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Developing a circumpolar programme for the monitoring of Arctic terrestrial biodiversity

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Abstract The Arctic is undergoing biological and environmental changes, and a coordinated effort to monitor is critical to detect these changes. The Circumpolar Biodiversity Monitoring Programme (CBMP) of the Arctic Council biodiversity working group, Conservation of Arctic Flora and Fauna (CAFF), has developed pan-Arctic biodiversity monitoring plans that aims to improve the ability to detect and report on long-term changes. Whilst introducing this special issue, this paper also presents the making of the terrestrial monitoring plan and discusses how the plan follows the steps required for an adaptive and ecosystem-based monitoring programme. In this article, we discuss how data on key findings can be used to inform circumpolar and global assessments, including the *State of the Arctic Terrestrial Biodiversity Report*, which will be the first terrestrial assessment made by the CBMP. Key findings, advice for future monitoring and lessons learned will be used in planning next steps of pan-Arctic coordinated monitoring.

Keywords Adaptive monitoring · Arctic · CAFF · CBMP · State of the Arctic Biodiversity Report · Terrestrial biodiversity monitoring

INTRODUCTION

Arctic environments experience some of the harshest conditions for life including extreme cold, strong winds, drought, extended darkness, and short growing seasons. Arctic ecosystems harbour highly specialized organisms, including endemic taxa that have adapted to survive in these severe conditions, and migratory species that exploit rich Arctic resources during summer breeding periods. Despite the remoteness of Arctic regions, their ecosystems and species are under increasing pressure from threats within and outside of northern latitudes, including contaminants, over-exploitation of endemic and migratory species, anthropogenic disturbance, resource extraction and landscape alteration, habitat loss and fragmentation, shifting distributions of prey and pathogens, and climate change.

Climate change is by far the most serious threat to Arctic ecosystems and biodiversity (CAFF 2013). According to the Intergovernmental Panel on Climate Change (IPCC 2019), Arctic surface air temperature has increased at more than twice the global rate, doubling over the past two decades (Notz and Stroeve 2016; Richter-Menge et al. 2017; Overland et al. 2019), with a plethora of effects (Box et al. 2019). Climate change will result in physical, ecological, social, and economic impacts, and there is an urgent need to adapt to the expected changes (Pachauri and Reisinger 2007; IPCC 2014; AMAP 2017a, b, 2018, 2019).

Understanding the complex dynamics in the Arctic is confounded by a lack of long-term monitoring data to determine trends and develop adequate responses to the challenges facing biodiversity. Effective conservation and management of Arctic ecosystems requires comprehensive long-term information on the status of species, habitats, and ecological processes and functions, as well as potential drivers of change. Further, ecosystem-based monitoring approaches that capture the interactions of components at multiple scales are necessary to investigate complex compositional, functional, and structural changes (CAFF 2013).

The Arctic Council has recommended that adaptive long-term ecosystem and biodiversity monitoring efforts should be increased and focused to address key knowledge gaps in order to better inform development and implementation of conservation and management strategies for the Arctic (CAFF 2013; CAFF/AMAP/IASC 2004). In response, the Arctic Council working group Conservation of Arctic Flora and Fauna (CAFF) established the Circumpolar Biodiversity Monitoring Programme (CBMP) to address the need for an adaptive, coordinated, and standardized monitoring of Arctic environments for the marine, terrestrial, freshwater, and coastal ecosystems (Petersen et al. 2004; CAFF 2018). The CBMP is an international network, involving scientists, conservation organizations, government agencies, and experts. Overall guidance on direction of the CBMP is defined through strategic plans that are approved by the Arctic Council. The current strategic plan, *Circumpolar Biodiversity Monitoring Programme Strategic Plan 2018–2021* (CAFF 2018), includes tasks related to the adaptive monitoring approach, assessments of the status and trends of Arctic biodiversity, and how programme outputs can be communicated to support national, regional, and global needs (Barry and Christensen 2019). Information gathered by the CBMP is designed to assist policy and decision-making at global, national, regional, and local levels.

