STATE OF THE ARCTIC TERRESTRIAL BIODIVERSITY REPORT

MAY 2021

ARCTIC COUNCIL

CAFF
Conservation of Arctic Flora and Fauna

CIRCUMPOLAR BIODIVERSITY MONITORING PROGRAM

Acknowledgements

CAFF Designated Agencies:

- Environment and Climate Change Canada
- Faroese Museum of Natural History
- Finnish Ministry of the Environment
- Ministry for Agriculture, Self Sufficiency, Energy and Environment, Government of Greenland
- Icelandic Institute of Natural History
- Norwegian Environment Agency
- Ministry of Natural Resources and Environment of the Russian Federation
- Swedish Environmental Protection Agency
- United States Department of the Interior, Fish and Wildlife Service

CAFF Permanent Participant Organizations:

- Aleut International Association (AIA)
- Arctic Athabaskan Council (AAC)
- Gwich'in Council International (GCI)
- Inuit Circumpolar Council (ICC)
- Russian Association of Indigenous Peoples of the North (RAIPON)
- Saami Council

This report should be cited as: Aronsson, M., S. Heiðmarsson, H. Jóhannesdóttir, T. Barry, J. Braa, C.T. Burns, S.J. Coulson, C. Cuyler, K. Falk, H. Helgason, K.F. Lárusson, J.P. Lawler, P. Kulmala, D. MacNearney, E. Oberndorfer, V. Ravolainen, N.M. Schmidt, M. Soloviev, C. Coon and T. Christensen. 2021. State of the Arctic Terrestrial Biodiversity Report. Conservation of Arctic Flora and Fauna International Secretariat, Akureyri, Iceland. ISBN 978-9935-431-94-3.

Editing: Mora Aronsson, Tom Barry, Starri Heiðmarsson and Hrefna Jóhannesdóttir.

Authors and contributors of subchapters 3.1-3.5:

3.1: Lead authors: Virve Ravolainen, Anne D. Bjorkman. Contributing authors: Donald Walker, Howard Epstein, Gabriela Schaepman-Strub

3.2: Authors: Stephen J. Coulson, Mark A.K. Gillespie, Toke T. Høye.

3.3: Lead authors: Knud Falk, Paul A. Smith, Casey T. Burns. Contributing authors: Anthony D. Fox, Alastair Franke, Eva Fuglei, Karl O. Jacobsen, Richard B. Lanctot, James O. Leafloor, Laura McKinnon, Hans Meltofte, Adam C. Smith, Mikhail Soloviev, Aleksandr A. Sokolov

3.4: Lead authors: James Lawler, Christine Cuyler, Douglas MacNearney. Contributing authors: Dominique Berteaux, Dorothee Ehrich, Anne Gunn, Jan Rowell, Don Russel, Niels Martin Schmidt

3.5: Lead author: Mora Aronsson. Contributing authors: Bruce Bennett, Casey T. Burns, Starri Heiðmarsson and Mikhail Soloviev.

3.6: Authors: Tom Barry, Liza K. Jenkins

This report is primarily based upon data presented in Schmidt N.M. and H. Jóhannesdóttir (eds.) 2021. Terrestrial biodiversity in a rapidly changing Arctic. Ambio, 49(3)

Contributors to Ambio special issue: Jan Adamczewski, Matthias Alfredsson, Ray Alisauskas, Skip Ambrose, David L. Anderson, Morgan Anderson, Anders Angerbjörn, Mora Aronsson, Isabel C. Barrio, Tom Barry, Christian Bay, Bruce Bennett, Peter J. Bente, Dominique Berteaux, Anne D. Bjorkman, John Blake, Travis Booms, Karl R. Bosse, Joe Bowden, Joseph J. Bowden, Jørund Braa, Tord Bretten, Vincent Brodeur, Kurt K. Burnham, Casey T. Burns, Chris T. Callahan, Mitch Campbell, Matthew Carlson, Sylvia L. Checkley, Tom Christensen, Karin Clark, H. Dean Cluff, Steve D. Côté, Peter Convey, Catherine Coon, Stephen J. Coulson, Mariana García Criado, Lauren E. Culler, William S. Currie, Christine Cuyler, Martin T. Dahl, Kathryn M. Daly, Tracy Davison, Marlene Doyle, Mathieu Dumond, Frauke Ecke, Dorothee Ehrich, Nina E. Eide, Isabell Eischeid, Johan Ekenstedt, Knud Falk, Mads Forchhammer, Barrie Ford, Anthony D. Fox, Erik Framstad, Jay Frandsen, Alastair Franke, Ivan Fufachev, Eva Fuglei, Sergey Ganusevich, Hans Gardfjell, Gilles Gauthier, Olivier Gilg, Lynn J. Gillespie, Mark A.K. Gillespie, Marie-Andrée Giroux, Mikhail Golovatin, Alexander Gruzdev, Anne Gunn, Jannik Hansen, Kevin Hawkshaw, Starri Heiðmarsson, John-André Henden, Heikki Henttonen, Birger Hörnfeldt, Toke T. Høye, Stefanie Ickert-Bond, Rolf A. Ims, Arkady P. Isaev, Liza K. Jenkins, Kenneth Johansen, Jeff A. Johnson, Patrick Jones, Ingibjörg Svala Jónsdóttir, Gennadiy D. Kataev, Sergey P. Kharitonov, Sergey Kharitonov, Siw T. Killengreen, Amanda M. Koltz, Seppo Koponen, Pertti Koskimies, Charles J. Krebs, Paul Henning Krogh, Olga Kulikova, Pauliina Kulmala, Susan Kutz, Richard B. Lanctot, Johannes Lang, James P. Lawler, James O. Leafloor, Lisa-Marie Leclerc, Nicolas Lecomte, Peter Lindberg, Berth-Ove Lindström, Sarah Loboda, Sara Longan, Douglas MacNearney, Conor Mallory, Kathy Martin, Yuri Marusik, William G. Mattox, Fabien Mavrot, Carol L. McIntyre, Laura McKinnon, Svetlana Mechnikova, Hans Meltofte, Irina E. Menyushina, Richard A. Merizon, Oleg Y. Mineev, Yuri N. Mineev, Douglas W. Morris, Guy Morrisson, Jesper Bruun Mosbacher, Dave Mossop, Isla H. Myers-Smith, Søren Møller, Ólafur K. Nielsen, Erlend B. Nilsen, Signe Normand, Innokentiy Mikhailovich Okhlopkov, Lauri Oksanen, Tarja Oksanen, Tuomo Ollila, Johan Olofsson, Åshild Ø. Pedersen, Ivan G. Pokrovsky, Kim Poole, Igor Yu. Popov, Virve Ravolainen, Donald Reid, Marco Restani, Patricia Reynolds, Bryce W. Robinson, Robert Rosenfield, James D. Roth, Janice Rowell, Don Russell, Sarah T. Saalfeld, Jeffery M. Saarela, Gustaf Samelius, Jonas P. Sandström, Niels Martin Schmidt, Steven S. Seefeldt, Alexander N. Sennikov, Robert A. Shuchman, Derek S. Sikes, Taras Sipko, Benoit Sittler, Sergey M. Sleptsov, Jozef Slowik, Adam C. Smith, Paul A. Smith, Eeva M. Soininen, Aleksandr A. Sokolov, Vasiliy Sokolov, Natalya A. Sokolova, Mikhail Soloviev, Diana V. Solovyeva, Katie Spellman, Laerke Stewart, Mike Suitor, Ted Swem, Danielle Tanzer, Jason J. Taylor, Matilde Tomaselli, Henry Väre, Katrin Vorkamp, René van der Wal, Pawel Wasowicz, Kristine Bakke Westergaard, Maria Hørnell Willebrand, Bjørnar Ytrehus and Arve Østlyngen.

CBMP Terrestrial Steering Group: Mora Aronsson (co-chair), Starri Heiðmarsson (co-chair), Hrefna Jóhannesdóttir (coordinator), Jørund Braa, Casey T. Burns, Stephen Coulson, Christine Cuyler, Knud Falk, James P. Lawler, Pauliina Kulmala, Douglas MacNearney, Erica Oberndorfer, Virve Ravolainen, Niels Martin Schmidt, Mikhail Soloviev, Tom Christensen and Kári Fannar Lárusson.

CBMP Leads: Tom Christensen and Catherine Coon.

CAFF secretariat: Tom Barry, Courtney Price, Kári Fannar Lárusson, Hólmgrímur Helgason and Olga Pálsdóttir.

Layout: María Rut Dýrfjörð

Graphics: Kári Fannar Lárusson, Hólmgrímur Helgason and Courtney Price

Funding and support: CAFF would like to acknowledge funding provided by the Nordic Council of Ministers, Swedish Environmental Protection Agency, Environment and Climate Change Canada, Finnish Ministry of the Environment and the Icelandic Institute of Natural History.

This document is licensed under the Creative Commons Attribution-NonCommercial 4.0 International License. To view a copy of the license, visit http://creativecommons.org/licenses/by-nc/4.0

Cover photograph: Einar Guðmann, Photographingiceland.is

— CAFF Designated Area

For more information please contact:
CAFF International Secretariat
Borgir Norðurslóð
600 Akureyri
Iceland
www.caff.is

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

EXECUTIVE SUMMARY

The State of the Arctic Terrestrial Biodiversity Report (START) is a product of the Circumpolar Biodiversity Monitoring Program (CBMP) Terrestrial Group of the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) Working Group. The START assesses the status and trends of terrestrial Focal Ecosystem Components (FECs)—including vegetation, arthropods, birds, and mammals—across the Arctic, identify gaps in monitoring coverage towards implementation of the CBMP's Arctic Terrestrial Biodiversity Monitoring Plan; and provides key findings and advice for monitoring. The START is based upon primarily published data, from a special issue of Ambio containing 13 articles by more than 180 scientists.

Climate change is the single most important driver influencing Arctic biodiversity. Other drivers are listed and classified as biotic, abiotic, or anthropogenic and their effects considered where applicable. Key findings include an increase in vegetation productivity documented by remote sensing, although plot-based studies give mixed results. An increase of alien plant species is evident and there are also indications of increasing phenological mismatch between pollinators and flowering plants. Most bird species have at least one population that is increasing or stable although there are declines in the populations of one fifth of all species considered. Mammal species show various trends with the exception of Rangifers (Reindeer/Caribou) whose populations are mostly declining. There are knowledge gaps amongst all organism groups although they are most obvious for microscopic species belonging to soil biota and Arthropods.

Biodiversity monitoring at a circumpolar scale requires extensive coordination and cooperation among the Arctic states. Data collection needs to utilize all possible sources including remote sensing, Indigenous Knowledge, local knowledge, citizen science and long-term monitoring. A harmonized, accessible, and long-term taxonomic backbone for all known Arctic taxa is essential.

The START lists actions that should be taken to ensure more coordinated and responsive monitoring of biodiversity in the Arctic. Independent of the taxonomic group, securing long-term monitoring is of the utmost significance. START is an important accomplishment in helping improve monitoring of the Arctic's terrestrial biodiversity and achieving a more holistic monitoring strategy on a circumpolar scale where interactions among different drivers as well as other habitats, i.e., marine, coastal, and freshwater, are included. It is an important step towards better knowledge and understanding of the status and threats facing biodiversity in the Arctic and is an important baseline to guide future work.

Chukotka, Russian Federation. Photo: Vladimir Yakovlev

1 INTRODUCTION

Tundra in Nenets Autonomous Okrug, Russia
Photo: Nick Pecker/Shutterstock.com

The *State of the Arctic Terrestrial Biodiversity Report* (START) describes status and trends on key biotic elements in the terrestrial Arctic. It is the first report based on *Arctic Terrestrial Biodiversity Monitoring Plan* (Christensen et al. 2013) and provides an important milestone towards its implementation. CBMP (Circumpolar Biodiversity Monitoring Program) is the core programme of the Conservation of Arctic Flora and Fauna Working Group (CAFF) of the Arctic Council.

Building on the baseline established in the *Arctic Biodiversity Assessment* (CAFF 2013a), the START presents a summary of the status and trends of key biotic elements—referred to as Focal Ecosystem Components (FECs)[1]—to detect and understand changes in circumpolar terrestrial biodiversity. Through data integration and analysis of available datasets, it presents a synthesis of the state of knowledge, detectable changes, and important knowledge gaps for assessing status and trends. Changes in the status of FECs is expected to be indicative of changes in the broader terrestrial environment.

Where data is available, the START:

- describes current and/or historical status of FECs;
- evaluates trends;
- considers how changes in biodiversity may be linked to potential stressors;
- describes the state of Arctic biodiversity monitoring;
- identifies research priorities and knowledge gaps; and
- provides advice for future terrestrial biodiversity monitoring efforts.

The START also gives an opportunity to evaluate some of the originally chosen FECs to determine gaps in monitoring effort and if the monitoring is sufficient or realistic for various FECs. This can be used to refine and adapt future monitoring allowing the programme to evolve in response to the key findings, advise for future monitoring, lessons learned and not least new questions.

This report represents the first step in ongoing efforts to advance circumpolar terrestrial biodiversity monitoring and to understand the impact of changes on Arctic terrestrial ecosystems. It builds on the Arctic Terrestrial Monitoring Plan (Christensen et al. 2013) and an associated process of data compilation, analysis, and scientific publication lead by the Terrestrial Group of the Circumpolar Biodiversity Monitoring Programme (CBMP), that has been published in a special Issue of the AMBIO Journal (Schmidt & Johannesdottir 2020). The first two chapters in this report provide some context on terrestrial biodiversity monitoring in the Arctic and outline the drivers of change. Chapter 3 presents a summary of status and trends, with a focus on the FECs within the groups—vegetation, arthropods, birds, and mammals—and their key attributes, and then brings the FECs together to discuss the state of the terrestrial ecosystem as a whole, links to drivers, and presents overall integrated key findings. Chapter 4 describes the state of terrestrial biodiversity monitoring across the Arctic, identifies gaps and provides advice for monitoring.

1.1 ARCTIC TERRESTRIAL BIODIVERSITY MONITORING PLAN

The CBMP–Terrestrial Plan, one of four ecosystem-based plans of the Circumpolar Biodiversity Monitoring Program (CBMP) (see Box 1-1), is an agreement by Arctic states to compile, harmonise and compare results from Arctic terrestrial biodiversity and circumpolar ecosystem monitoring efforts. It capitalises on existing resources, monitoring capacity and data, and, where opportunities for new monitoring exist, recommends priority monitoring elements and methodologies (Berteaux et al. 2017; Christensen et al. 2020).

Preparation of the CBMP–Terrestrial Plan involved: (a) defining the scope and priority management questions; (b) developing conceptual ecological models; (c) identifying FECs and associated attributes and parameters; (d) developing and designing a monitoring approach; (e) collecting data; (f) developing a reporting approach; (g) modifying the design as a result of key findings; and (h) providing advice for future monitoring and describing lessons learned as illustrated in Fig. 1.1(Christensen et al. 2013, 2020, CAFF 2017). The approach considers the integrity of ecosystems and their interactions, focusing on FECs (see Section 1.1 and Table 2-1). Based on the findings of the START, revisions to some FECS are recommended.

When aggregating information from various monitoring initiatives and across a vast geographic range, the CBMP–Terrestrial Plan relies on the process of harmonisation that extracts comparable information from across different methodologies. This includes direct integration, combining derivative products or meta-analyses and modelling. The CBMP core function of targeted monitoring and reporting on selected FECs, supports numerous functions and networks required for ecosystem-based monitoring, and broader national and international reporting needs. This includes detailed core attribute monitoring at the site or plot scale, as well as the development of a harmonised database for use by national and international reporting. Importantly, the CBMP–Terrestrial Plan provides recommendations for standardised methods to facilitate future data comparisons.

This approach aligns with other initiatives, including the Essential Biodiversity Variables approach (Pereira et al.

---

[1] The FECs are identified in the CBMP–Terrestrial Plan and further explained in Section 2.2 and Table 2.1.

BOX 1-1. CIRCUMPOLAR BIODIVERSITY MONITORING PROGRAM

Effective conservation and management of Arctic ecosystems requires an understanding of the complex dynamics and trends of species, habitats and ecological processes and functions, drivers of change, and their interactions at multiple scales. Long-term monitoring data is required to obtain this knowledge. Recognising the lack of this type of information in the Arctic, the Arctic Council, in 2004, recommended that long-term ecosystem and biodiversity monitoring efforts be increased and focused to address key knowledge gaps to better inform conservation and management of the Arctic's biodiversity and ecosystems (Petersen, et al. 2004, CAFF 2013b). In response, CAFF established the Circumpolar Biodiversity Monitoring Program (CBMP) to provide adaptive, coordinated, and standardised monitoring of Arctic marine, terrestrial, freshwater, and coastal ecosystems. Today the CBMP, an international network of scientists, conservation organisations, government agencies and other experts, is the cornerstone program of CAFF.

Overall direction for the CBMP is provided through regularly updated strategic plans that use an adaptive, question-driven approach (e.g., CBMP Strategic Plan for 2018–2021 (CAFF 2018), Navarro et. al 2017). Four ecosystem-based biodiversity monitoring plans—marine (Gill et al. 2011), freshwater (Culp et al. 2012), terrestrial (Christensen et al. 2013) and coastal (Jones et al. 2019)—provide more detailed frameworks for data collection, analysis, interpretation, reporting and communications that improve our ability to detect and understand changes. Each plan employs a similar process and structure including the identification of key elements, or FECs, expected to be good indicators of change for both the single component and the ecosystem in general. The four monitoring plans aim to incorporate science, Indigenous Knowledge and/or Local Knowledge in inventory, monitoring and assessments.

Implementation of the plans is iterative, allowing the program to adapt in response to key findings, provide advice for future monitoring, lessons learned and the emergence of new questions. The resulting adaptive platform (Figure 1.1) facilitates the development and improvement of collaborative, cross-jurisdictional monitoring programs on broad geographic scales, including for areas where capacity is limited.

Figure 1-1. CBMP's adaptive, integrated ecosystem–based approach to inventory, monitoring and data management.

This figure illustrates how management questions, conceptual ecosystem models based on science, Indigenous Knowledge, and Local Knowledge, and existing monitoring networks guide the four CBMP monitoring plans—marine, freshwater, terrestrial and coastal. Monitoring outputs (data) feed into the assessment and decision-making processes and guide refinement of the monitoring programmes themselves. Modified from CAFF 2017.

2012) developed by the Group on Earth Observations Biodiversity Observation Network (GEO BON), and the results provide decision makers and other users with information needed for effective conservation, mitigation, and other actions. It also helps to track and evaluate progress towards meeting the objectives of CAFF, and supports the reporting on the Aichi Biodiversity Targets of the United Nations ***Strategic Plan for Biodiversity 2011–2020*** (Convention on Biological Diversity 2010) and relevant United Nations Sustainable Development Goals (UNEP WCMC & IUCN 2016; Christensen et al. 2020), as well as other future processes including the post2020 Global Biodiversity Framework (Convention on Biological Diversity, 2020) and future assessments under the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, https://www.ipbes.net/).

The geographic boundaries (see Figure 1.2) and ecosystems included in the CBMP–Terrestrial Plan align, in most cases, with those of the ***Arctic Biodiversity Assessment***, covering high and low Arctic regions consistent with the ***Circumpolar Arctic Vegetation Map*** (CAVM Team 2003).

Conceptual models represent working hypotheses about key relationships, functions, and the organisation of a system (Guerra et al. 2019, Beever & Woodward 2011) can help guide the identification of priority monitoring elements, that meaningfully describe the status of many parts of the ecosystem and probable causes of change. 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. 2017). Based on the priority questions and conceptual models, a list of priority FECs and related attributes, and parameters were identified.

Through expert input, the CBMP–Terrestrial Plan developed an overall conceptual model of the Arctic terrestrial system, characterising key relationships between biotic groups and interactions with abiotic components. Furthermore, detailed conceptual models relevant to each taxonomic group—vegetation, arthropods, birds, and mammals—were also developed and refined at workshops and follow-up meetings. Collectively, the conceptual models helped identify key system elements, processes, and relationships, ultimately informing the selection of FECs (Christensen et al. 2020). Four criteria were used to prioritise FECs and their attributes to monitor and report on (see Section 2.2). Chapter 2 describes these FECs and the drivers considered important in the conceptual models. Chapter 3 includes the status and trends for each FEC.

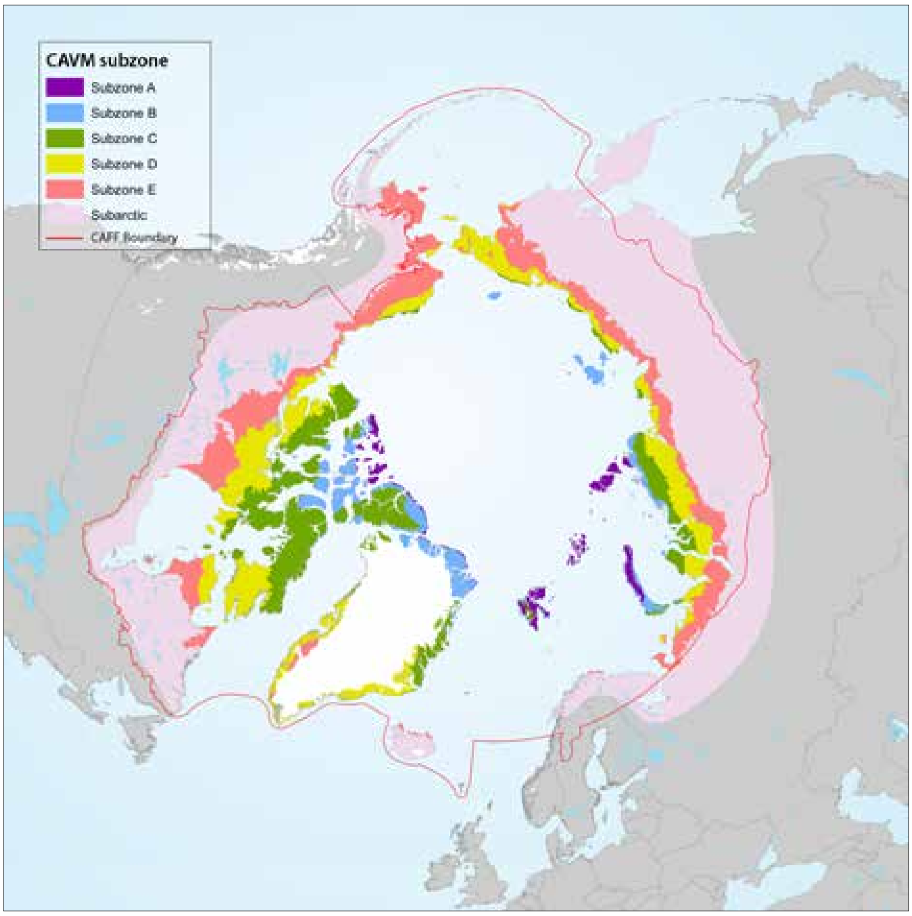


Figure 1-2. Geographic area covered by the Arctic Biodiversity Assessment and the CBMP–Terrestrial Plan.

Subzones A to E are depicted as defined in the Circumpolar Arctic Vegetation Map (CAVM Team 2003). Subzones A, B and C are the high Arctic while subzones D and E are the low Arctic. Definition of high Arctic, low Arctic, and sub-Arctic follow Hohn & Jaakkola 2010.

Ornithologist discusses bird nesting locations with a Chukchi reindeer herder, Chukotka, Russia. Photo: Julia Darkova

1.2 KNOWLEDGE AND DATA

1.2.1 INDIGENOUS KNOWLEDGE AND/OR LOCAL KNOWLEDGE

To obtain a comprehensive understanding of the state of Arctic biodiversity and how it is changing, it is necessary to consider Indigenous Knowledge and Local Knowledge[2], in addition to knowledge generated through Western science[3] (Peacock et al. 2020). The CBMP–Terrestrial Plan endeavours to build a network based on all sources of knowledge, and to bring knowledge holders together to work collaboratively. One key challenge has been a lack of resources and capacity, hindering effective inclusion of Indigenous Knowledge and/or Local Knowledge in this report. Chapter 4 presents recommendations for effectively supporting the collaborative work of Permanent Participants, Indigenous Knowledge holders, Local Knowledge holders and scientists.

Although an incomplete treatment, START includes case study examples from the published literature that showcase the biodiversity knowledge residing with Indigenous Knowledge holders (Box 3-2). As implementation progresses, the CBMP will continue to strive for meaningful engagement of Indigenous Knowledge holders and Local Knowledge holders throughout the process, and to further recognise Indigenous Knowledge and Local Knowledge monitoring methodologies.

1.2.2 ARCTIC BIODIVERSITY DATA SERVICE

In assessing the status and trends of the FECs, START draws on a variety of sources of data, most published in peer reviewed scientific journals. The most significant is a special issue of ***Ambio*** (Schmidt & Jóhannesdóttir 2020) which provides the foundation for START. Where possible, data are available through the Arctic Biodiversity Data Service (ABDS) (www.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 species and ecosystems. It provides the structure to ensure a legacy that facilitates data access and analysis, increases understanding of biodiversity and change and ultimately supports well-informed and rapid decision making.

---

[2] Local knowledge is the knowledge that people in a given community have developed over time and continue to develop. It is based on experience, often tested over centuries of use, and adapted to the local culture and environment (Warburton & Martin 1999).

[3] In this report, Western science is defined using the criteria of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES): "*Western scientific knowledge is used … as a broad term to refer to knowledge typically generated in universities, research institutions and private firms following paradigms and methods typically associated with the 'scientific method' consolidated in Post-Renaissance Europe on the basis of wider and more ancient roots … Some of its central tenets are observer independence, replicable findings, systematic scepticism, and transparent research methodologies with standard units and categories*" (IPBES). This report uses the term Western science in the context of the Ottawa Traditional Knowledge Principles (2015) adopted by the Arctic Council and Permanent Participants, which states that "*Traditional Knowledge and [Western] science are different yet complementary systems and sources of knowledge, and when appropriately used together may generate new knowledge and may inform decision making, policy development and the work of the Arctic Council.*"

Link to IPBES definition: https://ipbes.net/glossary/western-science, and Ottawa Traditional Knowledge Principles: https://www.arcticpeoples.com/knowledge#indigenous-knowledge

1.3 GLOBAL LINKAGES

The size and character of Arctic ecosystems makes them critically important to the biological, chemical, and physical balance of ecosystems on a global scale. At the same time processes and activities outside of the Arctic directly or indirectly can affect Arctic biodiversity (e.g., migratory birds on wintering grounds) (CAFF 2013a). CAFF, therefore, makes significant efforts to develop strategic partnerships and ensure that Arctic biodiversity information provides value to other Arctic Council and global initiatives. This approach helps CAFF contribute to the achievement of global biodiversity goals, targets and commitments, under various multilateral environmental agreements and other international fora. Endorsed by the United Nations Convention on Biological Diversity (CBD 2010, 2012, CAFF 2018), the CBMP is also the official Arctic Biodiversity Observation Network of the GEOBON and was one of the first regional BONs and has been used for inspiration to the overall global approach (Christensen et al. 2020).

Partnerships have been established with international data platforms, including the Arctic Spatial Data Infrastructure (Arctic SDI), GEOBON, the International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT) and as an Arctic node of the Global Biodiversity Information Facility (GBIF), any appropriate data added to the ABDS is automatically made accessible via the GBIF. Information generated by the CBMP–Terrestrial Plan is thus available to inform regional and global assessments and to bring monitoring data collected at the local and circumpolar scale into international reporting. Information has been used, for example, in global biodiversity outlooks of the Convention on Biological Diversity (CBD 2010, 2014) and assessments under the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, https://www.ipbes.net/) assessments.

The outputs of START will contribute to these and other assessments and processes, including assessing progress towards the Convention on Biological Diversity's Aichi Biodiversity Targets, the upcoming post-2020 biodiversity targets and any regional or global processes that affect Arctic biodiversity.

Vegetation monitoring. Photo: Lawrence Hislop

2 SETTING THE SCENE

Photo: Andrei Stepanov/Shutterstock.com

2.1 ARCTIC TERRESTRIAL ECOSYSTEMS

The Arctic contains large terrestrial areas with diverse ecosystems that sustain important and unique biodiversity. The conditions that govern Arctic terrestrial ecosystems differ from other terrestrial ecosystems (with exception of the Antarctic) across the globe due to the extreme cold, strong winds, drought, extended darkness during winter with consequent brightness during summer, albeit with a short growing season. Arctic ecosystems harbour highly specialised organisms, including some endemic taxa that have adapted to survive in these severe conditions and migratory species that exploit rich Arctic resources during summer breeding periods.

The terrestrial Arctic comprises an area of approximately 7 million square kilometres of which 46% is vegetated, 29% is ice, 21 % is barren while a mere 4% is freshwater (Raynolds et al. 2019). The freshwater habitats do, however, influence the terrestrial ecosystems substantially for various reasons, for example, larval stages of insects living in freshwater habitats (Lento et al. 2019) and foraging areas for water birds and waders. The vegetation of the terrestrial Arctic can be categorised into five bioclimatic subzones (Figure 1-2 and Figure 2-1). The bioclimatic subzones are primarily differentiated by annual average temperature, resulting in a vertical structure of plant cover ranging from subzone A (less than 5% vascular plant cover, mostly moss and lichen) to subzone E (100% vascular plant cover, with shrubs up to 80 centimetres) (Christensen et al. 2013, CAVM Team 2003). This is accompanied by a strong latitudinal gradient in primary production; with net annual production ten times lower in the high Arctic islands than in the low Arctic. Primary production also varies longitudinally, with primary production significantly greater in Arctic Alaska, coastal Russia west of Novaya Zemlya and on the Taymyr Peninsula, than elsewhere.

There is a great variation and heterogeneity among terrestrial Arctic ecosystems. This is further described as biogeographical areas in the Annotated Checklist of the Pan-Arctic Flora (Elven et al. 2020), as vegetation zones (Walker et al. 2005, Raynolds et al 2019) or as ecoregions recognised by Terrestrial Ecoregions of the World (Olson et al. 2001). The START focuses on high and low Arctic regions consistent with the CAVM's subzones A to E, as shown in Figure 1-2 and Figure 2-1.

Endemism has only been studied in detail in the Arctic for terrestrial mammals, birds and vascular plants and is not very common. Among vascular plants, however, there is great geographical variation, with endemic species concentrated in some areas (e.g., Taymyr, Chukotka, northern Alaska, Ellesmere Island, and east Greenland) and none known in some others (CAFF 2013a).

2.2 FOCAL ECOSYSTEM COMPONENTS

Given the complexity of ecosystems, even systems with relatively few species, such as the Arctic, benefit from the selection of surrogates for monitoring targets (Boutin et al. 2009). A process to identify and rank potential priority monitoring and reporting targets is particularly critical due to resource and logistical constraints. Even the most ambitious monitoring programme cannot monitor and report on all desired elements, everywhere, all the time. This is especially true for remote Arctic locations where access is logistically challenging and very costly (Schmidt et al. 2017, Christensen et al. 2020).

To address this, the CBMP employs the FEC approach developed for the CBMP–Terrestrial Plan. A list of priority FECs and related attributes and parameters were identified based on the priority questions and conceptual models outlined in the CBMP–Terrestrial Plan. Priority attributes were identified using four criteria:

- ecological significance (central to the function of the ecosystem and/or sensitive to potential stressors) as identified through the development of conceptual ecological models;
- relevance to ecosystem services;
- value to Arctic Indigenous and non-Indigenous Peoples; and
- usefulness for management and legislative needs.

FECs are, therefore, the biotic taxa that are ecologically pivotal, charismatic and/or sensitive to changes in biodiversity and/or environmental conditions. Arctic terrestrial experts chose the most representative FECs as indicators of Arctic terrestrial ecosystem status and trends. FECs are considered central to the functioning of an ecosystem, of major importance to Arctic residents and/or likely to be good proxies of change in the environment; for example, species of vegetation that provide forage.

Parameters to be measured in the field furthermore were refined by several criteria, among them sensitivity to drivers of change (Christensen et al. 2013). Furthermore, more consideration was given to the likelihood of the identified FEC having regular representation in existing databases for the circumpolar Arctic. For example, although microbial soil biota are an important part of the biodiversity and functions of terrestrial habitats, they are not routinely monitored in the Arctic and cannot therefore be assessed across the circumpolar region at this time.

The list of essential and recommended FEC attributes and their parameters were refined through expert workshops (Christensen et al. 2020). The results are presented in Table 2-1 which is based on Table 4-1, 4-4, 4-5 and 4-6 in Christensen et al. (2013). Chapter 3 describes the status and trends of each FEC where data is available and relevant. Chapter 4 includes a summary of the state of data availability across FEC attributes.

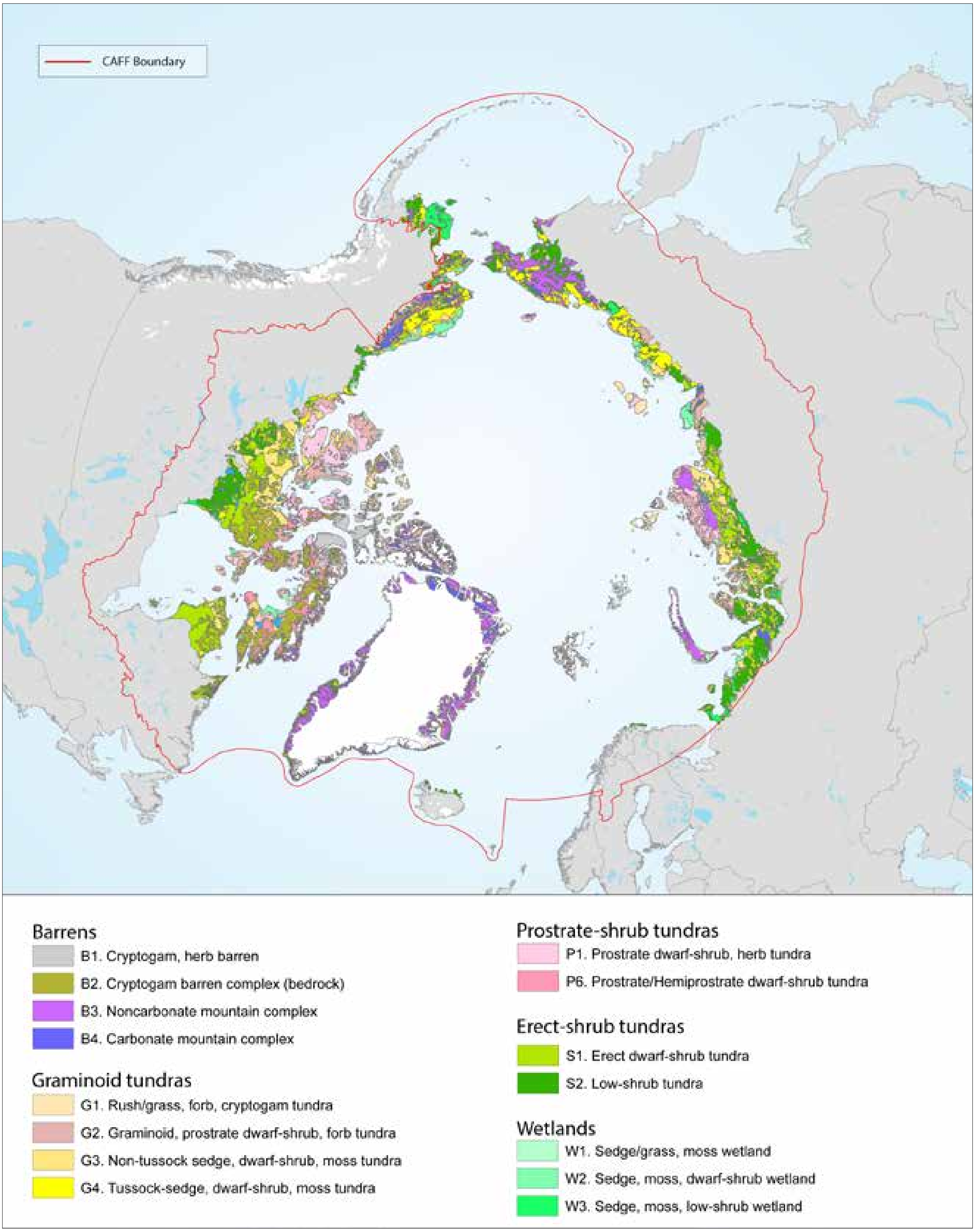


Figure 2-1. Map of the vegetation zones of the circumpolar Arctic.

Modified from Walker et al. 2005

Table 2-1. FEC components and their key attributes. Coverage of 'essential' (E) and 'recommended' (R) attributes or each FEC are as defined in the CBMP–Terrestrial Plan.

	FEC ATTRIBUTES														
FECS	EXAMPLES, GROUPS	ABUNDANCE	DEMOGRAPHICS	DEMOGRAPHICS, PRODUCTIVITY, AND PHENOLOGY	PHENOLOGY	DIVERSITY	DIVERSITY, COMPOSITION, AND ABUNDANCE	DIVERSITY GENETIC	DIVERSITY, SPATIAL STRUCTURE, AND HEALTH	HEALTH	HEALTH: BODY CONDITION	SPATIAL STRUCTURE: DISTRIBUTION	TEMPORAL CYCLES	ECOSYSTEM FUNCTIONS AND PROCESSES	PRODUCTIVITY
Vegetation															
All plants					E		E								E
Rare species, species of concern		E/R						R		R		R			
Non-native species		E										E			
Food species	berries				E					R					E/R
Arthropods															
Pollination	flies, bees	R			R	E						E		E	
Food prey for vertebrates	midges, springtails, spiders	E			E	R				R (wolf spiders)		R			
Decomposers and nutrient cycling	soil mites, springtails	E		R		E						E	E	R	
Herbivores	aphids, moth larvae	R		R	R	E				R		E		E	
Blood-feeding	mosquitoes, fleas	R	R		R	E						R			
Birds															
Herbivores	geese, ptarmigan	E		E			R		R	R	R	E			
Insectivores	waders, passerines	E		E			R		R	R	R	E			

	FEC ATTRIBUTES														
FECS	EXAMPLES, GROUPS	ABUNDANCE	DEMOGRAPHICS	DEMOGRAPHICS, PRODUCTIVITY, AND PHENOLOGY	PHENOLOGY	DIVERSITY	DIVERSITY, COMPOSITION, AND ABUNDANCE	DIVERSITY GENETIC	DIVERSITY, SPATIAL STRUCTURE, AND HEALTH	HEALTH	HEALTH: BODY CONDITION	SPATIAL STRUCTURE: DISTRIBUTION	TEMPORAL CYCLES	ECOSYSTEM FUNCTIONS AND PROCESSES	PRODUCTIVITY
Carnivores	falcons, owls	E		E			R		R	R	R	E	R		
Omnivores	ravens, cranes	E		E		R			R	R	R	E			
Piscivores	loons	E		E			R		R	R/R		E			
Mammals															
Large herbivores	*Rangifer**, muskoxen, moose	E	E		E			R		E		E			
Medium-sized herbivores	hares	E	E		E			R		E		R			
Small herbivores	lemmings, voles	E	R		E			R		E		R			
Large predators	brown bear, grey wolf	E	E		E			R		E		R			
Medium-sized predators	wolverine, lynx, foxes	E	R		E			R		E		R			
Small predators	stoat/weasel/ ermine	E	R		E			R		E		R			

*Refers to caribou and reindeer collectively.

2.3 THREATS AND DRIVERS OF CHANGE

Despite the remoteness of the Arctic, ecosystems and species are under increasing pressure from threats within and outside of northern latitudes. These include contaminants, overexploitation, anthropogenic disturbance, resource extraction, landscape alteration, habitat loss and fragmentation and invasive alien species. The unique situation in the Arctic (e.g., being relatively pristine and with few native species) makes it especially vulnerable to invasive alien species (see 3.1.3).

Climate change is the most significant threat to Arctic ecosystems and biodiversity (CAFF 2013a). According to the Intergovernmental Panel on Climate Change (IPCC 2019), Arctic surface air temperature has increased at more than twice the global rate that is, when expressed in degrees Celcius, doubling over the past two decades (Notz & Stroeve 2016, Ballinger et al. 2020) with a plethora of effects (see Box et al. 2019). The physical, ecological, social, and economic impacts from climate change underpin the urgent need to adapt to and mitigate warming (IPCC 2007, IPCC 2014, AMAP 2017a, 2017b, 2018, 2019).

Box 2-1 provides examples of climate change trends reported in the 2020 National Oceanic and Atmospheric Administration Arctic Report Card (Thoman et al. 2020). The impact of this threat on terrestrial biodiversity and ecosystems is included throughout this report.

2.3.1 DRIVERS

Understanding links between FEC attributes and the drivers of change (i.e., the underlying cause of changes) is critical to understanding the changes observed in the biotic elements and the impact on food webs and trophic interactions. Drivers are, therefore, extremely important to include in conceptual models (see Section 1.1).

Drivers influencing Arctic terrestrial biodiversity can be categorised as biotic, abiotic, or anthropogenic, although substantial connections exist between drivers of these categories. Thus, many drivers belong in more than one category; for example, most abiotic climatic drivers could be considered anthropogenic because climate change is driven mainly by human activity.

Drivers having negative effects often have corresponding stressors. For example, climate is a driver of 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 (as defined in the CBMP–Terrestrial Plan).

The CBMP–Terrestrial Plan identifies several key drivers that influence FECs. Box 2-2 and Box 2-3 provide examples of key biotic and abiotic drivers, respectively. The key abiotic drivers are all, either directly or indirectly, linked to climate. Amongst the most important is the length of the growing season. Some stochastic events, such as ice on snow and related winter freezing events (rain on snow), can also be significant as well as defoliate events caused by ***Epirrita autumnata*** (Ruohomäki et al. 2000). Biotic drivers may be dependent upon, or result from, abiotic or anthropogenic drivers. Box 2-4 presents key anthropogenic drivers, which are partly connected to other drivers, in particular climate.

The Arctic is diverse and different areas respond differently to the same drivers depending upon both ecosystem and species composition and abiotic factors such as geology, permafrost, and pH. Details on the specific effects of drivers on individual FECs are discussed in Chapter 3.

Oil and gas development, Russia. Photo: Alexey Ivanov/Shutterstock.com

BOX 2-1. CLIMATE CHANGE AND ITS IMPACTS IN THE ARCTIC.

Warming in the Arctic has been significantly faster than anywhere else on Earth (Ballinger et al. 2020). Trends in land surface temperature are shown on Figure 2 2.

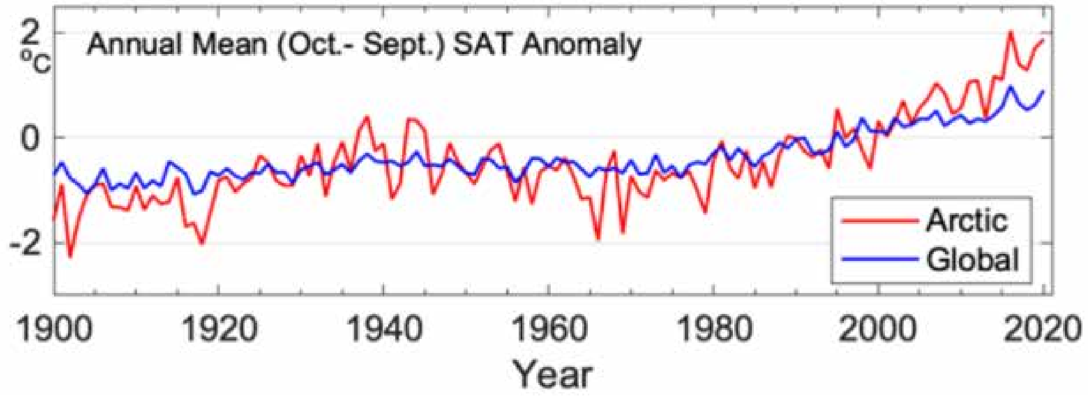


Figure 2-2. Mean annual SAT anomalies (in °C) for terrestrial weather stations located in the Arctic (60-90°N; red line) and globally (blue line) for the 1900–2020 period, relative to the 1981-2010 means. (Ballinger et al. 2020).

This temperature increase has multiple effects, for example a shorter amount of time with snow cover (Mudryk et al. 2020) as seen in Figure 2-3.

