl Rosa	U.S. Arctic Research Commission, USA
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