Between 2011 and 2019, four Arctic Biodiversity Monitoring Plans were developed, aiming to inform our ability to detect and understand changes in Arctic marine (Gill et al. 2011), freshwater (Culp et al. 2012), terrestrial (Christensen et al. 2013), and coastal ecosystems (Jones et al. 2019). Each plan has identified key elements for each ecosystem, designated as Focal Ecosystem Components (FECs), that are expected to indicate changes not only in the individual FEC, but in the ecosystem in general.

The present paper focuses on the creation of the CBMP Terrestrial Biodiversity Monitoring Plan (Christensen et al. 2013), describing the plan's development process and lessons learned. Further, it serves as a background paper for this special issue, *Terrestrial Biodiversity in a Rapidly Changing Arctic*, which presents the scientific basis for much of the CBMP *State of the Arctic Terrestrial Biodiversity Report,* which will be the first terrestrial circumpolar biodiversity assessment made by the CBMP. Prior to the State of the Arctic Terrestrial Biodiversity Report, CAFF has published the State of the Arctic Marine Biodiversity Report (CAFF 2017) and the State of The Arctic Freshwater Report (Lento et al. 2019).

DEVELOPMENTAL PROCESS FOR THE CBMP TERRESTRIAL BIODIVERSITY MONITORING PLAN

The CBMP Terrestrial Biodiversity Monitoring Plan (Christensen et al. 2013) was developed following a two-year collaborative process. The process was expert-driven by international participants with scientific and process expertise, traditional knowledge, and community-based knowledge. A Terrestrial Expert Monitoring Group (TEMG), composed of representatives from Arctic Council States and Arctic Council indigenous organization (Permanent Participants), led the initiative and served as primary contributors to development of the CBMP Terrestrial Biodiversity Monitoring Plan. Three consensus-based workshops (2011, Hvalsø, Denmark; 2012, Anchorage, Alaska, USA; and 2012, Akureyri, Iceland) were held. More than 70 participants, representing a cross section of experts with a range of skills, attended these workshops. The TEMG attended all workshops to provide consistency, integrate national needs and understanding of limitations, and ensure that perspectives from participants were considered in the development of the CBMP Terrestrial Biodiversity Monitoring Plan. A monitoring plan was developed based on best practices, the scope of the initiative, capacity of participants, and nature of expected outcomes. Key steps in the creation of the CBMP Terrestrial Biodiversity Monitoring Plan, the following reporting and adaptation of monitoring design based on key findings are described below. The steps includes scoping, identification of priority management questions, development of conceptual ecological models, identification of FECs, and their associated attributes and parameters, development of monitoring approach and design, collection of data, development of a reporting approach, adjustment of design, based on key findings, advise for future monitoring and lessons learned (Svoboda et al. 2012; Christensen et al. 2013; CAFF 2014, 2018).

Scoping defined the breadth of the analysis, identified key stakeholders to engage, and positioned the work within the broader ecological context (Green et al. 2005; Lindenmayer and Likens 2018). Scoping was closely linked to capacity assessment, defining management questions, and creating conceptual ecological models. Inputs from stakeholders and the CAFF Board were given to the TEMG.

An important component of the scoping process defined the audience of potential collaborators and users of products generated by implementation of the terrestrial plan. The plan aimed at responding to questions and information needs at the circumpolar scale. Given the geographic extent of the Arctic and the differences between the various regions that the plan covers, it is not feasible for a circumpolar biodiversity monitoring programme to fully represent all potentially important Arctic terrestrial ecosystems and ecosystem components. Therefore, it was decided by the TEMG that the plan should include a scaled approach applicable at regional or finer scales of resolution allowing for the detection of changes in Arctic biodiversity at multiple scales, fill knowledge gaps, and provide relevant information to decision-makers, researchers, and community members.