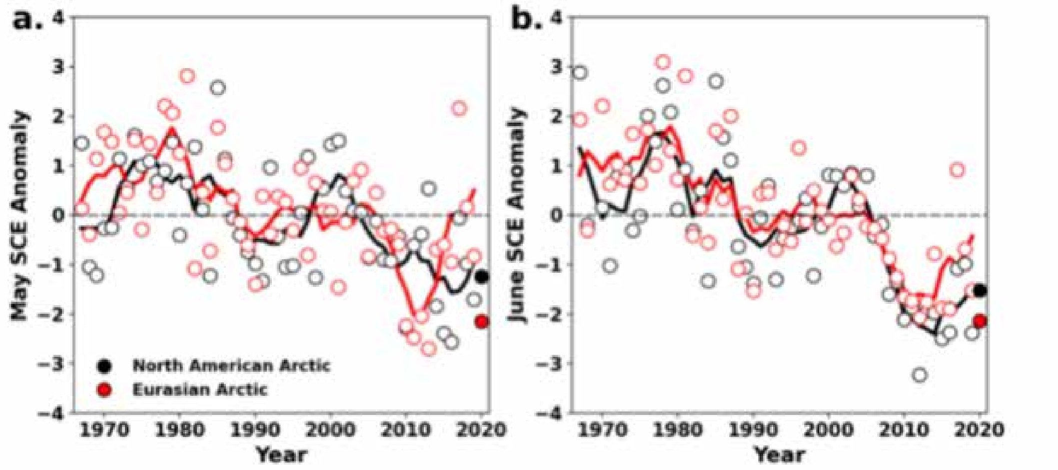


Figure 2-3. Monthly snow cover extent (SCE) for Arctic land areas (>60° N) for (a) May and (b) June 1967–2020, a 54-year record. Anomalies are relative to the 1981–2010 average and standardised (each observation was differenced from the mean and divided by the standard deviation, and thus unitless). Solid black and red lines depict 5-year running means for North America and Eurasia, respectively. Filled circles are used to highlight 2020 anomalies. (Mudryk et al. 2020).

BOX 2-2. KEY BIOTIC DRIVERS OF CHANGE

Biotic drivers (slightly modified the CBMP–Terrestrial Plan) may be dependent upon abiotic or anthropogenic drivers. They are from:

- competition and other interspecific processes
- invasive alien species
- shrubification and tree encroachment
- grazing/foraging
- pollination
- pathogens and parasites
- insect outbreaks/defoliation events
- habitat quality
    - connectivity
    - natural disturbance
    - breeding habitat
    - water availability
- health of soil biota
- species distribution and composition

BOX 2-3. KEY ABIOTIC DRIVERS OF CHANGE

Abiotic drivers (slightly modified from the CBMP–Terrestrial Plan) are:

- climate
    - length of growing season
    - temperature of air and soil
    - precipitation (rain, snow, snow cover duration and extent, icing events)
    - cloud coverage
    - extreme weather events (e.g., rain on snow, freeze-thaw cycles)
- site characteristics
    - soil type
    - soil pH
    - permafrost
    - soil moisture
    - topography
- hydrology
- solar radiation
- wind
- wildfires

BOX 2-4. KEY ANTHROPOGENIC DRIVERS OF CHANGE

Anthropogenic drivers of change (slightly modified from the CBMP–Terrestrial Plan) may be dependent on abiotic or anthropogenic drivers. They include:

- land use changes and habitat conversion within the Arctic including:
  - fragmentation (linear features such as roads and pipelines)
  - infrastructure (facilities)
  - resource extraction (minerals, oil, and gas)
  - agriculture
- anthropogenic noise/visual/vibrations from ground/air traffic
- habitat change outside the Arctic (related to effects on migratory species)
- unsustainable harvest
- contaminants and pollution, including dust, generated locally and outside the Arctic
- climate change
- introduction of invasive alien species (see also Box 2-2)
- tourism
- nutrification and enrichment
- domestication

BOX 2-5. HARVESTING, FOOD SECURITY, AND BIODIVERSITY

Arctic Indigenous Peoples have been sustainably interacting with Arctic biodiversity for millennia as part of an interconnected system. Healthy Arctic ecosystems are critical to the food security of Arctic Indigenous Peoples, and to all the social, cultural, economic, and spiritual components that food security encompasses (Inuit Circumpolar Council Alaska 2020). Harvesting provides nutritious, accessible, and culturally relevant foods for Arctic Indigenous Peoples. In turn, long-term harvesting, herding and other Indigenous cultural practices can have enduring effects on biodiversity patterns, such as increasing habitat heterogeneity (Josefsson et al. 2009) and promoting distinct assemblages of native flora (Oberndorfer et. al 2020). Sustainable harvesting both depends on and supports biodiversity.

A Khanty reindeer herder, Russia. Photo: Alexander Chizenok/Shutterstock.com

2.3.2 DRIVERS AND CUMULATIVE EFFECTS AS PART OF THE CONCEPTUAL MODEL

A single driver may put relatively little pressure on the environment but in combination multiple repeated drivers can create cumulative effects. It is therefore important to treat drivers as related phenomena with biotic responses and, as they can enhance or inhibit each other's effects (synergistic or antagonistic effects). Drivers may also have direct and indirect effects on the ecosystem, further complicating our understanding of the relationships between drivers and consequent change.

Using a conceptual model is important for structuring analysis of the interactions between drivers and their effects on ecosystems, and for forming hypotheses for testing regarding their influence. Figure 2-4 provides the conceptual model for high Arctic terrestrial food web energy flow, including drivers and FECs, that are being used for the START. This figure is based upon the conceptual model defined in the CBMP–Terrestrial Plan.

Ecosystems have always been changing, but the pace, magnitude, and cumulative impact of biodiversity drivers at present could push ecosystems beyond historic limits. There is an increasing awareness worldwide of cumulative effects and the need to take a holistic, integrated approach to management to ensure the sustainability of ecosystems. Ecosystem-based management has been identified by Arctic states as a key adaptive way to sustainably manage Arctic ecosystems. Its interdisciplinary approach considers the political, regional, and cultural context of an area and provides a flexible means to manage the effects of multiple pressures on Arctic ecosystems. Little is known about the patterns of cumulative effects and the changes these effects may cause, and no method or standardised approach for determining the impacts of cumulative effects currently exists. However, knowledge about spatial data on important areas for species and ecosystems and data on the distribution and intensity of human activities are essential in establishing a more adaptive and ecosystem-based approach to environmental management (ICC–Alaska 2015).

Drivers and ecosystem change can ultimately threaten species. The International Union for the Conservation of Nature (IUCN) has developed internationally adopted criteria for assessing and classifying the extinction risk for individual taxa and ecosystems—the Red List (IUCN 2020b) and comparable criteria for the collapse risk of ecosystems (Bland et al. 2017). They have initiated a process to assess the status of Arctic species; however, to date, few species have been subject to assessment at the pan-Arctic scale (see Section 3.5).

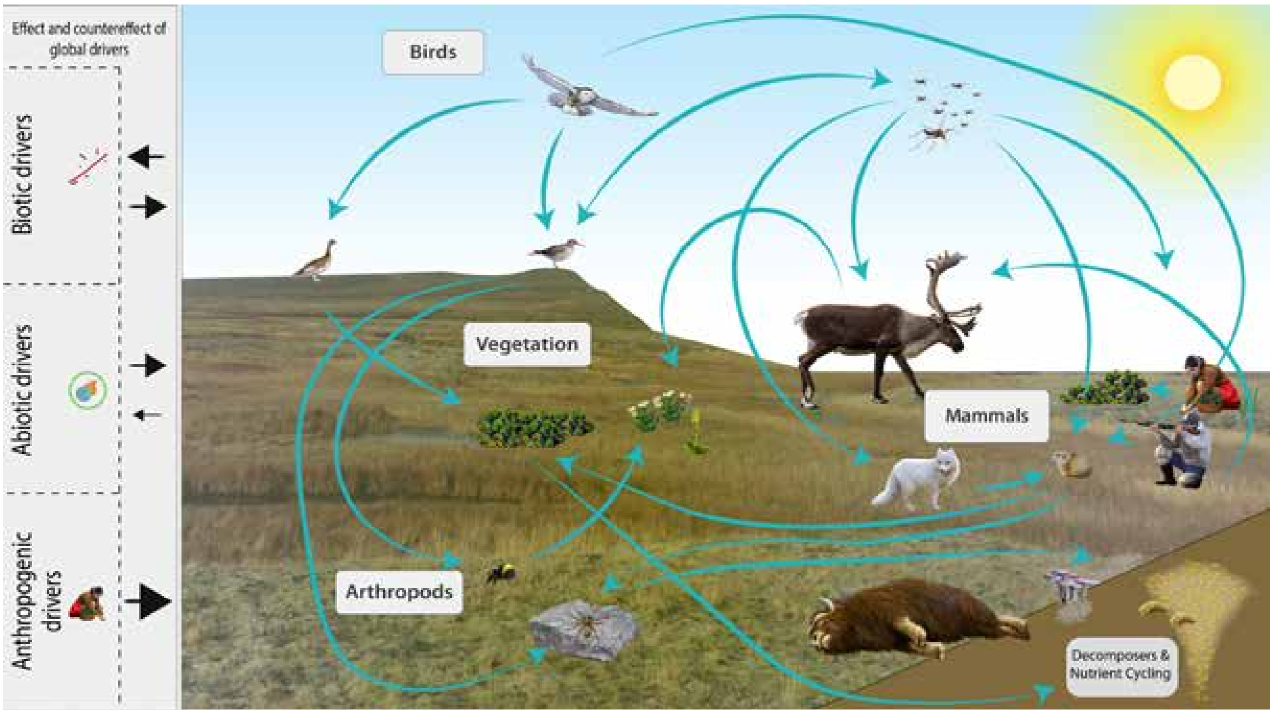


Figure 2-4. Conceptual model of energy flow through the high Arctic terrestrial food web.

The Arctic terrestrial food web includes the exchange of energy and nutrients. Arrows to and from the driver boxes indicate the relative effect and counter effect of different types of drivers on the ecosystem.

3 STATUS AND TRENDS IN ARCTIC TERRESTRIAL BIODIVERSITY

Muskoxen, Greenland. Photo: Lars Holst Hansen

This chapter describes the status, patterns of change, trends, drivers and state of monitoring and knowledge of vegetation, arthropod, bird, and mammal FECs and the associated essential FEC attributes (Table 2-1). In addition, some recommendations for revising FECs and associated attributes are provided. The process of selecting FECs and prioritising them is presented in the CBMP–Terrestrial Plan. In this report, the focus is on essential FEC attributes because data on recommended attributes are rarely available and recommended attributes are of lower priority to stakeholders.

Taxonomic knowledge is variable within and across groups. While some groups, such as birds, mammals, and vascular plants, have common Pan-Arctic taxonomic consensus, this is not the case for others, such as arthropods, mosses, and fungi.

The emphasis is on FECs with sufficient data to determine status and trends. FECs can be one or more species in a guild or can represent a relatively heterogeneous assembly of taxa occupying a similar position in the Arctic terrestrial food web (for example, decomposing arthropods). Arctic ecosystems are relatively simple and are usually driven by primary production; decreased vegetation productivity and complexity as you move north, providing a determining force in the tundra biome´s zonal structure (***Arctic Biodiversity Assessment*** Chapter 12). A conceptual model of the energy flow in the Arctic terrestrial food web is provided in Figure 2-4. Conceptual models depicting different subzones identified in the CAVM can be found in the ***Arctic Biodiversity Assessment*** (Ims & Ehrich 2013).

Arctic ecosystems are characterised by species adapted to cold climate. They have a relatively high coverage of mosses and lichens, while shrubs are more or less absent from the most northern regions—subzones A and B (Figure 1-2 and Figure 2-1). Productivity is relatively high during summer with almost constant sunshine, providing the opportunity for numerous migrating species—in particular, birds—to travel north. Mammals, unlike birds, are more likely to remain local; for example, the few highly cold-adapted mammals living on the tundra. There are few species of amphibians and reptiles found in the Arctic, non are exclusive to the Arctic (Box 3-7).

Data used for assessing status and trends in different FECs vary. This report depends heavily upon data presented and reviewed in the articles published in an ***Ambio*** special issue, but also draws on other publications and datasets (see individual sub-sections for references).

While the interrelations and dependability between different FECs and drivers are complex and not fully understood, they are briefly discussed at the end of this chapter.

Tundra vegetation, Samantha Crimmin/Shutterstock.com; fly, Fiona Patton; Red knots, Danita Delimont/Shutterstock.com; and Arctic fox, Lars Holst Hansen.

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

3.1 VEGETATION

Knowledge on different groups of vegetation, which includes plants and fungi, is very heterogeneous. Although the taxonomy of vascular plants is relatively well known, the checklists for both mosses and lichens are disparate with substantial knowledge gaps. Fungi and terrestrial algae are little known in the area. Plants are the main producers in Arctic ecosystems, while fungi, arthropods and different microorganisms are the main decomposers (Figure 2-4).

3.1.1 PATTERNS AND TRENDS OF FECS AND THEIR ATTRIBUTES

The CBMP–Terrestrial Plan identifies four FECs for monitoring vegetation: all plants (species, life-form groups and associated communities); rare species and species of concern; invasive alien species; and species that humans use as food (culturally important species). This section focuses on 'all plants'—specifically those with existing monitoring data—and on 'invasive alien species.' Results for the 'species of special concern' FEC are included in Section 3.5. The 'food species' FEC was not included as data were too disparate.

Lead authors:
Virve Ravolainen, Anne D. Bjorkman

Contributing authors:
Donald Walker, Howard Epstein, Gabriela Schaepman-Strub

Forty key attributes (essential and recommended) that pertain to vascular plants, bryophytes and lichens were identified for monitoring (Table 2-1). This section focuses on the essential attributes for which sufficient data exist. For 'all plants,' this includes productivity, composition, abundance, and phenology. For 'invasive alien species' it includes abundance and distribution.

This summary is based on the overviews and references within Bjorkman et al. (2020), Ravolainen et al. (2020), Jenkins et al. (2020) and Wasowicz et al. (2020), as well as other recent relevant literature

3.1.1.1 All Plants/Vegetation

Productivity

Primary productivity can be assessed on a circumpolar scale using satellite imagery that provides vegetation indices; frequently using an index called the Normalised Difference Vegetation Index (NDVI). Analysis of temporal trends in the greenness indices include the maximum NDVI (MaxNDVI) and time integrated NDVI. The U.S. National Oceanic and Atmospheric Administration reports on these annually (e.g., Frost et al. 2020). Results show an overall increasing trend from 1982 to 2017 for both the MaxNDVI (Figure 3-1) and time-integrated NDVI. Nevertheless, some regions show a negative trend, such as the Yukon–Kuskokwim Delta of western Alaska, the high Arctic of the Canadian Archipelago, and the north-western and north coastal Siberian tundra. There is large heterogeneity in satellite-derived vegetation change, also found in recent studies (Myers-Smith et al. 2020). This result is supported by Jenkins et al. (2020) which found a circumpolar NDVI increase between 2000 and 2017 (see also Figure 3-1). While positive trends can be linked to climate change, the cause of the different positive and negative trends in different geographic areas over the same time period is not clear. It is thought to be at least partially linked to changes in the distribution of Arctic sea ice versus open water (Bhatt et al. 2010, 2017), to variation in climate and soil moisture (Berner et al. 2020). and to divergent NDVI data resulting from different sensors (Guay et al. 2014).

Composition and Abundance

Observations from plot-based studies of community composition and abundance also show heterogeneous trends (Elmendorf et al. 2012). A recent review (Bjorkman et al. 2020) found large variation among sites and species in the direction and magnitude of change in abundance. Forb, graminoid and shrub abundance changed significantly (increased or decreased) over time in roughly a third of published studies, while approximately half of the studies identified no significant trends (Figure 3-2). In contrast to mixed temporal trends, experimental warming led to clear changes in the abundance of lichens, which were far more likely to decrease in abundance in response to experimental warming than to increase or remain stable.

Shrub abundance is generally considered to be particularly sensitive to environmental change and the 'greening' observed in many areas of the Arctic is often attributed to the increased growth or expansion of shrubs. However, multiple aspects of shrub development (for example, area expansion, height change and upslope or northward movement) also demonstrate considerable heterogeneity, and no directional change in any variable consistent across the entire Arctic is evident (Myers-Smith et al. 2015).

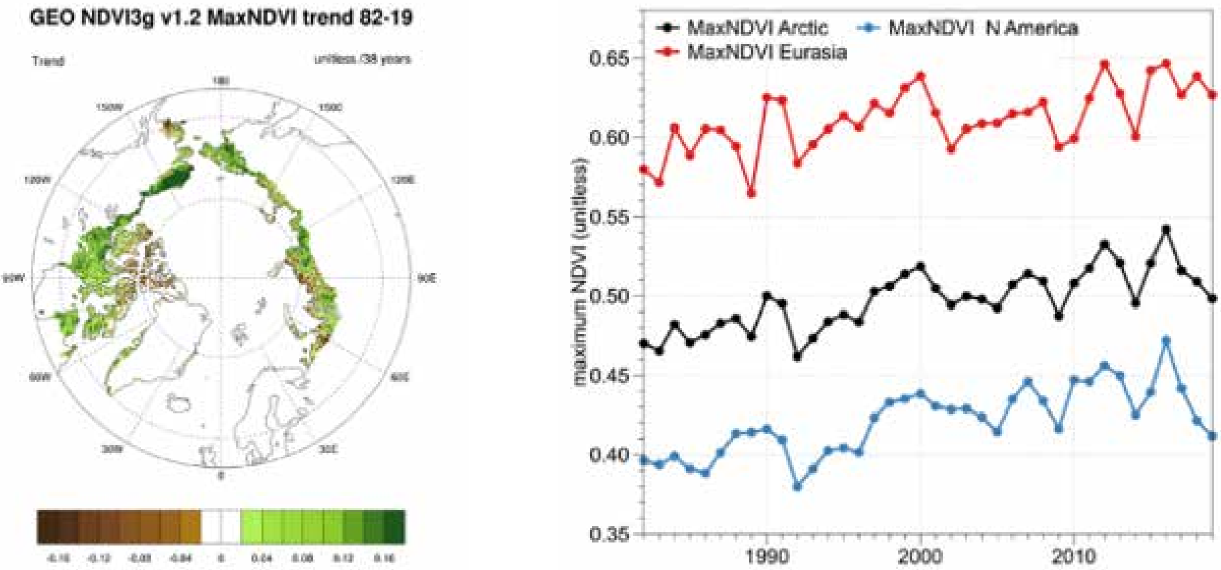


Figure 3-1. Circumpolar trends in primary productivity as indicated by the maximum Normalised Difference Vegetation Index, 1982–2017. (a) Brown shading indicates negative MaxNDVI trends, green shading indicates positive MaxNDVI trends. (b) Chart of trends for the circumpolar Arctic, Eurasia, and North America. Modified from Frost et al. 2020.

Phenology

Phenology—the timing of life events such as green up, flowering and leaf senescence—is identified by the CBMP–Terrestrial Plan as an essential attribute. Changes in phenology can influence the reproductive success of an individual plant and consequently the population size of a species, potentially leading to shifts in the composition of Arctic plant communities. Studies have shown that leaf emergence (green up) and flowering typically occur earlier in response to experimental warming (Bjorkman et al. 2020). Many plot-based monitoring studies also documented trends toward earlier flowering over the duration of the studies, which ranged from 9 to 21 years (Figure 3-3); however, this varied by site and species (Bjorkman et al. 2015). Phenological observations through remote sensing between 2000 and 2017 indicate an earlier start of the season (green update) in most southern and middle latitude regions (subzones E and C) while in other regions (subzones A, B and D) there was no change in green up (Jenkins et al. 2020).

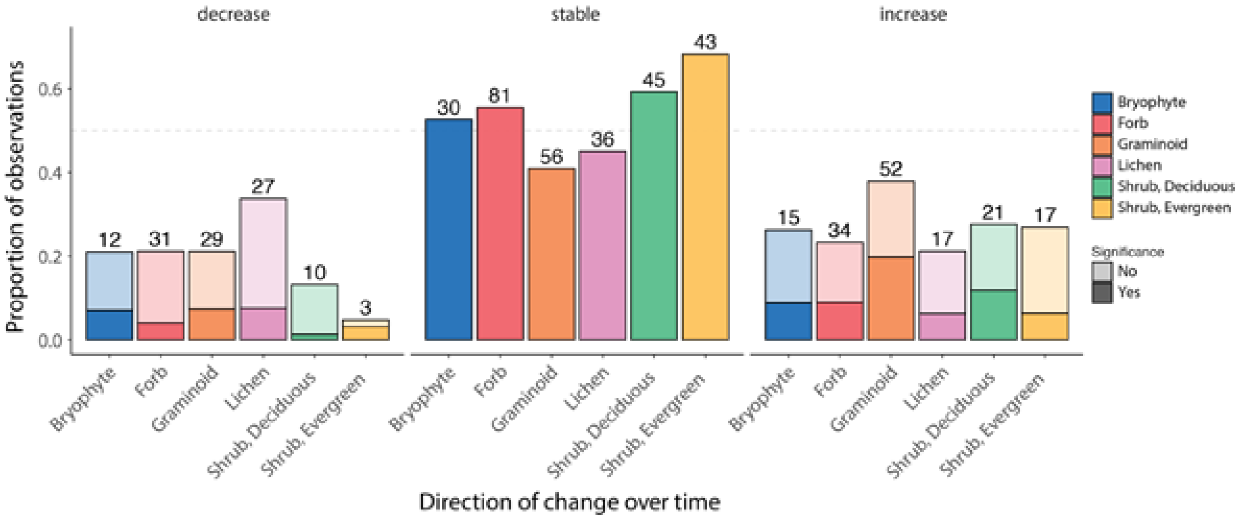


Figure 3-2. *Change in forb, graminoid and shrub abundance by species or functional group over time based on local field studies across the Arctic, ranging from 5 to 43 years of duration. The bars show the proportion of observed decreasing, stable and increasing change in abundance, based on published studies. The darker portions of each bar represent a significant decrease, stable state, or increase, and lighter shading represents marginally significant change. The numbers above each bar indicate the number of observations in that group. Modified from Bjorkman et al. 2020.*

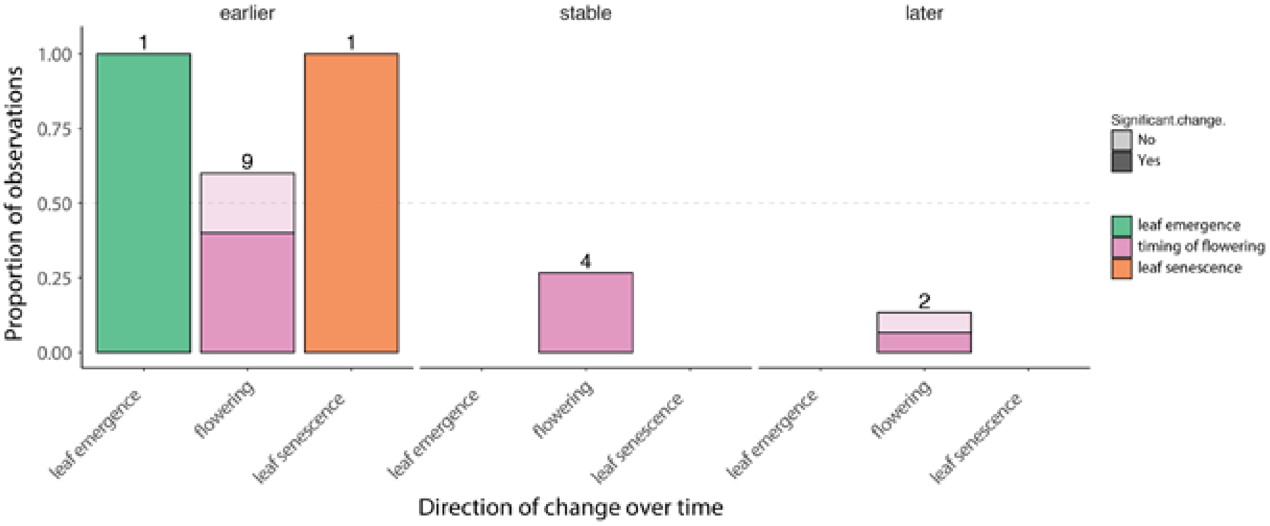


Figure 3-3. Change in plant phenology over time based on published studies, ranging from 9 to 21 years of duration.

The bars show the proportion of observations where timing of phenological events advanced (earlier) was stable or were delayed (later) over time. The darker portions of each bar represent visible decrease, stable state, or increase results, and lighter portions represent marginally significant change. The numbers above each bar indicate the number of observations in that group. Figure from Bjorkman et al. 2020.

At the end of the growing season, leaf senescence shows different patterns in experimental warming and in long-term monitoring studies (Bjorkman et al. 2020) for reasons currently unknown. These results correspond with a 2013 synthesis of leaf senescence (Oberbauer et al. 2013) finding mixed trends, as well as satellite records where no trend was observed in senescence date.

In addition to monitoring studies assessing change in vegetation over time, studies of vegetation change along spatial temperature gradients that traverse the Arctic, such as the Eurasia Arctic Transect (e.g., Walker et al. 2019), can also increase our understanding of how changing temperature might influence the plant communities.

3.1.1.2 Non-native Species

In 2019, 341 non-native vascular plant species were confirmed in the Arctic; 11 are considered invasive (Wasowicz et al. 2020). Regional and local studies indicate that invasive alien plant species are largely confined to areas close to human settlements (Wasowicz et al. 2020) and studies hitherto found that in natural habitats, they tend to disappear over the course of some years to a decade (Alsos et al. 2015).

Although non-native plant species are found throughout the Arctic, they show a clustered distribution pattern (Figure 3-4).

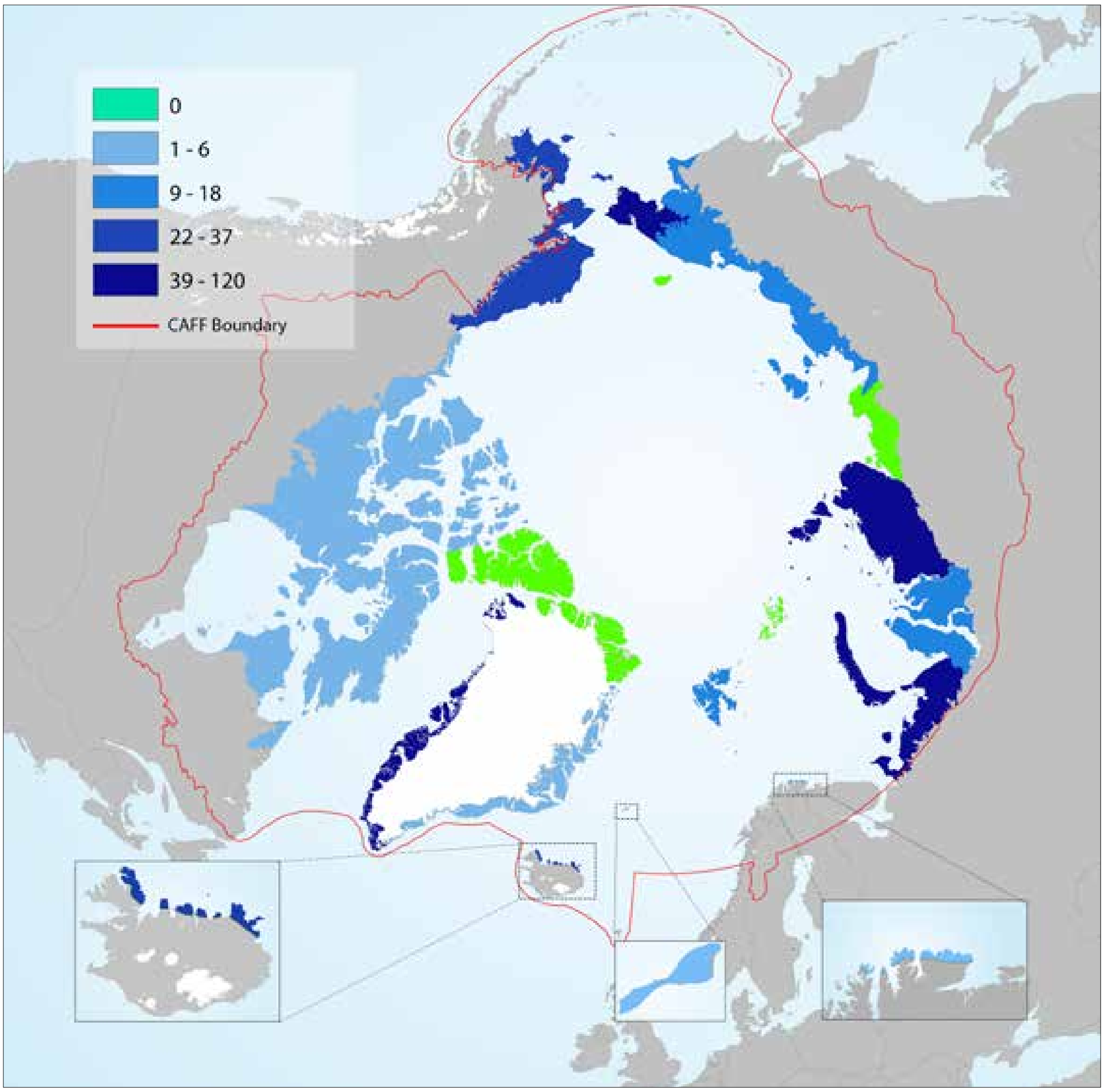


Figure 3-4. Number of non-native plant taxa that have become naturalised across the Arctic. No naturalised non-native taxa are recorded from Wrangel Island, Ellesmere Land – northern Greenland, Anabar-Olenyok and Frans Josef Land. Modified from Wasowicz et al. 2020.

Photo: Evgeniy Trufanov

3.1.2 EFFECT OF DRIVERS ON FECS AND THEIR ATTRIBUTES

The high inter- and intra-annual variability in vegetation parameters may give the impression that little general change in vegetation in the Arctic has occurred. This heterogeneity is, however, inherent to plant life in the Arctic, and a response to the drivers that influence plants on local and regional scales. Arctic plants are generally slow growing and long-lived, but they are also adapted to a highly variable environment. Their growth and abundance are tightly linked to summer temperature (van der Wal & Stien 2014), given sufficient moisture (Elmendorf et al. 2012, Myers-Smith et al. 2015). As temperature, moisture and other environmental conditions have varied greatly historically within and between seasons, a natural consequence is large variation in above ground plant abundance, phenology, and productivity between consecutive years at any given location.

Summer temperature is one of the most important drivers affecting plant above-ground abundance in the Arctic. Plant abundance strongly correlates with July temperature in the high Arctic as shown in Svalbard (van der Wal & Stien 2014); however, as demonstrated in Section 2.3.1, few, if any, spatially consistent, large-scale trends in documented plant responses to temperature drivers exist (Elmendorf et al. 2012). Locally, effects of summer and winter climate can be pronounced (Milner et al. 2016). In the winter, mild events followed by cold temperatures or ice layers on the ground can damage plants in some parts of the landscape. Shrubs are particularly vulnerable to winter damage and several studies have documented damage or mortality due to severe winter climate events (Bjerke et al. 2017). Effects of climate are modified both locally/regionally (Bråthen et al. 2017) and globally (Barrio et al. 2016) by biotic interactions and especially by grazing animals.

3.1.3 COVERAGE AND GAPS IN KNOWLEDGE AND MONITORING

Vegetation change may be more pronounced at particular locations, habitats within landscape, or within vegetation types, and may not be uniform among similar habitat types across different regions. Vegetation parameters can be decreasing or increasing at hyper-local scales, even if compound measures that average the parameters over several ecological contexts show no change. The spatial heterogeneity in vegetation change over time and in response to environmental drivers suggests that effects of change in drivers needs to be investigated and interpreted in the context of each ecosystem and even in habitat-specific contexts (Ravolainen et al. 2020).

To accommodate changes in vegetation in response to outside influences—that is, context dependency—monitoring programmes and long-term ecological research should include conceptual models on expected vegetation responses and their drivers, for example, the International Tundra Experiment (ITEX) (2020). These would help decipher which vegetation parameters are expected to change in a given ecosystem or habitat, what drivers are likely to play an important role, and how they can be monitored to provide information on trends and causal relationships.

Vegetation monitoring occurs across the Arctic, but the duration of monitoring efforts is variable and is dependent upon both study design and access to resources. Although many field studies on vegetation have been conducted in the Arctic (Figure 3-5), not all can be considered monitoring since some recorded only select measurements over limited time frames. Studies reporting on abundance and composition of vegetation reflect a larger and more widespread geographical coverage than the typically more site-limited and time-consuming phenology studies (Figure 3-5). Geographical gaps in coverage of Siberia and large parts of the Canadian Arctic are evident.

Relatively few time series are maintained with annual or nearly annual recording in the Arctic. These time series are restricted to a handful of sites, including Svalbard (e.g., van der Wal & Stien 2014), the Norwegian mainland (e.g., Soininen et al. 2018), Greenland (e.g., Westergaard-Nielsen et al. 2017), the Canadian high Arctic (e.g., Hudson & Henry 2009) and the U.S. Arctic (e.g., Wahren et al. 2005). In most cases, the vegetation monitoring at these sites is integrated with monitoring of other ecosystem components and environmental conditions, as well as climate. The International Tundra Experiment (ITEX) and other relevant networks, contribute valuable information to long-term studies of plants and their responses to climate change. Great variability in the frequency and duration of measurements occurs within these networks. Only recently have ecosystem-based monitoring programmes been developed in some of the Arctic states, such as Norway and Greenland (Ims et al. 2013).

Whilst used over large areas, the resolution of the satellite imagery and computational and analytical power sets limits on what kind of information is available for the largest scale, such as Arctic-wide studies. Currently, circumpolar studies use 250 metres or larger units in the analysis. This scale limits the parameters to compound measures such as vegetation indices that give no or little information about which vegetation type is changing. Vegetation models can be used for spatial studies of vegetation change, but with the same limitations regarding spatial resolution, precision, and accuracy as with satellite imagery.

3.1.3.1 Recommended Revisions to FECs and Attributes

Based on experience obtained from producing the START, there are no revisions recommended for vegetation FECs. The FECs in themselves cover a broad spectrum of topics but are largely lacking in monitoring (see below).

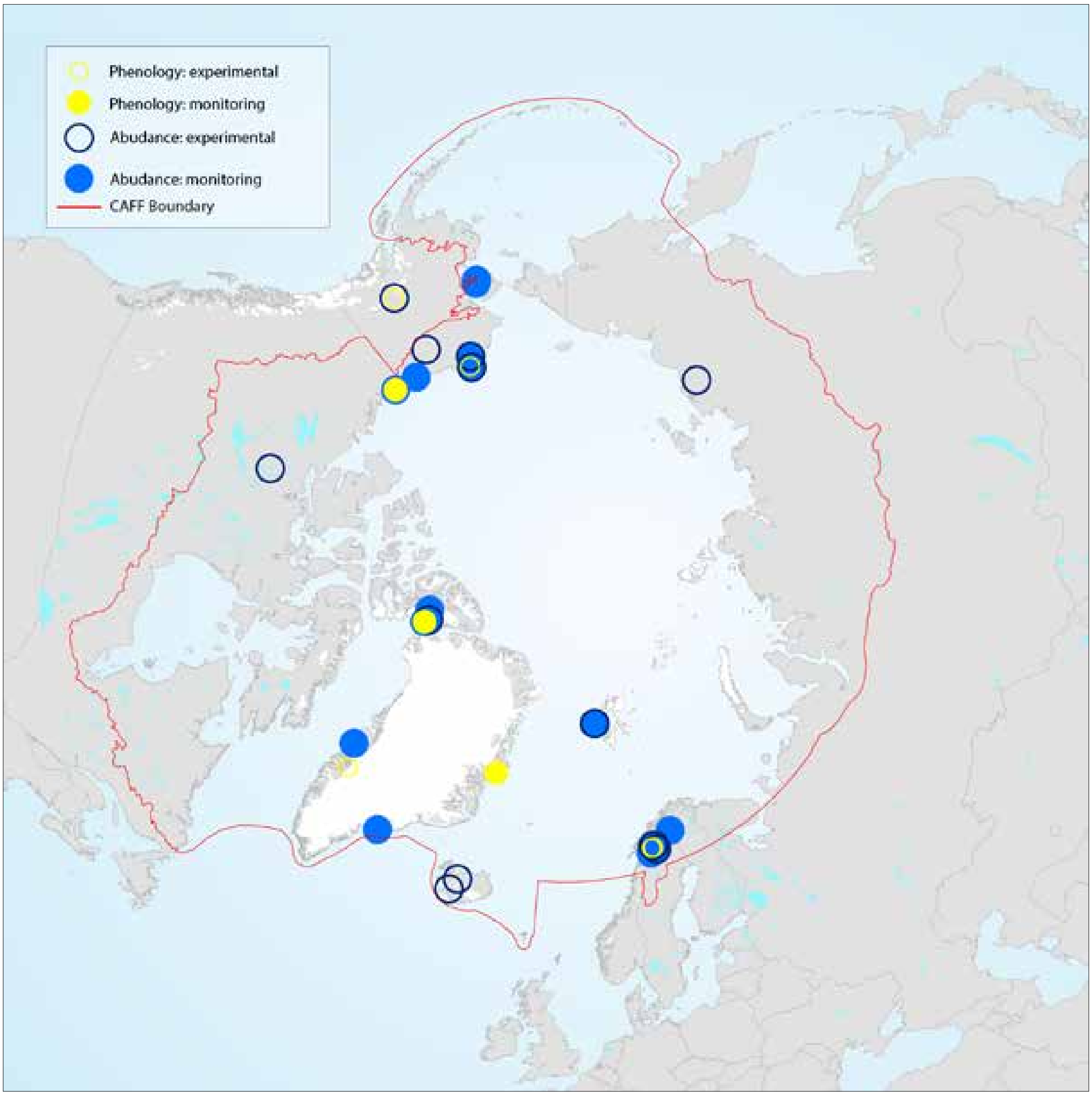
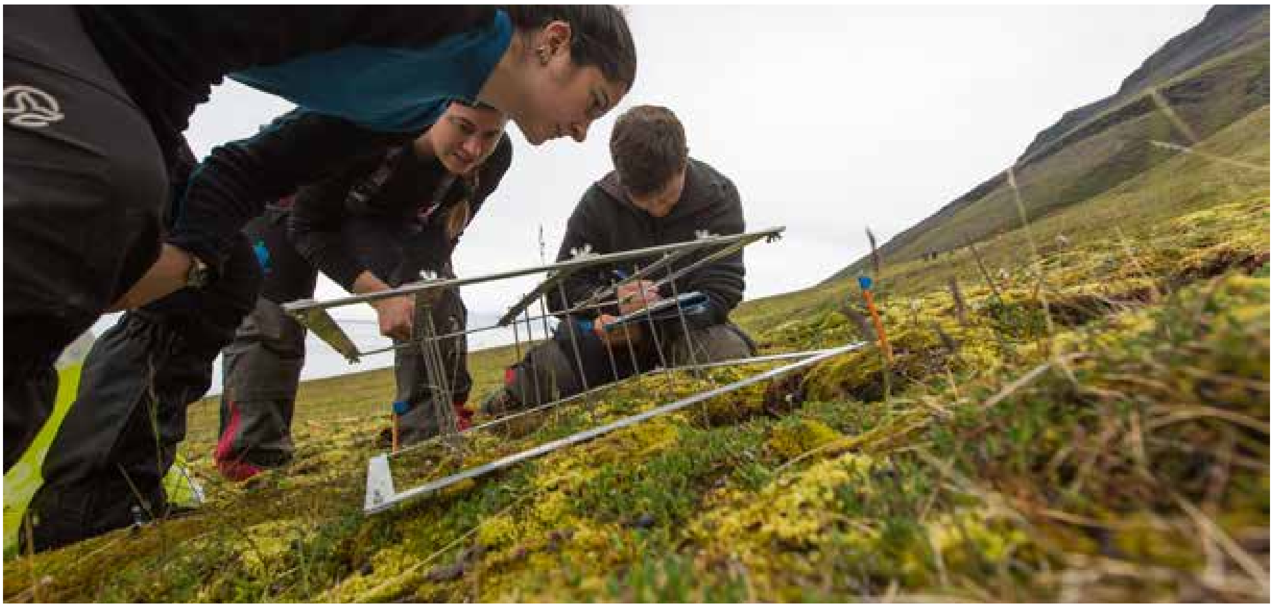


Figure 3-5. Geographic distribution of long-term studies or monitoring sites of abundance and phenology of plants in the Arctic. Modified from Bjorkman et al. 2020.



Vegetation monitoring, Svalbard, Norway.
Photo: Lawrence Hislop

3.1.4 CONCLUSIONS AND KEY FINDINGS

Many of the physical and ecological parameters that drive terrestrial vegetation have experienced significant change over the past decades; for example, seasonal land surface temperature has increased significantly since 2001 (Jenkins et al. 2020). These rapid changes in the physical environment highlight the importance of a systematic approach to monitoring across the Arctic, including ecological responses associated with Arctic vegetation.

The plant productivity FEC attribute measured with remote sensing, had a general positive trend from the early 1980s to 2017. Some relatively large regions in the Arctic showed a negative trend, although the reasons are not fully understood. Plot-based studies of the 'community composition' and 'abundance' attributes show large variation among sites and species in the direction and magnitude of change. In the majority of the studies, abundance of different plant groups remained stable. Amongst the responsive groups, shrub and graminoid abundance often increased, while lichen abundance commonly decreased over time. Shrub abundance increased more often in southern parts of the tundra than in the northern parts. Experimental warming studies and observational long-term studies show somewhat different trends. Invasive plant species are largely confined to human settlements, and, when observed in natural habitats, have been found to disappear in less than a decade.

Climate is one of the most important environmental drivers for vegetation. Plant abundance is closely linked to summer temperature and variable climate is reflected in variable above ground biomass. In some regions, damage to vegetation from the increasingly mild winters and especially ground-ice formation has been reported. Effects of climate can be modified by biotic interactions. Changes to vegetation occur in the context of each ecosystem and there can be strong local effects of environmental drivers on vegetation even if averaged trends may seem heterogenous or stable.

Key Findings

- There is considerable spatial and temporal heterogeneity in vegetation development in the Arctic; some areas show increases in production and abundance, while others are decreasing or remaining stable. However, remote sensing shows that since 2001 there has been a significant increase in vegetation productivity across the entire Arctic.
- Responses to climate change include an increase in the abundance of shrubs and grasses and a decrease in lichens and mosses.
- Non-native plant species are increasingly moving into the Arctic and are largely found localised in areas with human activity. Between 2013 and 2019 the numbers of non-native plants detected increased by 80%, to 341. Most are still non-invasive.
- Experimental warming has shown that green-up and flowering can happen earlier. This trend has also been found in many plot-based monitoring studies, although not as conclusively. Remote sensing indicates an earlier start of the season in the most southern and middle latitude regions of the Arctic.
- There is a need for more long-term monitoring on all FECs.

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

3.2 ARTHROPODS

Authors:
Stephen J. Coulson, Mark A.K. Gillespie and Toke T. Høye

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

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

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

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

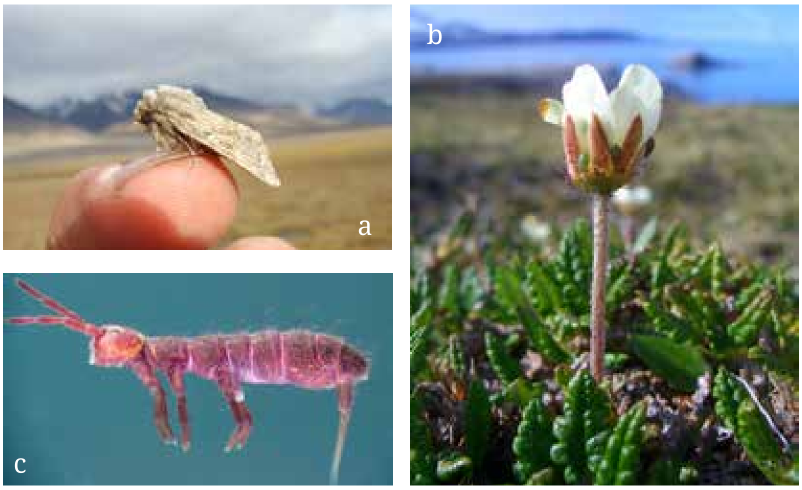


Figure 3-6. Examples of arthropod fauna of the Arctic.

