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DRIVERS AND FEEDBACKS OF CHANGES IN ARCTIC TERRESTRIAL BIODIVERSITY (CHARTER)

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Call: H2020-LC-CLA-2019-2
Topic: LC-CLA-07-2019 (The changing cryosphere: uncertainties, risks and opportunities)

Key words: Changes in Arctic biodiversity; Arctic tundra, Social-ecological resilience, Indigenous peoples, Participatory; research, Permafrost dynamics, Sea-ice cover, Rain-on-Snow, Earth System Model, Biogeoengineering, Mitigation, Adaptation

Objectives

CHARTER is an ambitious effort **to advance adaptive capacity of Arctic communities** to climatic and biodiversity changes through state-of-the-art synthesis based on thorough data collection, analysis and modelling of Arctic change with major socio-economic implications and feedbacks. To achieve this goal, we will combine expertise from Earth System sciences and biodiversity studies **within the social-ecological system (SES) framework and strongly participatory approach**. Strategies co-developed in CHARTER with indigenous and local communities will comprise synergies between their ambitions for adaptation actions with novel forms of land management geared towards climate mitigation and sustainable development. In order to achieve our overall objective of improved understanding of Arctic change and how ecosystems and communities will navigate this change, CHARTER proposes a coherent framework, in which research questions will be addressed by seven transdisciplinary Work Packages (hereafter WPs) to address three central aims:

1) **Better understand** the responses of Arctic terrestrial social-ecological systems to changes in the cryosphere (e.g. permafrost, snow and sea ice cover, and rain-on-snow (ROS) events), biodiversity and their feedbacks and interactions, using observations at decadal (WPs 1 and 4), centennial (WP2) and recent (WP3) time scales
2) **Project, and simulate** the effects of social-ecological changes for linked indigenous and local communities and traditional livelihoods sharing the affected

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territories out to the year 2050, especially herding and hunting of large semi-domesticated and wild ungulate herds (WPs 3 and 5).

3) **Work** with Arctic communities to co-develop strategies and policy pathways for locally and regionally critical livelihoods, including herding, hunting and fishing, that reflect, and enhance adaptation to, the changing Arctic (WPs1-6).

CHARTER has *two wide cross-cutting themes for all WPs: "Tools and data for Arctic Strategies", and "Public dialogue on the Arctic"*.

1.2 Relation to the work programme

We address LC-CLA-07-2019-Sub-topic B (Changes in Arctic biodiversity). We consider combined social-ecological systems (SESs). Of the United Nation's Sustainable Development Goals (hereafter SDGs), the following are highly relevant for us: SDG 13 (Climate Action), 6, 11 (Sustainable Communities), 14, 15 (Life on Land).

Arctic air temperatures have increased at a rate of 0.76°C/decade during 1998–2012, more than six times the global average for the same time period (Huang et al. 2017). Even if existing COP21 Paris Agreement commitments are met, winter temperatures over the Arctic Ocean will increase 3-5°C by mid-century compared to 1986-2005 levels (Scholmeester et al. 2019). This will have profound consequences for indigenous and local communities as well as SES resilience. The questions CHARTER seeks to answer are thus:

1) How does the Arctic warming and related events such as snow onset and melt, permafrost thaw and the increased frequency of extreme weather events, such as winter rain storms, result in increased pressure on terrestrial biodiversity and linked SESs (see literature cited, JOIN 2016; CCIVE 2017)?
2) What are the dynamics of climate feedbacks in relation to terrestrial Arctic biodiversity and its relevant characteristics, such as albedo (surface reflectance) (JOIN 2016; CCIVE 2017)?

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3) How will policy and strategies developed both for the Arctic, and globally, affect thawing permafrost and its potential for releasing greenhouse gases (JOIN 2016)?
4) What kinds of socio-economic stresses caused by Arctic warming affect indigenous populations and local communities? In particular how will it affect traditional livelihoods, such as reindeer management (CCIVE 2017)?
5) What strategies have Arctic communities and indigenous peoples developed to mitigate and adapt to the linked changes in climate and SESs (JOIN 2016)?
6) How can direct engagement and more sustained interaction with residents from local communities and indigenous societies be deepened and their voices be better integrated into more adaptive reindeer rangeland and SES management (JOIN 2016)?