The geographic boundaries, species, and ecosystems to be included in the Terrestrial Biodiversity Monitoring Plan were selected to align with those outlined in the Arctic Biodiversity Assessment (CAFF 2013), covering High and Low Arctic regions consistent with the Circumpolar Arctic Vegetation Map's subzones A–E (CAVM Team 2003) and alpine sub-Arctic regions (Fig. 1). Terrestrial species that reproduce or have resident populations within the Arctic are considered within the Terrestrial Monitoring Plan and thus include birds, mammals, invertebrates, plants, and fungi. Though microbes play a crucial role in ecosystem processes, they are not comprehensively addressed due to limited monitoring capacity, costs, logistics, or feasibility. In keeping with an ecosystem-based approach to monitoring (Schmidt et al. 2017a), the Terrestrial Biodiversity Monitoring Plan is aimed at generating data that would allow for the assessment of the integrity, structure, and function and the impact of main drivers, along with tracking of specific biodiversity elements in the terrestrial Arctic ecosystem.

PRIORITY QUESTIONS TO ADDRESS MANAGEMENT NEEDS

To be relevant and efficient for decision-making, the development of the CBMP Terrestrial Biodiversity Monitoring Plan started with an understanding of the information required by the target audiences and a set of clear questions to be addressed by the monitoring programme (Green et al. 2005; Nichols and Williams 2006; Lindenmayer and Likens 2010, 2018; Ims et al. 2013; Christensen and Topp-Jørgensen 2016). Answering these questions should generate results to inform policy and management decisions (Fancy et al. 2009; Lindenmayer and Likens 2010). The three expert and stakeholder workshops (see

Fig. 1 Boundary (grey line) of the geographic area covered by the Arctic Biodiversity Assessment and the terrestrial CBMP, defined by the divisions between High Arctic, Low Arctic, and sub-Arctic according to the Circumpolar Arctic Vegetation Map (CAVM Team 2003). Map from Christensen et al. 2013 modified after Hohn and Jaakkola 2010

above) focused on identifying the type of information desired by communities, administrators, managers, and decision-makers. An outcome of these workshops was a comprehensive set of questions (Svoboda et al. 2012), which guided the development of the Terrestrial Biodiversity Monitoring Plan. The result was a small set of key questions for each biotic group and a list of broader, cross-cutting priority questions under which the biotic group questions are nested. The key questions to be addressed include: What are the status, trends, and distribution of terrestrial FECs?; What are the primary environmental and anthropogenic drivers?; How are these influencing changes in biodiversity and ecosystem function? (Christensen et al. 2013).

Based on the scoping process and the priority questions, an inventory of existing long-term monitoring programs related to terrestrial biodiversity was compiled by the TEMG, to illustrate existing capacity to monitor as part of the plan (Christensen et al. 2013)

CONCEPTUAL ECOLOGICAL MODELS

A conceptual model represents a working hypothesis about key relationships, functions, and organization of a system (Beever and Woodward 2011). Structured, conceptual ecological models based on science and other expert and stakeholder input are tools that can provide a "common language" to elucidate and communicate critical components, processes, functions and drivers of change within a system. Conceptual models can be used to guide the identification and selection of priority monitoring elements that meaningfully describe the status of many parts of the ecosystem and likely cause(s) of change with the least effort possible (Gross 2003; Green et al. 2005; Lindenmayer and Likens 2010; Ims et al. 2013; Taylor et al. 2014; Christensen and Topp-Jørgensen 2016; Lindenmayer and Likens 2018).

Through expert input, the CBMP created an overall conceptual model of the Arctic terrestrial system, characterizing key relationships between biotic groups and interactions with abiotic components (Fig. 2). Further, detailed conceptual models relevant to each taxonomic group (vegetation, arthropods, birds, and mammals) were developed and refined at workshops and follow-up meetings. Collectively, the conceptual models were used to identify key system elements, processes, and relationships, ultimately informing the selection of FECs. This approach served as a starting point for developing an integrated site-based monitoring design that allowed for local-scale adjustments prior to implementation.

IDENTIFICATION AND RANKING OF FECS AND THEIR ASSOCIATED ATTRIBUTES AND PARAMETERS

Given the complexity of ecosystems, even systems with relatively few species such as the Arctic may require the selection of monitoring target surrogates (Boutin et al. 2009). A process to identify and rank potential priority monitoring targets was critical, due to financial and logistical constraints. Even the most ambitious monitoring programme cannot monitor everything, everywhere, all of the time. This is especially true for remote Arctic locations, where access is logistically challenging and costly (Schmidt et al. 2017b). Based on the priority questions and conceptual models, a list of priority FECs and related attributes (Table 1), and parameters were identified. Four criteria were used to prioritize FEC attributes: (1) ecological significance as identified through the development of conceptual ecological models; (2) relevance to ecosystem services; (3) value to Arctic Indigenous and non-Indigenous Peoples; and (4) essential for management and legislation needs.