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

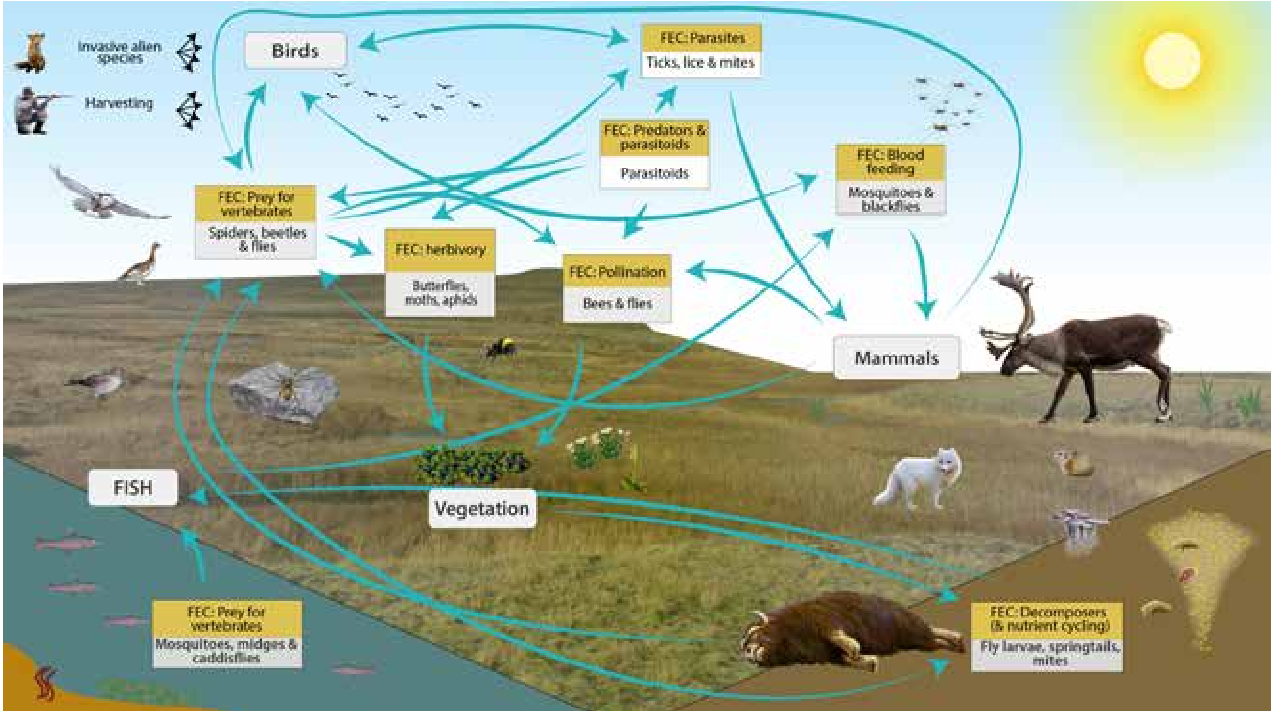


Figure 3-7. Conceptual model of the FECs and processes mediated by more than 2,500 species of Arctic arthropods known from Greenland, Iceland, Svalbard, and Jan Mayen.

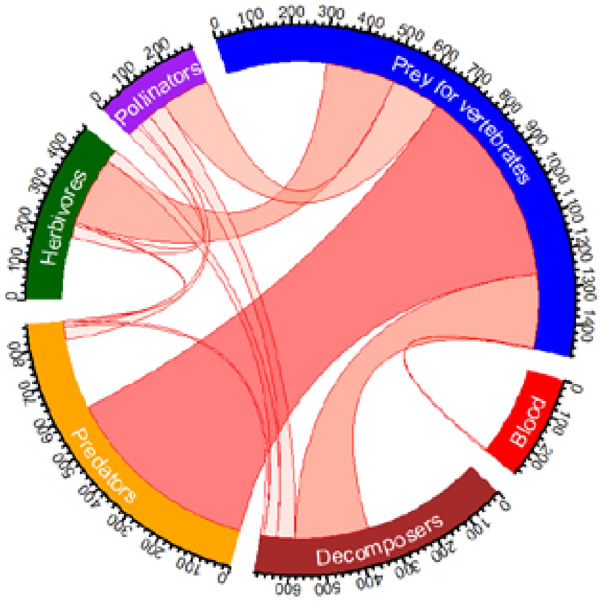


Figure 3-8. Chord diagram illustrating the multi-functionality of Arctic arthropods.

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

3.2.1 PATTERNS AND TRENDS OF FECS AND THEIR ATTRIBUTES

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

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

3.2.1.1 Pollinators

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

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

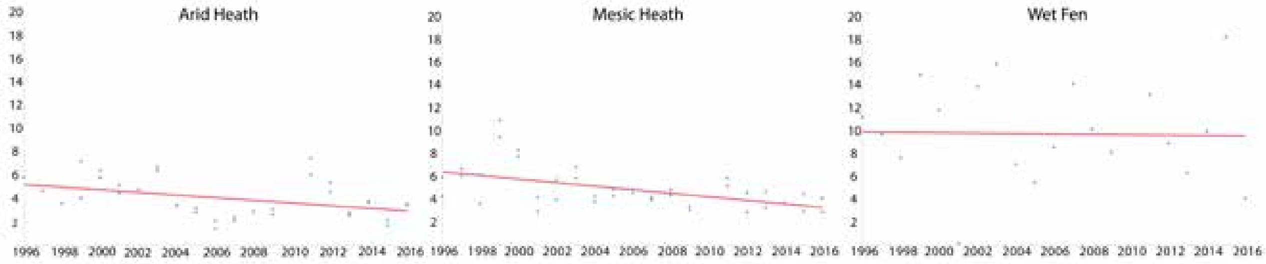


Figure 3-9. Temporal trends of arthropod abundance for three habitat types at Zackenberg Research Station, Greenland, 1996–2016. Data are grouped as the FEC 'arthropod prey for vertebrates' and separated by habitat type. Solid lines indicate significant regression lines at the p<0.05. Modified from Gillespie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

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

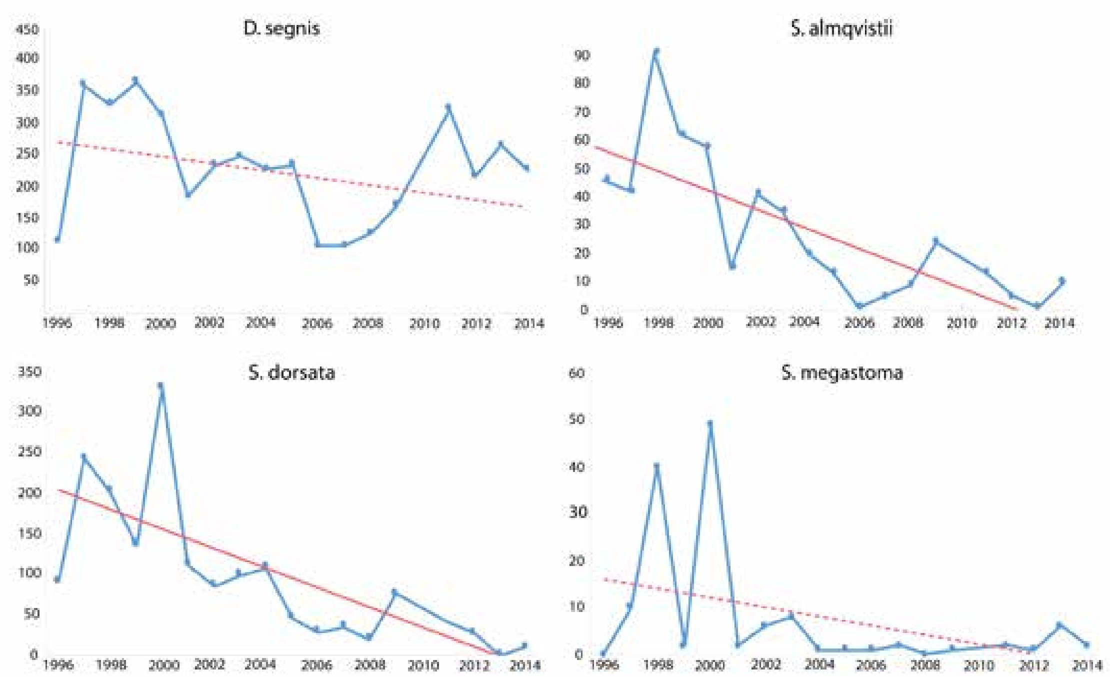


Figure 3-11. Trends in four muscid species occurring at Zackenberg Research Station, east Greenland, 1996–2014. Declines were detected in several species over five or more years. Significant regression lines drawn as solid. Non-significant as dotted lines. Modified from Gillespie et al. 2020a. (in the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

3.2.1.2 Decomposers

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

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

3.2.1.3 Herbivores

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

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

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

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

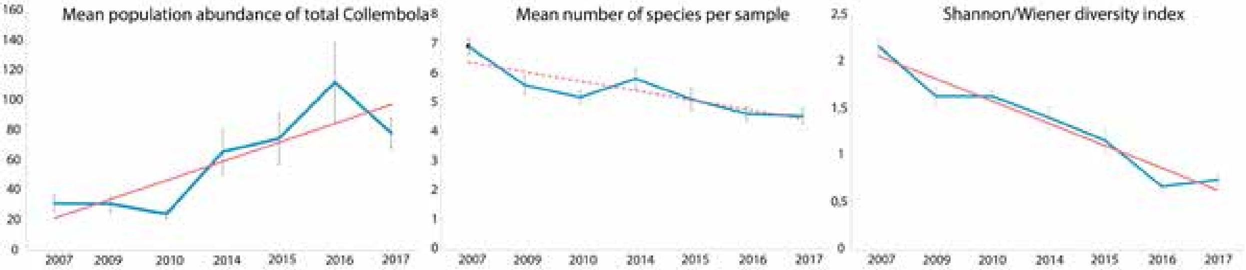


Figure 3-13. Population trends for springtails in Empetrum nigrum plant community in Kobbefjord, Greenland, 2007–2017. (a) mean population abundance of total Collembola in individuals per square metre, (b) mean number of species per sample, and (c) Shannon-Wiener diversity index per sample. Vertical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

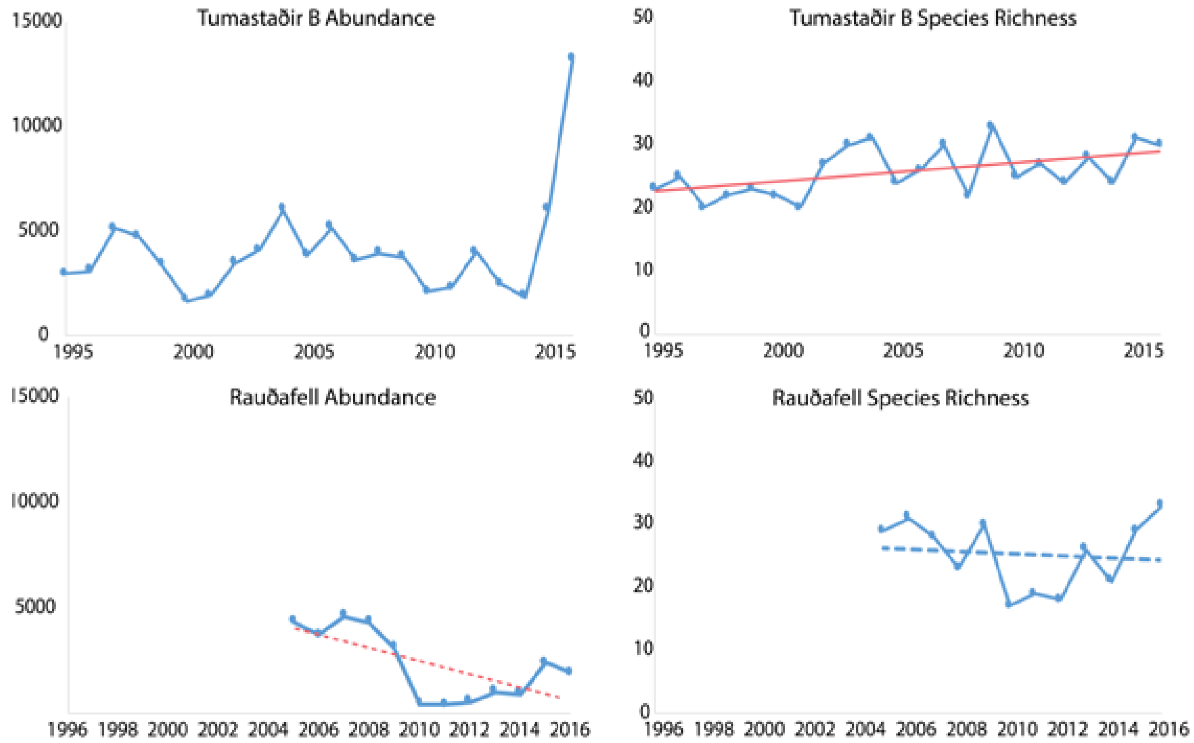


Figure 3-14. Trends in total abundance of moths and species richness, from two locations in Iceland, 1995–2016. Trends differ between locations. The solid and dashed straight lines represent linear regression lines which are significant or non-significant, respectively. Modified from Gillespie et al.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

3.2.1.4 Prey for Vertebrates

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

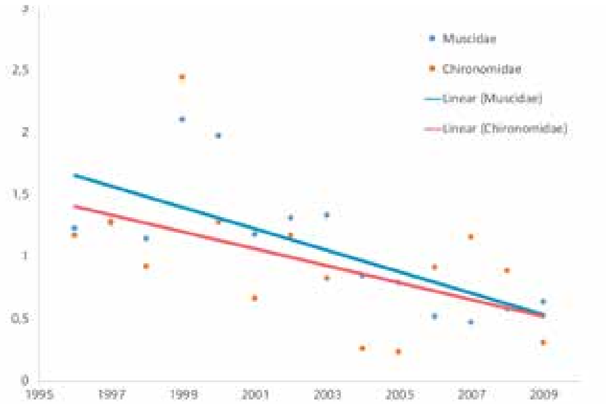


Figure 3-16. Temporal trends of arthropod abundance, 1996–2009. Estimated by the number of individuals caught per trap per day during the season from four different pitfall trap plots, each consisting of eight (1996–2006) or four (2007–2009) traps. Modified from Høye et al. 2013.

3.2.1.5 Blood-feeding

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

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

3.2.1.6 Predators and Parasitoids

As part of an intermediate trophic level of Arctic food webs, this group is critical for community dynamics and is likely to be more responsive to changes in lower trophic levels than vertebrate predators. This FEC was not initially defined in the CBMP–Terrestrial Plan, however, Gillespie et al. 2020a, highlighted the necessity of including it as a distinct container for some arthropod species (Figure 3-18). While predatory arthropods make up a large proportion of the 'prey for vertebrates' FEC, less knowledge exists regarding arthropod predatory behaviour than for vertebrate prey selectivity.

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

3.2.1.7 Distribution of Species

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

3.2.2 EFFECT OF DRIVERS ON FECS AND THEIR ATTRIBUTES

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

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

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

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

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

3.2.3 COVERAGE AND GAPS IN KNOWLEDGE AND MONITORING

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

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

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

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

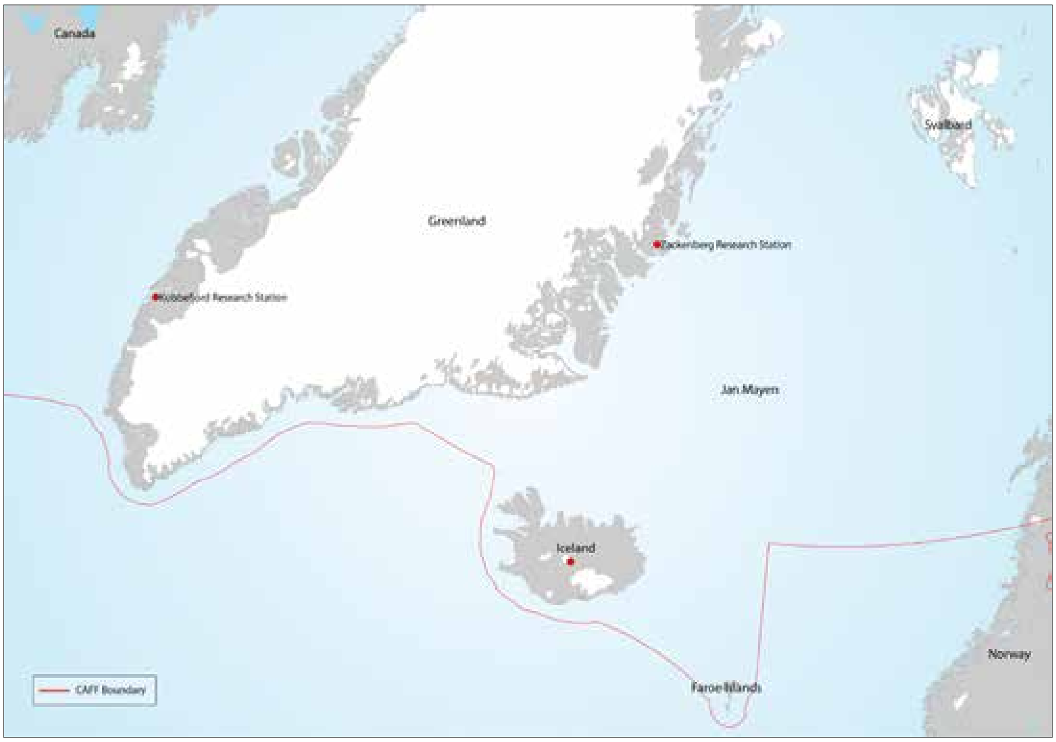


Figure 3-19. Location of long-term arthropod monitoring sites in Greenland and moth monitoring in Iceland Modified from Gillespie et al. 2020a

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

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

3.2.3.1 Recommended Revisions to FECs and Attributes

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

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

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

3.2.4 CONCLUSIONS AND KEY FINDINGS

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

Photo: Micha Mylmages/Shutterstock.com

Key Findings

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

Red knot. Photo: Danita Delimont/Shutterstock.com

3.3 BIRDS

There are few true Arctic specialist birds that remain in the Arctic throughout their annual cycle. They include the willow and rock ptarmigan (Lagopus lagopus and L. muta), gyrfalcon (Falco rusticolus), snowy owl (Bubo scandiacus), Arctic redpoll (Carduelis hornemanni) and northern raven (Corvus corax)—a cosmopolitan species with resident populations in the Arctic. All other terrestrial Arctic-breeding bird species migrate to warmer regions during the northern winter, connecting the Arctic to all corners of the globe. Hence, their distributions are influenced by the routes they follow. These distinct migration routes are referred to as flyways and are defined by a combination of ecological and political boundaries and differ in spatial scale. The CBMP refers to the traditional four north–south flyways, in addition to a circumpolar flyway representing the few species that remain largely within the Arctic year-round (Figure 3-20).

The CBMP–Terrestrial Plan identifies five FECs for monitoring terrestrial birds; herbivores, insectivores, carnivores, omnivores and piscivores. Due to their migratory nature, a wider range of drivers, from both within and outside the Arctic, affect birds and their associated FEC attributes compared to other terrestrial FECs. Figure 3-21 illustrates a conceptual model for Arctic terrestrial

Lead authors:
Knud Falk, Paul A. Smith, Casey T. Burns

Contributing Authors:
Anthony D. Fox, Alastair Franke, Eva Fuglei, Karl O. Jacobsen, Richard B. Lanctot, James O. Leafloor, Laura McKinnon, Hans Meltofte, Adam C. Smith, Mikhail Soloviev, Aleksandr A. Sokolov

birds that includes examples of FECs and key drivers.

This summary is based on Smith et al. (2020) which provides the most recent and comprehensive analysis—and literature references—of status and trends of Arctic terrestrial bird FECs. Additional information is drawn from Fuglei et al. (2020), Franke et al. (2020), Fox & Leafloor (2018) and references therein. For information not included in these papers, key references are provided. This report uses international English names for bird species (Gill & Donsker 2019). Scientific names are found in Table 3-2.

3.3.1 PATTERNS AND TRENDS OF FECS AND THEIR ATTRIBUTES

While over 200 species of birds are known to breed regularly in the Arctic, this assessment focuses on 88 terrestrial species (Table 3-2). The list excludes seabirds and some sea ducks that are included under the CBMP Arctic Marine Biodiversity Monitoring Plan (Gill et al. 2011) but includes waders/shorebirds and geese that are also partly considered under the Arctic Coastal Biodiversity Monitoring Plan (CAFF 2019a). The CBMP–Terrestrial Plan FECs are; insectivores (waders, passerines), carnivores (birds of prey), herbivores (geese, swans, ptarmigan) and omnivores (cranes, ducks, raven). For some analyses, species are grouped into foraging guilds, which are equivalent to the CBMP–Terrestrial Plan FECs with the addition of piscivores which are included with the other omnivores in the CBMP FECs. Status and trends are reported for both the FECs and taxonomic groupings (waterfowl, waders, other water birds, land birds) (Table 3 2).

Although the CBMP–Terrestrial Plan defines desirable monitoring attributes for the FECs, only some are widely or regularly monitored, including CBMP's essential attributes; abundance, demographic parameters and distribution for herbivores, carnivores, and insectivores (Figure 3-22).

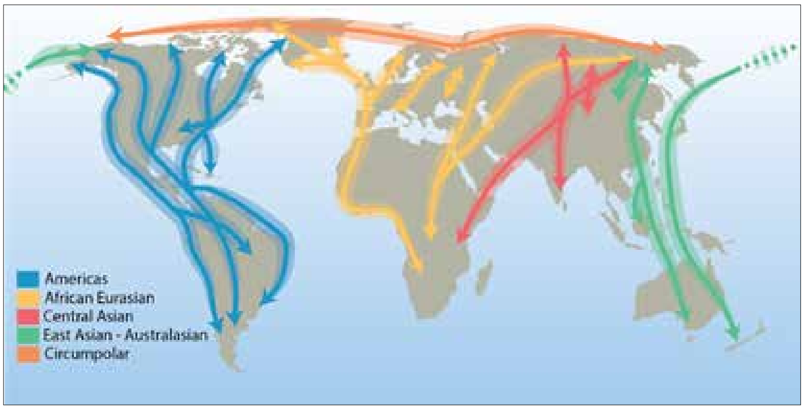


Figure 3-20. Simplified illustration of the global migratory bird flyways.

Modified based on Arctic Migratory Birds Initiative and Deinet et al. (2015).

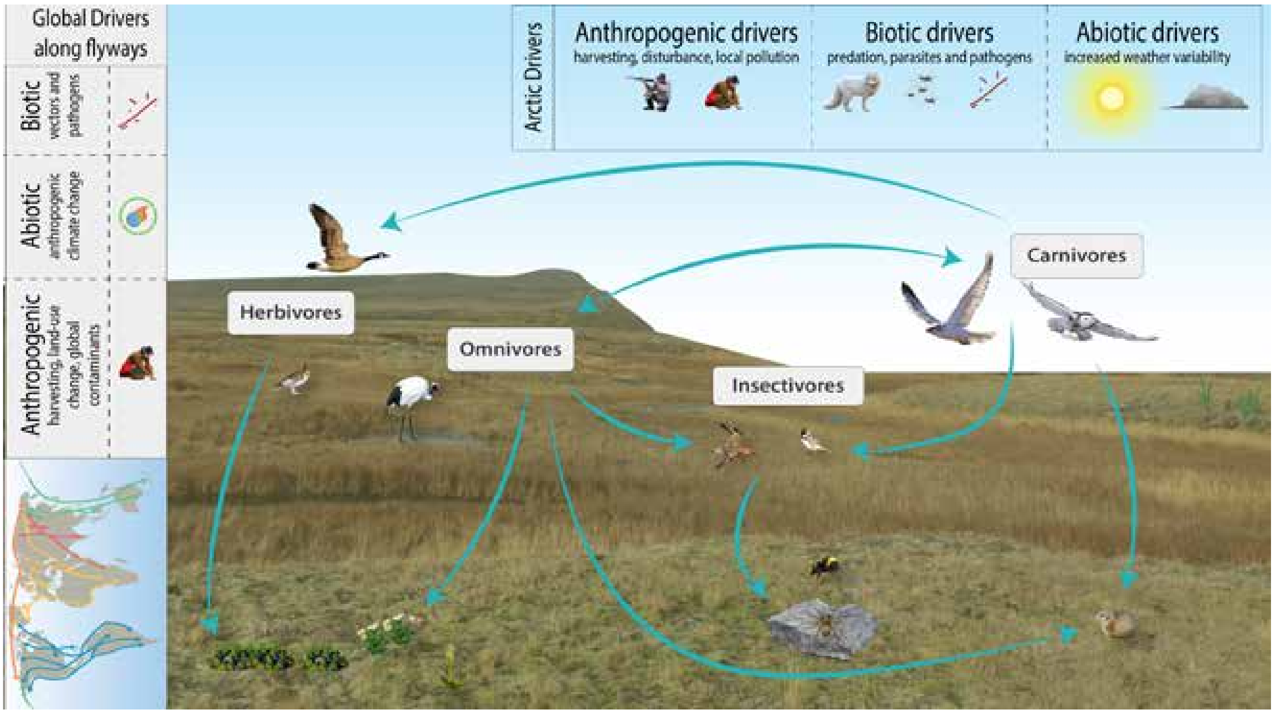


Figure 3-21. Conceptual model for Arctic birds, illustrating examples of FECs and key drivers at different scales.

Table 3-2. Trends in Arctic terrestrial bird populations by flyway. Birds are included in this table if the (sub)species has 50% or more of their breeding range confined to the Arctic or is known to occupy the Arctic and is non-migratory; for species on the global red list (IUCN 2012a), respective IUCN categories are indicated in red font after species names. Redrawn from Smith et al. (2020).

TREND COLOUR CODES	
🟩 Increasing	🟥 Decreasing
🟦 Increasing/Stable	🟪 Mixed
🟨 Stable	▨ Unknown
🟧 Stable/Decreasing	⬜ Out of range

FOCAL ECOSYSTEM COMPONENT^ OR FORAGING GUILD	COMMON NAME	SCIENTIFIC NAME	GROUP	NUMBER OF POPULATIONS BY FLYWAY*				
				AMERICAS	EAST ASIAN - AUSTRAL-ASIAN	CENTRAL ASIA	AFRICA-EURASIA	CIRCUM-POLAR
Herbivore	Willow Ptarmigan	Lagopus lagopus	Landbird	🟥 1	🟥 1	🟥 1	🟪 1	🟪 1
Herbivore	Rock Ptarmigan	Lagopus muta	Landbird	▨ 1	🟪 1	🟪 1	🟪 1	🟪 1
Herbivore	Greater White-fronted Goose	Anser albifrons	Waterfowl	🟪 3		🟪 3	🟪 5	
Herbivore	Pink-footed Goose	Anser brachyrhynchus	Waterfowl				🟩 2	
Herbivore	Lesser White-fronted Goose (VU)	Anser erythropus	Waterfowl			🟥 2	🟥 2	
Herbivore	(Tundra) Bean Goose	Anser fabalis (rossicus/serriristris)	Waterfowl		🟨 3	🟥 1	🟪 2	
Herbivore	Brant Goose	Branta bernicla	Waterfowl	🟨 2	🟨 2		🟩 3	
Herbivore	Cackling Goose	Branta hutchinsii	Waterfowl	🟪 4				
Herbivore	Barnacle Goose	Branta leucopsis	Waterfowl				🟩 3	
Herbivore	Red-breasted Goose (VU)	Branta ruficollis	Waterfowl				🟩 1	
Herbivore	Snow Goose	Chen caerulescens	Waterfowl	🟩 4				
Herbivore	Emperor Goose (NT)	Anser (Chen) canagica	Waterfowl		🟨 1			
Herbivore	Ross's Goose	Chen rossii	Waterfowl	🟩 1				
Herbivore	Tundra Swan	Cygnus columbianus	Waterfowl	🟩 2	🟩 1		🟦 2	
Insectivore	Red-throated Pipit	Anthus cervinus	Landbird		🟨 1		🟨 1	
Insectivore	Buff-bellied Pipit	Anthus rubescens	Landbird	🟥 1	🟥 1	🟥 1		
Insectivore	Lapland Longspur	Calcarius lapponicus	Landbird	🟩 1	🟥 1	🟥 1	🟥 1	
Insectivore	Smith's Longspur	Calcarius pictus	Landbird	🟩 1				
Insectivore	Common Redpoll	Carduelis flammea	Landbird	🟩 1	🟩 1	🟩 1	🟩 1	
Insectivore	Arctic Redpoll	Carduelis hornemanni	Landbird	▨ 1	▨ 1	▨ 1	▨ 1	▨ 1
Insectivore	Little Bunting	Emberiza pusilla	Landbird		🟨 1	🟨 1	🟨 1	
Insectivore	Horned Lark	Eremophila alpestris	Landbird	🟥 1	🟥 1	🟥 1	🟥 1	

FOCAL ECOSYSTEM COMPONENT^ OR FORAGING GUILD	COMMON NAME	SCIENTIFIC NAME	GROUP	NUMBER OF POPULATIONS BY FLYWAY*				
				AMERICAS	EAST ASIAN - AUSTRAL-ASIAN	CENTRAL ASIA	AFRICA-EURASIA	CIRCUM-POLAR
Insectivore	Citrine Wagtail	Motacilla citreola	Landbird			1	1	
Insectivore	Savannah Sparrow	Passerculus sandwichensis	Landbird	1				
Insectivore	McKay's Bunting	Plectrophenax hyperboreus	Landbird	1	1			
Insectivore	Snow Bunting	Plectrophenax nivalis	Landbird	1	1	1	1	
Insectivore	Siberian Accentor	Prunella montanella	Landbird		1	1		
Insectivore	American Tree Sparrow	Spizella arborea	Landbird	1				
Insectivore	Surfbird	Aphriza virgata	Wader	1				
Insectivore	Ruddy Turnstone	Arenaria interpres	Wader	2	1	1	3	
Insectivore	Black Turnstone	Arenaria melanocephala	Wader	1				
Insectivore	Sharp-tailed Sandpiper	Calidris acuminata	Wader		1			
Insectivore	Sanderling	Calidris alba	Wader	1	1	1	2	
Insectivore	Dunlin	Calidris alpina	Wader	2	4	1	4	
Insectivore	Baird's Sandpiper	Calidris bairdii	Wader	1				
Insectivore	Red Knot (NT)	Calidris canutus	Wader	2	2		2	
Insectivore	Curlew Sandpiper (NT)	Calidris ferruginea	Wader		1	1	2	
Insectivore	White-rumped Sandpiper	Calidris fuscicollis	Wader	1				
Insectivore	Stilt Sandpiper	Calidris himantopus	Wader	1				
Insectivore	Purple Sandpiper	Calidris maritima	Wader	1			4	
Insectivore	Western Sandpiper	Calidris mauri	Wader	1				
Insectivore	Pectoral Sandpiper	Calidris melanotos	Wader	1	1			
Insectivore	Little Stint	Calidris minuta	Wader			1	2	
Insectivore	Least Sandpiper	Calidris minutilla	Wader	1				
Insectivore	Rock Sandpiper	Calidris ptilocnemis	Wader	3	3			
Insectivore	Ruff	Calidris pugnax	Wader			1	2	

FOCAL ECOSYSTEM COMPONENT^ OR FORAGING GUILD	COMMON NAME	SCIENTIFIC NAME	GROUP	NUMBER OF POPULATIONS BY FLYWAY*				
				AMERICAS	EAST ASIAN - AUSTRAL-ASIAN	CENTRAL ASIA	AFRICA-EURASIA	CIRCUM-POLAR
Insectivore	Semipalmated Sandpiper (NT)	Calidris pusilla	Wader	3				
Insectivore	Red-necked Stint (NT)	Calidris ruficollis	Wader		1			
Insectivore	Temminck's Stint	Calidris temminckii	Wader		1	1	2	
Insectivore	Great Knot (EN)	Calidris tenuirostris	Wader		1	2	1	
Insectivore	Common Ringed Plover	Charadrius hiaticula	Wader	1			3	
Insectivore	Semipalmated Plover	Charadrius semipalmatus	Wader	1				
Insectivore	Eurasian Dotterel	Eudromias morinellus	Wader			1	1	
Insectivore	Spoon-billed Sandpiper (CR)	Eurynorhynchus pygmeus	Wader		1			
Insectivore	Broad-billed Sandpiper	Limicola falcinellus	Wader		1		1	
Insectivore	Long-billed Dowitcher	Limnodromus scolopaceus	Wader	1				
Insectivore	Hudsonian Godwit	Limosa haemastica	Wader	2				
Insectivore	Bar-tailed Godwit (NT)	Limosa lapponica	Wader		2		3	
Insectivore	Eskimo Curlew (CR)	Numenius borealis	Wader	1				
Insectivore	Whimbrel	Numenius phaeopus	Wader	2	1	1	4	
Insectivore	Bristle-thighed Curlew (VU)	Numenius tahitiensis	Wader		1			
Insectivore	Red Phalarope	Phalaropus fulicarius	Wader	2			1	
Insectivore	Red-necked Phalarope	Phalaropus lobatus	Wader	1	1		1	
Insectivore	European Golden Plover	Pluvialis apricaria	Wader				3	
Insectivore	American Golden Plover	Pluvialis dominica	Wader	1				
Insectivore	Pacific Golden Plover	Pluvialis fulva	Wader	1	1	1		
Insectivore	Grey Plover	Pluvialis squatarola	Wader	3	1	1	2	
Insectivore	Spotted Redshank	Tringa erythropus	Wader			2	2	
Insectivore	Buff-breasted Sandpiper (NT)	Tryngites subruficollis	Wader	1				
Carnivore	Snowy Owl (VU)	Bubo scandiacus	Landbird	1	1	1	1	1

FOCAL ECOSYSTEM COMPONENT^ OR FORAGING GUILD	COMMON NAME	SCIENTIFIC NAME	GROUP	NUMBER OF POPULATIONS BY FLYWAY*				
				AMERICAS	EAST ASIAN - AUSTRAL-ASIAN	CENTRAL ASIA	AFRICA-EURASIA	CIRCUM-POLAR
Carnivore	Rough-legged Buzzard	Buteo lagopus	Landbird	2	2	2	2	
Carnivore	Gyrfalcon	Falco rusticolus	Landbird	1	1	1	1	1
Carnivore	Peregrine Falcon	F. peregrinus tundrius & calidus	Landbird	1	1	1	1	
Carnivore	Long-tailed Jaeger	Stercorarius longicaudus	Waterbird	1	1		1	
Carnivore	Pomarine Jaeger	Stercorarius pomarinus	Waterbird	1	1	1	1	
Omnivore	Northern Raven	Corvus corax	Landbird	1	1	1	1	1
Omnivore	Siberian Crane (CR)	Grus leucogeranus	Waterbird		1	1	1	
Omnivore	Ross's Gull	Rhodostethia rosea	Waterbird	1	1			1
Omnivore	Greater Scaup	Aythya marila	Waterfowl	1	1		2	
Omnivore	Long-tailed Duck (VU)	Clangula hyemalis	Waterfowl	1	1		2	
Omnivore	Common Scoter	Melanitta nigra	Waterfowl				1	
Omnivore	Steller's Eider (VU)	Polysticta stelleri	Waterfowl		1		1	
Omnivore	Spectacled Eider (NT)	Somateria fischeri	Waterfowl		1			
Omnivore	King Eider	Somateria spectabilis	Waterfowl	2	1		1	
Piscivore	Yellow-billed Loon (NT)	Gavia adamsii	Waterbird	1	1			
Piscivore	Black-throated Loon	Gavia arctica	Waterbird		1		2	
Piscivore	Pacific Loon	Gavia pacifica	Waterbird	1	1			
Piscivore	Red-throated Loon	Gavia stellata	Waterbird	1	1		2	
			TOTAL NUMBER OF POPULATIONS BY FLYWAY*	**83**	**64**	**40**	**95**	**7**

* - Note that bird population totals on this figure are not additive by species due to instances of populations that share multiple flyways, or species that are not divided into populations, but are present in two or more flyways. In these cases, a ‘1’ was inserted into all columns that share a population or a species that is not split into populations.

^ - See Arctic Terrestrial Biodiversity Monitoring Plan (Christensen et al. 2013) for more information on Focal Ecosystem Components

Migrant insectivore passerine: Lapland longspur. Photo: Knud Falk

Resident herbivore: rock ptarmigan. Photo: Knud Falk

Resident carnivore: gyrfalcon. Photo: Knud Falk

Migrant herbivore: snow geese. Photo: Martin Robarts/WCS

Migrant insectivore: dunlin with geolocator for migration tracking. Photo: Ryan Askren/USGS

Migrant piscivore: yellow-billed loon. Photo: Bob Wick/BLM

Figure 3-22. Example of Arctic terrestrial bird species and their FEC/foraging guilds.

3.3.1.1 Herbivores

In Arctic tundra habitats, geese are the dominant herbivores—ptarmigan and tundra swans are the other herbivorous species. An estimated 39 million wild geese belonging to 68 populations of 15 species use Arctic habitats for part of their lifecycle. Of these, 42 populations of 11 species are primarily Arctic tundra birds. The 68 populations are distributed throughout all four north-south flyways, with the greatest diversity in the African–Eurasian and Americas flyways.

The Arctic 'white' geese (genus ***Chen***) of North America are most numerous—17.1 million individuals in six populations. All have increased in abundance and distribution over the last decade mostly due to changing conditions (e.g., increased access to agricultural food) on stop-over and wintering grounds, with several considered overabundant by management authorities in Canada and the United States (see Box 3-1). The Arctic taxa of 'black' geese (genus ***Branta***) number approximately 6.1 million individuals in 15 populations from four species. All but one of these populations have been stable or increasing over the long term (more than 30 years). The Arctic 'grey' geese (genus ***Anser***) comprise 21 populations of four species, totalling approximately 6.4 million individuals. Of these, seven populations have declined in abundance over the long term, seven have increased and the remaining five were stable.

Rock and willow ptarmigan belong to the Circumpolar Flyway and are resident across the Arctic; although the latter occurs mainly outside the Arctic (Birdlife International 2016a, 2016b). Both are important harvested species and are prey species for endemic Arctic predators. No reliable global population estimates exist, however, crude estimates are 5 to 25 million rock ptarmigan and 10 to 30 million willow ptarmigan. Although ptarmigan population sizes are poorly understood, variation in relative abundance is monitored across the Arctic (Fuglei et al., 2020). Rock ptarmigan showed an overall negative trend in Iceland (between 1980 and 2015) and Greenland (between 1995 and 2017), a positive trend in Svalbard (between 2000 and 2017) and no significant trend in Alaska (between 1978 and 2016). For willow ptarmigan, a negative trend was found in eastern Russia, while northern Fennoscandia and North America[4] showed no significant trends. Some periods of population cycles—3 to 6 year 'short' and 9 to 12 year 'long' cycles—were evident in both species, with cyclicity changing through time. Collapses and emergences of cycles over time within the same populations seems to be emergent properties of ptarmigan population dynamics in the Arctic.

---

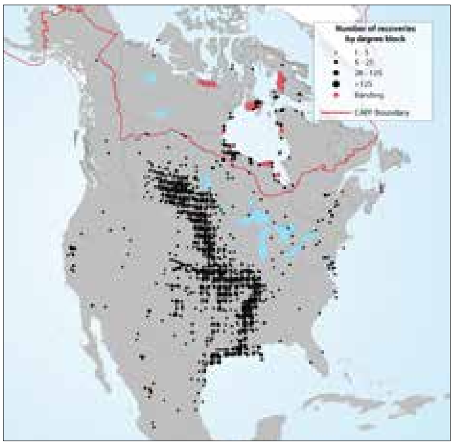
[4] Data for North American includes the island of Newfoundland in Canada which is outside the Arctic.

BOX 3-1. MIGRATING GEESE; CONTRASTING EXAMPLES

Geese are the most abundant Arctic avian herbivore, with many species, subspecies and sub-populations distributed across the circumpolar Arctic (see Fox & Leafloor 2018). Arctic goose populations provide a good example of the variation within a FEC in level of knowledge, population trend, spatial distribution, and influence of external drivers outside the Arctic.

In North America, mid-continent lesser snow geese have been monitored since 1955 using midwinter counts on the wintering grounds in the southern U.S. and from the mid–1960s until 2013 using photographic surveys of known Arctic breeding grounds. Most recently, abundance has been estimated using mark-recapture methods. The population increased from less than a million adult birds in 1955 to 12.6 million on average between 2006 and 2015. It was legally designated as overabundant in 1999, allowing for spring harvesting of the population (Koons et al. 2013). The rapid population increase is largely a result of increased survival in response to increased access to food in agricultural areas in winter. It follows an increased use of nitrogen fertilizers that resulted in increased yields of rice, corn, and wheat on the wintering grounds and along the flyways (Abraham et al. 2005).

In contrast, the lesser white-fronted goose in the Palaearctic is distributed in many small, distinct breeding and moulting sites (some yet unknown) across the vast Russian tundra with sub-populations using different migration flyways and facing highly diverse conditions in relatively few distinct wintering sites. The eastern main population almost exclusively winters within the Yangtze River floodplain in China, where the birds are increasingly concentrated at one single site. Such concentration makes the population extremely vulnerable to local land management; a risk recognised by CAFF's Arctic Migratory Birds Initiative (AMBI, CAFF 2019b). Population trends are based on sparse data, but it is thought that as many as 65,000 geese wintered in China in late 1980s, while winter counts from 2002 to 2009 showed a maximum of 18,000 individuals.



Mid-continent lesser snow goose; red areas (ringing sites) on the map above are approximate breeding areas, black dots are ring recoveries; inserted graph shows midwinter counts in the southern U.S., 1955–2016.

Lesser white-fronted goose breeding, moulting and staging areas; blue arrows indicate the inferred routes taken by the western main and eastern main populations, respectively; green and yellow lines indicate migration routes of the small Fennoscandian population (all examples from CAFF 2018).

3.3.1.2 Insectivores

At the species level, Arctic terrestrial birds are dominated by waders, comprising 41 of the 88 species (47%). When waders and insectivorous land birds are combined into an insectivore guild, the guild is clearly dominant across all flyways. Several small passerine species have distributions that extend across the entire circumpolar Arctic and the five species within this guild with the largest population sizes are all passerines. The most abundant Arctic terrestrial bird, the Lapland longspur (Figure 3-22) is estimated to have a global population size of approximately 130 million individuals. This is greater than the sum of all non-passerine's species combined.

Most passerine species monitored in the Arctic appear to show stable or increasing abundance over the long-term. However, continuous time series from North American wintering grounds suggests that in the last decade, many passerine species have begun to show declines. There are also observations of declines of insectivorous passerines in some parts of Russia and sharp declines of Lapland longspur populations in Scandinavia over the last 20 years. Despite their ubiquity, the quality of trend information for these species is poor, partly due to difficulties in combining regional trend estimates across their broad and contiguous geographic ranges.

Waders in the Arctic may number up to 50 million individuals with special concentrations on the Arctic coastal plain and the Yukon–Kuskokwim delta of northern and western Alaska, and in the Indigirka, Yana, Kolyma, and Lena Deltas of Russia. Figure 3-23 summarises trends in wader populations.

3.3.1.3 Carnivores

Only four species of birds of prey are considered true Arctic tundra species—snowy owl, gyrfalcon, peregrine falcon, and rough-legged buzzard—and each is distributed broadly across the circumpolar Arctic. The first two are largely Arctic residents belonging to the Circumpolar Flyway (although some move to boreal areas in winter), while the latter two are migratory. Estimates of population size are uncertain. The rough-legged buzzard is the most abundant with an estimated 0.3 to 1 million adult individuals. The peregrine falcon population in the Arctic is estimated to be well over 20,000 pairs (of different subspecies) and the gyrfalcon population is estimated to be fewer than 21,000 pairs. Population size for the snowy owl—a small mammal specialist in the breeding areas, with local breeding densities fluctuating widely in response to cyclic small mammal abundance—has been the subject of debate. In 2013, the population was estimated at 200,000 individuals, subsequently revised to be as low as 28,000 adult individuals (Birdlife International 2017a).