CHARTER **will include and integrate natural and social sciences and humanities with views from local Arctic and indigenous professionals and experts**. In compliance with the "Agreement on Enhancing International Arctic Scientific Cooperation", signed in May 2017 by the Arctic Council members, CHARTER is a global effort with partners from beyond the EU including Iceland, Greenland, Norway and Switzerland as well as from the United States of America, Canada, the People's Republic of China, the Russian Federation and Japan.

1.3 Concept and methodology

(a) Concept

Box 1: Key terminology

Narratives: We define narratives as internally consistent qualitative descriptions of how future pathways might develop. Narratives can be articulated in many ways, both by expert elicitation providing narratives of relevance for communities, or by communities themselves constructing narratives based on discussions about challenges and possibilities for future developments (Daniels & Endfield 2009; Nilsson et al. 2019). CHARTER's narratives will take into account how different drivers will behave, interact and feed back to influence development pathways.

Grazing: We define grazing as the total impact of large herbivores on tundra rangelands including consumption of plants, trampling and fertilization via defecation and urination.

Social–ecological systems (SES): We follow the definition provided by Forbes et al. (2009), emphasizing that the delineation between social and ecological systems in the Arctic is artificial and arbitrary, requiring integrated approaches to analysis. Human activities and livelihoods are intrinsically connected with the environment – and with biodiversity (Folke 2006).

Adaptation: We define climate change adaptation according to the IPCC's definition as the process of adjustment to actual or expected climate and its effects (IPCC 2014). Adaptation in human systems is seen as the ability to moderate or avoid harm or exploit beneficial opportunities, whereas in some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Local knowledge includes the practitioners' knowledge (Forbes et al. 2006) of local populations (indigenous or not) pertaining to local environments, to experiential knowledge, and to

social relations. In this sense local knowledge is very similar to definitions of traditional (ecological) knowledge that view this knowledge as a locally anchored way of knowing and way of living (Berkes 2012).

The circumpolar Arctic (Fig. 1.1a) plays a significant role in regulating future global climate. Warming temperatures, melting sea and land ice, together with thawing permafrost are transforming marine and terrestrial ecosystems in the Arctic, faster than elsewhere on the planet. Bare ground is becoming vegetated and plants grow faster and taller than they did a generation ago (Macias-Fauria et al. 2012; Miller & Smith 2012; Bjorkman et al. 2019). In West Siberia and Northern Fennoscandia, indigenous Sámi and Nenets reindeer herders have, respectively, reported *in situ* changes in height and/or encroachment of woody plants (e.g. *Salix* and *Alnus* shrubs, mountain birch saplings) that have led to alterations in their grazing regimes (Forbes & Stammler 2009; Macias-Fauria et al. 2012; Horstkotte et al. 2017). An important result is that surface albedo and radiation balance are changing, especially in winter and spring, as snow in tundra areas has far higher albedo than in areas with woody plants protruding above the snow surface (Cohen et al. 2013). Such shifts in Holarctic vegetation cover feed back into at least local (Cohen et al. 2013) and regional Arctic climate change (Loranty et al. 2011; Loranty & Goetz 2012). Thus, changes in vegetation have the capacity to increase tundra soil temperatures and affect permafrost dynamics (Myers-Smith et al. 2011, 2018). Arctic permafrost contains twice as much carbon as is currently in the atmosphere, and its stability is crucial if the world is to meet agreed limits to global temperature rise by mitigating greenhouse gas emissions (Belshe 2013; Crowther et al. 2016; Grosse et al. 2016).