The identified priority FEC attributes are the targets of the monitoring effort, since they represent biodiversity entities that indicate critical functioning and resiliency of Arctic ecosystems and/or are vitally important to subsistence lifestyles and/or economies of Arctic communities. FEC attributes describe various aspects or characteristics of each component. For each attribute, desired/proposed sampling parameters (metrics), methods, monitoring frequency, and spatial scales were identified. The list of essential and recommended FEC attributes, their parameters, collection methods and frequency were refined following peer review.

While a set of priority FEC attributes was identified for each taxonomic group, a set of common, core attributes emerged across all groups and FECs (Table 1). The selected FEC attributes align with the Essential Biodiversity Variables (Pereira et al. 2012) and relevant Aichi Biodiversity indicator targets (Convention on Biological Diversity 2010; Christensen et al. 2013).

ADAPTIVE MONITORING APPROACH: DESIGN, REPORTING, AND ADJUSTMENTS

The CBMP strategic plan for 2018–2021 (CAFF 2018) describes how advice and key findings resulting from CBMP will be used, together with lessons learned related to the development and implementation steps of the CBMP Biodiversity Monitoring Plans. The adaptive approach includes the development conceptual models that are based on question settings. CBMP is the monitoring programme

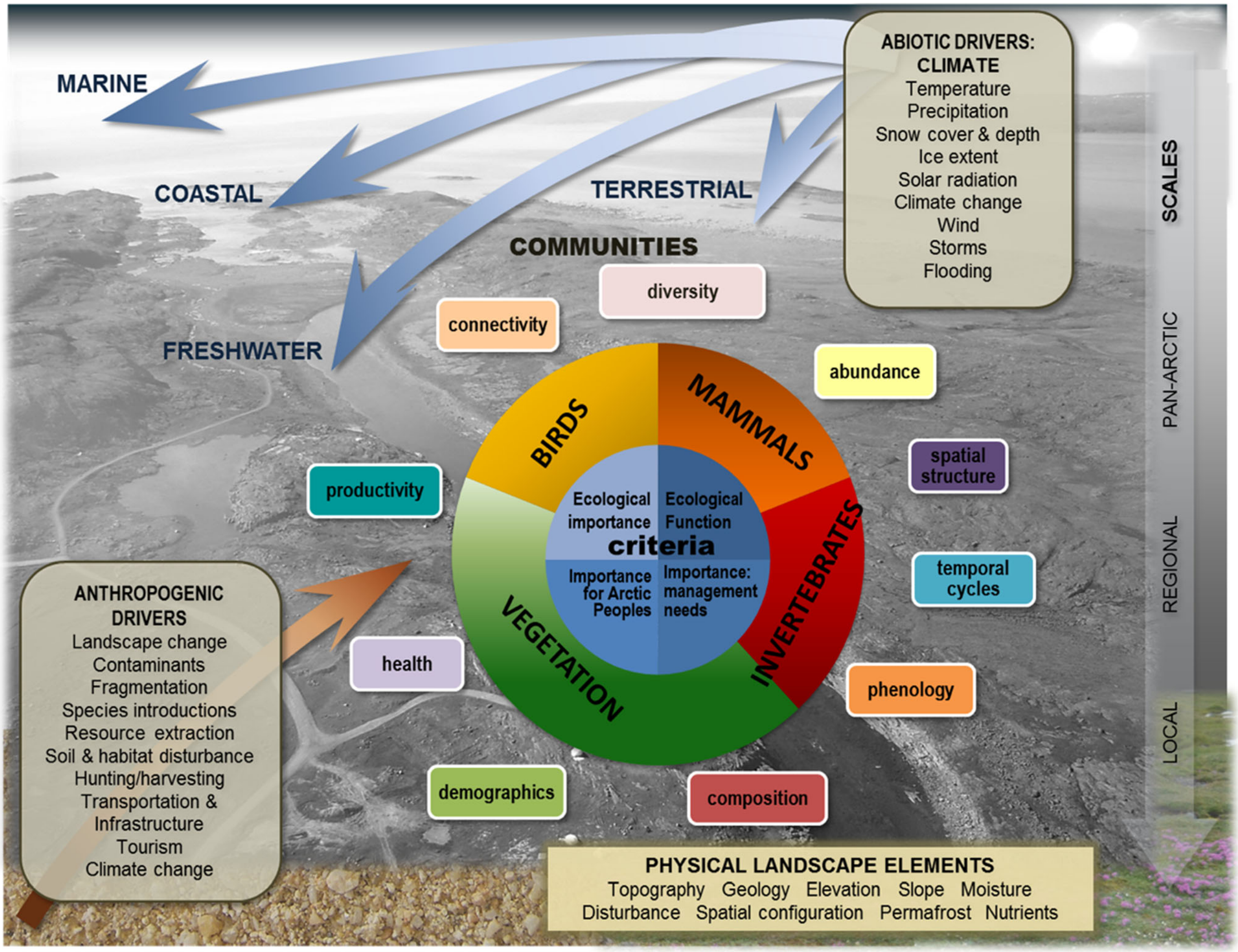

Fig. 2 High-level conceptual model of the Arctic terrestrial biome. The figure is showing key biotic and abiotic model elements of the ecosystem and their primary interactions. For each of the four ecological compartments (vegetation, birds, mammals, invertebrates), more detailed conceptual models have been developed. The figure also gives examples on suggested core attributes that can be monitored. This is explained more in Table 1 (Figure is from Christensen et al. 2013)

under the Arctic Council Working Group; *Conservation of Arctic Flora and Fauna* (CAFF). The question settings are therefore motivated by and include the needs that the Governments of the Arctic countries and the Arctic Indigenous Organizations may have. The next steps in the process include the development of the CBMP monitoring plan, data collection, data analysis, data interpretation and reporting and communication. The different steps are linked as an iterative process. The adaptive steps are following the reporting. This allows the programme to evolve in response to the key findings, advise for future monitoring, lessons learned and not least new questions. All together this provides a valuable adaptive approach platform (Fig. 3) for the development of future collaborative, cross-jurisdictional monitoring programs across broad geographic scales, especially where capacity to support the programme is limited.