Breeding parameters of gyrfalcons (Barraquand & Nielsen 2018), snowy owls and rough-legged buzzards are strongly linked to prey exhibiting cyclical abundance patterns (i.e., ptarmigan and microtine rodents). In Scandinavia, the rough-legged buzzard population has declined by almost 50% since the 1970s and has been partly decoupled from rodent cycles (Hellström 2014). Populations of both falcon species are considered stable; most low- and sub-Arctic peregrine populations have increased over the past four decades as they recovered from the pesticide-induced population crash,

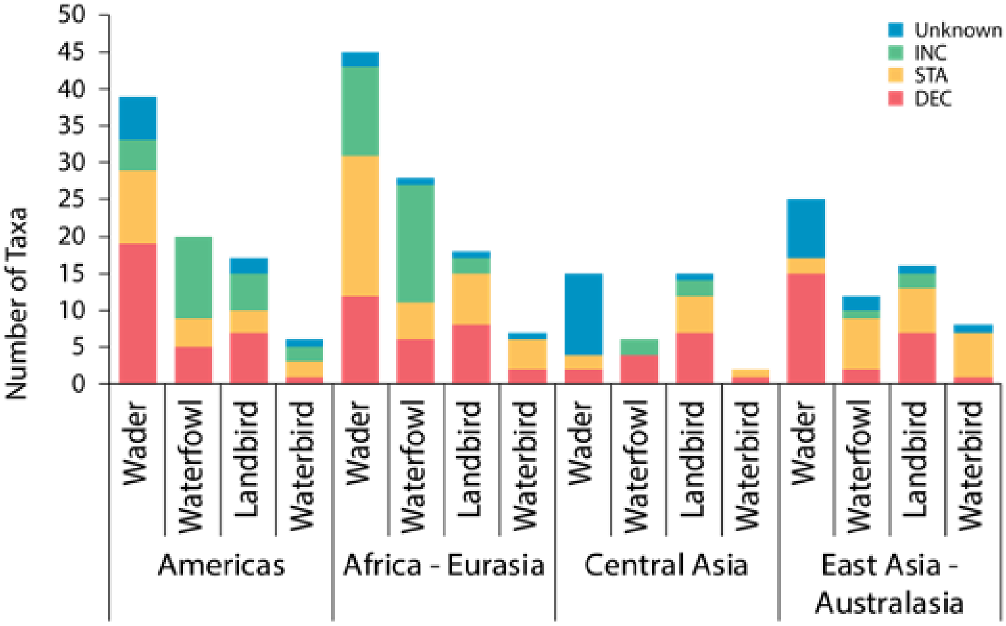


Figure 3-23. Trends in Arctic terrestrial bird population abundance for four taxonomic groupings in four global flyways. Data are presented as total number of taxa (species, subspecies). Modified from Smith et al. 2020.

which reached a low in mid–1970s. As an Arctic resident preying mainly on ptarmigan, ground squirrels and waterfowl, the gyrfalcon was not exposed to pesticide residues that affected the peregrine.

Although the CBMP–Terrestrial Plan includes the northern raven in the carnivore group, it is more accurately described as an omnivore. While no systematic monitoring of raven populations occurs in the Arctic, data indicate populations in North America and Europe have increased, likely due to increased availability of food and nest structures associated with anthropogenic disturbance and decreased persecution (Birdlife International 2017b).

3.3.1.4 Overall Trends

Data were insufficient to assess trends for 14% of Arctic terrestrial bird taxa (species, subspecies, or populations). Excluding those taxa from the analysis, declines were most prevalent in waders (51% of 91 taxa with estimated trends) and least prevalent in waterfowl (25% of 61 taxa). Conversely, increasing population trends were most common in waterfowl (47% of 61 taxa) and least common in waders (15% of 91 taxa) and other waterbirds (13% of 15 taxa) (Figure 3-23).

These broad patterns were generally consistent across flyways, with some exceptions. Fewer waterfowl populations increased in the Central Asian and East Asian–Australasian Flyways. The largest proportion of declining species was among the waders in all but the Central Asian Flyway where the trends of a large majority of waders are unknown. Although declines were more prevalent among waders than other taxonomic groups in both the African–Eurasian and Americas Flyways, the former had a substantially larger number of stable and increasing species than the latter (Figure 3-23).

Regional differences are more pronounced in the insectivore guild (Figure 3-24). Although diversity of waders was moderate in the East Asian–Australasian Flyway, 88% (15 of 17) of taxa with known trends were declining—the largest proportion of any group. Both short-term (the last 15 years) and long-term (more than 30 years) trends were available for 157 taxa. Trends were unchanged over the two time periods for 80% of taxa, improved for 11% and worsened for 9%.

Estimates of quantitative indices of trends within North America are possible due to continuous time series monitoring data for most waterfowl and waders. Current estimates of Arctic-breeding waterfowl abundance tripled relative to the 1980s—largely due to increases in white geese—while Arctic-breeding waders halved in abundance and land birds declined by one-fifth.

While several taxa are declining, 10 species (in some cases subspecies) are currently included on the global Red List (see criteria in IUCN 2012a) as either Critically Endangered—three species, including the possibly extinct Eskimo curlew; Endangered—one species (great knot); or Vulnerable—six species. In addition, nine species are ranked in the less critical category Near Threatened (see the ranking of the species in Table 3-2). Nevertheless, based on current data many waders in North America meet the criteria for various Red List categories but formal designation is pending status review by IUCN (see further in Section 3.5).

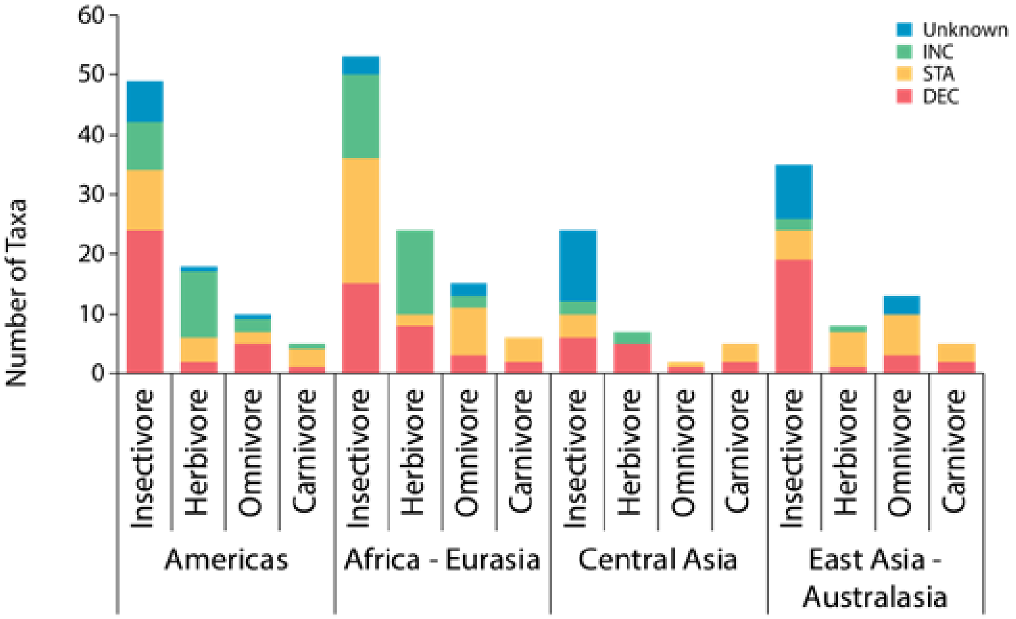


Figure 3-24. Trends in population abundance for four guilds of Arctic terrestrial bird species across flyways. Data is presented as total number of taxa. Modified from Smith et al. 2020.

3.3.2 EFFECT OF DRIVERS ON FECS AND THEIR ATTRIBUTES

Weather and Climate Stressors in the Arctic

Reproductive success of Arctic birds is highly variable across space and time for many reasons. For waders, predation—the primary cause of nest failure—may decrease with increasing latitude, vary with snow conditions, and weather, or change with variation in predator abundance and their preferred small mammal prey. Increased variability in snow cover observed in some of the Arctic breeding areas, as a manifestation of changing climatic conditions, can influence both the timing and the success of breeding efforts of ground-nesting waders. Whatever the underlying cause, recent results suggest declines in reproductive success of Arctic tundra waders since the 1990s, potentially contributing to the documented accelerating population declines. For some top predators, more variable weather during the breeding season, including increased frequency of heavy rain events and massive blackfly outbreaks in warm spells, is considered a contributing factor to reduced breeding success in some Arctic breeding populations of peregrine falcons (Anctil et al. 2014, Franke et al. 2016, Carlzon et al. 2018).

Changes in climate, and the resulting northward shifts in habitats, are expected to result in a corresponding shift in the range of Arctic species. For some bird species in northern regions this can result in improved living conditions, while for high Arctic species in particular, it may cause an 'Arctic squeeze' as suitable conditions are pushed northwards and upwards. There have been no long-term, multi-species reviews of distributional changes of Arctic birds, although standardised atlas censuses in sub-Arctic parts of Scandinavia have shown northward range shifts of 0.7 kilometres per year for northern bird species. The ***Arctic Biodiversity Assessment*** (CAFF 2013a) provides examples of range shifts, including snowy owls breeding further north in western Siberia and the range expansion of short-eared owl into the high Arctic in eastern Canada. In addition, in 2017, Lapland longspurs were found breeding six latitudinal degrees further north of the previous known range in east Greenland (Lee 2018). A slightly longer summer has been suggested as a reason for expanding peregrine falcon population in high Arctic northwest Greenland (Burnham et al. 2012). Modelling of future changes suggest that shrubification of tundra habitat and a shrinking high Arctic climate zone may influence the breeding ecology of Arctic-breeding raptors mediated through impacts on their prey, particularly for gyrfalcons via early season ptarmigan availability. For wader species, modelling has shown that climatically suitable breeding conditions could shift, contract, and decline over the next 70 years, with 66–83% of species losing the majority of currently suitable area, and that predicted spatial shifts of breeding grounds could affect the species composition of the world's major flyways (Wauchope et al. 2017).

Phenological mismatches are considered among the leading stressors of wildlife populations arising from climate change. The accelerated rate of warming at high latitudes advances spring causing arthropod activity to start and peak, potentially resulting in a mismatch in phenology between long-distance migrant bird populations and their food resources in the Arctic breeding grounds. For herbivores, mismatched timing of breeding can impair chick growth because of a reduced nutrient content of forage plants later in the growing season. However, the consequences of mismatch are arguably most acute for migrating breeding insectivorous species and, potentially, their predators. Arctic-nesting waders, for example, travel thousands of kilometres each spring to take advantage of a burst of arthropod prey during the Arctic summer. A phenological mismatch between the timing of reproduction and the period during which these arthropods are abundant is one of the key hypothesised effects of climate change on Arctic insectivores, with evidence of reduced growth rates of chicks due to mismatch, and reduced body size of juvenile red knots during years of early snowmelt in high Arctic Siberia. However, not all studies concur; Hudsonian godwits in Alaska remain appropriately timed with respect to arthropods, sanderling chicks in Greenland have not been affected by the apparent mismatch documented there, and evidence shows that temperature increases can alleviate some of the negative effects of phenological mismatch for waders via reduced thermoregulation costs. Similarly, for geese, higher spring temperatures result in less snow cover, elevated nesting densities, earlier nesting, and greater nesting success, although other aspects of warmer summers may negate such demographic benefits at other stages of the breeding season. For more information on phenology, see Box 3-3.

Stressors along the Flyways

Causal factors for trends in many taxa are found outside the Arctic along the flyways. Declines among waders in the East–Asian Australasian Flyway are thought to be related to a greater than 65% loss of intertidal habitat in the Yellow Sea (between China and the Korean Peninsula). The proportions of species' populations staging in the Yellow Sea was the strongest predictor of population trend, suggesting that failure to accrue sufficient resources during staging impacted a birds' survival post departure. Similarly, in the west Atlantic portion of the Americas Flyway, individuals of the endangered subspecies of red knot have been shown to have reduced survival when they depart the primary staging site, Delaware Bay, U.S., in poor body condition, as a consequence of reduced availability of their preferred forage, the eggs of horseshoe crabs (***Limulus polyphemus***). A study of bar-tailed godwits migrating from West Africa to the Siberian Arctic showed that the birds tried to catch up with earlier snow melt and main insect emergence in the breeding grounds by reducing refuelling time at their European staging site. Hence, conditions in the temperate zone may determine the ability of godwits to cope with climate-related changes in the Arctic. Finally, differential migration strategies may explain why Curlew sandpipers within the East Asian-Australasian Flyway are declining rapidly (9.5%– 5.5% per year) while Red-necked stints remain relatively stable (-3.1%–0%): While Curlew sandpipers rely mainly on the Yellow Sea region, which has recently experienced a sharp decline in suitable habitat, Red-necked stints make use of additional sites and spread their relative time en-route across sites more evenly (Lisovski et al., 2020).These examples demonstrate the crucial importance of conditions at migratory staging sites for Arctic waders, most of which are long-distance migrants. In addition, sea level rise may lead to the loss of dry tidal flats – along with other factors like aquaculture and infrastructure development – on the key stopover sites for Arctic waders along their flyways (Murray et al. 2019, Reneerkens 2020).

Similarly, most Arctic goose populations, that stage or winter in North America and western Europe, have increased as a result of reduced hunting pressure and increased food availability in agricultural landscapes outside of the breeding season. In Arctic North America, goose populations have increased to such an extent that they are adversely affecting some staging and breeding habitats through intensive grazing and consumption of the below-ground plant parts (known as grubbing). In some cases, this leads to lasting vegetation loss. Climate change has also been linked to the increase in the east Greenland population of white-fronted geese due to warmer and wetter conditions in the staging (Iceland) and wintering areas (Scotland and Ireland) affecting survival rates (Doyle et al. 2020). In contrast, many goose populations are declining in central and eastern Asia, in particular where species are confined outside of the breeding period to natural habitats of declining quality.

Figure 3-25. Geographical coverage of terrestrial bird FEC monitoring in the Arctic.

Much of the information on populations of migrant species summarised in this section builds on monitoring on wintering and staging sites outside the Arctic (not mapped). Modified from Taylor et al. 2020.

3.3.3 COVERAGE AND GAPS IN KNOWLEDGE AND MONITORING

Spatial and Temporal Coverage

Many population counts of gregarious migrant species, such as waders and geese, take place along the flyways and at wintering grounds outside the Arctic which stresses the importance of continued development of movement ecology studies. Monitoring of FEC attributes related to breeding success and links to environmental drivers within the Arctic takes place in a wide network of research sites across the Arctic, although with low coverage of the high Arctic zone (Figure 3-25). For some species, such as ptarmigan and carnivores, the coverage of monitoring sites is most dense in parts of North America, Europe, and western Russia, while vast areas of eastern Russia, the Canadian Archipelago and Greenland are sparsely covered. Nevertheless, a lack of geographical as well as temporal coverage of monitoring efforts is a problem across the circumpolar Arctic, limiting the ability to detect key changes. The monitoring coverage is currently uneven across FECs as well. Detecting and monitoring change requires comparisons across long time scales. For several terrestrial Arctic bird taxa, several decades of monitoring data from either breeding, staging, or wintering grounds are available. Examples include most geese populations (Fox and Leafloor, 2018), some waders (Deinet et al. 2015), ptarmigan (Fuglei et al. 2020) and falcons (Franke et al. 2020) – see these for discussion on variable data quality over decades of monitoring with shifting efforts and methods. Time spans covered by the monitoring programmes also differs widely across the Arctic with a tendency of longest time series from Europe and North America.

Data Quality

Despite efforts to monitor bird populations throughout the Arctic, ongoing efforts to improve and coordinate monitoring through the development of schemes such as the CBMP–Terrestrial Plan, important data gaps remain. Nearly half of all populations of Arctic tundra birds have monitoring information that is considered poor or worse. More than a quarter of tundra bird populations lack trends in abundance and the quality of monitoring information has not improved over the last 15 years compared with trends over longer time periods.

The quality of the monitoring data documenting trends in population abundance varies widely among regions and taxonomic groups (Figure 3-26). Trend data were lacking altogether, for any time period, for 36 of 224 taxa (16%). In all flyways, waterfowl and waders had the highest quality monitoring data followed by land birds and then water birds. The quality of monitoring in the Americas and African–Eurasian Flyways was markedly better than for the East Asian–Australasian and Central Asian Flyways. Population estimates and trends are generally best for species that congregate at well-identified staging sites during migration or winter, such as geese and some waders, and less precisely known for widespread species, such as many passerines, or solitary and thinly dispersed species such as the carnivores.

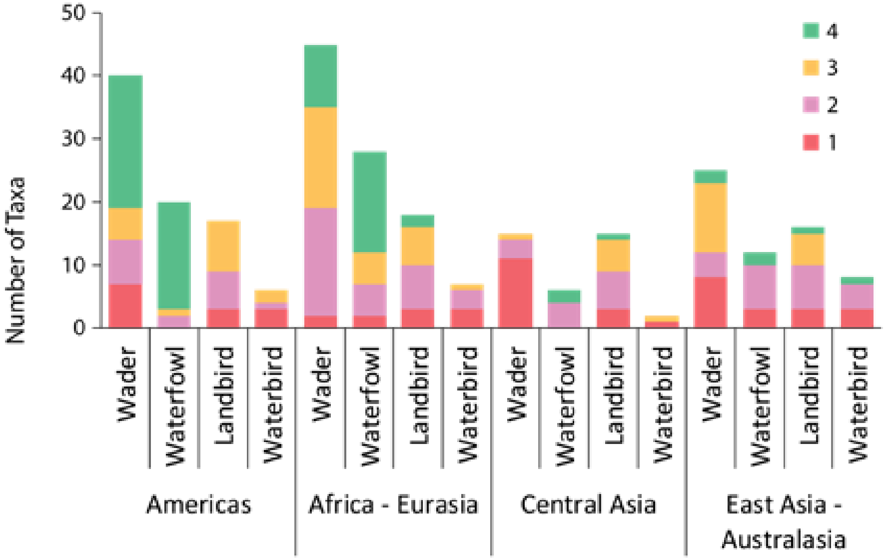


Figure 3-26. Quality of monitoring information used to describe trends in abundance for the taxonomic groups in four global flyways.

Trend quality categories are: (1) data are lacking such that trends are unknown, (2) regional and site-specific monitoring allow for assumptions of trend, (3) international monitoring allows estimation of trend direction, and (4) rigorously designed international monitoring programmes yield estimates of precision. Modified from Smith et al. 2020.

Willow ptarmigan. Photo: Nick Pecker/Shutterstock.com

However, it should be noted that the wintering ranges of some Arctic bird species populations overlap, reducing the reliability of population estimates based on winter counts. Moreover, flyway delineations of many biogeographic populations of Arctic migratory birds are still insufficiently known. Hence, there is a need to expand on the efforts of identifying and delineating flyways as well as on conducting censuses on the breeding grounds.

Information on status and trends in demographic parameters is generally even more fragmentary and is lacking for the majority of species in even the best monitored flyways. However, data on juvenile ratios have been collected for half a century, particularly by British ringing groups on Arctic and sub-Arctic wader populations. If the huge data sets could be worked up and published it would be a significant contribution to monitoring of CBMP–Terrestrial Plan FEC attribute 'demography' and benefit northern wader conservation (see Robinson et al. 2005). For some species, such as widespread Arctic passerines, even population structure is poorly defined, making regional gaps in monitoring difficult to identify.

The coverage of the 'essential' and 'recommended' FEC attributes across foraging guilds is best for 'abundance' and 'distribution'; for some guilds/species also 'temporal cycles', 'demography' (productivity) is relatively well monitored in parts of the Arctic.

As noted above, climate-related phenological mismatches are among the leading stressors of wildlife populations arising from anthropogenic climate change. Nevertheless, studies to date have shown considerable variation in the extent and effects of mismatch among species, which could be due to the short-term nature of many studies, the influence of local environmental drivers across study sites, life-history traits across species, or a combination of all of these factors. Thus, additional long-term, coordinated monitoring of wader and arthropod populations at different sites is required to improve our understanding of variation in mismatch vulnerabilities and the potential for population level effects.

There is also inadequate monitoring of expected shifts in distribution due to climate change. Consistent large-scale monitoring efforts that have shown range shifts in Scandinavia are lacking from the North American and Russian Arctic, making similarly rigorous analyses impossible. In addition, the network of research sites in the high Arctic is relatively limited, making range expansions and density changes difficult to detect. Wider involvement of community-based observations and citizen science can serve as an important gap-filler in monitoring shifts in bird species distributions.

3.3.3.1 Recommended Revisions to FECs and Key Attributes

The FEC attributes for birds are listed in Table 2-1. However, the FECs contain widely differing groups so additional distinction is required for practical monitoring and for interpreting the information in relation to ecosystems and effects of drivers. Table 3-3 recommends some revised groupings of FECs and 'essential' attributes for the future.

Table 3-3. Summary and recommended revisions of bird FECs and key attributes.

Recommended revisions are shown in ***bold italics*** *with the current category in brackets. The attribute considered most important for reporting for each FEC is highlighted in* ***orange****.*

'E' means essential attributes. 'R' means recommended attributes. Dashes indicate attributes not deemed as key for the particular FEC.

		FEC ATTRIBUTES							
FEC	GROUP	ABUNDANCE	DEMOGRAPHY (PRODUCTIVITY, SURVIVAL ETC.)	PHENOLOGY	DIVERSITY (COMMUNITY, GENETIC)	HEALTH (PATHOGENS, BODY CONDITION, CONTAMI-NANTS)	DISTRIBUTION (SPATIAL STRUCTURE, MIGRATION)	TEMPORAL CYCLES (PREDATOR-PREY INTERACTIONS)	REASONS FOR RECOMMENDED CHANGES
Herbivores	ptarmigan	***E***	E	E	R	R	E	E	Arctic residents, cyclic patterns in population density/productivity
	waterfowl (geese)	***E***	E	E	R	R	E		Migratory
Insectivores	waders	***E***	E	E	R	R	E	R	Long-distance migrants, partly aquatic ecology, monitored in Arctic and stopover/wintering sites
	passerines	***E***	E	E	R	R	E		Largely short -distance migrants, entirely terrestrial ecology, very limited monitoring in and outside Arctic
Carnivores	falcons, rough-legged buzzard, snowy owl, jaegers	E	***E***	E	R	***E*** (R)	E	***E*** (R)	Cyclic patterns in occupancy and productivity (except peregrine falcon); top predators ideal for continued contaminant monitoring
Omnivores	cranes, ducks, raven	***E***	E	E	R	R	E		Raven moved from carnivores; ducks recommended move to CBMP Freshwater or Coastal
Piscivores	loons, grebes	-	-	-	-	-	-	-	Not a terrestrial FEC, recommended move to CBMP Freshwater or Coastal

3.3.4 CONCLUSION AND KEY FINDINGS

The 88 Arctic-breeding terrestrial bird species are an integral component of Arctic ecosystems. They are both affected by biotic and abiotic factors and affect ecological change themselves. Overall, declines were most prevalent in waders and least prevalent in waterfowl (geese) and ptarmigan. Increasing population trends were most common in geese and least common in waders and other water birds. Within flyways, increases were generally most common in geese and least common among waders and water birds. Fewer waterfowl populations were increasing in the Central Asian and East Asian–Australasian flyways. The largest proportion of declining species was among the waders in all but the Central Asian Flyway, where a large majority of waders had unknown trends. Although declines were more prevalent among waders than other taxonomic groups in both the African–Eurasian and Americas flyways, the former had a substantially larger number of stable and increasing species.

Key Findings

Most species showed contrasting trends between different populations/flyways. This variation complicates drawing broad conclusions, except that since most bird species leave the Arctic in winter they are affected by a wider range of drivers and geographical scales than other FECs. A meta-view on 88 terrestrial Arctic tundra birds shows that:

- Many populations are stable or increasing; for some populations (mainly geese) the increase may be effects of global change – including land use outside the Arctic – allowing populations to increase beyond levels likely under undisturbed conditions.
- Variability across FECs is high, with more than half of all wader species ***declining*** and nearly half of all geese ***increasing***. Variability across flyways is also high, even within FECs. For example, 88% of waders are declining in the East Asian - Australasian Flyway, compared with 70% of wader populations stable or increasing in the African - Eurasian Flyway.
- For more than half of all species, there are reasons for concern for some flyway populations—57% of all species had at least one population in decline and for 21% of the species ***all*** populations were declining.
- Trends are unknown for at some populations in a quarter of species—mostly in the Central Asian Flyway; for the remaining species, the quality of trends information is highly variable.
- Ten species are ranked in the global ‘threatened’ categories according to IUCN criteria— including two species as Critically Endangered.
- Populations of both ptarmigan species showed both positive and negative trends with no clear links to geographical regions, and most populations displayed short and long population cycles linked to cycles in other herbivore species or driven by predation.
- Among the predators, breeding parameters of gyrfalcons, snowy owls and rough-legged buzzards are linked to prey with cyclic abundance like ptarmigan and rodents—for both falcon species, it is likely that breeding populations in the Arctic are relatively stable.
- Climate change affects different species and populations very differently with no consistent pattern—examples include breeding failure in ground-nesting waders in years of late snow melt, reduced breeding success in peregrine falcons due to increased frequency of heavy rain events and massive blackfly outbreaks in warm spells, and possible range expansion of peregrine falcons due to longer summer season in high Arctic. Although evidence is diverse, phenological mismatches are considered among the leading potential stressors of wildlife populations arising from climate change. The accelerated rate of warming at high latitudes advances spring, causing arthropod activity to start and peak, potentially resulting in a mismatch in phenology between long-distance migrant bird populations and their food resources in the Arctic breeding grounds.
- Main drivers of population change—positive as well as negative—outside the Arctic include harvesting and intensified land management (including agricultural practises, land reclamation and urban development).

Northern goshawk.
Photo: Andrei Stepanov/Shutterstcok.com

BOX 3-2. INDIGENOUS KNOWLEDGE AND ARCTIC BIRD RESEARCH AND CONSERVATION

Few people are more in tune with their environment and the wildlife they depend upon than Arctic Indigenous Peoples. Indigenous Knowledge[5] is essential for daily life and cultural resilience amongst Arctic Peoples. This knowledge can also help inform bird research, monitoring, management, and conservation. Due to the remoteness of most of the Arctic, scientific studies by non-resident scientists can be expensive, time-consuming and are often limited to small areas or short time periods.

Indigenous Knowledge holders carry lived experience, as well as wisdom passed down through millennia. This knowledge often covers larger areas, encompasses entire annual cycles, and covers more extended time periods than scientific studies. This long-term perspective provides unique insights into emerging issues and research priorities, and can help researchers select suitable species, locations, and habitats for studies. The rich historical context of Indigenous Knowledge offers baseline information that is otherwise unattainable but critical for identification of changes. Research pairing Indigenous Knowledge with mainstream science, the “two-eyed seeing” approach as developed by Mi’kmaw Elder Dr. Albert Marshall, is more robust and can lead to more effective and sustainable conservation outcomes. Partnerships between Indigenous Knowledge holders and visiting researchers build relationships through long-term monitoring and habitat management, which facilitates future collaborations. Much progress has been made at increasing the awareness of the scientific community of the need for meaningful collaboration with Indigenous Knowledge holders. However, there is room for increased partnership and cross-training.

Examples of successful collaborations include:

- Inuit from the Kivalliq region of Nunavut, Canada, along with Environment and Climate Change Canada (ECCC), had mutual concerns about changes occurring in coastal tundra wetlands due to climate change and degradation caused by increasing goose populations, and how these changes might influence bird populations in Nunavut. Inuit and scientists collaborated to define the research priorities and undertook a series of scientific and Indigenous Knowledge (Inuit Qaujimajatuqangit; IQ) studies to establish current status and reconstruct baselines of distribution and abundance that stretched back to the 1940s, far beyond the scientific records.
- The Kangut Project trained local researchers to carry out an IQ study in the communities of Arviat and Coral Harbour, Nunavut, Canada. This IQ study provided entirely new insights into snow goose nesting and moulting locations, timing of migration, and changes over time. Moreover, it provided crucial local perspectives on management concerns and priorities.

---

[5] Indigenous Knowledge is a systematic way of thinking and knowing that is elaborated and applied to phenomena across biological, physical, cultural, and linguistic systems. Indigenous Knowledge is owned by the holders of that knowledge, often collectively, and is uniquely expressed and transmitted through Indigenous languages. It is a body of knowledge generated through cultural practices, lived experiences including extensive and multi-generational observations, lessons and skills. It has been developed and verified 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 (ACPP 2014).

Members of the Ahiak Comanagement Committee, composed of five Inuit and one staff from Environment and Climate Change Canada. Photo: Vicky Johnston/ECCC

BOX 3-3. PHENOLOGICAL SHIFTS: CAN ARCTIC BIRDS KEEP UP WITH CHANGING CONDITIONS?

The Arctic is warming at a greater rate than other places on earth, with spring arriving up to two weeks earlier in some areas, compared to 3-4 decades ago. With rapid climate change, the potential for phenological mismatches increases, when the timing of ecological events and the responses of bird behaviours change at different rates, potentially leaving birds lacking necessary resources – a phenological mismatch. Arctic migratory birds may be particularly susceptible to the changes due to the narrow window of ideal conditions on breeding grounds. Climate changes and subsequent ecological alterations to habitat, food sources, predators and competitors could impact egg hatching success, chick fledging success and adult survival, all of which could affect bird species populations; see map below for Arctic sites where phenological mismatch has been studied.

Arctic-breeding birds expend energy resources and face risks migrating long distances each year. Over millennia, despite annual variability in reproductive output, this strategy has proven worthwhile. Birds use environmental cues in wintering and migratory stopover habitats to determine timing of migration and arrival on the breeding grounds. The timing of spring in the Arctic has always been variable, and Arctic-breeding bird species have adapted to survive this level of unpredictability over time, at the population level. Determining the best time for migration is important to an individual's breeding success and survival. Early arriving individuals may face snow and cold temperatures, while late arrivals may miss peak food resource availability, or may not allow enough time for their offspring to grow, fledge and gain energetic reserves for migration prior to the arrival of fall.

A few case studies illustrate the changes the Arctic is experiencing and the response of breeding birds:

- Around Utqiaġvik, Alaska, between 2003 and 2016, eight wader species showed an advancement of nest initiation between 0.1 to 0.9 days per year, while snowmelt advanced 0.8 days per year. This rate of change in snowmelt timing was six times faster than the rate of change over the previous 60-year period. The waders showed flexible nest initiation dates, varying from June 11 to June 21. No species appeared to be able to advance egg laying at the pace of snowmelt change. Species with an opportunistic nesting settlement strategy were more likely to respond to changing snowmelt conditions and later nesting species exhibited higher response rates to changes in snowmelt. A related recent seven-year study indicated that waders are experiencing phenological mismatches with invertebrate food resources from earlier snowmelt. Birds that nested earlier generally had more food availability during brood rearing. However, food availability related not only to initial invertebrate emergence timing but to variable daily weather conditions following initial emergence (Saalfeld & Lanctot 2017, Saalfeld et al. 2019).
- From 1977 to 2008, researchers monitored the arrival time of 12 wader species in the Yukon-Kuskokwim Delta, Alaska. Mean arrival dates for all species occurred over a 16-day period in May but species showed variability of over two weeks year to year. This arrival of most species correlates with the timing of 10% snow cover. To date, birds appear to be adjusting arrival in response to the variable annual spring conditions and show no long-term trends of change in arrival date (Ely et al. 2018).
- As Spring temperatures warm, certain reproductive strategies become advantageous. In Alaska, lesser snow geese and greater white-fronted geese are benefitting from improved foraging conditions due to warm temperatures arriving earlier, while black brant may be at a disadvantage. Snow geese and white-fronted geese utilise on-site resources at their Arctic breeding sites to provide fat and protein for egg development, while brant rely on resources accumulated prior to arrival at their nesting sites. Over time, as the warming trend continues, these changes could have significant population-level effects and potentially initiate other ecological consequences (Hupp et al. 2018).
- Studies of phenological mismatches between timing of reproduction and peak abundance of food in some species are shown in the map below. For example, for sanderlings in East

> Greenland, an increase in phenological mismatch of 22 days was observed in a period of 18 years (Reneerkens et al. 2016). Other species, for example Bar-tailed Godwits in the central-Russian Arctic, have been able to keep their timing of reproduction in synchrony with peak abundance of food, as observed during a study period of 17 years (Rakhimberdiev et al. 2018). Despite the differences in phenological mismatch, the fitness consequences of mismatches apparently vary and are still under scientific debate.

Many questions remain: What happens when climate continues to change at different rates in breeding areas versus migration and wintering habitats? Will changing conditions favour some species over others? What ecological effects will the changes in species composition have on other species and their habitat? The answers will likely vary by species, population, and location. Further ecological studies, combined with increased climatological data, will continue to increase the understanding of these changes, and will allow for informed adjustments in species and habitat management.

Study sites across the Arctic where phenological mismatches between timing of reproduction and peak abundance in food have been studied for terrestrial bird species. **Grey symbols** show study sites where this phenomenon has been studied for <10 years, **light red** symbols show sites with >10 years of data but no strong evidence of an increasing mismatch, and **dark red symbols** indicate sites with >10 years of data and strong evidence of an increasing mismatch. **Circles** indicate studies of shorebirds, **squares** for waterfowl and **diamonds** for both shorebirds and passerines. Graphic: Thomas Lameris, adapted from Zhemchuzhnikov (submitted).

Greater white-fronted goose nesting in snow. Photo: Dan Ruthrauff/USGS

Ruddy turnstone arriving in high Arctic breeding area, at Zackenberg, northeast Greenland. Photo: Erik Thomsen

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

3.4 MAMMALS

Lead authors:
James Lawler, Christine Cuyler, Douglas MacNearney.

Contributing authors:
Dominique Berteaux, Dorothee Ehrich, Anne Gunn, Jan Rowell, Don Russel, Niels Martin Schmidt

The CBMP described six FECs for the monitoring of Arctic terrestrial mammals: large herbivores (***Rangifer***—reindeer/caribou, muskoxen, moose); medium-sized herbivores/omnivores (hares, ground squirrels); small herbivores (lemmings, voles); large predators (wolves, bears); medium-sized predators (wolverine, lynx, fox); and small predators (small mustelids, shrews). Not all mammal FECs are found throughout the circumpolar Arctic and this is particularly true for individual species within a FEC. For this reason, the CBMP–Terrestrial Plan focused on three FECs comprising four species that occupy a major role in the ecosystem and have circumpolar (or near circumpolar) distribution: large herbivores (***Rangifer***, muskoxen); small herbivores (lemming); and medium-sized predators (Arctic fox) (Figure 3-27). It also identified key attributes considered to be essential or recommended for monitoring of these functional groups (Table 2-1).

This section summarises the primary biotic, abiotic, and anthropogenic drivers of the terrestrial mammal populations and how they influence the various FECs (Figure 3-28), with a focus on the large and small herbivores

Figure 3-27. Examples of Arctic terrestrial mammal species representing the large herbivore, small herbivore, and medium-sized predator FECs.

*(a) Lemming, Photo: Anna Smirnova/Shutterstock.com, (b) Muskoxen (*Ovibos moschatus*), Photo: NaturesMomentsuk/Shutterstock.com, (c) Caribou/reindeer, Photo: Streamside Adventures/Shutterstock.com, and (d) Arctic fox (*Vulpes lagopus*), Photo: Joanna Perchaluk/Shutterstock.com.*

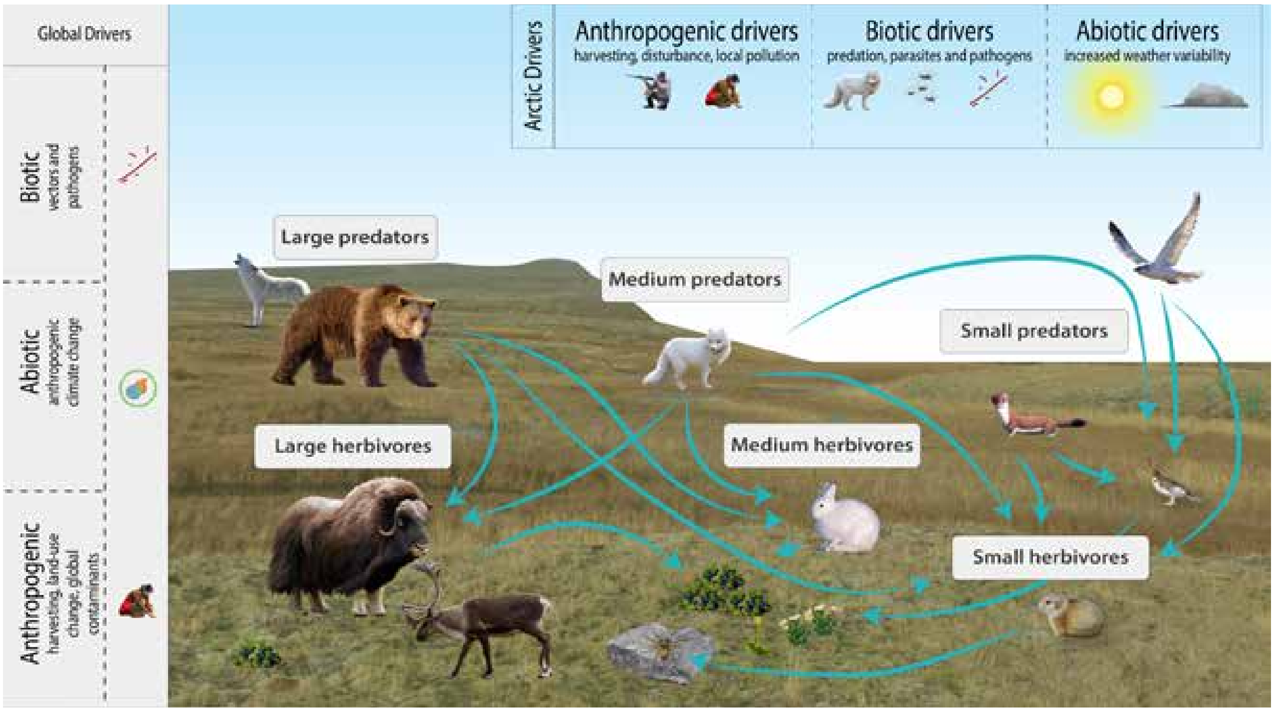


Figure 3-28. Conceptual model of Arctic terrestrial mammals, showing FECs, interactions with other biotic groups and examples of drivers and attributes relevant at various spatial scales.

and medium-sized predators for which international monitoring networks have been established. It is largely based on Berteaux et al. (2017), Cuyler et al. (2020) and Ehrich et al. (2020). For information and references not included in these articles, references are provided. The information for ***Rangifer*** is from the Circumarctic Rangifer Monitoring and Assessment (CARMA) network, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), Environment and Climate Change Canada, the Alaska Department of Fish and Game and the Canadian provincial wildlife management agencies of Ontario, Quebec, and Yukon. The remaining three mammal FECs (large and small predators and medium-sized herbivores) remain challenging to summarise at this time in the absence of consistent, widespread monitoring efforts throughout the circumpolar Arctic.

Large Herbivores

The two large herbivore species this report focuses on are ***Rangifer tarandus*** and ***Ovibos moschatus*** (muskoxen). Both species are circumpolar in distribution. In North America and Greenland, ***R. tarandus*** is known as caribou, whereas the same species is known as reindeer in Eurasia. This report uses the term ***Rangifer*** to refer to the species collectively. In almost all Arctic nations, semi-domestic populations of ***Rangifer*** are managed as free-ranging livestock and, in some cases, these outnumber wild populations (for example in Sweden and Finland). This report however refers to the wild or native ***Rangifer*** unless otherwise specified.

While 12 subspecies of ***Rangifer*** are recognised, the ecology of local populations varies more in accordance with the available landscape than by genotype; thus, populations are more commonly classified into four ‘ecotypes’ delineated by local environmental conditions that influence habitat use and behaviour (Mallory & Hillis 1998). The migratory tundra or barren-ground ecotype of ***Rangifer*** is the most numerous and conspicuous in the Arctic, known for large aggregations of thousands of individuals and wide-ranging annual migrations of hundreds of kilometres between calving and winter ranges. The Arctic islands ecotype differs in that populations are constrained by available habitat and while some populations are migratory others are not. The mountain ecotype inhabits mountainous regions and migrations are limited to seasonal movements between high and low elevations to avoid predators and access resources. Finally, the forest or boreal ecotype inhabits sub-Arctic regions and typically occurs at the lowest population densities of all ecotypes and makes minimal seasonal migrations.

Muskoxen are split into two subspecies, ***O. m. wardi*** and ***O. m. moschatus***. Unlike ***Rangifer***, muskoxen exhibit very low genetic diversity, even when comparing the two subspecies. This low diversity is exacerbated by a number of translocated populations, often founded by low numbers of individuals from predominantly one source, northeast Greenland, which had already lost much of its diversity.

Rangifer and muskoxen play important roles in Arctic ecosystems. Muskoxen and some ***Rangifer*** populations are relatively sedentary, whereas the migrations of some ***Rangifer*** populations are among the longest of any land mammals (Tucker et al. 2018, Joly et al. 2019). This has important ramifications for ecosystem function as well as the availability of this resource to predators, including humans, in the Arctic. Both ***Rangifer*** and muskoxen alter the distribution of plant species and nutrients. In addition to their role in ecosystem function, they are important for food security in Arctic communities, the cultural identity of Northern Peoples and, in some instances, provide economic opportunities.

The CBMP–Terrestrial Plan identified both ***Rangife***r and muskoxen as essential FECs for assessing status and trends. These species are tracked by international groups of experts. For ***Rangifer***, this is the CARMA network. CARMA maintains data sets on migratory populations and gathers information on non-migratory populations. For muskoxen, the Muskox Knowledge Network (MOXNET) consists of government and non-governmental agencies, Indigenous Peoples, businesses, and academics, who exchange information.

Until the creation of the CBMP mammal networks, there was only minimal collaboration or interaction within or between states, jurisdictions or even among scientists. By including a broad variety of stakeholders, the CBMP networks are building bridges of communication and collaboration that can facilitate the creation and effective implementation of standardised monitoring protocols. With collaboration, integrating the cumulative effects of the drivers (essentially climate and anthropomorphic related) changing species abundance and demographics will be possible. Ultimately, integration across ecosystems is the goal.

Small herbivores

This report focuses on the status and trends of lemmings as representing the truly Arctic small herbivores. Voles, the other small herbivores present in the low Arctic, are mainly boreal species that are also found in the Arctic. Lemmings are a key component of Arctic food webs and changes in their dynamics can affect the whole ecosystem through:

- flow of energy from plants to avian and mammalian predators, with effects on the vertebrate food web;
- population cycles with large (periodic) outbreaks, impacting predator–prey dynamics and vegetation;
- pulses of herbivory and resources for predators; and
- indirect effects of lemming cycles on many tundra-breeding birds, such as geese and waders, which serve as alternative prey for predators.

Brown lemmings (***Lemmus spp***.) and collared lemmings (***Dicrostonyx spp.***) are central FECs of Arctic ecosystems because they are the only small rodents with natural distributions in high Arctic regions. They are also found throughout the low Arctic, where they usually co-exist with vole species. Both genera are widespread throughout the Arctic and often occur together; but there is never more than one species per genus at a given locality.

Brown lemmings include the Siberian brown lemming (***L. sibiricus***), the Norway lemming (***L. lemmus***), the Wrangel Island brown lemming (***L. portenkoi***) and the Nearctic brown lemming (***L. trimucronatus***) (the only species of brown lemming in North America). Collared lemmings include four species in the Nearctic (North America and Greenland)—Nearctic collared lemming (***D. groenlandicus***), Nelson's collared lemming (***D. nelsoni***), Richardson's collared lemming ***(D. richardsoni***) and Ungava collared lemming (***D. hudsonicus***)—and two species in the Palaearctic—Palaearctic collared lemming (***D. torquatus***) and Wrangel Island lemming (***D. vinogradovii***). The exact number of geographic species/sub-species has been revised several times during the last decades (Wilson & Reeder 2005).

Medium-sized Predators

This report focuses on the status and trends of Arctic fox (***Vulpes lagopus***), the only medium-sized terrestrial mammalian predator that occurs throughout the circumpolar Arctic. It is recognised as an FEC due to its circumpolar distribution, role in the trophic dynamics of the tundra—where they often are the main predator and mediator of indirect trophic interactions—and strong sensitivity to climate change (IUCN 2009). As a widespread predator, Arctic foxes use a variety of resources. Two different ecological strategies have been identified in Arctic foxes, one focused mainly on lemmings and the second focused on birds, marine food, or large mammal carcasses, although recent research emphasises that these are two extremes of a gradient of strategies. While Arctic fox is the focal medium-sized predator in this report, red fox (***V. vulpes***) occur at over half of the Arctic fox monitoring sites. Typically, this overlap occurs at study sites where mean summer temperatures are above 8°C.