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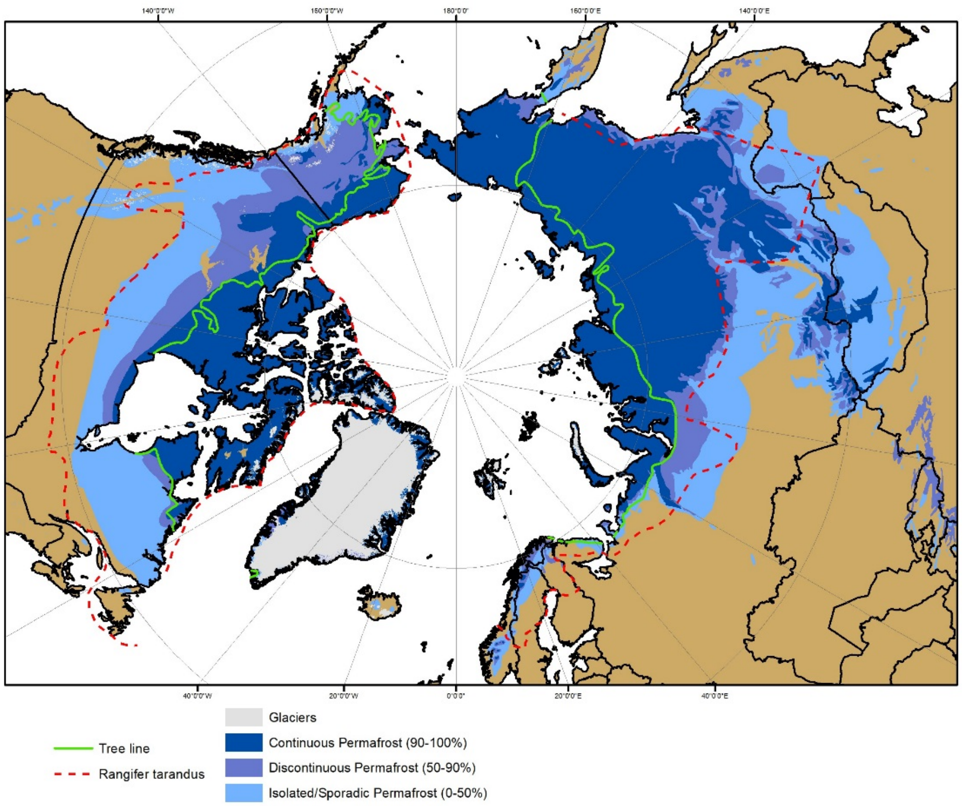

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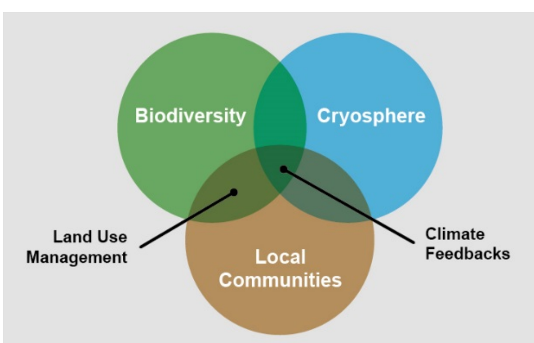

Figure 1.1. a) Geography of key biophysical variables across the circumpolar Arctic most relevant for CHARTER and b) the geographic and social-ecological interactions that CHARTER will address. Biodiversity and the cryosphere are changing due to rapid Arctic climate and land use changes, which in turn affect land cover type and extent, including some 1.8Mkm^2 of reindeer rangelands in NW Eurasia.

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Local Arctic communities have long exploited tundra ecosystems as rangelands and their relationship with the animals as sentient beings, and nature in general, has been central to their worldview and well-being (Anderson 2000; Natcher et al. 2007; Crate et al. 2017). In turn, herbivory has modified significant portions of the tundra biome, particularly in NW Eurasia (Forbes et al. 2006; Olofsson et al. 2009; Horstkotte et al. 2017; Olofsson & Post 2018) (Fig. 1.3c). These communities are now under pressure to adapt to a rapidly changing climate, along with globalization and urbanization and their desire to preserve ways of life across the generations. Yet how these changes will unfold, how communities can adapt, and how those pathways might shape the Arctic environment remain unclear. **A critical step towards resolving this knowledge gap is on the one hand to understand the drivers of Arctic tundra, permafrost, and grazing land change and on the other hand to engage in a sincere dialogue with multiple stakeholders**. The latter legitimately expect to be consulted and involved already at the start of the project, and have assisted in its co-design. Co-production of knowledge must also consider shifting biodiversity and interactions among Arctic species, and as well as their feedbacks with land users and climate.

Observed Arctic biodiversity transitions include changes in phenology (timing of leaf emergence, flowering/senescence of plants), growth and resulting changes in vegetation composition, and traits of affected vegetation types (e.g. plant height or leaf and stem characteristics), all of which contribute to the overall functional diversity of ecosystems (Elmendorf et al. 2012; Pearson et al. 2013; Bjorkman et al. 2018). It is this functional diversity that links species traits to the key ecosystem functions, such as carbon storage in Arctic ecosystems (Myers-Smith et al. 2018) and interactions between trophic levels. Arctic terrestrial ecosystems have low plant and animal species richness, but in a warming climate, species are projected to expand their ranges northward, thus potentially increasing overall diversity, at the expense of endemic Arctic species (Normand et al. 2013). Simultaneously, changing cryosphere conditions – including snow season duration, winter rain-on-snow (ROS) events, and permafrost thaw – may affect biodiversity in multiple ways (Niittynen et al. 2018).