STANDARDIZATION OF MONITORING EFFORTS AND DATA GATHERING

The Terrestrial Biodiversity Monitoring Plan is designed to take advantage of existing resources, monitoring capacity and data; however, where opportunities for new monitoring activities exist, the plan provides suggested priority monitoring elements and methodologies (Berteaux et al. 2017). Hence, when aggregating information from past or current monitoring initiatives the Terrestrial Biodiversity Monitoring Plan relies on the process of harmonization, i.e. extracting comparable information across different methodologies, of which the various papers in this special issue are good examples. The process of harmonization may encompass different methods, either through direct integration, combining derivative products, or through meta-analyses and modelling. The CBMP “core” function

Table 1 Core attributes and examples of associated parameters for monitoring in Arctic terrestrial ecosystems (birds, invertebrates, mammals, and vegetation) monitoring that emerged as common across all biotic groups and FECs Modified from Christensen et al. (2013)

Attributes	Examples of parameters for monitoring as appropriate for biotic group
Diversity	Taxonomy, species and spatial distribution (α, β, γ-diversity), genetic diversity and heterozygosity, community composition, rare and non-native species, etc.
Abundance	Number, density, per cent cover, population size
Composition	Community structure, morphology, ecological traits
Phenology	Timing of 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
Health	Parasite loads, pathogens, mass and size, body condition, contaminants
Productivity	Biomass, NDVI, reproductive output, nutrient content
Ecosystem functions and processes	Nutrient cycling, decomposition, pollination

of targeted monitoring and reporting on selected FECs support a myriad of other functions and networks required for ecosystem-based monitoring, and broader national and international reporting needs. This includes detailed core attribute monitoring at the site/plot scale as well as the development of a harmonized database to be used by relevant and targeted reporting on both national and international scales. Importantly, the Terrestrial Biodiversity Monitoring Plan provides suggestions for standardized methods to facilitate future comparisons.