3.4.1 PATTERNS AND TRENDS OF FECS AND THEIR ATTRIBUTES

3.4.1.1 Large Herbivores

Rangifer

Abundance of ***Rangifer*** populations vary substantially through natural cycles and fluctuations due to density-dependent processes. Variations in abundance can exceed ten-fold through population cycles over several decades. Trends in ***Rangifer*** populations should be assessed in this context. Some populations are also vulnerable to stressors such as a warming climate and industrial impacts—including habitat fragmentation and degradation and disturbance from noise, dust, and light. These multiple and interacting stressors are cause for concern and may contribute to the historic lows currently observed in some populations. Although not all populations fluctuate synchronously, there can be a strong degree of synchrony among adjacent populations in large regions, for example mainland Canada (CARMA 2020).

In 2017, the migratory tundra population of ***Rangifer*** was approximately 2.2 million individuals in the U.S. (Alaska), Canada, Greenland, and Russia (Table 3-4). This represents a decline from about 5 million in the 1990s, when many populations were at peak size. This global declining trend has critical implications for the food security of Arctic Peoples (CARMA 2020).

Between 2003 and 2017, three Alaskan populations declined by an average of 54%. Two other populations, shared with Canada, are increasing. One population, the Forty–Mile, is increasing due to targeted conservation efforts that have permitted natural rebounded from approximately 5,000 individuals in the 1970s to 73,000 individuals in 2017. The second population shared with Canada, the Porcupine, increased by an exponential rate of 0.05 between 2001 and 2017 (Table 3-4, Figure 3-29). Caribou populations are an important resource for subsistence harvesters in Alaska and Canada.

Reindeer. Photo: Evgenii Mitroshin/Shutterstock.com

Table 3-4. Population estimates and trends for Rangifer populations of the migratory tundra, Arctic island, mountain, and forest ecotypes where their circumpolar distribution intersects the CAFF boundary.

Population trends (Increasing, Stable, Decreasing, or Unknown) are indicated by shading. Data sources for each population are indicated as footnotes.

POPULATION	ECOTYPE	JURISDICTION	MOST RECENT SURVEY YEAR	POPULATION ESTIMATE AND TREND
Mulchatna[1]	Migratory tundra	U.S. (Alaska)	2013	18,308 🟥
Northern Peninsula[2]	Migratory tundra	U.S. (Alaska)	2013	2,700 🟩
Southern Peninsula[3]	Migratory tundra	U.S. (Alaska)	2013	877 ▨
Unimak[4]	Migratory tundra	U.S. (Alaska)	2013	192 🟥
Adak[5]	Migratory tundra	U.S. (Alaska)	2012	2,900 🟨
Western Arctic[6]	Migratory tundra	U.S. (Alaska)	2016	201,000 🟥
Teshekpuk[6]	Migratory tundra	U.S. (Alaska)	2015	41,542 🟥
Central Arctic[6]	Migratory tundra	U.S. (Alaska)	2016	22,630 🟥
Forty Mile[7]	Migratory tundra	U.S. (Alaska)/Canada (Yukon)	2017	73,009 🟩
Porcupine[8]	Migratory tundra	U.S. (Alaska)/Canada (Yukon)	2013	197,000 🟩
Tuktoyaktuk Peninsula[8]	Migratory tundra	Canada (Northwest Territories)	2015	1,701 🟥
Cape Bathurst[8]	Migratory tundra	Canada (Northwest Territories)	2015	2,259 🟥
Bluenose West[8]	Migratory tundra	Canada (Northwest Territories)	2015	15,268 🟥
Bluenose East[8]	Migratory tundra	Canada (Northwest Territories/ Nunavut)	2015	38,592 🟥
Bathurst[8]	Migratory tundra	Canada (Northwest Territories/ Nunavut)	2015	19,769 🟥
Ahiak/Beverly[8]	Migratory tundra	Canada (Northwest Territories/ Nunavut)	2011	195,529 🟥
Boothia Peninsula[8]	Migratory tundra	Canada (Nunavut)	1995	6,658 ▨
Lorillard and Wager Bay[8]	Migratory tundra	Canada (Nunavut)	2002	41,000 ▨
Qamanirjuaq[8]	Migratory tundra	Canada (Nunavut/Northwest Territories/Saskatchewan/ Manitoba)	2014	264,661 🟥
Baffin Island[8]	Migratory tundra	Canada (Nunavut)	2014	4,856 🟥
Southampton Island[8]	Migratory tundra	Canada (Nunavut)	2015	12,297 🟩
Coats Island[8]	Migratory tundra	Canada (Nunavut)	1991	500 ▨
Cape Churchill[9]	Migratory tundra	Canada (Manitoba/Ontario)	2007	2,937 🟨
Southern Hudson Bay[9]	Migratory tundra	Canada (Ontario)	2011	16,638 ▨
Leaf River[9]	Migratory tundra	Canada (Quebec)	2016	199,000 🟥
George River[9]	Migratory tundra	Canada (Quebec/Labrador)	2016	8,938 🟥
Inglefield Land	Migratory tundra	Greenland	1999	2,260 🟥
Olrik Fjord	Migratory tundra	Greenland	2001	31 ▨
Nuussuaq Halvø	Migratory tundra	Greenland	2002	1,164 ▨
Naternaq	Migratory tundra	Greenland	1995	271 ▨
Kangerluusuaq–Sisimiut[10]	Migratory tundra	Greenland	2010	98,300** 🟨
Akia–Maniitsoq[10]	Migratory tundra	Greenland	2010	24,000** 🟩
Ameralik	Migratory tundra	Greenland	2012	11,700** 🟩
Qeqertarsuatsiaat	Migratory tundra	Greenland	2012	4,800 ▨
Qassit	Migratory tundra	Greenland	2000	196 ▨
Neria	Migratory tundra	Greenland	2000	1,600 ▨
Ivittuut	Feral reindeer	Greenland	N/A	▨

POPULATION	ECOTYPE	JURISDICTION	MOST RECENT SURVEY YEAR	POPULATION ESTIMATE AND TREND
Taymyr[11]	Migratory tundra	Russia	2003	🟥 500,000
Lena–Olenyk[11]	Migratory tundra	Russia	2009	🟩 95,000
Yana Indigurka[11]	Migratory tundra	Russia	2015	🟥 34,000
Sundrun[11]	Migratory tundra	Russia	2002	🟥 28,500
Chukotka[11]	Migratory tundra	Russia	2005	🟩 93,700
Dolphin and Union[12]	Arctic Island	Canada (Nunavut/Northwest Territories)	2015	🟥 18,413
Banks–Victoria[13]	Arctic Island	Canada (Nunavut/Northwest Territories)	2015	🟩 2,252
Western Queen Elizabeth[13]	Arctic Island	Canada (Nunavut/Northwest Territories)	2013	🟩 7,300
East Queen Elizabeth[13]	Arctic Island	Canada (Nunavut)	2007	⬜ 3,173
Prince of Wales – Somerset – Boothia[13]	Arctic Island	Canada (Nunavut)	2005	🟥 6
Svalbard[14]	Arctic Island	Norway	2016	🟩 22,435
Novaya Zemlya Island[15]	Arctic Island	Russia	Ca.2015	🟥 5,000
Severnaya Zemlya Islands[15,16]	Arctic Island	Russia	Ca.1985	🟥 300
New Siberian Islands[15]	Arctic Island	Russia	Ca.2005	🟧 10–15,000
Bonnet Plume[17]	Mountain	Canada (Yukon/Northwest Territories)	1982	⬜ 5,000
Coal River[17]	Mountain	Canada (Yukon/Northwest Territories)	2008	🟧 450–700
Finlayson[17]	Mountain	Canada (Yukon)	2003	🟥 3,100
Hart River[17]	Mountain	Canada (Yukon)	2015	🟧 2,660
Tay River[17]	Mountain	Canada (Yukon)	1991	⬜ 3,750
Redstone[17]	Mountain	Canada (Yukon/Northwest Territories)	2012	🟧 10,000
South Nahanni[17]	Mountain	Canada (Yukon/Northwest Territories)	2009	🟧 2,100
Labiche[17]	Mountain	Canada (Yukon/Northwest Territories)	1993	⬜ 450–700
Liard Plateau[17]	Mountain	Canada (Yukon/British Columbia)	2011	🟧 150
Muskwa[18]	Mountain	Canada (British Columbia)	2007	⬜ 1,000
Pink Mountain[18]	Mountain	Canada (British Columbia)	1993	⬜ 1,725
Graham[18]	Mountain	Canada (British Columbia)	2009	🟧 708
Torngat Mountains[19]	Mountain	Canada (Quebec/Nunavut/Labrador)	2017	🟥 1,326
Iceland[20]	Mountain	Iceland	2015	🟧 5,000
Gwich’in, Inuvialuit, Sahtú, Wek’èezhìı, southern NWT[21]	Forest	Canada (Northwest Territories)	2012	⬜ 6,500
Maxhamish, Calendar, Snake-Sahtahneh, Parker, Prophet[21]	Forest	Canada (British Columbia)	2012	🟥 1,000
Chinchaga, Bistcho, Yates, Caribou Mountains[21]	Forest	Canada (Alberta)	2012	🟥 1,100

POPULATION	ECOTYPE	JURISDICTION	MOST RECENT SURVEY YEAR	POPULATION ESTIMATE AND TREND
Spirit, Swan, Ozhiski, Missisa, James Bay, Kesagami[22]	Forest	Canada (Ontario)	2011	2,112
Quebec boreal caribou[23]	Forest	Canada (Quebec)	2012	6,740
Lac Joseph, Red Wine, Mealy Mountain[21]	Forest	Canada (Labrador)	2012	2,983
Karelia and other Russian populations[24]	Forest	Russia	2015	12,800

[1]Barten 2015, [2]Crowley 2015a, [3]Peterson 2015, [4]Crowley 2015b, [5]Ricca et al. 2014, [6]ADFG 2017, [7]Harvest Management Coalition 2019, [8]COSEWIC 2016, [9]COSEWIC 2017b, [10]Cuyler et al. 2016, [11]CARMA 2020, [12]COSEWIC 2017a, [13]COSEWIC, 2015, [14]Le Moullec et al. 2019, [15]Mizin et al. 2018, [16]Belikov and Kupriyanov 1985, [17]Environment Yukon 2016, [18]COSEWIC 2014, [19]Couturier et al. 2018, [20]Þórisson 2018, [21]Environment Canada 2012, [22]MNRF 2014a,b, [23]Équipe de Rétablissement du Caribou Forestier du Québec 2013, [24]Gunn 2016

**2010 and 2012 survey (Cuyler et al. 2011) results considered out of date; 2018 survey suggests decline in Kangerlussuaq–Sisimiut while 2019 survey suggests increase in Akia–Maniitsoq and Ameralik (Cuyler unpublished)

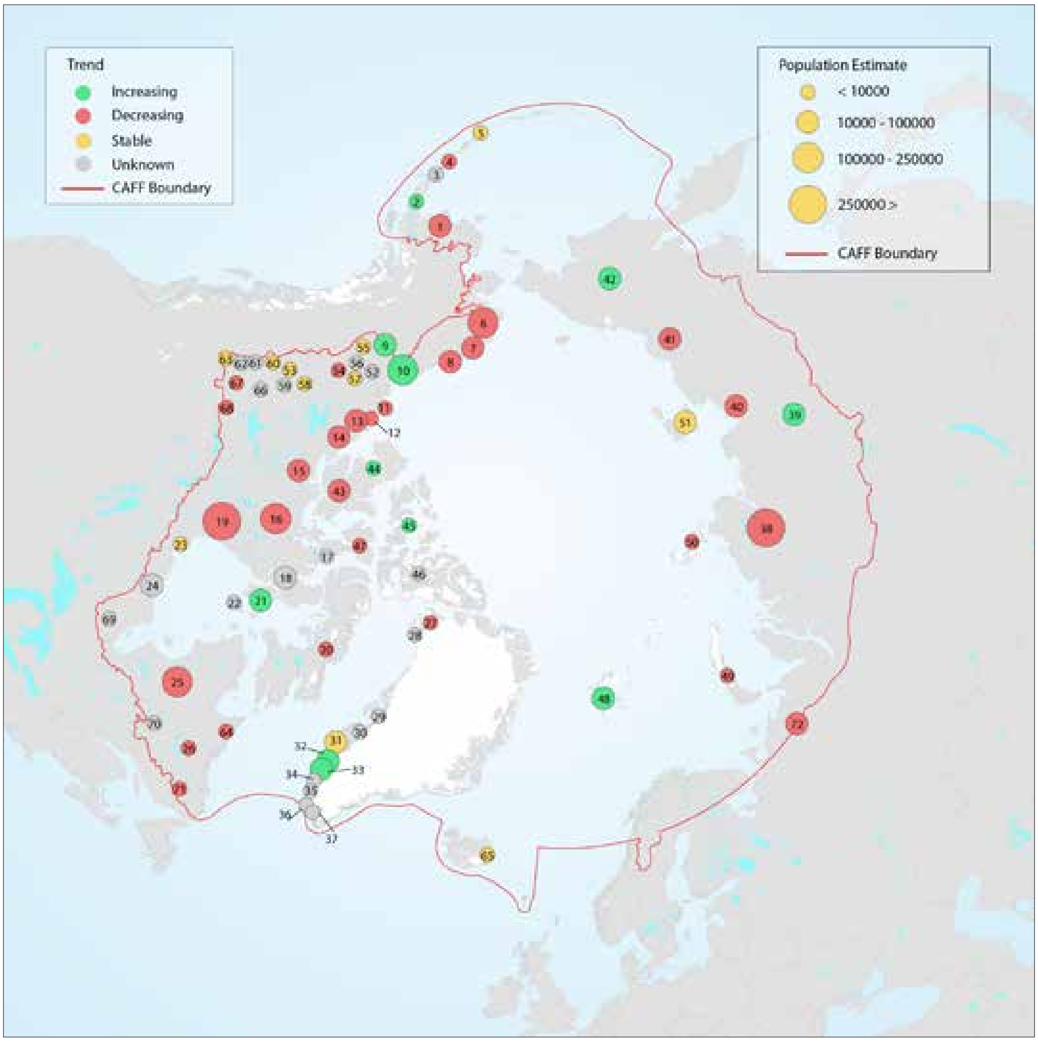


Figure 3-29. Trends and distribution of Rangifer populations based on Table 3-4.

Several smaller populations of caribou inhabit sub-Arctic portions of Alaska, including five populations along the Aleutian Archipelago and west coast. These populations are considered part of the migratory tundra ecotype based on genetics, although in some instances their ecology and habitat are similar to the mountain caribou ecotype found in western Canada. Population dynamics and trends for these populations are variable (Figure 3-29). They are managed by the Alaska Department of Fish and Game through hunting quotas.

In Canada, migratory tundra caribou belong to two sets of populations that share similar ecological characteristics but different genotypes—the barren-ground caribou inhabiting the mainland tundra and lower Arctic islands to the north and west of Hudson Bay and the eastern migratory populations along the south and eastern shores of Hudson Bay through to Labrador. Overall, numbers of migratory tundra caribou have declined (Figure 3-29) from approximately 3 to 1 million across 17 populations between 1989 and 2016 (COSEWIC 2016, 2017b). The average decline is estimated at 56% since 1989, and five populations declined by more than 80% from peak numbers. While natural fluctuations were common for these populations in the past, current demographic data and threats from changing climate and industrial development are without historical precedent. Barren-ground caribou are assessed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2016) and the eastern migratory population to be designated as endangered (COSEWIC 2017b). See also Box 3-4.

Although Greenland caribou are typically included with the migratory tundra populations, expanses of tundra similar to that of North America and Russia are absent in mountainous Greenland. Furthermore, Greenland caribou exhibit minimal seasonal movements, which are highly individualistic rather than the aggregations typical of the migratory tundra populations. As such, Greenland caribou ecology resembles a mixture of mountain and Arctic island populations (Cuyler & Linnell 2004, Cuyler et al. 2017). In Greenland, harvest management regulates 11 caribou populations of which 10 are likely a genetic mix of native caribou and feral semi-domestic reindeer. Monitoring is infrequent and typically only includes the four commercially important populations in southwest Greenland. These are the Kangerlussuaq–Sisimiut, Akia–Maniitsoq, Ameralik and Qeqertarsuatsiaat populations. The four populations combined make up 96 to 97% of all caribou in Greenland. The Kangerlussuaq–Sisimiut and Akia–Maniitsoq populations are the two largest in Greenland and are CARMA reference populations. Although changes in census methods and surveyed areas obscure trends, Local Knowledge for southwest Greenland is unanimous that there was an increase in abundance in the 1970s and populations have remained high since. Between 2000 and 2012, the status of Greenland caribou appeared stable (Figure 3-29) at approximately 140,000. The 2018 and 2019 aerial surveys covered only the Kangerlussuaq–Sisimiut, Akia–Maniitsoq and Ameralik populations in southwest Greenland. The as yet unpublished preliminary results suggest decline in the Kangerlussuaq–Sisimiut population but growth in both Akia–Maniitsoq and Ameralik.

In Russia, the current status of migratory tundra reindeer is 510,000 individuals, with an overall declining trend (Figure 3-29). The largest population, the Taymyr population, declined from an estimated 1 million in 2000 to 370,000 in 2017. On the Yamal Peninsula, abundance has declined from 3,000 to 2,000 between 1991 and 2015. The North Yakutia populations (Yana–Indigurka and Sundrunskaya) peaked in the 1990s and then subsequently declined. In contrast, the Lena–Olenek population increased from 55,000 in 1985 to 95,000 in 2009 and the Chukotka population increased from 33,000 in 1991 to 93,700 by 2015. Evaluating trends is complicated in some instances due to the loss of semi-domestic reindeer to wild populations.

Arctic island populations of ***Rangifer*** are found in Canada, Norway (Svalbard) and Russia. The current population is estimated at approximately 62,000 (Table 3-4). Russia and Canada report long-term declines in abundance since the 1960s (Figure 3-29).

On the Russian Arctic islands, the Russian endemic subspecies ***R. t. pearsoni*** is restricted to Novaya Zemlya Island, where the population declined to about 5,000 individuals in 2015 from an estimated 15,000 in 1998 (Mizin et al. 2018). In addition to Novaya Zemlya, there is a stable population of 10,000 to 15,000 individuals on the New Siberian Islands. A small population also occurs on Severnaya Zemlya—300 individuals in the 1980s (Belikov & Kupriyanov 1985)—although no surveys have been conducted recently and current status is uncertain (Mizin et al. 2018).

In the Canadian Archipelago, Arctic island ***Rangifer*** consist of Peary caribou (R. t. pearyi) and Dolphin and Union caribou (***R. t. groenlandicus***). Peary caribou occur in four populations based on movement of individuals between groups of islands. Peary caribou have declined by about 75% from an estimated 22,000 individuals in 1987 to 5,400 individuals in the mid-1990s, partly due to a large die-off around that time related to severe icing events. In 2014, the total Peary caribou population was estimated at 14,000, mostly due to rebounds in the Banks–Victoria and the Western Queen Elizabeth populations; however, in the most recent surveys of the Prince of Wales–Somerset–Boothia population only six individuals were observed and there is no sign of recovery (COSEWIC 2015). Dolphin and Union caribou are unique for their sea-ice dependent migration between Victoria Island and the continental mainland. They have undergone several range contractions and expansions since the beginning of the 20th century, however in the past two decades they have declined by 50 to 60% from about 34,000 individuals in 1997 to 18,400 in 2015. While fluctuations in the Dolphin and Union population have occurred naturally in the past, concerns remain that recovery from current declines may be hampered by multiple novel threats, including decreases in sea ice connectivity between winter and summer ranges due to increased icebreaker and commercial shipping traffic as well as climate change.

Arctic island ***Rangifer*** are also found in areas of the Svalbard Archipelago. Historic (pre-1925) overharvest nearly eradicated this endemic subspecies (***R. t. platyrhynchus***). Nevertheless, this has been followed by over half a century of total protection. Recently, strict harvest management has been permitted. Today, this population has recolonised almost all previous ranges. Current population estimate for the entire Archipelago is approximately 22,500 (Le Moullec et al. 2019).

Populations of ***Rangifer*** of the mountain ecotype occur within the CAFF boundary in Canada and Iceland (in Norway only south of the CAFF boundary). Generally, mountain ***Rangifer*** populations occur at lower densities than migratory tundra populations, however it is unclear whether this is due to the resource limitations of the mountainous terrain they inhabit or a longer history of habitat fragmentation and degradation in sub-Arctic regions with larger human populations and more resource development. Currently, within the CAFF boundary there are approximately 37,000 mountain ***Rangifer*** in at least 14 recognised populations in Arctic and sub-Arctic mountains (Table 3-4).

In Canada, the majority of mountain populations within the CAFF boundary are in the Mackenzie Mountains and northern Rocky Mountains of British Columbia, the Northwest Territories and Yukon. There is an additional population of mountain caribou in the Torngat Mountains of northeast Quebec, Labrador, and Nunavut. The western populations number 31,000 individuals. Many of the largest populations, such as Redstone and Bonnet Plume, are considered stable at 10,000 and 5,000 individuals respectively (COSEWIC 2014). The Torngat Mountain population, however, has been assessed by COSEWIC as endangered, with a decline from 5,000 individuals to 930 individuals between 1980 and 2014 (COSEWIC 2017), although the peak population size may have been overestimated (Couturier et al. 2018). A more recent aerial survey estimated the Torngat Mountains population at 1,326 individuals, although with only two rigorous aerial surveys the trend of this population is still uncertain (Couturier et al. 2018).

The ***Rangifer*** of Iceland are descended from 35 semi-domestic reindeer translocated in the late 1700s from Norway. Numbers were estimated at approximately 3,500 in 2002 and currently number around 10,000 individuals. The population is free from large predators and abundance is closely managed using hunter harvest.

The forest populations of ***Rangifer*** live in sub-Arctic boreal regions along the southern CAFF boundary. In general, these populations do not form large aggregations like those of migratory tundra ***Rangifer*** and migrate only short distances to nearby seasonal ranges. In Canada, forest ***Rangifer*** are known as boreal caribou. There are 20 recognised populations, whose ranges are primarily located within the CAFF boundary, numbering approximately 20,500 individuals in total (Environment and Climate Change Canada 2012). Boreal caribou are legally listed as threatened under the Species at Risk Act in Canada, largely due to the impacts of industrial development on habitat and predator–prey dynamics.

Several populations of forest ***Rangifer*** also occur in Russia (Gunn 2016), although not all populations are within the CAFF boundary. Determining the status of these populations is challenging due to partial range overlap with migratory tundra populations and the difficulty of distinguishing between the two during survey efforts. Forest ***Rangifer*** also occur in low numbers in the Kainuu Region of Finland (Gunn 2016); however, these populations are south of the CAFF boundary.

Monitoring data on demographic, health, genetic diversity, and phenology parameters for ***Rangifer*** are less available than abundance data. CARMA (2015) found that monitoring frequency, methods and target data used to assess ***Rangifer*** populations varied among surveys, limiting comparative analyses across populations. A synthesis of trends of the FEC attributes for ***Rangifer*** is not currently available. Data are available for some of the populations through CARMA (Gunn & Russell 2015).

Distribution is also important for the assessment of ***Rangifer*** populations. ***Rangifer*** are distributed across tundra and boreal forests. Changes in the distribution of continental tundra ***Rangifer*** from historic eras to contemporary times are poorly known. Syroechkovskiy (2000) reported that Russian ***Rangifer*** distribution has contracted to the North and West, and become fragmented over 85% of its former range. Likewise, and based on Indigenous Knowledge, the southern extent of the winter distribution of migratory tundra populations in the boreal forests of central Canada has declined since 1935.

CARMA recently (2017) compiled available collar data (unpublished) for North American populations and found overall distributions have declined for all seasons since 2010 with the most marked decline being calving grounds (22% decline) and winter range (18% decline). Conversely, the area change for summer range was a 2% decline.

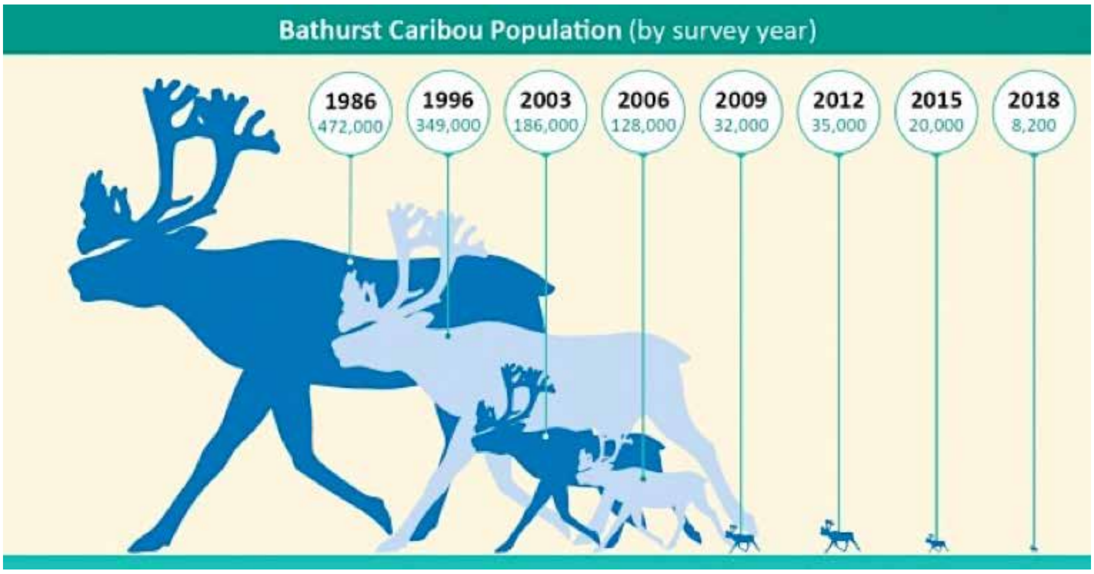
BOX 3-4. DRAMATIC *RANGIFER* POPULATION AND DISTRIBUTION DECLINES: TWO CASE STUDIES FROM THE CANADIAN ARCTIC

Migratory ***Rangifer*** populations have cyclical population dynamics and large fluctuations are well documented due to the cultural importance of Rangifer for Indigenous Peoples and the highly conspicuous phenomenon of long-distance seasonal migrations. However, while most historic accounts of declines in the early 20th century were followed by rebounds in population, current declines in migratory populations are more concerning due to unprecedented and sustained reductions in population size, and a novel set of obstacles to population recovery due to climate change and increased industrial development.

In the case of the George River population in northern Quebec and Labrador, at peak population size in the early 1990s it was considered the largest population of a migratory ungulate at nearly 1 million individuals, which was followed by a 99% reduction to less than 9,000 individuals in 2016 and an 85% reduction in range. The decline is thought to have been driven in part by density-dependence, as evidenced by overgrazed lichen habitats and poor body condition; however, other factors are thought to have contributed, such as industrial impacts on habitat, overharvesting, and changes in climate. While the exact mechanisms remain uncertain, the decline of the George River population prompted an assessment and classification by COSEWIC of endangered and threatened the food security and cultural wellbeing of the Indigenous Peoples of Labrador and northern Quebec who traditionally depend on the population. In addition to reaching the lowest population size since assessments began in the 1940s, the threats to recovery for this population include, further habitat change due to climate change, increasing industrial development within the population's range—including calving and migration routes—and amplified harvesting effects in the context of low populations levels. The Ungava Peninsula Caribou Aboriginal Round Table was assembled in 2017 and has brought together Indigenous governments to work together to conserve the George River population for future generations.

Ungava Peninsula Caribou Aboriginal Roundtable. Photo:Nadia Saganash, used with permission

Over a similar timeframe, the Bathurst migratory population in Northwest Territories declined by 98% between 1986 and 2015, from approximately 450,000 to 8,200. Simultaneously, the size of post-calving and autumn ranges declined based on Indigenous Knowledge and data from satellite telemetry of collared individuals. In addition to changes in spatial use, by 2017, the population also changed their use of habitat—previously they wintered in the boreal forest and presently they winter on the tundra. This change in wintering grounds reduced the extent of the spring migration by a straight line distance of approximately 500 kilometres, a 50% reduction from the spring migrations typical in the late 1990s. Indigenous communities, concerned by the decline and impact on harvest opportunities and cultural wellbeing over the short- and long-terms, requested the aid of the federal and territorial governments in the establishment of a Bathurst Caribou Advisory Committee and to co-develop a range plan to provide the herd with a resilient landscape to support the population through multi-decadal dynamics and manage cumulative impacts of landscape disturbance with harvest opportunities for Indigenous communities.



Graphic from Northwest Territories Department of Environment

Muskoxen

MOXNET identified 55 muskox populations (Table 3-5), including both native and translocated animals. The designated populations often reflect administrative or political regions rather than distinct muskox populations and their distribution within a region. Two subspecies of muskoxen, ***O. m. wardi*** and ***O. m. moschatus***, are recognised. They are often referred to as 'white-faced' and 'barren-ground', respectively.

Table 3-5. Global overview of muskox populations, location, subspecies designation, origin, most recent survey year, population size and trend over the last 10 years.

Population trends (🟩 Increasing, 🟨 Stable, 🟥 Decreasing, or 🟫 Unknown) are indicated by shading. Modified from Cuyler et al. 2020.

POPULATION	SUBSPECIES	ORIGIN	MOST RECENT SURVEY YEAR	POPULATION SIZE AND TREND
U.S. (Alaska)				
Nunivak Island	*wardi*	Translocated	2015	🟨 740
Nelson Island	*wardi*	Translocated	2018	🟨 444
Yukon Kuskokwim Delta	wardi	Translocated	2017	🟩 252
Seward Peninsula	*wardi*	Translocated	2017	🟨 2,353
Cape Thompson	*wardi*	Translocated	2017	🟥 227
North East	*wardi*	Translocated	2018	🟩 285
CANADA–mainland				
Yukon Yukon North Slope	*wardi*	Translocated	2018	🟩 344
Northwest Territories				
Inuvik	*moschatus*	Native	2009	🟨 2,855
Sahtu	*moschatus*	Native	1997	🟩 1,457
North Great Slave	*moschatus*	Native	2018	🟩 8,098
South Great Slave	*moschatus*	Native	2011	🟩 164
Nunavut				
MX-09	*moschatus*	Native	2018	🟨 539
MX-11	*moschatus*	Native	2013	🟫 13,592
Thelon, MX-12	*moschatus*	Native	1994	🟥 1,095
MX-13	*moschatus*	Native	2010	🟩 4,736
MX-10	*moschatus*	Native	2013	🟩 3,685
Boothia Peninsula MX-08	*wardi*	Native	2018	🟩 3,649
Quebec (Nunavik)				
Ungava Bay	*wardi*	Translocated	2019	🟩 3,000
Eastern Hudson Bay	*wardi*	Translocated	2016	🟩 1,000
CANADA–Arctic Archipelago				
Northwest Territories				
Banks Is.	*wardi*	Native	2014	🟥 14,021
NW. Victoria Is.	*wardi*	Native	2015	🟨 14,547
Melville Is. Complex	*wardi*	Native	2012	🟩 3,716
Nunavut				
E. Victoria Is. MX-07	*wardi*	Native	2014	🟥 10,026
Pr. Wales/Somerset Is. MX-06	*wardi*	Native	2016	🟫 3,052
Bathurst Is. Complex MX-05	*wardi*	Native	2013	🟩 1,888
Ringnes & Cornwall Is. MX-03	*wardi*	Native	2007	🟫 21
Axel Heiberg Is. MX-02	*wardi*	Native	2007	🟫 4,237
Ellesmere Is. MX-01	*wardi*	Native	2015	🟩 11,315
Devon Is. MX-04	*wardi*	Native	2016	🟩 1,963

POPULATION	SUBSPECIES	ORIGIN	MOST RECENT SURVEY YEAR	POPULATION SIZE AND TREND
GREENLAND				
Inglefield Land	*wardi*	Mixed	2000	▨ 273
Cape Atholl	*wardi*	Translocated	2017	🟨 212
Sigguk (Svartenhuk)	*wardi*	Translocated	2002	▨ 193
Naternaq	*wardi*	Translocated	2004	▨ 112
Sisimiut	*wardi*	Translocated	2018	▨ 2,622
Kangerlussuaq	*wardi*	Translocated	2018	▨ 20,334
Nuuk	*wardi*	Translocated	2016	▨ 14
Ivittuut	*wardi*	Translocated	2017	🟥 812
Nanortalik	*wardi*	Translocated	2018	🟩 32
Inner Kangertittivaq Fjord	*wardi*	Native	2004	▨ 562
Jameson Land	*wardi*	Native	2000	▨ 1,761
North East Greenland	*wardi*	Native	1992	▨ 12,500
SCANDINAVIA				
Norway: Dovre	*wardi*	Translocated	2018	🟨 244
Sweden: Rogen Nature Reserve	*wardi*	Translocated	2017	▨ 10
RUSSIA				
Yamal Peninsula	*wardi*	Translocated	2017	🟩 300
Taymyr Peninsula	*wardi*	Translocated	2017	🟩 12,100
Begicheva Island	*wardi*	Translocated	2017	🟨 230
Putorana Plateau	*wardi*	Translocated	2004	▨ 20
Anabarskay	*wardi*	Translocated	2017	🟩 1,040
Bulunskay	*wardi*	Translocated	2017	🟩 700
Indigirskay	*wardi*	Translocated	2017	🟩 350
Kolymskay	*wardi*	Translocated	2017	🟩 30
Magadan Oblast	*wardi*	Translocated	2015	▨ 16
Magadan Omulevka River	*wardi*	Translocated	2015	▨ 6
Chukotka	*wardi*	Translocated	2017	🟥 4
Wrangel Island	*wardi*	Translocated	2018	🟩 1,000
GLOBAL TOTAL MUSKOXEN				**circa 168,778**

The current circumpolar population size estimate is 170,000 individuals. This represents an increase from previous estimates of 134,000 to 137,000 in 2008, approximately 135,000 in 2013 and 111,000 to 135,000 in 2017, and represents the best approximation considering all data ambiguities. Of the total, 80% of wild muskoxen are ***O. m. wardi*** and 20% are ***O. m. moschatus***—which occur primarily on mainland Canada. Translocations over the past century have resulted in the return to a circumpolar distribution. All reintroduced or translocated animals have been ***O. m. wardi.*** As evident in Table 3 5, 71% of muskox populations are native and 29% are translocated. Geographically, the majority of muskoxen are in Canada, followed by Greenland, Russia, Alaska, and Scandinavia. While some populations are in decline (historically some of the largest populations – most notably Banks Island), others have expanded their range or experienced increases typical of translocated populations (Figure 3-29). For two small populations in Greenland, a stable or decreasing trend is the result of wildlife management interventions designed around specific goals.

Recent trends for 38 muskox populations/regions (Table 3-5) show 23 increasing (36.2% of present global abundance), 9 stable (13.1%) and 6 decreasing (15.5%). Conspicuously, in 2000, two of today's declining populations were then the largest native populations in the world, with a combined total of approximately 87,000 muskoxen. Today, they number about 24,000. Mortality events caused by infectious agents have been identified but are unlikely the sole cause of the decline. Recent trends are unknown for 17 populations (35.1% of present global abundance). Thus, interpreting the true impact of these declines relative to the total global population is difficult. Regardless, it is evident that population status can change quickly.

Information on muskox demographics is difficult to obtain and therefore not commonly collected or reported. Although circumpolar in extent, available data are typically only available for small areas or areas with high muskox densities. Demographic data are collected using ground-based surveys, which can be costly and logistically difficult to execute. Currently, our ability to compare sex and age across populations is limited. Adoption of standardised methodology would allow for interpretation of trends and population dynamics in the future.

Although the general distribution of muskoxen is well defined, detailed information on spatial structure is mostly not available. This species is widely dispersed and in many cases surveys are infrequent. Some populations of muskoxen have been observed to be relatively sedentary while others move between seasonal ranges. Muskoxen have also been observed vacating one region and moving to occupy new ranges. These factors make monitoring of spatial distribution challenging. Infrequent surveys also negatively impact our understanding of phenology in muskoxen.

Although in the past muskoxen have survived major shifts in climate, current genetic information reveals that they have gone through a number of bottlenecks and extirpation events resulting in low genetic variability. One of the consequences of this low variability is very low diversity in the major histocompatibility complex, which may lower their ability to respond to infectious diseases. In general, conservation of muskoxen could be enhanced with better understanding of muskox genetics.

Attention to disease in muskoxen is relatively new. Although infectious disease agents have been identified in declining populations in Alaska, Canada and Norway, documentation of occurrence and impacts of these pathogens could be improved. Attention could focus on overall muskox health, paired with demographic or abundance surveys. Cuyler et al. (2020) provide an up-to-date overview of pathogens and diseases described in muskoxen in their electronic supplementary materials.

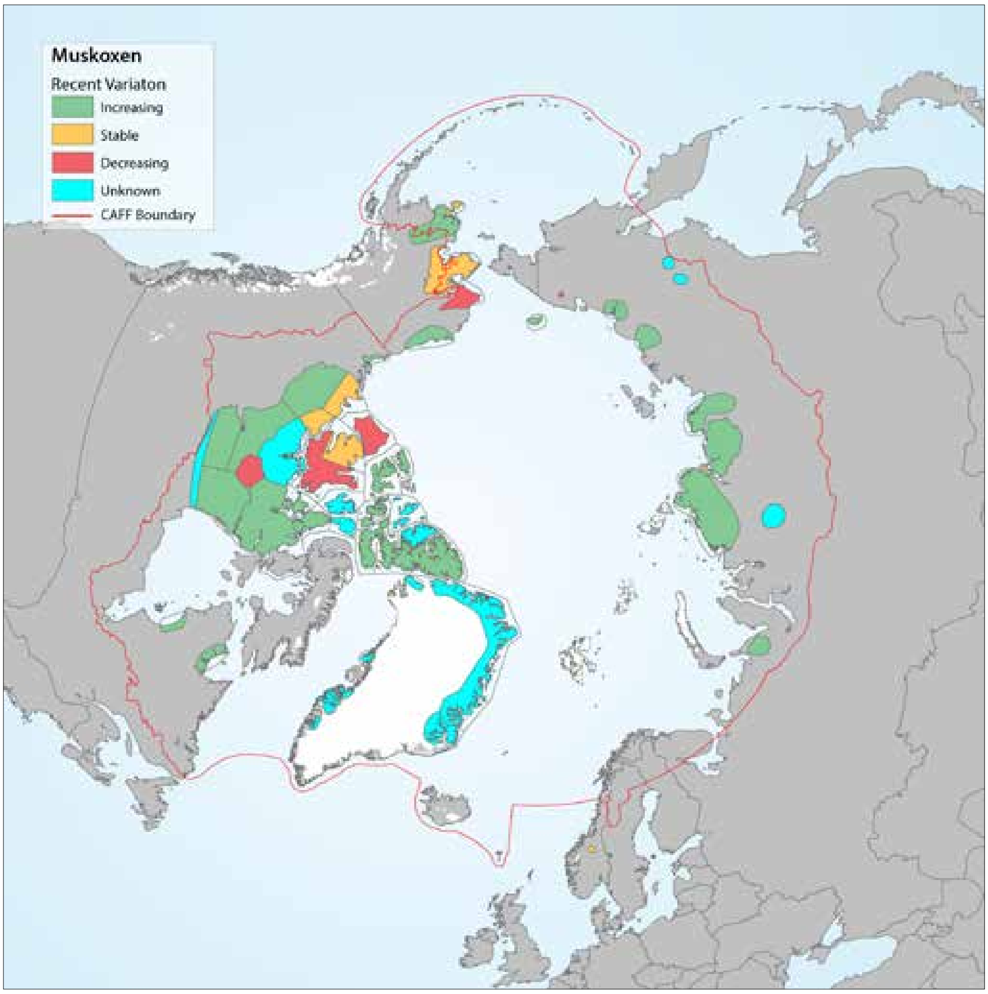


Figure 3-30. Trends and distribution of muskoxen populations based on Table 3-5.

Modified from Cuyler et al. 2020.

3.4.1.2 Small Herbivores

Lemmings

Lemmings are currently being monitored at 38 sites. Their status and trends were determined based on data from these sites as well as recent data (since 2000) from an additional 11 previous monitoring sites (Figure 3-31). Of those sites monitored, Fennoscandia is overrepresented relative to the geographical area it covers, whereas Russia is underrepresented. Based on the skewed geographical coverage, more information is available for some species of lemmings than others, particularly the Norwegian lemming.

Methods for monitoring small mammals varied by site and ranged from live trapping with multiple sampling events in a given year (mark–recapture studies) to systematically recorded incidental observations and qualitative indices. Annual lemming abundances were recorded at all sites, but mostly in the form of relative abundance indices. Quantitative density estimates based on mark-recapture live trapping were available only for four high Arctic sites.

As noted in the *Arctic Biodiversity Assessment*, large variability in amplitude of lemming cycles is the norm, making trends difficult to identify without long-term, multi-cycle time-series data. Given that caveat, and the heterogeneity of available data types, there is no current evidence that pan-Arctic lemming populations have been increasing or decreasing over the last 25 years. There are two exceptions—a negative trend detected for low Arctic populations sympatric with voles, and indications of a negative trend in Russia.

Abundance data for lemmings showed large amounts of heterogeneity across years, sites, and species. Patterns of fluctuations also varied. Norwegian lemmings exhibited regular outbreaks at three to six-year intervals, but sometimes much longer periods without outbreaks, and with large variation in amplitude. Vole peaks in Fennoscandia were often synchronous with lemming peaks, but not always. Outside of Fennoscandia, heterogeneity was also large. Regular cycles with a period of three to four years were observed at some sites, but this pattern varied considerably. In many cases, patterns were difficult to discern because of large differences in amplitude or changes in monitoring methodology. Change in species composition were noted at two low Arctic lemming monitoring sites: in 2010 in Churchill, Manitoba, meadow voles (***Microtus pennsylvanicus***) were recorded after having been absent during monitoring in the 1990s; and in 2013 and 2014, voles (***M. middendorffii***) were observed in south-eastern Taymyr for the first time despite years of monitoring.

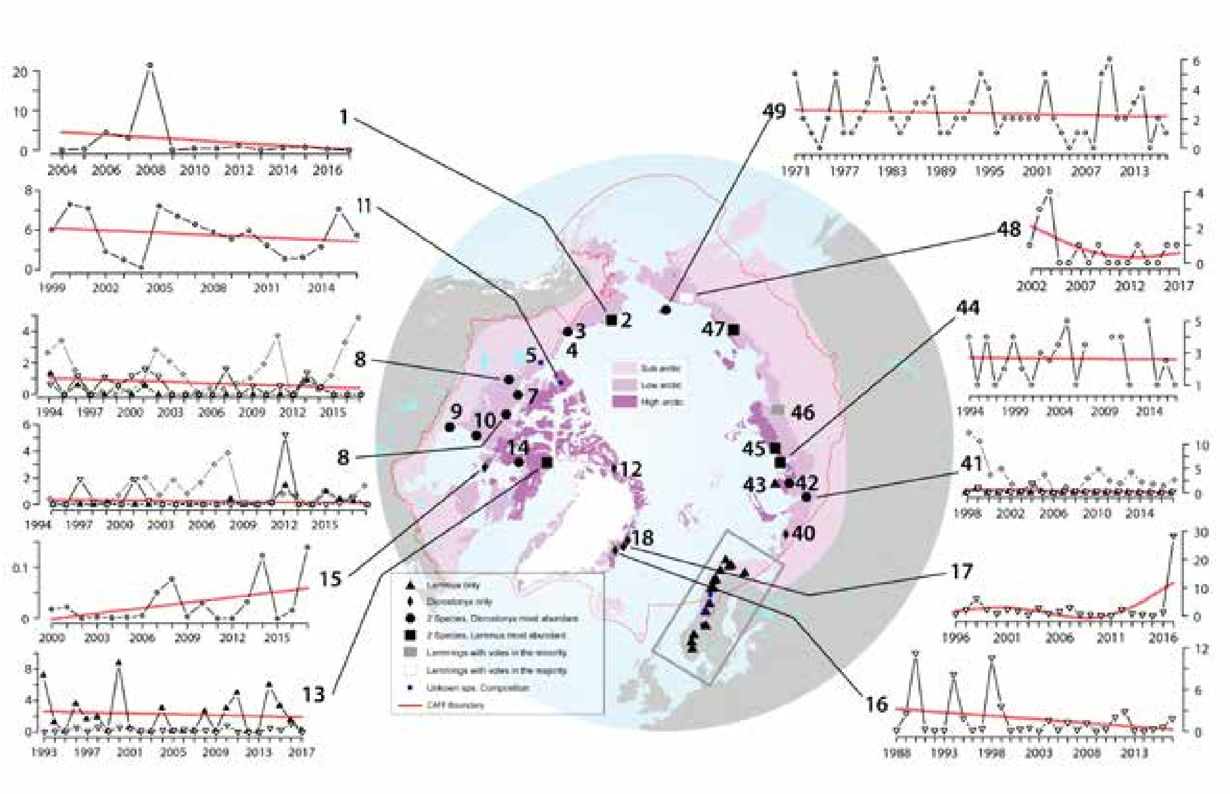


Figure 3-31. Location and trends of lemming populations at monitoring sites across the circumpolar region. Numbers refer to sites in Ehrich et al. 2020. Symbols indicate small rodent community composition. Modified from Ehrich et al. 2020.

Lemming. Photo: Frank Fichtmueller/Shutterstock.com

In addition to abundance, the CBMP–Terrestrial Plan considered two other attributes to be essential for monitoring lemmings—health and phenology. These, however, were seldom monitored. Diseases and parasites were only monitored systematically at a few sites and phenology was only regularly monitored on Wrangel Island (one of the discontinued monitoring programmes). Phenological information gathered at this site included first appearances on the snow, migration to summer habitat and observations of first juveniles.

The CBMP–Terrestrial Plan recommended monitoring demographics, spatial structure, and genetic diversity of small mammals. Approximately half of the sites regularly collected data on sex and age classes of captured individuals and occasionally on reproductive status. Spatial data is also available for a number of sites. Genetic diversity has been assessed in some cases but often only once at a given site. Other data sometimes collected in association with monitoring included diet, abundance and reproduction of lemming predators, availability of alternative prey, plant productivity and phenology, and abiotic factors.

3.4.1.3 Medium-sized Predators

Arctic Fox

Arctic foxes are currently monitored at 34 sites throughout the North, with most monitoring efforts concentrated in Fennoscandia (Figure 3-32). The duration of monitoring across all sites is variable at between 2 and 56 years and was ongoing at 27 of the 34 sites (79%) as of 2015. Monitoring projects cover almost equally the four climate zones of the species' distribution—high Arctic, low Arctic, sub-Arctic, and montane/alpine.

Fox dens are monitored because they are long-lasting reproductive structures used repeatedly by territorial individuals. Typically, data collected for Arctic foxes include, den density, number of active dens, number of breeding dens and litter size. Beyond that, monitoring programmes vary greatly with respect to other variables. Almost all sites monitor fox abundance, reproductive effort, and litter size. Additional variables for informing population status are less well represented. Additional metrics include, pup survival and genetic parameters monitored in more than 20 (59%) projects, contaminant levels monitored in 13 (38%) and disease exposure monitored in five (15%).

Arctic fox ecology was highly variable between sites with regards to long term population trends, annual and multi-annual fluctuations, diet composition and interaction with red foxes and humans. Densities of known dens varied 100–fold across monitoring sites, from 0.01 to 1 den per square kilometre (mean of 0.18 ± 0.25 dens per square kilometre). Minimum and maximum numbers of Arctic fox breeding pairs were available for most monitoring sites. Between-year variations can reflect multi-annual fluctuations, long term changes in fox abundance or variation in monitoring effort. Of the 34 monitoring sites, long term population trends were stable (17 populations, 50%) or increasing (nine populations, 26%), with only three populations (9%) decreasing. Trends were unclear in five (15%).

Most populations showed strong multi-annual fluctuations (22 populations, 64%) and the majority of these fed primarily on lemmings (90%; 20 of 22). Nine showed no multi-annual fluctuations and these groups fed primarily on birds, marine food, or large mammal carcasses (89%; 8 of 9). Three showed weak or unclear fluctuations.

The circumpolar population of Arctic fox shows little genetic differentiation with the exception of the diverged Commander Islands populations. Monitoring data exist for phenology of pup emergence (19 sites) and phenology of moulting (17 sites), but no synthesis of these data is available. A full assessment of phenology is also challenging as projects typically concentrate fieldwork in summer. Samples have been collected to provide health data on levels of contamination (22 sites), parasites (18 sites) and disease exposure (6 sites), but samples were analysed only partially and again no data synthesis is available

Figure 3-32. Arctic fox monitoring study sites. Modified from Berteaux et al. 2017; Arctic fox distribution area modified from Angerbjörn & Tannerfeldt 2014.

3.4.2 EFFECT OF DRIVERS ON FECS AND THEIR ATTRIBUTES

Climate change is the primary driver influencing biodiversity, abundance, and ecological function for all CBMP focal mammal species; it is indeed the most important driver of change in terrestrial Arctic ecosystems (CAFF 2013a). In terrestrial environments, impacts from climate change on all FEC functional groups include a general warming trend and increased variability in the Arctic climate that can manifest as interannual variability as well as short- and long-term cyclical climatic fluctuations. Interannual variability in weather may include severe storms, extraordinarily warm or cold winters and summers, variable amounts of snow in all seasons, midwinter rain and thaw events, rainy summers, drought summers and strong winds. In autumn and spring, variability can include erratic timing of snowmelt and snow arrival.

For Arctic ungulates, annual variability in weather patterns affects calf productivity and survival. Deep snow and icing events—such as winter rain and melting temperatures that create ice cover on the ground or in the snowpack—make it difficult for large herbivores to access forage. This may lead to decreased calf recruitment and, in extreme cases, can cause die-offs. Meanwhile, summer drought can negatively affect vegetation that is essential winter forage for large herbivores. Temporal and spatial scale are important considerations when judging the impact of weather events. The impacts of increasing frequency, distribution, severity, and extent of stochastic weather events on population dynamics remain unknown.

For lemmings, autumn and winter rain and midwinter thaws lead to hard snow and icing at the bottom of the snowpack. These impenetrable layers impact movement and limit access to food plants, resulting in reduced reproduction and survival. Lemming populations appear to be more sensitive to this change in winter climate than northern voles, resulting in a fading out of lemming outbreaks in areas of lower abundance (documented in Fennoscandia). This loss of outbreaks may contribute to reduced amplitude and extend the time period between lemming cycles, however, to date, there is no detectable regional (Fennoscandia) or circumpolar trends of decreasing lemming populations. In addition, later onset of snow in autumn and earlier spring melt reduce the duration of snow cover and may impact lemming winter reproduction. Local/regional changes in lemming populations may cascade to predator populations through declines in prey availability, with particularly dramatic consequences for specialist species, such as snowy owls or Arctic foxes.

Impacts of warming temperatures on specific mammalian habitat is variable and depends on local conditions, including precipitation patterns, presence of permafrost, soil moisture conditions and the presence of herbivore taxa. Warming temperatures may also result in range extensions of wildlife pathogens, particularly those from sub-Arctic regions, which may change the pattern of transmission and exposure of native host populations to new pathogens. Changes in the distribution and prevalence of pathogens are likely to play a role in future distribution and dynamics of Arctic mammal populations. For Rangifer and muskoxen, there is already evidence that increasing temperature influences development, distribution, and emergence of some pathogens.

Range extension of boreal mammalian species into Arctic tundra areas is also introducing new herbivore competitors and potential predators into true Arctic ecosystems. Examples of species with northward range extensions include red fox, moose (***Alces americanus***), Eurasian elk (***A. alces***), American beaver (***Castor canadensis***), snowshoe hare (***Lepus americanus***), Middendorff's vole (***Microtus middendorffii***) and meadow voles (***M. pennsylvanicus***). Populations of North American species introduced into Eurasia, such as muskrat (***Ondatra zibethicus***) and American mink (***Neovison vison***), are also moving into low Arctic areas (CARMA 2013a). For muskoxen, increased range overlap with grizzly bears in north-eastern Alaska (***Ursus arctos***) has resulted in new predator–prey dynamics (Reynolds et al. 2002).

Contaminants also pose a threat to Arctic mammals, particularly predators. Contaminants have the potential to impact the health and fecundity of Arctic wildlife, and there are concerns regarding food security and health in northern communities for whom harvest of ***Rangifer*** is a critical resource. Lack of data, however, makes it difficult to understand the extent and magnitude of the impacts.

Humans may also have more direct impacts on biodiversity/abundance of Arctic mammals. Impacts that directly affect habitat and populations include infrastructure (roads, structures associated with resource development), harvest, introduction or reintroduction of plants and animal species, disturbance from tourism, and greater human activity due in part to technological changes (modern boats, snow machines and all-terrain vehicles) that facilitate more frequent and widespread travel sometimes into formerly inaccessible habitats. These impacts may be direct, such as overharvest, or indirect, such as displacement from essential habitats (calving grounds, denning locations, pupping and feeding areas).

Conversely, overabundant semi-domestic reindeer may be problematic. Heavy grazing and trampling impact terrestrial Arctic habitats by reducing lichen cover and favouring graminoids (Bernes et al. 2015). High abundance of semi-domestic reindeer, coupled with mortality though winter icing events, increases the number of reindeer carcasses available to predators. This appears to have propelled red fox population increases and range expansion, as well as benefited other boreal generalist predators such as corvids, while having detrimental effects on Arctic fox and many species of ground-breeding birds such as ptarmigan and waders.

Additional direct and indirect human impacts on Arctic fox include feeding (positive or negative), removal of competitors, killing and transmission of disease by pets. In Fennoscandia, Arctic foxes are considered critically endangered. They are currently benefiting from a comprehensive conservation programme including supplemental feeding, culling of red fox and release from captive breeding. This has resulted in increasing trends for several populations. At present, it is unclear whether these populations would maintain a positive trend without these supporting measures. The northward expansion of red fox, to the detriment of Arctic fox, has often been attributed to a warming climate but evidence suggests that direct and indirect food supplementation by humans may be the main causal factor.

3.4.3 COVERAGE AND GAPS IN KNOWLEDGE AND MONITORING

Large Herbivores–Rangifer and Muskoxen

In many areas, large herbivore surveys are infrequent, lack measures of variance (or exhibit large variability) and methodology and effort lack consistency. All these factors lead to uncertainties in the data and is a barrier to comparing among regions and states.

Abundance trends are difficult to ascertain for a number of populations from survey estimates alone. The implementation of standardised methods for improving ***Rangifer*** population estimates has been in place for the last 30 years and represent a significant advance, providing a useful template for muskoxen. Surveys for both ***Rangifer*** and muskoxen are hampered by the species' diffuse distribution and remote locations. Most abundance estimates do not differentiate sex and age classes. Demographics are difficult to obtain, due in part to the need for more intensive, and, for muskoxen, often ground-based surveys. Demographic data are critical for interpreting population trends, developing management strategies and allowing for comparisons across regions.

For both ***Rangifer*** and muskoxen, more information is needed on population specific vulnerability to the cumulative effects of climate change and other human impacts. Access to timely and accurate data is critical for identifying management actions that build adaptive capacity and resilience within populations, particularly those that have declined to historic lows that may be outside of the natural range of population fluctuation. The only populations showing strong and stable numbers are in Greenland, Iceland, and Svalbard, and this may skew conclusions. Experts – scientific, indigenous, and local – play a critical role in reporting and integrating this information.

Little is known about the impacts of changing climate on the distribution and prevalence of disease. Recent mortality events in Alaska and Canada have illustrated our limited understanding of disease in ***Rangifer*** and muskoxen. There is widespread recognition of the need to develop standardised health assessment protocols capable of providing basic information on the prevalence, significance, and role of disease in large herbivore population dynamics.

For Arctic ungulates, there is a general lack of both reliable harvest data and effective models to determine sustainable harvesting levels. This is unexpected considering the high degree of regulation of present-day harvests. Hunting was presumed to be a contributing factor to the decline of muskoxen in North America in the early 1900s. Changes in overall harvest, as well as the sex and age composition of the harvest, can impact population composition, group dynamics and overall abundance. Accurate harvest data are needed to inform conservation efforts as well as provide insights into the economic benefits of commercial harvests.

Small Herbivores—Lemmings

While lemming abundance is monitored across all sites, methods as well as levels of precision vary. Quantitative density estimates (such as through mark–recapture analysis) are rare because they are often quite invasive, labour intensive and, consequently, typically limited to small spatial scales. Most small mammal monitoring programmes therefore rely on abundance indices. Fauteux et al. (2018) found good correlation of mark–recapture estimates with indices based on systematic incidental observations and snap trapping. Although simple to implement, incidental observations have a number of shortcomings, that is, the challenge of distinguishing between small mammal species. Snap trapping is the most common method for monitoring lemmings, but sampling designs vary.

The variety of methods used for monitoring small mammals may be a challenge when looking at large-scale patterns. While all quantitative methods allow comparisons of trends and relative dynamic patterns, it can be difficult to compare abundance among sites, which is critical for examining trophic interactions. Qualitative index series may exhibit more regular cycles than quantitative series, and in long qualitative time series, there can also be an effect of shifting baseline, making it difficult to identify long term trends. Standardisation of monitoring methods across sites would address many of these issues. Adoption of standardised methods in a number of disparate long-term monitoring programmes is difficult to implement without losing the value of the historic data. The old and new protocols should be implemented simultaneously for a number of years to establish correction factors between time series. The end result, however, should be a number of comparable long-term time series.

Parasites and diseases of lemmings have been studied at a few monitoring sites but are not generally included in regular monitoring protocols. Likewise, genetic structure has not been investigated regularly. Progress could be made in monitoring of genetic structure, as well as health, through analysis of previously collected tissues and could provide a historical context. As previously noted, the majority of lemming monitoring efforts occur in the summer. Consequently, little information is available on annual or site-specific phenology.

Geographically, lemmings are most intensively monitored in Scandinavia. This geographical bias is particularly evident in the lack of representativeness of the Russian and Canadian Arctic's. In Russia for example, which encompasses the majority of the Eurasian Arctic, there are only four ongoing long-term monitoring projects with more than five years of data. The lack of lemming monitoring in some locations is also indicative of gaps in knowledge of other ecosystem attributes.

Lack of good spatial coverage in small mammal monitoring south of the Arctic outside of Scandinavia is also an information gap. The distribution of several lemming species extends south of the Arctic and lack of monitoring in these areas make it difficult to assess changes in distribution. Similarly, several vole species are extending their ranges northward. Lack of range distribution information for these species make it difficult to document and understand changes.

Temporally, small mammal monitoring typically occurs during snow-free periods. Monitoring is usually conducted during one or two periods in summer. Insights into winter abundance and activity is generally restricted to counts of winter nests after snowmelt. Winter abundance is likely critical to understand the impact of climate change in lemmings—an animal specialised for life under the snow. This knowledge gap is well known, but the challenges of studying lemmings in the winter, under the snow, in remote Arctic locations are difficult to overcome. New technology is poised to open up new possibilities through the development of camera tunnels for monitoring lemmings year-round.

The CBMP–Terrestrial Plan recommends an ecosystem-based approach to monitoring that is structured around explicit models. One of the reasons to monitor small mammals, as well as the other mammal FECs, is for insights they yield on ecosystem function, trophic interactions, and drivers of environmental change. Analysing changes in lemming abundance as a function of ecological drivers is only possible if drivers of change are also measured. Less than half of lemming monitoring sites gather data annually on abiotic conditions. This is a lost opportunity.

Medium-sized Predators—Arctic Fox

Similar to international monitoring efforts for *Rangifer* and muskoxen, a circumpolar network of Arctic fox biologists facilitates information exchange. Although circumpolar, over a third of monitoring sites are geographically concentrated in Norway, Sweden, and Finland. Arctic fox abundance, reproductive effort and litter size were assessed in almost all monitoring projects. Other variables indicative of population status were also monitored but these variables were not uniform in type or extent across projects. For example, pup survival and genetic parameters were monitored in many populations but not all. One challenge in assessing abundance is a measure of non-breeding adults. In some years, this may be the majority of adults in the population. Better harmonisation across monitoring projects can allow sharing of protocols and data for greater inference for this important variable.

Many projects monitored some variables indicative of ecosystem structure. The variables monitored and the techniques used, however, differed across projects, reflecting differences in effort, objectives, and ecosystem structure. In addition, less than 30% of projects monitored two or more variables indicative of ecosystem function.

Large and Small Predators and Medium-sized Herbivores

The CBMP–Terrestrial Plan identified large predators, small predators, and medium-sized herbivores FECs as part of the mammalian monitoring framework and recommended that these FECs and their attributes be monitored when feasible. Presently, monitoring of these FECs takes place sporadically and on a regional basis with limited scope tailored to specific regional issues and it is challenging to summarise the attributes for these FECs in the absence of consistent, widespread monitoring efforts throughout the circumpolar Arctic. Monitoring of these FECs would benefit from an organised international collaborative approach, much as CARMA, MOXNET and other networks that have facilitated the synthesis of data across geographical areas.

3.4.3.1 Recommended revisions to FECs and key attributes

The FEC attributes for mammals as defined in the CBMP–Terrestrial Plan are listed in Table 2-1. In many instances, monitoring of attributes considered essential is lacking. Based on experience obtained from producing the START, some revisions are recommended to future monitoring. Attributes considered essential or recommended are presented in Table 3-6.

Muskox. Photo: Longtaildog/Shutterstock.com

Table 3-6. Summary and recommended revisions of mammal FECs and key attributes.

*Recommended revisions are shown in **bold italics** with the current category in brackets. "E' means essential attributes. 'R' means recommended attributes.*

	FEC ATTRIBUTES							
FECS	EXAMPLES	ABUNDANCE	DEMOGRAPHY	PHENOLOGY	DIVERSITY	HEALTH	SPATIAL STRUCTURE	COMMENTS - REASONS FOR RECOMMENDED CHANGE
Mammals								
Large herbivores	*Rangifer*, muskoxen, moose	E	E	E	***E*** (R)	E	E	For *Rangifer* in particular, conservation efforts often focus on specific ecotypes or genetic types. Good examples include forest Rangifer in North America and specific populations of Arctic Island *Rangifer*.
Medium–sized herbivores	hares	E	E	E	R	E	R	No change
Small herbivores	lemmings, voles	E	R	E	***E*** (R)	E	***E*** (R)	Small mammal diversity is a good indicator of environment change. As an important prey resource for many Arctic predators, spatial structure is essential for understanding food web dynamics in Arctic ecosystems.
Large predators	brown bear, grey wolf	E	E	E	R	E	R	No change
Medium–sized predators	wolverine, lynxes, foxes	E	R	E	***E*** (R)	E	***E*** (R)	Climate and human impacts in some areas of the Arctic may lead to barriers in connectivity
Small predators	stoat/ weasel/ ermine	E	R	E	R	E	R	No change

3.4.4 CONCLUSIONS AND KEY FINDINGS

Trends in abundance varied for the mammal species addressed in this report. Globally, populations of ***Rangifer*** have mostly declined since the 1990s, some dramatically. There are, however, notable exceptions, which begs the question of why some populations are doing well and others are not. Overall, present abundance for muskoxen is largely unchanged with some areas experiencing increases while other populations have declined. Circumpolar lemming abundance is fluctuating but appears stable overall, however there are indications that lemmings are declining in the southern portions of their range where voles also occur. In general, Arctic fox populations are either stable or increasing with just a few monitoring sites indicating a decline in abundance.

Key findings

- Globally, populations of ***Rangifer*** have mostly declined since the 1990s, some dramatically; however, there are notable exceptions. In addition, there are changes in distribution, range, and fragmentation.
- Conservation of ***Rangifer*** often focuses on ecotypes based on genetics and behaviour. Four ecotypes are widely accepted—migratory tundra, Arctic islands, mountain, and forest. The majority of migratory tundra and forest ***Rangifer*** herds have declined in population size. Trends for Arctic island and mountain ***Rangifer*** tend to be stable or unknown
- ***Rangifer*** trends are confounded by infrequent monitoring, variable methods, as well as introductions, local management and in some cases, mixing of domestic, feral, and native populations.
- Current circumpolar abundance estimate for muskoxen is higher than estimates from 2013 and 2017. Recent variations indicated that 23 muskox populations/regions were increasing, nine were stable, six were decreasing, while variation was unknown for 17. Of note, the two with steepest declines were, in 2000, the largest endemic populations in the world. Infrequent monitoring and variable methods confound comparisons.
- Trend is not detectable in pan-Arctic lemming populations over the last 25 years.
- Considering lemmings in different small mammal communities revealed a negative trend for low Arctic populations outside of Fennoscandia sympatric with voles. There were also indications of a negative trend in Russia, where several of the decreasing mixed community populations were located.
- With one exception, all low Arctic lemming populations occurred in mixed small rodent communities including one or more species of voles.
- Change in species composition was noted at two low Arctic monitoring sites with vole species appearing in 2010 and 2013 in Churchill Manitoba and south-eastern Taymyr, respectively.
- Although highly variable, Arctic fox abundance was either stable or increasing at the majority of monitoring sites with only a few in decline. Trend was unknown at a few of the sites.
- Arctic fox abundance, reproductive effort and litter size was assessed in almost all populations. Better harmonization of protocols and data sharing would allow for greater understanding among sites, identify data gaps and direct future research.
- Currently, international monitoring networks exist for only three of the six mammal FECs. Future monitoring efforts would benefit from the establishment or expansion of monitoring networks to collect data on the remaining three FECs.

Challenges exist for assessing the abundance of focal mammal species across the circumpolar Arctic. They include:

- reliability of abundance estimates—for example lack of precision;
- changing baselines—such as changes in species distribution, sampling methodology, changes in areas monitored;
- differences in frequency of monitoring by regions; and
- spatial extent of monitoring—expanding monitoring efforts in underrepresented areas would be beneficial to understanding circumpolar ecological changes.

Braya linearis. *Photo: Mora Aronsson*

3.5 RARE SPECIES, SPECIES OF CONCERN

Lead Author: Mora Aronsson,

Contributing authors:
Bruce Bennett, Casey T. Burns, Starri Heiðmarsson and Mikhail Soloviev.

As elsewhere in the world, the Arctic is home to species that are threatened and of conservation concern. While only identified as a FEC for plants and fungi, they have been assessed within other taxonomic groups as well, depending on data, and are presented here when applicable.

The IUCN sets a global standard for assessing and classifying threatened species and the ***IUCN Red List of Threatened Species*** (Red List) is the most comprehensive information source on species status and extinction risk. Nevertheless, although more than 120,000 species have been assessed to date (IUCN 2020a), there are many species, including many that live in the Arctic, that have not been assessed globally, and no regional assessment for the Arctic as a whole has been produced.

Species under threat are found throughout the Arctic; however, the collection of data and production of lists is not standardised across countries and regions. Most countries have species lists that follow the IUCN regional guidelines for application of the Red List criteria (IUCN 2012b), but most are not comprehensive nor are they completely consistent in the application of the criteria, making comparisons or summaries difficult. The amount of data is also differing between different groups, with much more relevant data collected for mammals and birds compared to invertebrates and fungi. As of 2020, Red Lists for three regions completely within the CAFF boundary are available for Greenland, Iceland, and Svalbard. There are also regularly updated Red Lists for Norway, Sweden and Finland that include species occurring within the CAFF boundary. Russia has Red Data Books, using criteria similar to IUCN, for regions that include parts of the Arctic. Both Canada and the U.S. have systems that assess species based on the IUCN criteria at the national and regional levels. They also have separate lists of species protected under legislation that do not necessarily include all species on the Red Lists.

In this chapter only species that are related to the terrestrial CBMP-plan are taken into concern, freshwater and marine species are omitted.

On the global scale, concerning the Arctic, there are only assessments made by IUCN on mammals and birds. The only mammal under the CBMP–Terrestrial Plan that meets any Red List criteria is caribou/reindeer ***Rangifer tarandus***, which is considered Vulnerable (VU). All other assessed mammals are considered Least Concern (LC).

Among the birds listed in Table 3-2 (88 species), 10 species fall within the 'threatened' IUCN Red List categories (IUCN 2012a). These are: Critically Endangered (CR) - spoon-billed sandpiper (***Eurynorhynchus pygmeus***), siberian crane (***Grus leucogeranus***) and eskimo curlew (***Numenius borealis***) (possibly extinct); Endangered (EN) - great knot (***Calidris tenuirostris***); and Vulnerable (VU) - lesser white-fronted goose (***Anser erythropus***), red-breasted goose (***Branta ruficollis***), snowy owl (***Bubo scandiacus***), long-tailed duck (***Clangula hyemalis***), bristle-thighed curlew (***Numenius tahitiensis***) and steller's eider (***Polysticta stelleri***). An additional nine species are considered Near Threatened (NT) — red knot (although some subspecies are Threatened), curlew sandpiper (***Calidris ferruginea***), semipalmated sandpiper (***Calidris pusilla***), red-necked stint (***Calidris ruficollis***), emperor goose (***Anser (Chen) canagica***), yellow-billed loon (***Gavia adamsii***), bar-tailed godwit (***Limosa lapponica***), spectacled eider (***Somateria fischeri***) and buff-breasted sandpiper (***Tryngites subruficollis***) (IUCN, 2020b), see also Chapter 3.3.2.4 and Table 3-2.

3.5.1 GREENLAND, ISLAND AND SVALBARD

Red Lists from the Nordic states, including Greenland, are based on the IUCN criteria (IUCN 2012a, 2012b). The latest Red List for Svalbard was published in 2015 as part of the Norwegian Red List (Henriksen & Hilmo 2015), the most recent for Iceland was published in 2018 (Icelandic Institute of Natural History 2018a, 2018b, 2018c) and the latest for Greenland in 2018 (Boertmann & Bay 2018). There are some differences in the coverage of groups of organisms between the lists, but they are all more or less complete assessments for the groups they do cover. All three Red Lists cover mammals, birds, and vascular plants. The Red List from Greenland also includes some few butterflies (Table 3-7 and Table 3-8). The caribou/reindeer in east Greenland (***Rangifer tarandus eogroenlandicus***) was last seen in 1899 and is probably Extinct (EX) due to some very harsh winters. The Regionally Extinct (RE) species from Greenland are: the vascular plant Melancholy Thistle (***Cirsium helenioides***) a marginal population of a common northwest European species; two bird species, Barrow's Goldeneye (***Bucephala islandica***) which was always rare in Greenland with unknown reason for disappearance, and Fieldfare (Turdus pilaris), a species on its margin that only occurred at southernmost Greenland for 50 years. The Regionally Extinct species from Iceland are: the vascular plant Greenland Primrose (***Primula egaliksensis***) known from one site, an outlier of the North American distribution with unknown reason for disappearance; and two birds, House Sparrow (***Passer domesticus***) and Water Rail (Rallus aquaticus), the latter being threatened by drainage of wetlands and introduction of the invasive American mink. No species is known to have become Regionally Extinct (RE) in Svalbard to date.

Future climate change is the most frequently reported threat on the Red Lists from all three areas, with various different effects.

Table 3-7. Number of species on Red Lists in Greenland (2018), Iceland (2018) and Svalbard (2015) by IUCN category.

	REGIONAL EXTINCT	CRITICALLY ENDANGERED	ENDANGERED	VULNERABLE	NEAR THREATENED	DATA DEFICIENT	TOTAL
Greenland	4	0	1	57	36	9	**107**
Iceland	3	9	12	44	15	8	**91**
Svalbard	0	9	19	17	40	0	**85**

Table 3-8. Number of species on Red Lists in Greenland (2018), Iceland (2018) and Svalbard (2015) by taxonomic group.

	MAMMALS	BIRDS	VASCULAR PLANTS	LICHENS	ARTHROPODS	TOTAL
Greenland	3	14	89	-	1	**107**
Iceland	0	30	61	-	-	**91**
Svalbard	0	8	60	17	0	**85**

3.5.2 FINLAND, SWEDEN, AND MAINLAND NORWAY

Norway (mainland), Sweden and Finland regularly produce Red Lists, updated at five to ten years intervals (last editions: Norway, Henriksen & Hilmo 2015; Sweden, SLU Artdatabanken 2020; and Finland, Hyvärinen et al. 2019). Table 3-9 and Table 3-10 show the Red-listed species from these countries whose distributions include the sub-Arctic part of the CAFF area (species with distribution only in the boreal forest part of the CAFF area are not included).

Knowledge differs between the three states regarding bryophytes, lichens, and invertebrates in the alpine environment. Finland and Sweden have many more Red-listed bryophytes than Norway and Finland has many more Red-listed lichens and invertebrates than Sweden and Norway, even though the three states have similar number of known species in the three groups. The main threats reported are primary and secondary effects from climate change, overgrowth, changing vegetation and disappearing snow patches. Some species are also impacted by overgrazing by reindeer.

Four species are listed as Regionally Extinct (RE) in Finland—two moth species, ***Catastia kistrandella*** and ***Anarta farnhami***; a hemipteran bug, ***Psammotettix frigidus***; and the wild subspecies of reindeer (***Rangifer tarandus tarandus***). The wild subspecies of reindeer is also classified as Regionally Extinct (RE) in Sweden. The cause of regional extinction of wild reindeer was hunting. The cause of the disappearance of the arthropods is unknown.

Table 3-9. Number of species on regional Red Lists within the CAFF boundary in Finland (2019), Sweden (2020) and Norway (2015) by IUCN status category.

	REGIONALLY EXTINCT	CRITICALLY ENDANGERED	ENDANGERED	VULNERABLE	NEAR THREATENED	DATA DEFICIENT	TOTAL
Norway	0	4	37	36	63	0	**140**
Sweden	1	4	25	84	98	26	**238**
Finland	4	85	145	174	251	99	**758**

Table 3-10. Number of species on regional Red Lists within the CAFF boundary in Finland (2019), Sweden (2020) and Norway (2015) by taxonomic group.

	MAMMALS	BIRDS	ARTHROPODS	MOLLUSCS	VASCULAR PLANTS	BRYOPHYTES	LICHENS	FUNGI	TOTAL
Norway	3	13	19	0	59	38	4	4	**549**
Sweden	3	14	65	1	40	110	4	1	**241**
Finland	5	26	190	0	77	178	267	15	**143**

3.5.3 RUSSIA

Russia has both national and regional Red Data books. Nine of the regions include portions of CAFF area. Red Data books for these regions have been published since 2000 and the criteria used have evolved to be consistent with the IUCN criteria. The main difference between the Russian and current IUCN criteria is the inclusion of a naturally rare species category. Most species listed in Russia are listed in this category. There is also a regional difference in the groups of organisms that are assessed, mainly due to different expert availability. More information on the Russian categories and criteria can be found in references listed in Table 3-11.

Table 3-12 shows the number of species within the CAFF area within each of the Russian Red Book categories and Table 3-13 lists the number of species by taxonomic group. Eight species have probably disappeared (IUCN Regionally Extinct). These are: five vascular plants on the edge of their ranges — Mountain Kidney Vetch (***Anthyllis vulneraria subsp. lapponica***) and Alpine Chamorchis (***Chamorchis alpina***) from Murmansk Region, narrow-leaved marsh orchid (***Dactylorhiza lapponica***) and Pale Gentian (***Gentianella aurea***) from Nenets Okrug and silver cloak fern (***Aleuritopsis argentea***) from Sakha Republic; one beetle from Sakha Republic (***Carabus cancellatus***) – also on the edge of its range; and two birds — Siberian Crane (***Grus leucogeranus***) in Nenets Okrug and Swan Goose (***Anser cygnoides***) in Kamchatka Krai. Both birds are on the global Red List; the Siberian Crane as Critically Endangered (CR) and the Swan Goose as Vulnerable (VU).

Table 3-11. Russian regional Red Data books that include portions of the CAFF area.

REGION	RED DATA BOOK	PORTION OF REGION INCLUDED WITHIN THE CAFF AREA
Murmansk Region	Asming et al. 2014	all except the southeast
Arkhangelsk Region	Andreev et al. 2008	Franz Josef land and Novaya Zemlya
Nenets Okrug	Matveeva et al. 2006	almost all
Yamalo–Nenets Okrug	Ektova et al. 2010	all except southeast
Krasnoyarsk Krai	Savchenko 2012, Stepanov 2012	northern third
Sakha Republic	Anonymous 2019, Danilova 2017	northern half
Chukotsky Okrug	Chereshnev et al. 2008a, 2008c	All
Magadan Region	Chereshnev et al. 2008b	northern half
Kamchatka Krai	Artyukhin et al. 2006, Chernyagina et al. 2007	northern third

Table 3-12. Number of species in Russian Red Data books (Table 3-11) within the CAFF boundary by status category. IUCN categories shown in brackets.

REGION	PROBABLY DISAPPEARED (IUCN REGIONALLY EXTINCT)	ENDANGERED (IUCN CRITICALLY ENDANGERED/ ENDANGERED)	DECLINING (IUCN VULNERABLE)	RARE (NO IUCN EQUIVALENT)	UNDEFINED BY STATUS (IUCN DATA DEFICIENT)	TOTAL
Murmansk Region	2	53	88	237	69	**449**
Archangelsk Region	0	0	3	2	0	**5**
Nenets Okrug	3	14	19	138	13	**187**
Yamalo–Nenets Okrug	0	3	10	101	10	**124**
Krasnoyarsk Krai	0	0	5	59	52	**116**
Sakha Republic	1	4	19	144	4	**172**
Magadan Region	0	2	6	84	5	**97**
Kamchatka Krai	2	60	33	28	0*	**123**
Chokotka Okrug	0	1	9	177	16	**203**

* Data deficient species of arthropods, vascular plants, bryophytes, and lichens are excluded from Kamchatka, because data on distribution was not reported in the Red Data books of Kamchatka, rendering it impossible to determine if they were present inside the CAFF boundary.

Table 3-13. Number of species in Russian Red Data books (Table 3-11) within the CAFF boundary in Russia by taxonomic group.

REGION	MAMMALS	BIRDS	REPTILES	AMPHIBIANS	ARTHROPODS	VASCULAR PLANTS	BRYOPHYTES	FUNGI	LICHENS	TOTAL
Murmansk Region	8	29	1	1	16	175	119	18	82	**449**
Archangelsk Region	0	5	0	0	0	0	0	0	0	**5**
Nenets Okrug	1	17	0	1	15	102	15	10	26	**187**
Yamalo–Nenets Okrug	1	16	1	4	24	56	9	8	5	**124**
Krasnoyarsk Krai	0	21	0	0	1	63	18	0	13	**116**
Sakha Republic	1	34	1	0	9	94	22	2	9	**172**
Magadan Region	13	22	0	1	7	47	0	7	0	**97**
Kamchatka Krai	6	38	0	0	1*	72*	6*	0	0*	**123**
Chokotka Okrug	9	34	0	0	4	92	37	7	20	**203**

* Data deficient species of arthropods, vascular plants, bryophytes, and lichens are excluded from Kamchatka Krai, because data on distribution was not reported in the Red Data books of Kamchatka, rendering it impossible to determine if they were present inside the CAFF boundary.

3.5.4 NORTH AMERICA

In Canada, national species assessments are carried out by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) based on the IUCN criteria. Of 661 terrestrial species that had been assessed by COSEWIC in 2019 (COSEWIC 2019), 95 occurred within the CAFF boundary (Table 3-14). There are many species that have not yet been assessed in Canada, particularly in the Arctic. This is due, in part, to sparse data for widely dispersed and cryptic species and a focus on species with known threats.

Documented extinctions and extirpations of terrestrial species within the CAFF boundary in Canada are limited to one species of bird, Labrador duck (***Camptorhynchus labradorius***), thought to have gone extinct in the mid-19th century, and the Ungava population of grizzly bear (***Ursus arctos***) which has not been documented since 1948. Another possible extinction is the Eskimo curlew, which, although currently assessed as Endangered, has not been observed since 1963.

Provinces and territories also assess their species and maintain regional lists based on IUCN Red List criteria. Regional lists that include areas within the CAFF boundary are Nunavut, Yukon, and the Northwest Territories.

In the U.S. (Alaska), conservation ranks are established by the state's NatureServe member programme, the Alaska Center for Conservation Science. NatureServe is the IUCN Red List authority for North American plants and their staff serve on IUCN Red List committees for vertebrates. The state conservation ranks established by the Alaska Center for Conservation Science are non-regulatory but may be used by agencies with regulatory authority to identify species in need of protection (such as the U.S. Endangered Species Act and Alaska Endangered Species Statute 2019). The U.S. Fish and Wildlife Service and National Marine Fisheries Service are responsible for listing endangered species at the national level and the Alaska Department of Fish and Game is responsible for listing fish and wildlife as endangered in the state of Alaska. Currently, two terrestrial Alaskan Arctic species are listed in the U.S. Endangered Species Act (Table 3-15).

3.5.5 CONCLUSION AND KEY FINDINGS

There is a general lack of data on rare and declining species across the Arctic, with the exception of a few birds and mammals. Today, only Arctic birds and mammals have been assessed by IUCN on a global scale and, while all Arctic states assess the threatened status of their species regionally, the results vary due to differences in resources, data, and availability of experts. There is also little pan-Arctic cooperation on data collection on occurrences, population numbers and trends for threatened species. These factors make it difficult to combine data and draw conclusions at a circumpolar scale.

Other complications in assessing status and trends of species of conservation concern include, the inclusion, in some cases, of naturally rare species in the same categories as those that are under threat, and the inclusion of species, particularly in the older Russian Red Data books, that are at the northernmost edge of their range. In terms of threats, the more recent the Red List assessment, the more likely climate change is identified as a significant threat.

Table 3-15. Terrestrial Arctic species in Alaska listed under the U.S. Endangered Species Act.

ENDANGERED	
Polystichum aleuticum	Aleutian Shield Fern
Numenius borealis	Eskimo Curlew*

*Also listed under the State of Alaska Endangered Species Statute. The Eskimo curlew is presumed Extinct, with the last confirmed sighting in 1963.

Table 3-14. Number of species at risk by threat category as assessed by COSEWIC and listed under the federal Species at Risk Act within the CAFF boundary in Canada, 201). IUCN categories are in brackets.

	EXTIRPATED (IUCN REGIONALLY EXTINCT)	ENDANGERED (IUCN CRITICALLY ENDANGERED/ ENDANGERED)	THREATENED (IUCN VULNERABLE)	SPECIAL CONCERN (IUCN NEAR THREATENED)	NOT AT RISK (IUCN LEAST CONCERN)	DATA DEFICIENT (IUCN DATA DEFICIENT)
Mammals*	1	5	3	5	3	1
Birds*	2	4	6	13	23	0
Amphibians	0	0	0	2	2	0
Arthropods	0	1	1	4	0	0
Vascular plants	0	1	1	8	5	0
Mosses	0	0	1	0	0	1

*COSEWIC can assess 'designatable units' or distinct populations and subspecies. This can result in multiple designations for some species. In the mammal group, for example, different populations and subspecies of ***Rangifer tarandus*** are listed as Endangered, Threatened and Special Concern depending upon the population. Also, and the subspecies Arctic grey wolf (***Canis lupus arctos***) is listed as Data Deficient while the Northern Grey Wolf (***Canis lupus occidentalis***) is listed as Not at Risk. In the bird group, different subspecies of Red Knot (***Calidris canutus***) are listed as Special Concern, Threatened and Endangered.

Photo: Andrei Stepanov/Shutterstock.com

3.6 LAND COVER CHANGE

Data collection in the Arctic is logistically challenging and very resource intensive, and as a result, data are sparse and disparate (Jenkins et al. 2020). Remote sensing data have frequently been used for specific studies at focused locations across the Arctic. However, few large-scale studies, at the landscape or pan-Arctic scale, have been conducted. Recognising these challenges and the need for a more comprehensive understanding of change across the Arctic, CAFF, through its Land Cover Change Initiative (CAFF 2020), developed a set of physical and ecological parameters) that represent key elements dictating seasonal processes in Arctic terrestrial ecosystems. (Box 3-5). These were analysed between 2001 and 2017 using a standard remote sensing platform (MODIS) to help understand changes occurring and evaluate remote sensing for use in Arctic biodiversity monitoring and assessment. A key challenge is to translate what these mean on the ground for Arctic terrestrial biodiversity and how this assessment coupled with the CBMP Terrestrial Biodiversity Monitoring Plan (Christensen et al 2013) can help improve our understanding of biotic responses to these broad-scale drivers.

Authors:
Tom Barry and Liza K. Jenkins

The Land Cover Change Initiative analysis showed that significant change is occurring in the Arctic's terrestrial ecosystem and identified statistically significant temporal rates of change across several parameters. The results (Figure 2-5) corroborate past findings indicating strong signals of ecosystem change in the Arctic terrestrial environments, for example, regarding vegetation greening. An important outcome of this work is helping to develop an understanding of the status of spatial and temporal trends across multiple parameters simultaneously and serving as potential explanatory variables for in situ changes observed across FECs.

The aggregated average annual pan-Arctic data showed significant temporal trends in land surface temperature and NDVI with both significantly increasing in CAVM (Fig 1-2) subzones A, B, D and E, and displaying a north–south variability in the seasonality of temperature change. The northernmost CAVM subzone experienced significant increasing temperatures in the autumn, winter, and spring, while the southernmost CAVM subzone showed a significant increase in temperature in late spring to early summer.

Three parameters for phenology were analysed: green-up date, senescence date and growing season length. Results indicated an earlier green-up by approximately six days and a growing season length extended by approximately four days, from 2001 to 2014. Subzones C and E showed a significant decrease for green-up date (by 4.5 days) and a shift to an earlier start to the growing season (by four days) over the 14 years. Subzones B and E showed a significant increase in growing season length (5 and 3.5 days respectively). No significant trends were observed in senescence date. There is a greater year-to-year variability in the date of senescence than green up, with results showing a somewhat cyclical trend.

No significant trends were observed in the average annual percent snow covered areas, although time series for individual months revealed significant trends—for example, significant declining trends were observed in subzones C and D for June, in subzone E for July and in subzones A and B for October. Observations of the seasonal data indicate a significant declining trend from 2000 to 2011, followed by a significant increasing trend from 2011 to 2014 in subzone B. No other significant seasonal trends were identified. No trends were found in the average annual burned area across the pan-Arctic with no burned areas found in subzones A and B.

A set of five parameters were also analysed for the Arctic's marine ecosystem—marine chlorophyll, coloured dissolved organic material, sea surface temperature, marine primary productivity, and sea ice extent. Both the terrestrial and marine environments experienced similar amounts of change with more statistically significant trends being observed in seasonal data. The rates of change of NDVI and sea ice were approximately the same.

The Land Cover Change analysis shows that significant change is occurring in the Arctic. We need to determine how resilient the Arctic is to these changes and where there may be certain thresholds, '"tipping points',' beyond which an abrupt shift of physical or ecological states occur. Only with a combination of in situ data, remote sensing data, and an understanding of the processes occurring at different scales can we begin to understand change in the Arctic Therefore the analyses developed in the Land Cover Change initiative should be repeated regularly to support CBMP efforts to improve our understanding of status and trends in the Arctic biodiversity.

Greenland willows. Photo: Skip Walker

BOX 3-5. PARAMETERS ANALYSED IN THE LAND COVER CHANGE INITIATIVE

- Land Surface Temperature
- Percentage of snow-covered area
- Normalised Difference Vegetation Index (NDVI)
- Enhanced vegetation index
- Green-up date
- Senescence date
- Growing season length

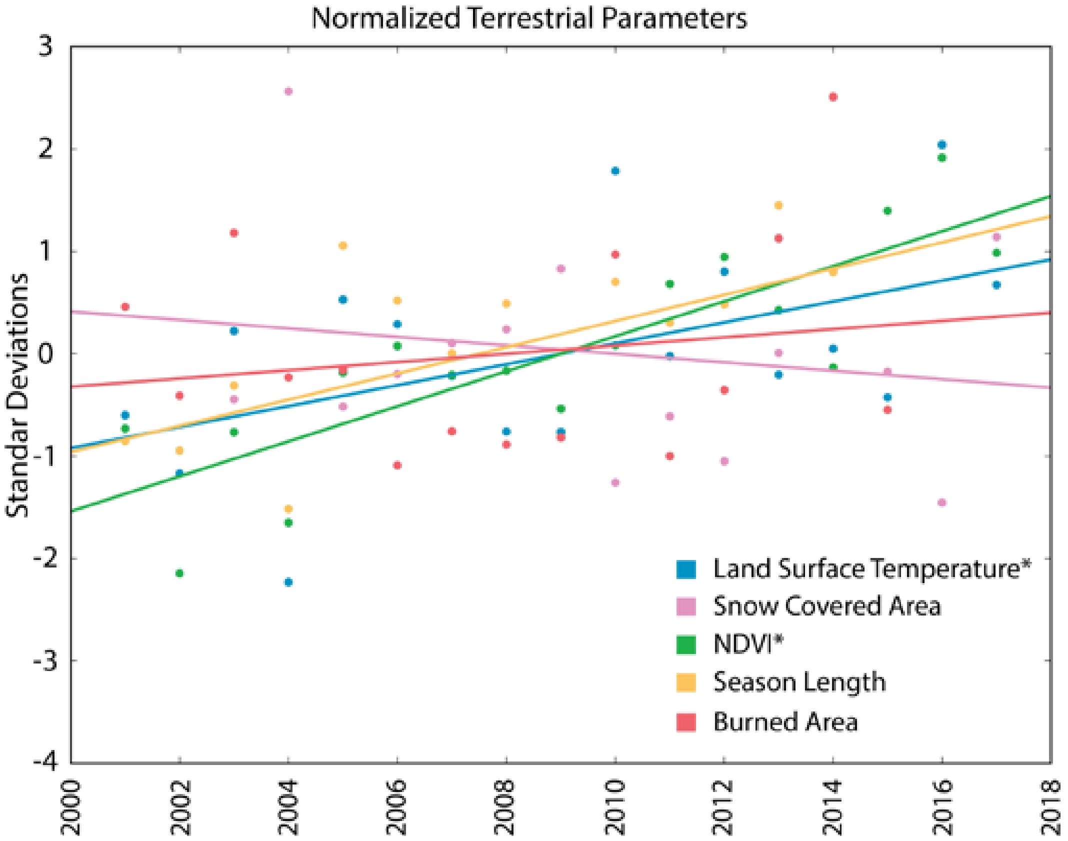


*Figure 3-33. Rates of change among different terrestrial parameters, using average annual standardised data for the pan-Arctic. *identifies parameters with statistically significant trends*

3.7 ECOSYSTEM-BASED MONITORING AND REPORTING

Arctic ecosystems are inherently interwoven, with numerous shared interactions (Schmidt et al. 2017). Recognising this, the CBMP–Terrestrial Plan takes an ecosystem approach, encompassing all taxonomic groups and their likely interrelationships. This includes both monitoring FECs and linking results to the main drivers of change, abiotic as well as biotic.