Data generated through the implementation of the Terrestrial Biodiversity Monitoring Plan will be available on the Arctic Biodiversity Data Service (ABDS) (www.abds.is). The ABDS is an online, interoperable data management system for biodiversity data generated through CAFF. The goal of the ABDS is to facilitate access, integration, analysis and display of biodiversity information for scientists, practitioners, managers, policy makers and others working to understand, conserve and manage the Arctic's wildlife and ecosystems. The vision of ABDS is to ensure that biodiversity data provided to CAFF are organized to guarantee a lasting legacy in a manner that facilitates data access and analysis, increases understanding, and thus ultimately promotes well-informed and rapid decision-making. Partnerships have been established with other international platforms, including the Arctic Spatial Data Infrastructure (Arctic SDI), Group on Earth Observations Biodiversity Observation Network (GEOBON), the International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT) and the Global Biodiversity Information Facility (GBIF) (CAFF 2018). As an Arctic node within GBIF, any data added to the ABDS are automatically harvested and accessible via GBIF. It is furthermore anticipated that the information generated by the Terrestrial Biodiversity Monitoring Plan will be used to inform sub-global and global assessments (e.g. CBD Global Biodiversity Outlooks (SCBD 2010, 2014) and global IPBES assessments (2019), and to bring monitoring data collected at the local scale into international reporting.

IMPORTANT LESSONS LEARNED

Be inclusive and relevant

Clearly defining the target audience for a monitoring programme is an essential first step. Designing a monitoring programme based on the needs of communities and decision-makers with clear monitoring questions will ensure that monitoring results are relevant to the intended audience(s). It is important to engage in early and sustained dialogue with groups, communities, and managers in the development process to identify key issues of concern and information needs. Aligning proposed monitoring, analysis, and reporting structures with the mandates of governments and other stakeholders can demonstrate relevance and encourage participation in implementation and support. A concerted effort may be required to engage with stakeholders with limited capacity to participate in initiatives such as an international monitoring programme development. Engagement requires time and financial support, so it is necessary to plan timelines and budgets accordingly.

Be creative and flexible

In addition to long-term ecosystem-based monitoring data, it will be vital to locate and assess complementary data from a number of sources and methods such as national monitoring inventories, traditional knowledge, local knowledge, academic research, collections and archives (e.g. museum specimens, records, artefacts), remote sensing, and aerial photographs. Identifying as many sources of data as possible early in programme development is critical because the scope or location of these data may determine where it will be most suitable, or even feasible, to develop