As outlined in Section 2.1.1, FECs were selected based on their ecological significance, value of the ecosystem services to Arctic Indigenous and non-Indigenous Peoples, and usefulness for management and legislation needs. The START draws upon expert knowledge to report on the status and trends of FECs individually and by taxonomic group; however, each section in Chapter 3 also includes information about relevant biotic interactions that might act as drivers for a particular taxon. Reconnecting the system through the inclusion of biotic interactions is pivotal for our ability to understand changes in Arctic terrestrial biodiversity and must permeate current and future monitoring and reporting.

The threats to global biodiversity and its subsequent decline are highlighted by various international biodiversity conservation conventions (see Section 1.3). Two important recent reports, the ***Global Assessment Report on Biodiversity and Ecosystem*** Services of the Intergovernmental Platform on Biodiversity and Ecosystem Services (2019) and the ***fifth Global Biodiversity Outlook*** of the CBD (2020), describe the most recent decline in biodiversity on a global scale and predict a dire future based on current trends. ***The Arctic Biodiversity Assessment*** and its accompanying summary for policymakers (CAFF 2013) highlights the particular threats to Arctic biodiversity.

Consistent with these reports, the START also finds that the overwhelming driver of change in terrestrial Arctic ecosystems is climate change. There is evidence of this in for instance the correlation between increasing temperatures and earlier onset, longer duration and increase of plant growth (see Section 2.2). Warming temperatures also contribute to the increased frequency of boreal and tundra wildfires as well as unprecedented intense rainfall and heat wave events. Examples of where these climate-related drivers can be linked to changes in diversity, abundance, composition, and structure of Arctic terrestrial vegetation, include:

- increased growth and encroachment of shrubs and trees in parts of the low Arctic (Bjorkman et al. 2020);
- increase in woody plants and expansion of their distribution into drier tundra communities (Hinzman et al. 2005);
- increases in cover of some graminoids and forbs (Bjorkman et al. 2020); and
- decreases in moss and lichen cover (Bjorkman et al. 2020).

Changes in landscape level vegetation, that are of particular concerns for endemic Arctic species, have led to phenological mismatches between herbivores and vegetation and changes in trophic level interactions (Post et al. 2008, Fauchald et al. 2017). Some examples include: reproductive failures in ***Rangifer*** (phenological mismatch with food plants); reproductive failure in predators of lemmings and their alternative prey (resulting from collapse of cycles, see Box 3-3); spread of new insect pest species and plant pathogens north to the forest-tundra transition zone; and warm periods in tundra areas causing massive outbreaks of blackflies affecting productivity of some Arctic birds (Franke et al. 2016).

Box 3-6 provides some examples of the complex relationship between top avian predators and other FECs and how this is influenced by changing Arctic conditions.

Of fundamental importance to an ecosystem approach to monitoring Arctic biodiversity is the relationship between Arctic Indigenous Peoples and the natural environment and they are thus included in CBMP–Terrestrial Plan conceptual models. Nevertheless, they are often not considered in biodiversity baseline assumptions nor in monitoring programmes. In our ecosystem-based approach to monitoring and reporting, it is important to include Arctic Indigenous Peoples.

Arctic lichens and bearberry. Photo: Roger Asbury/Shutterstock.com

BOX 3-6. TOP PREDATORS AND FEC INTERACTIONS

Most Arctic top bird predators rely on prey bases with cyclic abundance patterns. The snowy owl, rough-legged buzzard, and long-tailed jaeger, for example, are highly dependent on small mammals with highly cyclic occurrence, as shown in Figure 3-30; the predators either do not breed, or have very low productivity, in areas and years with lemming population lows. In areas with several rodent species (lemmings and voles), the buzzards do not utilize prey according to relative abundance but prefer lemmings—revealing complex interactions in a relatively simple ecosystem. It emphasises that lemmings and voles should be treated separately in Arctic monitoring and ecosystem studies to better understand the predator–prey interactions under changing Arctic conditions (Hellström et al. 2014).

For the gyrfalcon, ptarmigan species are the only prey available in the Arctic in the pre-breeding and early breeding season. The falcon is, therefore, highly dependent on these herbivores to initiate breeding. The links have been well studied in Iceland (Nielsen 2011) where the prey–predator cycles show a clear match with falcon territory occupancy and relative ptarmigan abundance, but with a 4–year lag (Figure 3-32). The lag was due to prey-mediated effects on adult gyrfalcon survival and juvenile recruitment into the breeding population. However, even in low ptarmigan years the gyrfalcon could have good breeding success; weather factors explained much more of the variation in breeding success than spring ptarmigan density. A shorter study in Alaska showed a more direct effect—a ptarmigan six-fold decline was mirrored by a significant decline in gyrfalcon breeding success (Barichello & Mossop 2011). In Sweden, high numbers of juvenile willow ptarmigan in autumn was linked to high breeding success of gyrfalcons the next spring (Falkdalen et al. 2011).

These regionally different and complex interactions may be affected by changing climate and habitat conditions in the future. A modelling study of gyrfalcon and two ptarmigan species in Alaska (Booms et al. 2011) concluded that the spatial extent of the fundamental niche of each of the three species will contract and become more heterogeneous and discontinuous and the amount of spatial overlap of the gyrfalcon's and ptarmigan's fundamental niche will decline. Coordinated monitoring projects should be following those changes in the Arctic.

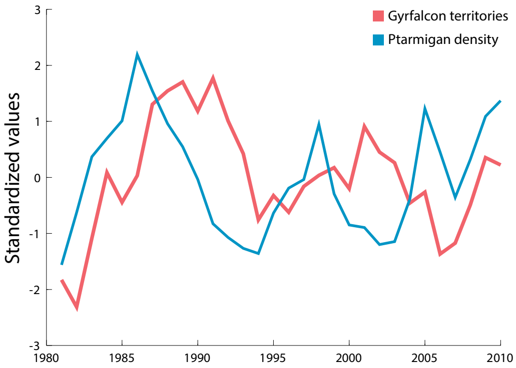


Figure 3-34. Rock ptarmigan density and occupancy rate of gyrfalcon territories. Modified from Nielsen 2011. Used with permission from the Peregrine Fund

Counting prey remains–mostly ptarmigan–at gyrfalcon breeding sites in Iceland. Photo: Daniel Bergmann

*Snowy owls feeding a grey-sided vole (*Myodes rufocanus*) to their chicks. Photo K.-O. Jacobsen*

BOX 3-7. AMPHIBIANS AND REPTILES OF THE ARCTIC

Amphibians and reptiles inhabit the Arctic but not in the abundance and diversity of the other taxa covered in this document. These species are unique as they occur in climatic conditions not normally associated with amphibians and reptiles and possess highly specialised adaptations to survive in the Arctic. Data on the distribution, status, and trend of these six species are generally lacking, but each can be locally and seasonally abundant. While not widespread in the high Arctic, these species are well distributed in the low Arctic and even more widespread and abundant in the sub-Arctic. All species are widespread south of the Arctic regions. According to IUCN classification, all have the range wide status of Least Concern and their trends are Stable, except the viviparous lizard, which is Unknown (Table 3-16). These species are predators of invertebrates and adults and larva serve as a food source for larger terrestrial, avian and aquatic predators. Amphibians serve as valuable indicators of changes to ecosystems. Threats such as climate change, habitat alterations, diseases and pollution do exist, but opportunities for range and population expansion may also present themselves as climate and habitats change. No FECs have been established for amphibians and reptiles. Monitoring should focus on obtaining a better understanding of the distribution, status, and trends within the Arctic, as well as on disease presence and climate change induced habitat alteration. For more information, see Chapter 5 of the Arctic Biodiversity Assessment (Kuzmin et al. 2013).

*Wood frog (*Lithobates sylvaticus*). Photo: Casey Burns/BLM*

Table 3-16. Arctic amphibian and reptile species, their habitats and status. For the purposes of this table, 'Arctic' species are found in the high– or low Arctic zones (see Figure 1-2)

COMMON NAME	SCIENTIFIC NAME	ARCTIC DISTRIBUTION	HABITAT AND THREATS (IUCN)	RED LIST STATUS/ TREND (IUCN)
wood frog	*Lithobates (Rana) sylvaticus*	United States, Canada	Habitats: forest, pond/stream edges, willow thickets and grass/ willow/aspen associations. Hides in logs, humus, leaf litter or under logs and rocks. Threats: include intensive timber harvesting in areas surrounding breeding sites.	Least Concern/ Stable (2015)
Siberian wood frog	*Rana amurensis*	Russia	Habitats: open and wet places in coniferous, mixed, and deciduous forests, shrublands and grasslands. Threats: general habitat loss (e.g., dams), drainage and pollution of breeding pools and overharvesting for food.	Least Concern/ Stable (2008)
moor frog	*R. arvalis*	Norway, Sweden, Finland, Russia	Habitats: tundra, forest, steppe, swamps, peatlands, moorlands, meadows, fields and bush lands, gardens. Threats: destruction and pollution of breeding ponds and adjacent habitats, drought, and predation of tadpoles by waterfowl. Chytrid fungus was detected in this species outside the Arctic.	Least Concern/ Stable (2008)
common frog	*R. temporaria*	Norway, Sweden, Finland, Russia	Habitats: coniferous/deciduous forests, forested tundra, and steppe, shrublands, glades, grasslands, meadows, marshes temporary and permanent ponds, lakes, and rivers. Threats: no major threats but locally by pollution, drainage of breeding sites and collection.	Least Concern/ Stable (2008)
Siberian newt	*Salamandrella keyserlingii*	Russia	Habitats: wet coniferous, mixed, deciduous forests in the taiga zone and riparian groves in tundra and forest steppe. Threats: no major threats to this species, but locally threatened by desiccation of wetlands, loss of terrestrial habitat, pollution, and urbanization.	Least Concern/ Stable (2008)
viviparous (common) lizard	*Zootoca (Lacerta) vivipara*	Norway, Sweden, Finland, Russia	Habitats: grassland, meadows, humid scrubland, open woodland, woodland edges, peat bogs, stream edges and coastal areas. Threats: locally from habitat loss from agricultural, urbanization and development of tourism facilities.	Least Concern/ Unknown (2018)

Photo: Ksenya/Shutterstock.com

3.8 KEY FINDING SYNTHESIS

Key findings about the status and trends of the FECs of each group—vegetation, invertebrates, birds and mammals—are outlined in the corresponding sections of Chapter 3. This section provides a discussion of commonalities across the FECs and presents overall key findings. It draws heavily upon the key findings summary from Taylor et al. (2020) and the individual papers in the ***Ambio*** special issue ***Terrestrial Biodiversity in a Rapidly Changing Arctic***.

- Heterogeneity was a predominant pattern of change particularly when assessing global trends for Arctic terrestrial biodiversity.
    - There is considerable spatial heterogeneity in vegetation development in the Arctic, some areas show increases in production and abundance, while others are decreasing or remaining stable. However, remote sensing shows that since 2001 there has been a significant increase in vegetation productivity across the entire pan-Arctic.
    - Endemism, only studied in detail for mammals, birds and vascular plants is not very common; however, among vascular plants, there is great geographic variation with many endemics concentrated in some regions (Taymyr, northern Alaska, Ellesmere Island, and east Greenland).
- There is a need for a comprehensive, integrated, ecosystem-based monitoring programmes, coupled with targeted research projects deciphering causal patterns.
    - Understanding of the patterns of cumulative effects and the changes these effects may have is poor and there is currently no method or standardised approach for determining the impacts of cumulative effects. Nevertheless, knowledge about casualties in the ecosystem, spatial data on important areas for species and ecosystems, and data on the distribution and intensity of human activities are essential in establishing a more adaptive and ecosystem-based approach to environmental management.
- Climate change is driving diverse and unpredictable change in the Arctic terrestrial environment with expected continued significant impacts, for example:
    - Responses to climate change include, in parts of the Arctic, an increase in the abundance of shrubs and grasses and a decrease in lichens and mosses.
    - Experimental warming has shown that green-up and flowering can happen earlier. That has also been shown in many plot-based monitoring studies, although not as conclusively. Remote sensing indicates an earlier start of the season in the most southern and middle latitude regions of the Arctic. Senescence does not change in response to warmer or longer summer seasons.

4 STATE OF ARCTIC TERRESTRIAL BIODIVERSITY MONITORING

Photo: Lawrence Hislop

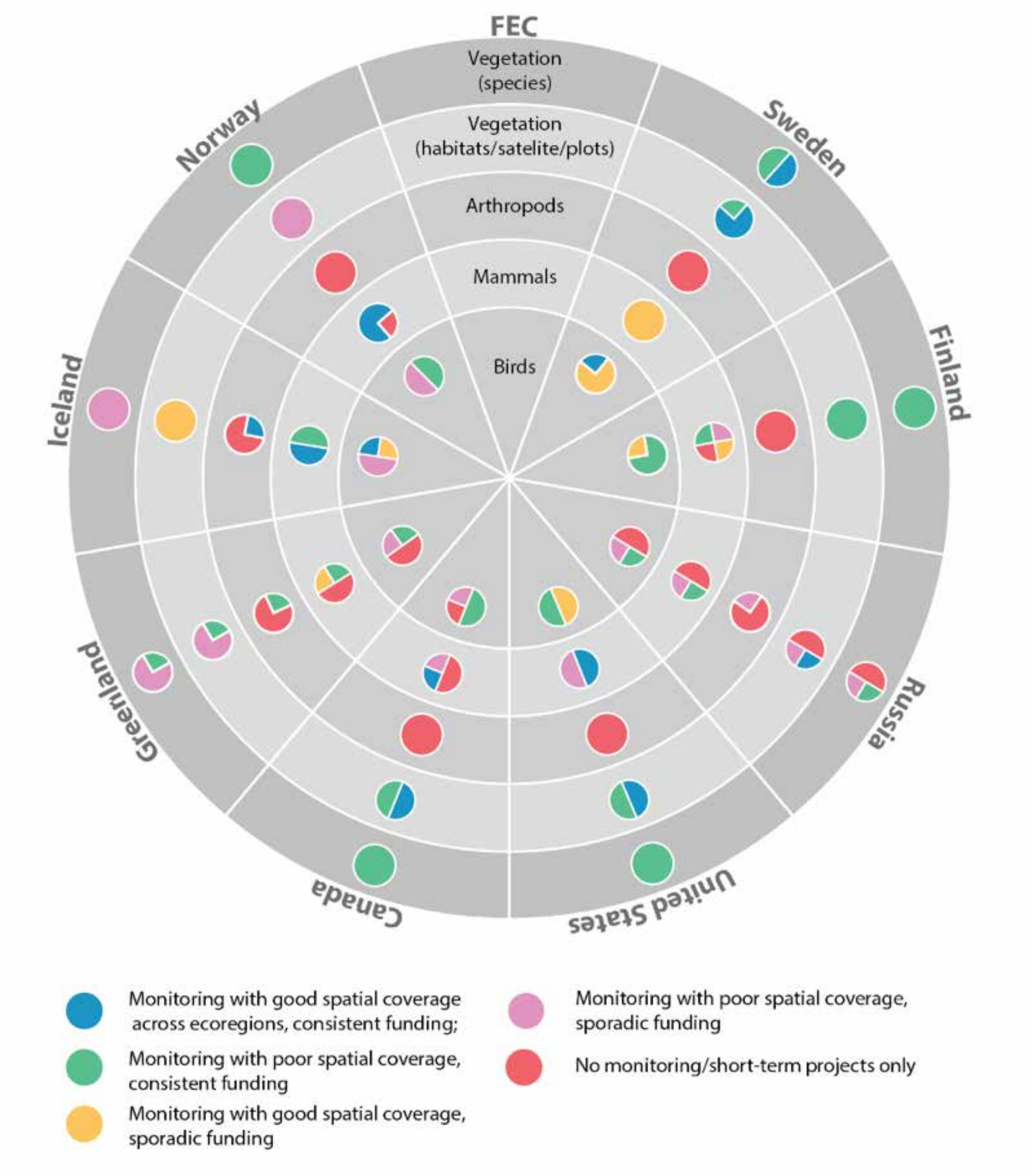


Figure 4-1. Current state of monitoring for Arctic terrestrial biodiversity FECs in each Arctic state.

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

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

4.1 CURRENT MONITORING IN ARCTIC STATES

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

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

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

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

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

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

Photo: USFWS

4.1.1 UNITED STATES

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

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

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

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

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

Photo: Marlene Doyle

4.1.2 CANADA

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

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

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

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

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

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

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

Zackenberg research station. Photo: NTNU

4.1.3 KINGDOM OF DENMARK (GREENLAND)

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

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

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

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

Photo: Iceland Blue Planet Studio/Shutterstock.com

4.1.4 ICELAND

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

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

Photo: Lawrence Hislop

4.1.5 NORWAY

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

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

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

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

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

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

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

4.1.6 SWEDEN

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

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

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

4.1.7 FINLAND

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

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

Approximately 30 harvested species of mammals and birds are monitored annually by a national network of Wildlife Triangle Counts. Several FEC species—such as willow ptarmigan, hare, large predator mammals and mustelids—are included in Wildlife Triangle counts. The monitoring provides some information on population sizes and changes in abundance and is primarily implemented by hunters on a voluntary basis. In northern Finland, however, the Wildlife Triangle network is sparse. In Finland, there have been no observations of breeding Arctic fox since 1996. Most known Arctic fox territories are monitored annually by Metsähallitus. The Arctic fox monitoring is primarily conducted in collaboration with Norway and Sweden. Population dynamics of Norwegian lemmings have been monitored intensively by the University of Helsinki, Kevo Research Station, and the Natural Resources Institute of Finland, who has been coordinating the monitoring for several decades. For other mammal species, monitoring is more sporadic. Annual monitoring of population change of wolverine, bear, lynx, and wolf is carried out through snow track interpretation; however, the monitoring is fragmentary. Populations of domesticated reindeer are well studied and monitored; wild reindeer do not occur in the Finnish sub-Arctic area.

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

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

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

Kola Peninsula. Photo: Vitaliy Kaplin/Shutterstock.com

4.1.8 RUSSIAN FEDERATION

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

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

4.2 ADVICE FOR FUTURE MONITORING OF ARCTIC TERRESTRIAL BIODIVERSITY

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

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

4.2.1 MONITORING DESIGN INCLUDING COORDINATION AND METHODS

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

Improved Coordination

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

Methods

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

4.2.2 INDIGENOUS KNOWLEDGE

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

Key Advice

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

4.2.3 LOCAL KNOWLEDGE AND CITIZEN SCIENCE

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

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

4.2.4 KNOWLEDGE GAPS

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

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

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

4.2.4.1 Vegetation

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

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

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

4.2.4.2 Arthropods

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

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

Red knot. Photo: Danita Delimont/Shutterstock.com

4.2.4.3 Birds

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

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

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

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

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

4.2.4.4 Mammals

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

5 REFERENCES

Abraham, K.F., R.L. Jefferies and R.T. Alisauskas, 2005. The dynamics of landscape change and snow geese in midcontinent North America. Global Change Biology 11: 841-855.

ADFG, 2017. Alaska Department of Fish and Game Staff Comments Tab 1.3 Region V Caribou for the Alaska Board of Game Meeting Fairbanks, Alaska February 17-25, 2017. Alaska Department of Fish and Game Division for Alaskan Board of Game, Kotzebue, AK, January 2017

Alsos, I.G., P.B. Eidesen, D. Ehrich, I. Skrede, K. Westergaard, G.H. Jacobsen, J.Y. Landvik, P. Taberlet and C. Brochmann, 2007. Frequent long-distance plant colonization in the changing Arctic. Science 316: 1601-1608.

Alsos, I. G., C. Ware and R. Elven, 2015. Past Arctic aliens have passed away, current ones may stay. Biological Invasions 17: 3113-3123.

AMAP, 2017a. Adaptation actions for a changing Arctic: Perspectives from the Bering-Chukchi-Beaufort Region. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

AMAP, 2017b. Adaptation actions for a changing Arctic: Perspectives from the Barents Area. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

AMAP, 2018. Adaptation actions for a changing Arctic: Perspectives from the Baffin Bay/Davis Strait Region. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

AMAP, 2019. AMAP climate change update 2019: An update to key findings of snow, water, ice, and permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP), Oslo

Anctil, A., A. Franke, and J. Bêty, 2014. Heavy rainfall increases nestling mortality of an arctic top predator: experimental evidence and long-term trend in peregrine falcons. Oecologia 174: 1033-1043.

Andreev, V.A., A.E. Batalov, I.N. Bolotov, V.V. Voronin, A.M. Gordienko, T.U. Dolgoshchekova, O.N. Yezhov, G.A. Kisileva, A.A. Kopytov, E.V. Kochergina, A.P. Novoselov, and E.Y. Churakova, 2008. Red Book of Arkhangelsk Region. – Arkhangelsk. Com on ecology of the Arkhangelsk region 351 pp.

Angerbjörn, A. and M. Tannerfeldt, 2014. Vulpes lagopus. The IUCN Red List of Threatened Species 2014: e.T899A57549321. https://dx.doi.org/10.2305/IUCN.UK.2014-2.RLTS.T899A57549321.en. Accessed on 11 April 2017.

Anonymous, 2019. Red Data book of the Sakha Republik (Yakutia). Vol. 2: Rare and endangered species of animals (insects, fishes, amphibia, reptiles, birds, mammals). Ministry of Nature Conservation of the Sakha Republik (Yakutia), Department of Biological Resources. Yakutsk, 'Sakhapolygraphizdat" Publishing House, 208 pp.

Arctic Shorebird Demographics Network, 2014. Breeding Camp Protocol Version 5 – April 2014. https://www.manomet.org/wp-–content/uploads/old-–files/ASDN_Protocol_V5_20Apr2014.pdf

Artyukhin, Y.B. et al., 2006. The Red Book of Kamchatka. Vol. 1: Animals – Peter and Paul-Kamchatsky, Kamch Pech Dvor, Book Publishing House 272 pp.

Asming, S.V., N.G. Berlin, O.A. Belkina, V.V. Bianchi, A.A. Bobrov, N.S. Boyko, E.A. Borovichev, E.G. Vorobyova, A.S. Gilyazov, T.V. Demakhina. D.B. Denisov, T.P. Drugova, T.A. Dudoreva, I.A. Erokhina, P.G. Efimov, I.V. Zenkova, L.G. Isaeva, N.N Kavtsevich, D.G. Kataev, H.P. Kirillova, M.N. Kozhin, L.A. Konoreva, N.A. Konstantinova, N.O.T. Koroleva, A.S. Koryakin, V.A. Kostina, V.D. Kokhanov, A.V. Kravchenko, A.Y. Likhachev, O.A. Makarova, A.I. Maximov, S.V. Malawenda, S.V.J.S. Mamonov, A.V. Melekhin, M.V. Melnikov, N.V. Mukhina, D.V. Osipov, N.G. Panarina, T.D. Paneva, O.V. Petrova, A.V. Field, I.V. Ryzhik,V.N. Svetochev, O.H. Svetocheva, A.N. Sennikov, I.E. Tatarinkova, P.M. Terentyev, I.N. Urbanavichene, G.P. Urbanavichyus, M.A. Fadeeva, U.R. Khimich, A.E. Humala, A.G. Shiryaev, F.N. Shklyarevich and E.V. Shutova, 2014. Red Book of the Murmansk Region. Murmansk: Murmansk Book Publishing House.

Bairlein, F., 1990. Nutrition and food selection in migratory birds. In: Gwinner E. (eds), Bird Migration. Springer, Berlin, Heidelberg.

Ballinger, T.J., J.E. Overland, M. Wang, U.S. Bhatt, E. Hanna, I. Hanssen-Bauer, S.-J. Kim, R.L. Thoman and J.E. Walsh, 2020. Surface Air Temperature In: (eds.) Thoman, R.L., J. Richter-Menge and M. L. Druckenmiller. Arctic Report Card 2020: 21-27.

Barichello, N. and D. Mossop, 2011. The overwhelming influence of ptarmigan abundance on Gyrfalcon reproductive success in the central Yukon, Canada. Pages 307–322 in R. T. Watson, T. J. Cade, M. Fuller, G. Hunt and E. Potapov (Eds.). Gyrfalcons and Ptarmigan in a Changing World, Volume I. The Peregrine Fund, Boise, Idaho, U.S. http://dx.doi.org/10.4080/gpcw.2011.0205

Barraquand, F. and Ó. K. Nielsen, 2018. Predator-prey feedback in a gyrfalcon-ptarmigan system? Ecology and Evolution. 8. 10. 1002/ece3.4563

Barrio, I.C., C.G. Bueno, M. Gartzia, E.M. Soininen, K.S. Christie, J.D.M. Speed, V.T. Ravolainen, B.C. Forbes, G. Gauthier, T. Horstkotte, K.S. Hoset, T.T. Hoye, I.S. Jonsdottir, E. Levesque, M.A. Morsdorf, J. Olofsson, P.A. Wookey and D.S. Hik, 2016. Biotic interactions mediate patterns of herbivore diversity in the Arctic. Global Ecology and Biogeography 25:1108-1118.

Barten, N.L., 2015. Mulchatna herd caribou, Units 9B, 17, 18 south, 19A and 19B. Chapter 3, Pages 3-1 through 3-22 [In] P. Harper and L. A. McCarthy, editors. Caribou management report of survey-inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau, AL.

Batt, B.D.J. (ed), 1998. The Greater Snow Goose: report of the Arctic Goose Habitat Working Group. Arctic Goose Joint Venture Special Publication. U.S. Fish and Wildlife Service, Washington, D.C. and Canadian Wildlife Service, Ottawa, Ontario. 88pp. https://www.agjv.ca/wp-content/uploads/2017/11/gsg.pdf#page=37

Beever E.A. and A. Woodward, 2011. Design of ecoregional monitoring in conservation areas of high-latitude ecosystems under contemporary climate change. Biological Conservation 144: 1258-1269.

Belikov S.E. and A.G. Kupriyanov, 1985. Evaluation and economic utilization of populations of wild reindeer on arctic islands. In: Ecology, Conservation and Economic Utilization of Wild Reindeer. Pages 46-54. (In Russian)

Berner, L.T., R. Massey, P. Jantz, B.C. Forbes, M. Macias-Fauria, I. Myers-Smith, T. Kumpula, G. Gauthier, L. Andreu-Hayles, B.V. Gaglioti, P. Burns, P. Zetterberg, R. D´Arrigo and S.J. Goetz, 2020. Summer warming explains widespread but not uniform greening in the Arctic tundra biome. Nat Commun 11, 4621 (2020). https://doi.org/10.1038/s41467-020-18479-5

Bernes, C., K.A. Bråthen, B.C. Forbes, J.D.M. Speed and J. Moen, 2015. What are the impacts of reindeer/caribou (Rangifer tarandus L.) on arctic and alpine vegetation? A systematic review. Environmental Evidence 4 (4). doi.org/10.1186/s13750-014-0030-3

Berteaux, D., A.-M. Thierry, R. Alisauskas, A. Angerbjörn, E. Buchel, L. Doronina, D. Ehrich, N.E. Eide, R. Erlandsson, Ø. Flagstad, E. Fuglei, O. Gilg, M. Goltsman, H. Henttonen, R.A. Ims, S.T. Killengreen, A. Kondratyev, E. Kruchenkova, H. Kruckenberg, O. Kulikova, A. Landa, J. Lang, I. Menyushina, J. Mikhnevich, J. Niemimaa, K. Norén, T. Ollila, N. Ovsyanikov, L. Pokrovskaya, I. Pokrovsky, A. Rodnikova, J.D. Roth, B. Sabard, G. Samelius, N.M. Schmidt, B. Sittler, A.A. Sokolov, N.A. Sokolova, A. Stickney, E.R. Unnsteinsdóttir and P.A. White, 2017. Harmonizing circumpolar monitoring of Arctic fox: benefits, opportunities, challenges, and recommendations. Polar Research 36: 2.

BirdLife International, 2016a. Lagopus muta (errata version published in 2017). The IUCN Red List of Threatened Species 2016: e.T22679464A113623562. http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22679464A89358137.en. Accessed on 18 December 2018.

BirdLife International, 2016b. Lagopus lagopus. The IUCN Red List of Threatened Species 2016: e.T22679460A89520690. http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22679460A89520690.en. Accessed on 18 December 2018.

BirdLife International, 2017a. Bubo scandiacus (errata version published in 2018). The IUCN Red List of Threatened Species 2017: e.T22689055A127837214. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T22689055A119342767.en. Accessed on 25 May 2020.

BirdLife International, 2017b. Corvus corax (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2017: e.T22706068A113271893. http://dx.doi.org/10.2305/IUCN.UK.2017-1.RLTS.T22706068A113271893.en. Accessed on 03 January 2019.

Bhatt, U. S., J.C. Comiso, H.E. Epstein, and G. Jia, 2010. Circumpolar Arctic tundra vegetation change is linked to sea ice decline. Earth Interact., 14, 1–20.

Bhatt, U. S., D.A. Walker, M.K. Raynolds, P.A. Bieniek, H.E. Epstein, J.C. Comiso, J.E. Pinzon, C.J. Tucker, M. Steele, W. Ermold and J. Zhang, 2017. Changing seasonality of panarctic tundra vegetation in relationship to climatic variables. Environmental Research Letters, 12(5), 055003. http://doi.org/10.1088/1748-9326/aa6b0b

Bjerke, J. W., R. Treharne, D. Vikhamar-Schuler, S. R. Karlsen, V. Ravolainen, S. Bokhorst, G. K. Phoenix, Z. Bochenek and H. Tommervik, 2017. Understanding the drivers of extensive plant damage in boreal and Arctic ecosystems: Insights from field surveys in the aftermath of damage. Science of the Total Environment 599:1965-1976.

Bjorkman, A., S. Elmendorf, A. Beamish, M. Vellend and G. Henry, 2015. Contrasting effects of warming and increased snowfall on Arctic tundra plant phenology over the past two decades. Global Change Biology 21(12), 4651 4661. https://dx.doi.org/10.1111/gcb.13051

Bjorkman, A.D., M. García Criado, I.H. Myers-Smith, V. Ravolainen, I.S. Jónsdóttir, K.B. Westergaard, J.P. Lawler, M. Aronsson, B. Bennett, H. Gardfjell, S. Heiðmarsson, L. Stewart and S. Normand, 2020. Status and trends in Arctic vegetation: Evidence from experimental warming and long-term monitoring. Ambio 49, 678–692. https://doi.org/10.1007/s13280-019-01161-6

Bland, L. M., D.A. Keith, R.M. Miller, N.J. Murray, and J.P. Rodríguez, 2017. Guidelines for the application of IUCN red list of ecosystems categories and criteria version 1.1. Gland, Switzerland: IUCN International Union for Conservation of Nature.

Boertmann, D. and C. Bay, 2018. Grønlands Rødliste. 2018. Fortegnelse over grønlandske dyr og planters trusselstatus. – Aarhus Universitet, Nationalt Center for Energi og Miljø (DCE) og Grønlands Naturinstitut.

Booms, T., M. Lindgren, and F. Huettmann, 2011. Linking Alaska's predicted climate, gyrfalcon and ptarmigan distributions in space and time: A unique 200-year perspective. In Gyrfalcons and Ptarmigan in a Changing World, Volume I, ed. R.T. Watson, T.J. Cade, M. Fuller, G. Hunt and E. Potapov, 177–190. The Peregrine Fund, Boise, Idaho, U.S.. http://dx.doi.org/ 10.4080/gpcw. 2011.0116

Boutin, S., D.L. Haughland, J. Schieck, J. Herbers and E. Bayne, 2009. A new approach to forest biodiversity monitoring in Canada. Forest Ecology and Management 258: 168-175.

Box, J.E., W.T. Colgan, T.R. Christensen, N.M. Schmidt, M. Lund, F.J. Parmentier, R. Brown, U.S. Bhatt, E.S. Euskirchen, V.E. Romanovsky, J.E. Walsh, J.E. Overland, M. Wang, R.W. Corell, W.N. Meier, B. Wouters, S. Mernild, J. Mård, J. Pawlak and M.S. Olsen, 2019. Key indicators of Arctic climate change: 1971-2017. Environmental Research Letters 14: 045010.

Bråthen, K.A., V.T. Ravolainen, A. Stein, T. Tveraa and R.A. Ims, 2017. Rangifer management controls a climate-sensitive tundra state transition. Ecological Applications 27 (8): 2416-2427. doi.org/10.1002/eap.1618

Brown, A.O., and J.N. McNeil, 2009. Pollination ecology of the high latitude, dioecious cloudberry (Rubus chamaemorus; Rosaceae) American Journal of Botany 96: 1096–1107

Burnham, K.K., W.A. Burnham, I. Newton, J.A. Johnson, and A.G. Gosler, 2012. The history and range expansion of peregrine falcons in the Thule area, northwest Greenland. Monographs on Greenland Bioscience 60: 1-106.

Cadieux, M.-C., G. Gauthier, and R.J. Hughes, 2005. Feeding ecology of Canada Geese (Branta Canadensis Interior) in sub-Arctic Inland Tundra During Brood-Rearing. The Auk 122: 144–157. https://doi.org/10.1093/auk/122.1.144

CAFF, 2013a. Arctic Biodiversity Assessment. Status and trends in Arctic biodiversity. CAFF, Akureyri, Iceland.

CAFF, 2013b. Arctic Biodiversity Assessment: Report for Policy Makers. CAFF, Akureyri, Iceland

CAFF, 2017. State of the Arctic Marine Biodiversity Report. Conservation of Arctic Flora and Fauna International Secretariat, Akureyri, Iceland. ISBN: 978-9935-431-63-9

CAFF, 2018. Circumpolar Biodiversity Monitoring Program Strategic Plan 2018-2021. CAFF Monitoring Series Report No. 29. Conservation of Arctic Flora and Fauna, Akureyri, Iceland. ISBN: 978-9935-431-71-4.

CAFF, 2019a. Arctic Coastal Biodiversity Monitoring Plan. Conservation of Arctic Flora and Fauna International Secretariat: Akureyri, Iceland. ISBN 978-9935-431-76-9

CAFF, 2019b. Arctic Migratory Birds Initiative (AMBI): Workplan 2019-2023. CAFF Strategies Series No. 30. Conservation of Arctic Flora and Fauna, Akureyri, Iceland. ISBN: 978-9935-431-79-0.

CAFF, 2020. Land Cover Change Initiatve: https://caff.is/indices-and-indicators/land-cover-change-index

Carlzon, L., A. Karlsson, K. Falk, A. Liess and S. Møller, 2018. Extreme weather affects peregrine falcon (Falco peregrinus tundrius) breeding success in south Greenland. Ornis Hungarica 26: 38-50. https://doi.org/10.1515/orhu-2018-0014

CARMA, 2020. CircumArctic Rangifer Monitoring and Assessment Network (https://carma.caff.is)

CAVM Team, 2003. Circumpolar Arctic Vegetation Map. Scale 1:7,500,000. Conservation of Arctic Flora and Fauna (CAFF) Map No. 1. U.S. Fish and Wildlife Service, Anchorage, Alaska. http://www.geobotany.uaf.edu/cavm/credits.shtml.

CBD, 2010. UN Convention on Biological Diversity (CBD): Decision X/13 New and emerging issues. Retrieved on January 11, 2020 at: https://www.cbd.int/decision/cop/?id=12279.

CBD, 2012. UN Convention on Biological Diversity (CBD): Decision XI/6/D. Collaboration on Arctic biodiversity'. Retrieved on January 11, 2020 at: https://www.cbd.int/decision/cop/?id=13167.

CBD, 2014. Global Biodiversity Outlook 4. Montréal, 155 pages.

CBD, 2020. Secretariat of the Convention on Biological Diversity. Global Biodiversity Outlook 5. Montreal.

CBD, 2020. Global Biodiversity Outlook 5. www.cbd.int/GBO5.

Chereshnev, I.A., A.B. Andreev, D.I. Berman, N.O.T. Dokuchaev and V.A. Kashin, 2008a. Red Book of the Chukotka Autonomous Okrug. Vol. 1. Animals. – Publishing house 'Wild North"235 pp.

Chereshnev, I.A., A.B. Andreev, D.I. Berman, N.O.T. Dokuchaev, V.A. Kashin and A.N. Polezhaev, 2008b. Red Book of the Magadan Region: Rare and Endangered Species of Plants and Animals. Administration of the Magadan Region, Department of Natural Resources; Institute of Biological Problems of the North FEB RAS 430 pp.

Chereshnev, I.A. (ed.), A.N. Berkutenko, A.N. Polezhaev and V.A. Kashin, 2008c. Red Book of the Chukotka Autonomous Okrug. Vol. 2: Plants. Publishing house 'Wild North" 217 pp.

Chernyagina, O.A. (ed.) et al., 2007. Kamchatka Red Book. Vol. 2: Plants, fungi, thermophilic microorganisms. – Peter and Paul-–Kamchatsky, Kamch Pech Dvor, Book Publishing House 341 pp.

Christensen, T., J. Payne, M. Doyle, G. Ibarguchi, J. Taylor, N.M. Schmidt, M. Gill, M. Svoboda, M. Aronsson, C. Behe, C. Buddle, C. Cuyler, A.M. Fosaa, A.D Fox, S. Heiðmarsson, P. Henning Krogh, J. Madsen, D. McLennan, J. Nymand, C. Rosa, J. Salmela, R. Shuchman, M. Soloviev and M. Wedege, 2013. The Arctic Terrestrial Biodiversity Monitoring Plan. CAFF Monitoring Series Report Nr. 7. CAFF International Secretariat. Akureyri, Iceland. ISBN 978-9935-431-26-4

Christensen, T., T. Barry, J.J. Taylor, M. Doyle, M, Aronsson, J. Braa, C. Burns, C, Coon, S. Coulson, C. Cuyler, K. Falk, S. Heiðmarsson, P. Kulmala, J. Lawler, D. MacNearney, V. Ravolainen, P.A. Smith, M. Soloviev and N.M. Schmidt, 2020, 'Developing a circumpolar programme for the monitoring of Arctic terrestrial biodiversity', AMBIO, bind 49, nr. 3, s. 655-665. https://doi.org/10.1007/s13280-019-01311-w

Convey, P., H.D.A. Abbandonato, F. Bergan, L.T. Beumer, E.M. Biersma, V.S. Bråthen, L. D'Imperio, C.K. Jensen, S. Nilsen, K. Paquin, U. Stenkewitz, M.E. Svoen, J. Winkler, E. Müller, and S.J. Coulson, 2015. Survival of rapidly fluctuating natural low winter temperatures by Arctic soil invertebrates. Manuscript resulting from project on UNIS masters/Ph.D. Arctic Winter Ecology course (AB329/829) 2012-13 Journal of Thermal Biology 54, 111–117 DOI: 10.1016/j.jtherbio.2014.07.009

COSEWIC, 2014. COSEWIC assessment and status report on the Caribou Rangifer tarandus, Newfoundland population, Atlantic—Gaspésie population and Boreal population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxiii + 128 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm).

COSEWIC, 2015. COSEWIC assessment and status report on the Peary Caribou Rangifer tarandus pearyi in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 92 pp. (http://www.registrelep-sararegistry.gc.ca/default_e.cfm).

COSEWIC, 2016. COSEWIC assessment and status report on the Caribou Rangifer tarandus, Barren-ground population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiii + 123 pp. (http://www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1).

COSEWIC, 2017a. COSEWIC assessment and status report on the Caribou, Dolphin and Union population, Rangifer tarandus, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 51 pp. (http://www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1).

COSEWIC, 2017b. COSEWIC assessment and status report on the Caribou Rangifer tarandus, eastern Migratory population and Torngat Mountains population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xvii + 68 pp. (http://www.registrelepsararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1).

COSEWIC, 2019. COSEWIC List of wildlife species assessed (including October 2019). https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/species/CanadianWildlifeSpeciesAtRisk-2019.pdf

Coulson, S.J. and T. Birkemoe, 2000. Long term cold tolerance in Arctic invertebrates: recovery after four years at below -20°C. Canadian Journal of Zoology 78; 2055-2058.

Coulson, S.J., H.P. Leinaas, R.A. Ims and G. Søvik, 2000. Experimental manipulation of the winter surface ice layer: the effects on a ***High Arctic*** soil microarthropod community. Ecography 23: 299-314

Couturier, S., A. Dale, B. Wood and J. Snook, 2018. Results of a spring 2017 aerial survey of the Torngat Mountains Caribou Herd. Torngat Wildlife, Plants and Fisheries Secretariat. Ser. 2018/40+ 10 pp.

Crowley, D.W., 2015a. Units 9C and 9E, Northern Alaska Peninsula caribou. Chapter 4, Pages 4-1 through 4-12 [In] P. Harper and L. A. McCarthy, editors. Caribou management report of survey-inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-–2015-4, Juneau.

Crowley, D.W., 2015b. Unit 10 Unimak caribou. Chapter 6, Pages 6-1 through 6-10 [In] P. Harperand L. A. McCarthy, editors. Caribou management report of survey and inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.

Culp, J.M., W. Goedkoop, J. Lento, K.S. Christoffersen, S. Frenzel, G. Gudbergsson, P. Liljaniemi, S. Sandoy, M. Svoboda, J. Brittain, J. Hammar, D. Jacobsen, B. Jones, C. Juillet, M. Kahlert, K. Kidd, E. Luiker, J. Olafsson, M. Power, M. Rautio, A. Ritcey, R. Striegl, M. Svenning, J. Sweetman, M. Whitman, 2012. The Arctic Freshwater Biodiversity Monitoring Plan; CAFF Monitoring Series Report Nr. 7; CAFF International Secretariat: Akureyri, Iceland, 2012; pp. 1–151.

Cuyler, C. and J.D.C. Linnell, 2004. Årlig vandringsmønster hos satellitmærkede rensdyr I Vestgrønland. Kapitel 6.: 189-–210 – In: Aastrup P. (ed.) Samspillet mellem rensdyr, vegetation og menneskelige aktiviteter i Vestgrønland Greenland Institute of Natural Resources. Technical report No. 49. 321 pp. (In Danish)

Cuyler, C., M. Rosing, H. Mølgaard, R. Heinrich and K. Raundrup, 2011; revised 2012. Status of two west Greenland caribou populations 2010; 1) Kangerlussuaq-Sisimiut, 2) Akia-Maniitsoq. Pinngortitaleriffik – Greenland Institute of Natural Resources. Technical Report No. 78. 158pp. (Part I: 1-86; Part II: 87-158)

Cuyler, C., J. Nymand, A. Jensen and H.S. Mølgaard, 2016. 2012 status of two west Greenland caribou populations, 1) Ameralik, 2) Qeqertarsuatsiaat. Greenland Institute of Natural Resources Technical Report No. 98, 179 pp.

Cuyler, C., J. Nagy, and K. Zinglersen, 2017. Seasonal movement and activity of Akia-Maniitsoq caribou cows in west Greenland as determined by satellite. Pinngortitaleriffik – Greenland Institute of Natural Resources. Technical Report No. 99. 19 July 94 pp.

Cuyler, C., J. Rowell, J. Adamczewski, M. Anderson, J. Blake, T. Bretten, V. Brodeur, M. Campbell, S.L. Checkley, H.D. Cluff, S.D. Côté, T. Davison, M. Dumond, B. Ford, A. Gruzdev, A. Gunn, P. Jones, S. Kutz, L.-M. Leclerc, C. Mallory, F. Mavrot, J.B. Mosbacher, I.M. Okhlopkov, P. Reynolds, N.M. Schmidt, T. Sipko, M. Suitor, M. Tomaselli and B. Ytrehus, 2020. Muskox status, recent variation, and uncertain future. Ambio 49, 805–819. doi.org/10.1007/s13280-019-01205-x

Danilova, N.S. (ed.), 2017. Red Data book of the Sakha Republik (Yakutia). Vol. 1: Rare and endangered species of plants and fungi. – Moscow: ‘Reart" publishing house. 412 pp.

Deinet, S., C. Zöckler, D. Jacoby, E. Tresize, V. Marconi, L. McRae, M. Svoboda, and T. Barry, 2015. The Arctic Species Trend Index: Migratory Birds Index. Conservation of Arctic Flora and Fauna, Akureyri, Iceland. ISBN: 978-9935-431-44-8

Doyle, S., D. Cabot, A. Walsh, R. Inger, S. Bearhop and B.J. McMahon, 2020. Temperature and precipitation at migratory grounds influence demographic trends of an Arctic-breeding bird. Global Change Biology 26: 5447-5458. https://doi.org/10.1111/gcb.15267

Ehrich, D., N.M. Schmidt, G. Gauthier, ***R. Alisauskas, A. Angerbjörn, K. Clark, F. Ecke, N.E. Eide, E. Framstad, J. Frandsen, A. Franke, O. Gilg, M.-A. Giroux, H. Henttonen, B. Hörnfeldt, R.A. Ims, G.D. Kataev, S.P. Kharitonov, S.T. Killengreen, C.J. Krebs, R.B. Lanctot, N. Lecomte, I.E. Menyushina, D.W. Morris, G. Morrisson, L. Oksanen, T. Oksanen, J. Olofsson, I.G. Pokrovsky, I.Y. Popov, D. Reid, J.D. Roth, S.T. Saalfeld, G. Samelius, B. Sittler, S.M. Sleptsov, P.A. Smith, A.A. Sokolov, N.A. Sokolova, M.Y. Soloviev, D.V., Solovyeva***2020. Documenting lemming population change in the Arctic: Can we detect trends? Ambio 49, 786–800 (2020). https://doi.org/10.1007/s13280-019-01198-7

Eidesen, P.B., E.D. Ehrich, V. Bakkestuen, I.G. Alsos, O. Gilg, P. Taberlet and C. Brochmann, 2013. Genetic roadmap of the Arctic: plant dispersal highways, traffic barriers and capitals of diversity. New Phytologist, 200;898.910.

Ektova, S.N. and D.O. Zamyatin (eds.), 2010. Red Book of the Yamalo—Nenets Autonomous Okrug. Animals. Plants. Mushrooms. – Yekaterinburg: Publishing House ‘Basco"308 pp.

Elmendorf, S. C., G. H. R. Henry, R. D. Hollister, R. G. Bjork, N. Boulanger-Lapointe, E. J. Cooper, J. H. C. Cornelissen, T. A. Day, E. Dorrepaal, T. G. Elumeeva, M. Gill, W. A. Gould, J. Harte, D. S. Hik, A. Hofgaard, D. R. Johnson, J. F. Johnstone, I. S. Jonsdottir, J. C. Jorgenson, K. Klanderud, J. A. Klein, S. Koh, G. Kudo, M. Lara, E. Levesque, B. Magnusson, J. L. May, J. A. Mercado-Diaz, A. Michelsen, U. Molau, I. H. Myers-Smith, S. F. Oberbauer, V. G. Onipchenko, C. Rixen, N. M. Schmidt, G. R. Shaver, M. J. Spasojevic, Þ. E. Þorhallsdottir, A. Tolvanen, T. Troxler, C. E. Tweedie, S. Villareal, C. H. Wahren, X. Walker, P. J. Webber, J. M. Welker and S. Wipf, 2012. Plot-scale evidence of tundra vegetation change and links to recent summer warming. Nature Climate Change 2:453-457.

Elven, R., D.F. Murray, V.Y. Razzhivin and B.A. Yurtsev (eds.), 2020. Annotated checklist of the Panarctic Flora (PAF) - Vascular plants. http://panarcticflora.org/

Ely, C. R., B.J. McCaffery and R.E. Gill Jr., 2018. Shorebirds adjust spring arrival schedules with variable environmental conditions: Four decades of assessment on the Yukon–Kuskokwim Delta, Alaska, in Trends and traditions: Avifaunal change in western North America (W. D. Shuford, R. E. Gill Jr. and C. M. Handel, eds.), pp. 296–311. Studies of Western Birds. https://doi.org/10.21199/SWB3.16

Environment Canada, 2012. Recovery Strategy for the Woodland Caribou (Rangifer tarandus caribou), Boreal population, in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. xi + 138pp.

Environment Yukon. 2016. Science-based guidelines for management of Northern Mountain caribou in Yukon. Yukon Fish and Wildlife Branch Report MR-16-01. Whitehorse, Yukon, Canada

Équipe de Rétablissement du Caribou Forestier du Québec, 2013. Plan de rétablissement du caribou forestier (Rangifer tarandus caribou) au Québec — 2013-–2023, produit pour le compte du ministère du Développement durable, de l’Environnement, de la Faune et des Parcs du Québec, Faune Québec, 110p

Falkdalen, U., M. Hörnell-Willebrand, T. Nygård, T. Bergström, G. Lind, A. Nordin and B. Warensjö, 2011. Relations between Willow Ptarmigan (***Lagopus lagopus***) density and Gyrfalcon (***Falco rusticolus***) breeding performance in Sweden. Extended abstract, pages 171–176 in R. T. Watson, T. J. Cade, M. Fuller, G. Hunt and E. Potapov (Eds.). Gyrfalcons and Ptarmigan in a Changing World, Volume II. The Peregrine Fund, Boise, Idaho, U.S. http://dx.doi.org/10.4080/gpcw.2011.0217

Fauchald, P., T. Park, H. Tømmervik, R. Myneni and V.H. Hausner, 2017. Arctic greening from warming promotes declines in caribou populations. ***Science Advances*** 26 Apr 2017: Vol. 3, no. 4, e1601365 DOI: 10.1126/sciadv.1601365

Fauteux, D., D. Gauthier, M.J. Mazerolle, N. Coallier, J. Bêty and D. Berteaux, 2018. Evaluation of invasive and non-invasive methods to monitor rodent abundance in the Arctic. Ecosphere 9: 449 e02124.

Fox, A.D. and J.O. Leafloor (eds), 2018. A global audit of the status and trends of Arctic and Northern Hemisphere goose populations. Conservation of Arctic Flora and Fauna International Secretariat: Akureyri, Iceland. ISBN 978-9935-431-66-0.

Franke, A., K. Falk, K. Hawkshaw, S. Ambrose, D.L. Anderson, P.J. Bente, T. Booms, K.K. Burnham, S. Carrièrre, J. Ekenstedt, I. Fufachev, S. Ganusevich, K. Johansen, J.A. Johnson, S. Kharitonov, P. Koskimies, O. Kulikova, P. Lindberg, B.-O. Lindström, W.G. Mattox, C.L. McIntyre, S. Mechnikova, D. Mossop, S. Møller, O.K. Nielsen, T. Ollila, A. Østlyngen, I. Pokrovsky, K. Poole, M. Restani, B.W. Robinson, R. Rosenfield, A. Sokolov, V. Sokolov, T. Swem and K. Vorkamp, 2020. Status and trends of circumpolar peregrine falcon and gyrfalcon populations. Ambio 49: 762–783 https://doi.org/10.1007/s13280-019-01300-z

Franke, A., V. Lamarre and E. Hedlin, 2016. Rapid Nestling Mortality in Arctic Peregrine Falcons Due to the Biting Effects of Black Flies. Arctic 69: 281—285

Frost, G.V., U.S. Bhatt, H.E. Epstein, I. Myers-Smith, G.K. Phoenix, L.T. Berner, J.W. Bjerke, B.C. Forbes, S.J. Goetz, J.T. Kerby, M.J. Macander, T. Park, M.K. Raynolds, H. Tømmervik and D.A. Walker, 2020. Tundra Greenness. Temperature In: (eds.) Thoman, R.L., Richter-Menge, J. & Druckenmiller, M.L. Arctic Report Card 2020: 68-78.

Fuglei, E., J.-A. Henden, C.T. Callahan, O. Gilg, J. Hansen, R.A. Ims, A.P. Isaev, J. Lang, C.I. McIntyre, R.A. Merizon, O.Y., Mineev, Y.N. Mineev. D. Mossop, O.K. Nielsen, E.B. Nilsen, Å.Ø. Pedersen, N.M. Schmidt, B. Sittler, M.H. Willebrand and K. Martin, 2020. Circumpolar status of Arctic ptarmigan: Population dynamics and trends. Ambio 49: 749–761

Gill, F., and D. Donsker (eds), 2019. IOC World Bird List (v9.1). doi : 10.14344/IOC.ML.9.1.

Gill, M.J., K. Crane, R. Hindrum, P. Arneberg, I. Bysveen, N.V. Denisenko, V. Gofman, A. Grant-Friedman, G. Gudmundsson, R.R. Hopcroft, K. Iken, A. Labansen, O.S. Liubina, I.A. Melnikov, S.E. Moore, J.D. Reist, B.I. Sirenko, J. Stow, F. Ugarte, D. Vongraven and J. Watkins, 2011. Arctic Marine Biodiversity Monitoring Plan (CBMP-MARINE PLAN), CAFF Monitoring Series Report No.3, April 2011, CAFF International Secretariat, Akureyri, Iceland. ISBN 1. 978-9979-9778-7-2

Gillespie, M.K.A., M. Alfredsson, I.C. Barrio, J. Bowden, P. Convey, L.E. Culler, S.J. Coulson, P.H. Krögh, A.M. Koltz, S. Koponen, S. Loboda, Y. Marusik, J.P. Sandstrøm, D. Sikes and T.T. Høye, 2020a. Status and trends of terrestrial arthropod abundance and diversity in the North Atlantic region of the Arctic. Ambio 49:718-731. https://doi.org/10.1007/s13280-019-01162-5

Gillespie, M.K.A., M. Alfredsson, I.C. Barrio, J. Bowden, P. Convey, S.J. Coulson, L.E. Culler, M.T. Dahl, K.M. Daly, S. Koponen, S. Loboda, Y. Marusik, J.P. Sandström, D.S. Sikes, J. Slowik and T.T. Høye, 2020b. Circumpolar terrestrial arthropod monitoring: A review of ongoing activities, opportunities, and challenges, with a focus on spiders. Ambio 49:704-717. https://doi.org/10.1007/s13280-019-01185-y

Guay, K.C., P.S.A. Beck, L.T. Berner, S.J. Goetz, A. Baccini and W. Buermann, 2014. Vegetation productivity patterns at high northern latitudes: a multi-sensor satellite data assessment. Global Change Biology 20:3147-3158.

Guerra C.A., L. Pendleton, E.G. Drakou, V. Proença, W. Appeltans, T. Domingos, G. Geller, S. Giamberini, M.J. Gill, H. Hummel, S. Imperio, M. McGeoch, A. Provenzale, I. Serral, A. Stritih, E. Turak, P. Vihervaara, A. Ziemba and H.M. Pereira, 2019. Finding the essential: improving conservation monitoring across scales. Global Ecology and Conservation 18: https://doi.org/10.1016/j.gecco.2019.e00601

Gunn, A., and D. Russell, 2015. Final Report: Review of monitoring indicators for Rangifer in preparation for Arctic caribou status and trend reporting. CARMA 27 March 2015.

Gunn, A., 2016. Rangifer tarandus. The IUCN Red List of Threatened Species 2016: e.T29742A22167140. https://dx.doi.org/10.2305/IUCN.UK.2016—1.RLTS.T29742A22167140.en. Accessed on 06 April 2020

Harvest Management Coalition, 2019. Fortymile caribou herd harvest plan 2019–2023. Alaska Department of Fish and Game, Fairbanks, Alaska.

Hellström, P., 2014. Predator responses to non-stationary rodent cycles. Stockholm: PhD thesis, Department of Zoology, Stockholm University.

Hellström, P., J. Nyström and A. Angerbjörn, 2014. Functional responses of the rough-legged buzzard in a multi-prey system. Oecologia 174: 1241. https://doi.org/10.1007/s00442-013-2866-6

Henriksen, S. and O. Hilmo (eds.), 2015. Norsk rødlista for arter 2015. – Artdatabanken, Norge.

Hinzman, L.D., N.D. Bettez, W.R. Bolton, F.S. Chapin, M.B. Dyurgerov, C.L. Fastie, B. Griffith, R.D. Hollister, A. Hope, H.P. Huntington, A.M. Jensen, G.J. Jia, T. Jorgenson, D.K. Kane, D.R. Klein, G.Kofinas, A.H. Lynch, A.H. Lloyd, A.D. McGuire, F.E. Nelson, W.C. Oechel, T.E. Osterkamp, C.H. Racine, V.E. Romanovsky, R.S. Stone, D.A. Stow, M. Sturm, C.E. Tweedie, G.L. Vourlities, M.D. Walker, D.A. Walker, P.J. Webber, J.M. Welker, K.S. Winker and K. Yoshikawa, 2005. Evidence and Implications of Recent Climate Change in Northern Alaska and Other Arctic Regions. Climatic Change 72, 251–298. https://doi.org/10.1007/s10584-005-5352-2

Hodkinson, I.D., 2018. Insect biodiversity in the Arctic. In: Insect Biodiversity: Science and Society, Volume 2 Robert G. Foottit and Peter H. Adler (Eds). ISBN: 978-1-118-94557-5 Wiley-Blackwell

Hohn J. and E. Jaakkola, 2010. Introduction to the Arctic Biodiversity Trends 2010: Selected Indicators of Change report (CAFF). Conservation of Arctic Flora and Fauna. [Accessed: 2013]. Available from: http://www.caff.is/component/dms/view_document/101-arctic-biodiversity-trends-2010-introduction?Itemid=217

Hudson, J.M.G. and G.H.R. Henry, 2009. Increased plant biomass in a ***High Arctic*** heath community from 1981 to 2008. Ecology 90:2657-2663.

Hullé, M., J. Bonhomme, D. Maurice and J.C. Simon, 2008. Is the life cycle of high Arctic aphids adapted to climate change? Polar Biology 31:1037–1042

Hupp, J., M. Brubaker, K. Wilkinson, and J. Williamson, 2015. How are your berries? Perspectives of Alaska's environmental managers on trends in wild berry abundance. International Journal of Circumpolar Health 74 28704. DOI: 10.3402/ijch.v74.28704

Hupp J.W., D.H. Ward, D.X. Soto, and K.A. Hobson, 2018. Spring temperature, migration chronology, and nutrient allocation to eggs in three species of arctic-nesting geese: Implications for resilience to climate warming. Global Change Biol. 24: 5056-5071. https://doi.org/10.1111/gcb.14418

Høye, T., E. Post, N.M. Schmidt, K. Trøjelsgaard and M.C. Forchhammer, 2013. Shorter flowering seasons and declining abundance of flower visitors in a warmer Arctic. Nature Climate Change 3:759-763

Hyvärinen, E., A. Juslén, E. Kemppainen, A. Uddström and U.-M. Liukko (eds.), 2019. The 2019 Red List of Finnish species. – Ministry of Environment and Finnish Environment Centre. Helsinki. 704 pp.

ICC-Alaska, 2015. Alaskan inuit food security conceptual framework: How to assess the Arctic from an inuit perspective. Summary and recommendations report.

Icelandic Institute of Natural History, 2018a. The IINH Red List for Vascular Plants from 2018. – (https://en.ni.is/resources/publications/red—lists/red—list—vascular—plants).

Icelandic Institute of Natural History, 2018b. The IINH Red List for Birds from 2018. – (https://en.ni.is/resources/publications/red—lists/red—list—birds).

Icelandic Institute of Natural History, 2018c. The IINH Red List for Mammals from 2018. – (https://en.ni.is/resources/publications/red--lists/red--list--mammals)

Ims, R.A. and D. Ehrich, 2013. Terrestrial ecosystems In: Meltofte, H. (ed.) 2013. Arctic Biodiversity Assessment. Status and trends in Arctic biodiversity. Conservation of Arctic Flora and Fauna, Akureyri: 385-440.

Ims, R. A., J. U. Jepsen, A. Stien and N. G. Yoccoz, 2013. Science plan for COAT: Climate-ecological Observatory for Arctic Tundra. Fram Centre Report Series 1, Tromsø, Norway.

Inuit Circumpolar Council Alaska. 2020. Food Sovereignty and Self-Governance: Inuit Role in Managing Arctic Marine Resources. Anchorage, AK.

IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]. IPCC, Geneva, Switzerland, 104 pp.

IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 688 pp.

IPCC, 2019: Summary for policymakers. In IPCC special report on the ocean and cryosphere in a changing climate, eds. H.-O. Po¨rtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama and N. Weyer.

IUCN, 2009. Species and climate change: more than just the polar bear. Cambridge: IUCN/Species Survival Commission.

IUCN, 2012a. IUCN Red List categories and criteria, version 3.1, second edition.

IUCN, 2012b. Guidelines for Application of IUCN Red List Criteria at Regional and National Levels: Version 4.0. Gland, Switzerland and Cambridge, UK: IUCN. iii + 41pp.

IUCN, 2020a. IUCN barometer. https://www.iucnredlist.org/about/barometer-of-lif, download 2020-09-30

IUCN, 2020b. THE IUCN RED LIST OF THREATENED SPECIES, version 2020-2. https://www.iucnredlist.org/

Jenkins, L.K., T. Barry, K.R. Bosse, W.S. Currie, T. Christensen, S. Longan, R.A. Shuchman, D. Tanzer and J.J. Taylor, 2020. Satellite-based decadal change assessments of pan-Arctic environments. Ambio 49, 820–832. https://doi.org/10.1007/s13280-019-01249-z

Ji, Y., T. Huotari, T. Roslin, N.M. Schmidt, J. Wang, D.W. Yu, and O. Ovaskainen, 2020. SPIKEPIPE: A metagenomic pipeline for the accurate quantification of eukaryotic species occurrences and intraspecific abundance change using DNA barcodes or mitogenomes. ***Molecular Ecology Resource***s 20: 256-267

Joly, K., E. Gurarie, M.S. Sorum, P. Kaczensky, M.D. Cameron, A.F. Jakes, B. Borg, D. Nandintsetseg, J.G.C. Hopcraft, B. Buuveibaatar, P.F. Jones, T. Mueller, C. Walzer, K.A. Olson, J.C. Payne, A. Yadamsuren and M. Hebblewhite, 2019. Longest terrestrial migrations and movements around the world. Sci Rep 9, 15333 (2019). https://doi.org/10.1038/s41598-019-51884-5

Jones, T., D. McLennan, C. Behe, M. Arvnes, S. Wesseberg, L. Sergienko, C. Harris, Q. Harcharek, T. Christensen, 2019. Arctic Coastal Biodiversity Monitoring Plan. Conservation of Arctic Flora and Fauna International Secretariat: Akureyri, Iceland. ISBN 978-9935-431-76-9

Josefsson T., G. Hörnberg, and L. Östlund, 2009. Long-term human impact and vegetation changes in a boreal forest reserve: Implications for the use of protected areas as ecological references. Ecosystems 12:1017–1036. doi: 10.1007/s10021-009-9276-yKoons, D.N., R.F. Rockwell and L.M. Aubry, 2013. Effects of exploitation on an overabundant species: the lesser snow goose predicament.

Kuzmin S.L. and D.F. Tessler, 2013. Chapter 5 Amphibian and Reptiles in CAFF (2013a) Arctic Biodiversity Assessment. Conservation of Arctic Flora and Fauna, Akureyri, Iceland.

Le Moullec, M, Å.Ø. Pedersen, A. Stien, J. Rosvold and B.B. Hansen, 2019. A century of conservation: the ongoing recovery of Svalbard reindeer. The Journal of Wildlife Management 1-11. DOI: 10.1002/jwmg.21761

Lee, W.Y., 2018. Bird observations in Siriuspasset, north Greenland, 2016 and 2017. Dansk Ornitologisk Forenings Tidsskrift 112: 53–58.

Lento, J., W. Goedkoop, J. Culp, K.S. Christoffersen, K.F. Lárusson, E. Fefilova, G. Guðbergsson, P. Liljaniemi, J.S. Ólafsson, S. Sandøy, C. Zimmerman, T. Christensen, P. Chambers, J. Heino, S. Hellsten, M. Kahlert, F. Keck, D. Laske, D. Chun Pomg Lau, I. Lavoie, B. Levenstein, H. Mariash, K. Rühland, E. Saulner-Talbot, A.K. Schartau and M. Svenning, 2019. State of the Arctic freshwater biodiversity. Akureyri: Conservation of Arctic Flora and Fauna International Secretariat. ISBN 978-9935-431-77-6.

Lisovski, S., K.Gosbell, C. Minton and M. Klaassen, 2020. Migration strategy as an indicator of resilience to change in two shorebird species with contrasting population trajectories. J Anim Ecol. DOI: 10.1111/1365-2656.13393

Mallory, F.F. and T.L. Hillis, 1998. Demographic characteristics of circumpolar caribou populations: ecotypes, ecological constraints, releases, and population dynamics. Rangifer Spec. Issue 10:49–60.

Matveeva, N.V. (ed.), O.V. Lavrinenko and I.A. Lavrinenko (sci. ed.), 2006. Red Book of the Nenets Autonomous OkrMilner, J. M., O. Varpe, R. van der Wal and B. B. Hansen. 2016. Experimental icing affects growth, mortality, and flowering in a high Arctic dwarf shrub. Ecology and Evolution 6:2139-2148.

Milner, J. M., O. Varpe, R. van der Wal and B. B. Hansen. 2016. Experimental icing affects growth, mortality, and flowering in a high Arctic dwarf shrub. Ecology and Evolution 6:2139-2148.

Mizin, I., T. Sipko, A. Davydov and A. Gruzdev, 2018. The wild reindeer (Rangifer tarandus: Cervidae, Mammalia) on the Arctic islands of Russia: A review. Nature Conservation Research. 3. 10.24189/ncr.2018.040

MNRF, 2014a. Integrated Range Assessment for Woodland Caribou and their Habitat in the Far North of Ontario: 2013. Species at Risk Branch, Thunder Bay, Ontario, xviii + 124 p

MNRF, 2014b. Integrated Range Assessment for Woodland Caribou and their Habitat: Kesagami Range 2010. Species at Risk Branch, Thunder Bay, Ontario xi + 83p.

Mudryk, L., A. Elias Chereque, R. Brown, C. Derksen, K. Luojus and B. Decharme, 2020. Terrestrial Snow Cover. Temperature In: (eds.) Thoman, R.L., J. Richter-Menge and M.L. Druckenmiller, 2020. Arctic Report Card 2020: 28-34.

Murray, N.J., S.R. Phinn, M. DeWitt, R. Ferrarri, R. Johnston, M.B. Lyons, N. Clinton, D. Thau and R.A Fuller, 2019. The global distribution and trajectory of tidal flats. Nature 565:222-225. https://doi.org/10.1038/s41586-018-0805-8

Myers-Smith, I. H., S. C. Elmendorf, P. S. A. Beck, M. Wilmking, M. Hallinger, D. Blok, K. D. Tape, S. A. Rayback, M. Macias-Fauria, B. C. Forbes, J. D. M. Speed, N. Boulanger-Lapointe, C. Rixen, E. Levesque, N. M. Schmidt, C. Baittinger, A. J. Trant, L. Hermanutz, L. S. Collier, M. A. Dawes, T. C. Lantz, S. Weijers, R. H. Jorgensen, A. Buchwal, A. Buras, A. T. Naito, V. Ravolainen, G. Schaepman-Strub, J. A. Wheeler, S. Wipf, K. C. Guay, D. S. Hik and M. Vellend, 2015. Climate sensitivity of shrub growth across the tundra biome. Nature Climate Change 5:887-891.

Myers-Smith, I.H., J.T. Kerby, G.K. Phoenix, J.W. Bjerke, H.E. Epstein, J.J. Assmann, C. John, L. Andreu-Hayles, S. Angers-Blondin, P.S.A. Beck, L.T. Berner, U.S. Bhatt, A.D. Bjorkman, D. Blok, A. Bryn, C.T. Christiansen, J.H.C. Cornelissen, A.M. Cunliffe, S.C. Elmendorf, B.C. Forbes, S.J. Goetz, R.D. Hollister, R. de Jong, M.M. Loranty, M. Macias-Fauria, K. Maseyk, S. Normand, J. Olofsson, T.C. Parker, F.-J.W. Parmentier, E. Post, G. Schaepman-Strub, F. Stordal, P.F. Sullivan, H.J.D. Thomas, H. Tømmervik, R. Treharne, C.E. Tweedie, D.A. Walker, M. Wilmking and S. Wipf, 2020. Complexity revealed in the greening of the Arctic. Nat. Clim. Chang. 10, 106–117 (2020). https://doi.org/10.1038/s41558-019-0688-1

Navarro, L.M., N. Fernández, C.A. Guerra, R. Guralnick, W.D. Kissling, M.C. Londoño, E. Turak, T. Yahara D. Kissling, A. Skidmore, E.-S. Kim, H. Kim, I. Geijzendorffer, M. Costello, T. Mwampamba, C. Martin, P. Balvanera, S. Vergara, G. El Serafy, A. Delavaud , I. Pinto, W. Jetz, M. McGeoch, J. Nel, H. Xu, P. Vihervaara, N. Pettorelli, S. Ferrier, G. Geller, F. Muller-Karger, R. Guralnick, E. Nicholson, M. Schaepman, M. Gill, and H.M. Pereira, 2017. Monitoring biodiversity change through effective global coordination. Current Opinion in Environmental Sustainability 29: 158-169.

Nielsen, Ó.K., 2011. Gyrfalcon population and reproduction in relation to Rock Ptarmigan numbers in Iceland. Pages 21–48 in R. T. Watson, T. J. Cade, M. Fuller, G. Hunt and E. Potapov (Eds.). Gyrfalcons and Ptarmigan in a Changing World, Volume II. The Peregrine Fund, Boise, Idaho, U.S. http://dx.doi.org/ 10.4080/gpcw.2011.0210

Norment, C.J. and M.E. Fuller, 1997. Breeding-season frugivory by Harris' sparrows (***Zonotrichia querula***) and white-crowned sparrows (***Zonotrichia leucophrys***) in a low-arctic ecosystem. Canadian Journal of Zoology 75: 670-679, https://doi.org/10.1139/z97-087

Notz, D. and J. Stroeve, 2016. Observed Arctic sea-ice loss directly follows anthropogenic CO2 emission. 6 Science 354 (6313), 747-750. DOI: 10.1126/science.aag2345

Oberbauer, S. F., S. C. Elmendorf, T. G. Troxler, R. D. Hollister, A. V. Rocha, M. S. Bret-Harte, M. A. Dawes, A. M. Fosaa, G. H. R. Henry, T. T. Hoye, F. C. Jarrad, I. S. Jonsdottir, K. Klanderud, J. A. Klein, U. Molau, C. Rixen, N. M. Schmidt, G. R. Shaver, R. T. Slider, O. Totland, C. H. Wahren and J. M. Welker. 2013. Phenological response of tundra plants to background climate variation tested using the International Tundra Experiment. Philosophical Transactions of the Royal Society B-Biological Sciences 368.

Oberndorfer, E., T. Broomfield, J. Lundholm, and G. Ljubicic, 2020. Inuit cultural practices increase local-scale biodiversity and create novel vegetation communities in Nunatsiavut (Labrador, Canada). Biodiversity and Conservation 29:1205–1240. doi: 10.1007/s10531-020-01931-9

Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D'amico, I. Itoua, H.E. Strand, J.C. Morrison, C.J. Loucks, T.F. Allnutt, T.H. Ricketts, Y. Kura, J.F. Lamoreux, W.W. Wettengel, P. Hedao and K.R. Kassem, 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51: 933-938.

Peacock, S. J., F. Mavrot, M. Tomaselli, A. Hanke, H. Fenton, R. Nathoo, O.A. Aleuy, J. Di Francesco, X.F. Aguilar, Na. Jutha, P. Kafle, J. Mosbacher, A. Goose, Ekaluktutiak Hunters and Trappers Organization, Kugluktuk Angoniatit Association, Olokhaktomiut Hunters and Trappers Committee and S.J. Kutz, 2020. Linking co-monitoring to co-management: bringing together local, traditional, and scientific knowledge in a wildlife status assessment framework. Arctic Science, 6(3), 247-266.

Pereira, H.M., L.M. Navarro, and I.S. Martins. 2012. Global biodiversity change: The bad, the good, and the unknown. Annual Review of Environment and Resources 37: 25–50.

Petersen, A.,C. Zöckler, and M.V. Gunnarsdóttir 2004. Circumpolar Biodiversity Monitoring Program – Framework Document. CAFF CBMP Report No. 1. CAFF International Secretariat, Akureyri, Iceland. 46 pp ISBN: 9979-59526-9-5.

Pääkkö, E., K. Mäkelä, A. Saikkonen, S. Tynys, M. Anttonen, P. Johansson, I. Kumpula, K. Mikkola, Y. Norokorpi, O. Suominen, M. Turunen, R. Virtanen and H. Väre, 2018. Fell habitats. In: Kontula, T. & A. Raunio, (eds). Threatened Habitat Types in Finland 2018. Red List of Habitats – Results and Basis for Assessment. Finnish Environment Institute and Ministry of the Environment, Helsinki. The Finnish Environment 2/2019. pp. 153-183. https://helda.helsinki.fi/handle/10138/308426

Peterson, C., 2015. Unit 9D southern Alaska Peninsula caribou. Chapter 5, Pages 5-1 through 5-11 [In] P. Harper and L. A. McCarthy, editors. Caribou management report of survey-inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.

Post, E., C. Pedersen, C.C. Wilmers and M.C. Forchhammer, 2008. Warming, plant phenology and the spatial dimension of trophic mismatch for large herbivores. Proc. R. Soc. B 275, 2005–2013 doi:10.1098/rspb.2008.0463

Rakhimberdiev, E., S. Duijns, J. Karagicheva, C.J. Camphuysen, A. Dekinga, R. Dekker, and M. Soloviev, 2018. Fuelling conditions at staging sites can mitigate Arctic warming effects in a migratory bird. Nature Communications 9:4263. https://doi.org/10.1038/s41467-018-06673-5

Ravolainen, V., E.M. Soininen, I.S. Jónsdóttir, I. Eischeid, M.C. Forchhammer, R. van der Wal and Å.Ø. Pedersen, 2020. High Arctic ecosystem states: Conceptual models of vegetation change to guide long-term monitoring and research. Ambio 49, 666–677. https://doi.org/10.1007/s13280-019-01310-x

Reich, R. M., N. Lojewski, J.E. Lundquist and V.A. Bravo, 2018. Predicting abundance and productivity of blueberry plants under insect defoliation in Alaska. Journal of Sustainable Forestry 37(4): 1-12.

Reynolds, P.E., H.V. Reynolds, and R. Shideler, 2002. Predation and multiple kills of muskoxen by grizzly bears. Ursus 13: 79-84.

Raynolds, M.K., D.A. Walker, A., Balser, C. Bay, M. Campbell, M.M., Cherosov, F.J.A. Daniëls, P.B. Eidesen, K.A. Ermokhina, G.V. Frost, B. Jedrzejek, M.T. Jorgenson, B.E. Kennedy, S.S. Kholod, I.A. Lavrinenko, O.V. Lavrinenko, B. Magnússon, N.V. Matveyeva, S. Metúsalemsson, L. Nilsen, I. Olthof, I.N. Pospelov, E.B. Pospelova, D. Pouliot, V. Razzhivin, G. Schaepman-Strub, J. Šibík, M.Y. Telyatnikov and E. Troeva, 2019. A raster version of the Circumpolar Arctic Vegetation Map (CAVM). Remote Sensing of the Environment 232.

Reneerkens, J., N. M. Schmidt, O. Gilg, J. Hansen, L. H. Hansen, J. Moreau & T. Piersma, 2016. Effects of food abundance and early clutch predation on reproductive timing in a high Arctic shorebird exposed to advancements in arthropod abundance. Ecology and Evolution 2016; 6(20): 7375–7386.

Reneerkens, J., 2020. Climate change effects on Wadden Sea birds along the East-Atlantic Flyway. Wadden Academy, Position paper 2020-02.

Ricca, M.A., D.H. Van Vuren, F.W. Weckerly, J.C. Williams, and A.K. Miles, 2014. Irruptive dynamics of introduced caribou on Adak Island, Alaska: an evaluation of Riney-Caughley model predictions. Ecosphere 5(8):94.http://dx.doi.org/10.1890/ES13–00338.1

Robinson, R.A., N.A. Clark, R. Lanctot, S. Nebel, B. Harrington, J.A. Clark, J.A. Gill, H. Meltofte, D.I. Rogers, K.G. Rogers, B.J. Ens, C.M. Reynolds, R.M. Ward, T. Piersma and P.W. Atkinson, 2005. Long term demographic monitoring of wader populations in non-breeding areas. Wader Study Group Bull. 106: 17-29.

Ruohomäki, K., M. Tanhuanpää, M. Ayres, P. Kaitaniemi, T. Tammaru and E. Haukioja, 2000. Causes of cyclicity of Epirrita autumnata (Lepidoptera, Geometridae): Grandiose theory and tedious practice. Popul. Ecol. 42: 211-223.

Saalfeld S.T. and R.B. Lanctot, 2017. Multispecies comparisons of adaptability to climate change: A role for life-history characteristics? Ecol Evol. 7: 10492-10502. https://doi.org/10.1002/ece3.3517

Saalfeld S.T., D.C. McEwen, D.C. Kesler, M.G. Butler, J.A. Cunningham, A.C. Doll, W.B. English, D.E. Gerik, K. Grond, P. Herzog, B.L. Hill, B. J. Lagassé, ***R.B. Lanctot***, 2019. Phenological mismatch in Arctic-breeding shorebirds: Impact of snowmelt and unpredictable weather conditions on food availability and chick growth. Ecol Evol. 9: 6693-6707. https://doi.org/10.1002/ece3.5248

Savchenko, A.P., A.A. Baranov, V.I. Emelyanov, V.A., Zadelenov , 12. Red Book of the Krasnoyarsk Territory, Vol. 1: Rare and Endangered Species of Animals. – Krasnoyarsk: Publishing house of the Siberian Federal University. 205 pp.

Schmidt, N.M., B. Hardwick, O. Gilg, T.T. Høye, P.H. Krogh, H. Meltofte, A. Michelsen, J.B. Mosbacher, K. Raundrup, J. Reneerkens, L. Stewart, H. Wirta and T. Roslin, 2017. Interaction webs in arctic ecosystems: Determinants of arctic change? Ambio 46: S12—S25.

Schmidt, N.M., and H. Jóhannesdóttir (eds), 2020. Special Issue: Terrestrial biodiversity in a rapidly changing Arctic. Ambio, Vol. 49, issue 3, March 2020.

SLU Artdatabanken, 2020. Rödlistade arter i Sverige. 2020. SLU, Uppsala.

Smith, P.A., L. McKinnon, H. Meltofte, R.B. Lanctot, A.D. Fox, J.D. Leafloor, M. Soloviev, A. Franke, K. Falk, M. Golovatin, V. Sokolov, A., Sokolov and A.C. Smith, 2020. Status and trends of tundra birds across the circumpolar Arctic. Ambio 49: 732–748. https://doi.org/10.1007/s13280-019-01308-5

Soininen, E. M., J. A. Henden, V. Ravolainen, N. G. Yoccoz, K. A. Bråthen, S. T. Killengreen and R. A. Ims, 2018. Transferability of biotic interactions: Temporal consistency of arctic plant–rodent relationships is poor. Ecology and Evolution 8:9697-9711.

Stepanov, N.V., E.B. Andreeva, et al., 2012. Red Book of the Krasnoyarsk Territory. Vol. 2: Rare and endangered species of wild plants and fungi. – Krasnoyarsk Siberian Federal University 572 pp.

Strathdee A.T., J.S. Bale, W.C. Block, N.R.Webb, I.D. Hodkinson, and S.J. Coulson, 1993. Extreme adaptive life cycle in a high Arctic aphid, Acyrthosiphon svalbardicum. Ecological Entomology 18: 254-258.

Syroechkovskiy, E.E., 2000. Wild and semi—domesticated reindeer in Russia: status, population dynamics and trends under the present social and economic conditions. Rangifer 20:113-126.

Taylor, J.J., J.P. Lawler, M. Aronsson, T. Barry, A.D. Bjorkman, T. Christensen, S.J. Coulson, C. Cuyler, D. Ehrich, K. Falk, A. Franke, E. Fuglei, M.A. Gillespie, S. Heiðmarsson, T.T. Høye, L.K. Jenkins, V. Ravolainen, P.A.Smith, P. Wasowics and N.M. Schmidt, 2020. Arctic terrestrial biodiversity status and trends: A synopsis of science supporting the CBMP State of Arctic Terrestrial Biodiversity Report. Ambio 49, 833–847. https://doi.org/10.1007/s13280-019-01303-

Thoman, R.L., J. Richter-Menge and M.I. Druckenmiller (Eds.), 2020. Arctic Report Card 2020

Tiusanen, M., T. Kankaanpää, N.M. Schmidt and T. Roslin, 2020. Heated rivalries: Phenological variation modifies competition for pollinators among arctic plants. Global Change Biology 26: 6313-6325

Tucker, M. A., K. Böhning-Gaese, W.F. Fagan, J.M. Fryxell, B. Van Moorter, S.C. Alberts, A.H. Ali, A.M. Allen, N. Attias, T. Avgar, H. Bartlam-Brooks, B. Bayarbaatar, J.L. Belant, A. Bertassoni, D. Beyer, L. Bidner, F.M. van Beest, S. Blake, N. Blaum, C. Bracis, D. Brown, P. J.N. de Bruyn, F. Cagnacci, J.M. Calabrese, C. Camilo-Alves, S. Chamaillé-Jammes, A. Chiaradia, S.C. Davidson, T. Dennis, S. DeStefano, D. Diefenbach, I. Douglas-Hamilton, J. Fennessy, C. Fichtel, W. Fiedler, C. Fischer, I. Fischhoff, C.H. Fleming, A.T. Ford, S.A. Fritz, B. Gehr, J.R. Goheen, E. Gurarie, M. Hebblewhite, M. Heurich, A. J.M. Hewison, C. Hof, E. Hurme, L.A. Isbell, R. Janssen, F. Jeltsch, P. Kaczensky, A. Kane, P.M. Kappeler, M. Kauffman, R. Kays, D. Kimuyu, F. Koch, B. Kranstauber, S.D. LaPoint, P. Leimgruber, J.D.C. Linnell, P. López-López, A.C. Markham, J. Mattisson, E.P. Medici, U. Mellone, E. Merrill, G.M. de Mourão, R.G. Morato, N. Morellet, T.A. Morrison, S.L. Díaz-Muñoz, A. Mysterud, D. Nandintsetseg, R. Nathan, A. Niamir, J. Odden, R.B. O'Hara, L.G.R. Oliveira-Santos, K.A. Olson, B.D. Patterson, R. Cunha de Paula, L. Pedrotti, B. Reineking, M. Rimmler, T.L. Rogers, C. Moe Rolandsen, C.S. Rosenberry, D.I. Rubenstein, K. Safi, S. Saïd, N. Sapir, H. Sawyer, N.M. Schmidt, N. Selva, A. Sergiel, E. Shiilegdamba, J.P. Silva, N. Singh, E.J. Solberg, O. Spiegel, O. Strand, S. Sundaresan, W. Ullmann, U. Voigt, J. Wall, D. Wattles, M. Wikelski, C.C. Wilmers, J.W. Wilson, G. Wittemyer, F. Zięba, T. Zwijacz-Kozica, T. Mueller, 2018. Moving in the Anthropocene: Global reductions in terrestrial mammalian movements. Science, 359(6374), 466-469.

UNEP-WCMC and IUCN, 2016. Protected Planet Report 2016. UNEP-WCMC and IUCN: Cambridge UK and Gland, Switzerland

U.S. Endangered Species Act and Alaska Endangered Species Statute, 2019. (https://www.fws.gov/alaska/pages/endangered-species-program)

Þórisson, S.G., 2018. Population dynamics and demography of reindeer (Rangifer tarandus L.) on the east Iceland highland plateau 1940–2015: A comparative study of two herds. MSc thesis, Agricultural University of Iceland http://hdl.handle.net/1946/30920

Van der Wal, R., and A. Stien. 2014. High-arctic plants like it hot: a long-term investigation of between-year variability in plant biomass. Ecology 95:3414-3427.

Wahren, C. H. A., M. D. Walker and M. S. Bret-Harte, 2005. Vegetation responses in Alaskan arctic tundra after 8 years of a summer warming and winter snow manipulation experiment. Global Change Biology 11:537-552.

Walker, D.A., M.K. Raynolds, F.J.A. Daniels, E. Einarsson, A. Elvebakk, W.A. Gould, A.E. Katenin, S.S. Kholod, C.J. Markon, E.S. Melnikov, N.G. Moskalenko, S.S. Talbot, B.A. Yurtsev, 2005. The Circumpolar Arctic vegetation map. Journal of Vegetation Science 16: 267–282.

Walker, D. A., H. E. Epstein, J. Sibik, U. Bhatt, V. E. Romanovsky, A. L. Breen, S. Chasnikova, R. Daanen, L. A. Druckenmiller, K. Ermokhina, B. C. Forbes, G. V. Frost, J. Geml, E. Kaarlejarvi, O. Khitun, A. Khomutov, T. Kumpula, P. Kuss, G. Matyshak, N. Moskalenko, P. Orekhov, J. Peirce, M. K. Raynolds and I. Timling, 2019. Vegetation on mesic loamy and sandy soils along a 1700-km maritime Eurasia Arctic Transect. Applied Vegetation Science 22:150-167.

Warburton, H., and A. Martin, 1999. Local people's knowledge in natural resources research. Socio-economic methodologies for natural resources research. Best practice guidelines. Natural Resources Institute, Chatham, UK.

Wasowicz, P., A.N. Sennikov, K.B. Westergaard, K. Spellman, M. Carlson, L.J. Gillespie, J.M. Saarela, S,-.S. Seefeldt, B. Bennett, C. Bay, S. Ickert-Bond, and H. Väre, 2020. Non-native vascular flora of the Arctic: Taxonomic richness, distribution, and pathways. Ambio 49, 693–703. https://doi.org/10.1007/s13280-019-01296-6

Wauchope. H.S., J.D. Shaw, Ø. Varpe, E.G. Lappo, D. Boertmann, R.B. Lanctot and R.A. Fuller, 2017. Rapid climate-driven loss of breeding habitat for Arctic migratory birds. Global Change Biology 23:1085–1094. doi: 10.1111/gcb.13404

Westergaard-Nielsen, A., M. Lund, S. H. Pedersen, N. M. Schmidt, S. Klosterman, J. Abermann and B.U. Hansen. 2017. Transitions in high-Arctic vegetation growth patterns and ecosystem productivity tracked with automated cameras from 2000 to 2013. Ambio 46:S39-S52.

Wilson, D.E and D.A.M. Reeder, 2005. Mammal species of the world: a taxonomic and geographic reference, 3rd edition. John Hopkins University Press, Baltimore, Maryland.

Wirta, H., G. Várkonyi, C. Rasmussen, R. Kaartinen, N.M. Schmidt, P. Hebert, M. Barták, G. Blagoev, H. Disney, S. Ertl, P. Gjelstrup, D. Gwiazdowicz, J. Huldén, J. Ilmonen, J. Jakovlev, M. Jaschhof, J. Kahanpää, T. Kankaanpää, P.H. Krogh, R. Labbee, C. Lettner, V. Michelsen, S.A. Nielsen, T.R. Nielsen, L. Paasivirta, S. Pedersen, J. Pohjoismäki, J. Salmela, P. Vilkamaa, H. Väre, M. von Tschirnhaus, and T. Roslin, 2016. Establishing a community-wide DNA barcode library as a new tool for arctic research. ***Molecular Ecology Resources*** 16: 809-822.

Conservation of Arctic Flora and Fauna

Conservation of Arctic Flora and Fauna (CAFF)
Borgir, Norðurslóð
600 Akureyri
Iceland
Tel: +354 462-3350
caff@caff.is
www.caff.is