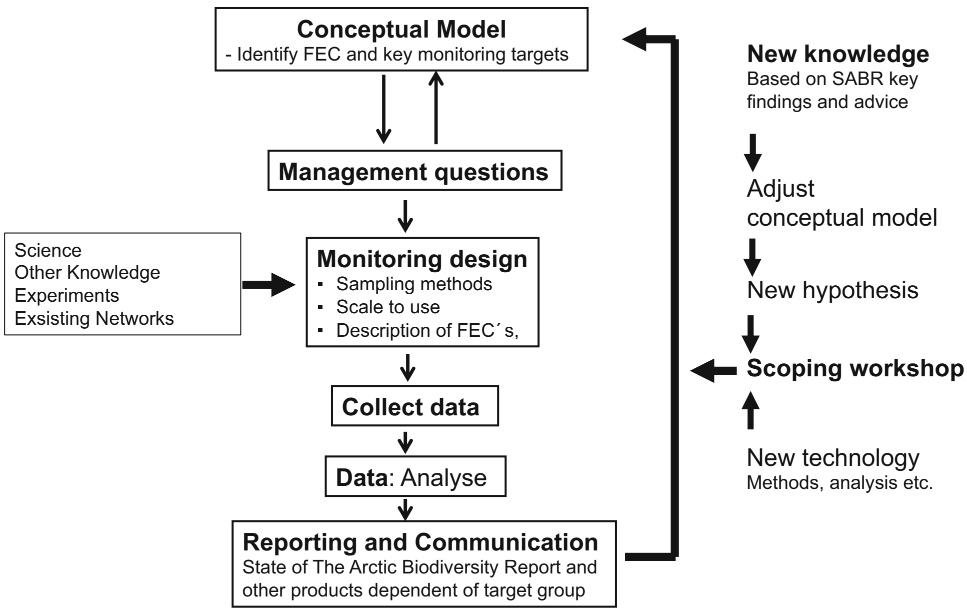

Fig. 3 The CBMP adaptive long-term monitoring approach. The adaptive approach is inspired by Lindemayer and Likens (2018) and is described further in the CBMP Strategic Plan CAFF (2018)

status and trend assessments or to decide where to deploy future monitoring efforts.

Be adaptable when developing a monitoring programme at an international scale

When developing a monitoring programme, at an international scale, across regions where monitoring has occurred in the past or is ongoing, harmonization (combining data collected with different methods) rather than standardization (requiring the use of identical methods) of monitoring effort will greatly increase geographic and temporal coverage of typically limited and sporadic data. Further, potential participants are often more willing to engage when they are not facing demands to change their own monitoring initiatives. Harmonization allows for flexibility in the integration of existing monitoring and to be completed successfully across disparate programs, may require generation of derivative products for analyses.

Plan and budget for data management and analysis

Data management is challenging for any monitoring programme, and this is specifically true of a programme relying on contributions from many partners. Clearly defining a data management strategy and ensuring there are adequate resources for data management are key to the success of a programme. It is equally important to address issues of intellectual property and publication rights related to data access, sharing, and publication. Data management and ensuring open data access will secure transparency of data sources and subsequently enhance the rigour of analyses undertaken. It will also enable others to reuse data for other purposes, thereby multiplying the impact of the monitoring effort. Finally, a well-supported data management system will ensure data are properly archived for future assessments.

Prepare communication products to feed into relevant local, regional, and international fora

Effectively communicating monitoring results to decision-makers and stakeholders is a priority outcome of the CBMP, and essential to relevance, as described above. Therefore, it is critical to have a well-articulated and financially supported strategy for reaching core audiences with monitoring results in a format that meets their needs. This may require multiple reporting products including, for example, online data and trend information, summarized reports (potentially multi-language), presentations, and peer-reviewed journal articles.

Start small and build on success

Monitoring biodiversity across the entire Arctic is a monumental task. While working towards the comprehensive set of objectives described, it has been necessary to set priorities for small and early successes within the broad framework for monitoring as outlined in the CBMP Terrestrial Biodiversity Monitoring Plan. To this end, CBMP has developed a suite of headline indicators (Gill and Zöckler 2008), which have helped keep CBMP visible while developing monitoring plans and the first State of the Arctic reports. These indicators are aligned with global biodiversity goals and targets and also allow CBMP to feed into those processes. Examples include the Arctic Protected Areas Indicator (Barry et al. 2017), which catalogues the extent of protected areas across the Arctic and the trends regarding protected area establishment. It helps track progress towards meeting the objectives of CAFF and supporting Aichi Biodiversity Targets and relevant targets within the Sustainable Development Goals (UNEP WCMC and IUCN 2016).

CONCLUDING REMARKS

This special issue represents a major milestone in providing key scientific input to a comprehensive assessment of status and trends for Arctic terrestrial biodiversity and existing monitoring efforts. The contents of this special issue will be consolidated and presented in the State of The Arctic Terrestrial Biodiversity Report by the CAFF Arctic Council Working Group.

The CBMP under CAFF has led the process in the development of this special issue. The process drew from best practices in monitoring design including new approaches building upon the capacities and strengths of existing monitoring networks while acknowledging the restraints imposed by limited resources for implementation. The process has yielded important lessons learned, which combined with the key findings and advice for future monitoring can help improve, target, and adapt future monitoring and assessment efforts

Finally, this special issue is an example of how data from different sources can be used to create a platform for future circumpolar assessments of Arctic terrestrial biodiversity.

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