Herbivory is a key process in shaping both plant and animal biodiversity in Arctic ecosystems. Plant-based vertebrate food webs include terrestrial species providing essential ecosystem services to local Arctic residents and indigenous cultures. Examples include wild or semi-domesticated reindeer/caribou (*Rangifer tarandus*; henceforth called 'reindeer') and most game species. Small rodents are also key herbivores in tundra ecosystems and affect the vegetation significantly at peak densities (Olofsson et al. 2009). These species are particularly vulnerable to changes in twinter snow cover, which they use as protection against harsh winter conditions.

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Snow drift and accumulation patterns vary widely across Arctic landscapes, causing regional co-occurrence of a wide range of plant and animal species with different ecological requirements. Future biodiversity patterns in high-latitude ecosystems are thus highly dependent on the changing terrestrial cryosphere. Some cryosphere-related habitats of flora and fauna have already been partially lost, and some key species utilized by Arctic residents are declining, such as caribou in parts of the North American Arctic (CCIVE 2017; Phoenix 2018; CAFF 2019). Snow-related extreme weather events can reduce the productivity and relative stability of Arctic vegetation and degrade biodiversity (e.g. Niittynen et al. 2018). Formation of ice in, on or under the snow cover (basal icing) caused by winter warm spells or ROS episodes potentially affects entire Arctic vertebrate food webs by preventing herbivores' access to forage (Forbes et al. 2016; Rasmus et al. 2018). Indirect effects can cascade through several trophic levels with dramatic consequences for endemic Arctic biodiversity. Harder basal snow layers may lead to a fading out of lemming cycles, a key process in the functioning of tundra ecosystems, and thus cause crashes of endemic Arctic predators such as snowy owls and arctic fox, which depend on them (Sokolov et al. 2016). Increased reindeer mortality caused by ground icing produces pulses of carrion in abundance for predators and favours the expansion of boreal generalists such as red foxes and corvids. These predators have a negative impact on medium-sized game species such as ptarmigan and hare, which are a valuable food resource for local people. Terrestrial SESs can also be strongly affected by Arctic sea ice extent (Forbes et al. 2016) and timing of the seasonal ice cover in Arctic lakes (Pointner et al. 2018). Both contribute to the land-atmosphere energy and moisture fluxes and to the probability of ROS events with devastating consequences when semi-domestic reindeer and/or freshwater fish populations decline (Forbes et al. 2016; Pointner et al. 2018).

The depth of seasonally frozen ground, and seasonally thawed permafrost active-layer thickness, both affect biodiversity through periglacial processes like landslides and paludification, thereby changing landscape structure and meso-scale topography (Frost et al. 2013). Simultaneously, permafrost thaw and subsequent carbon and methane releases, are also determined by local grazing history (Ylänne & Stark 2019). Long-term paleo-records extending beyond historic records are pivotal in assessing current ecosystem responses and resilience to change. Paleo-records can provide answers to questions that cannot be addressed by studying modern social ecological systems (SES) alone. Understanding biodiversity and biotic interactions across centuries and millennia is a key priority when assessing future ecosystem responses to climate warming (Seddon et al. 2014; Barnosky et al. 2017), and the need to generate such long-term records in the anomalous current warming phase of the Arctic is pressing. At the same time, it is essential to understand the extrinsic forcing mechanisms behind long-term biodiversity change, and the feedbacks of those changes to biogeochemical cycles. Paleo-archives of sea-ice change (e.g. Hole & Macias-Fauria 2017) and paleo-records of wetland and lake carbon dynamics, combined with millennial-scale biodiversity reconstructions, help us track feedback loops that warmer Arctic seas generate with adjacent terrestrial landscapes and land-use patterns. **Better understanding of changes in vegetation productivity and distribution in Arctic tundra is essential for accurately quantifying and predicting carbon and energy budgets and associated climate feedbacks** (Loranty et al. 2011).

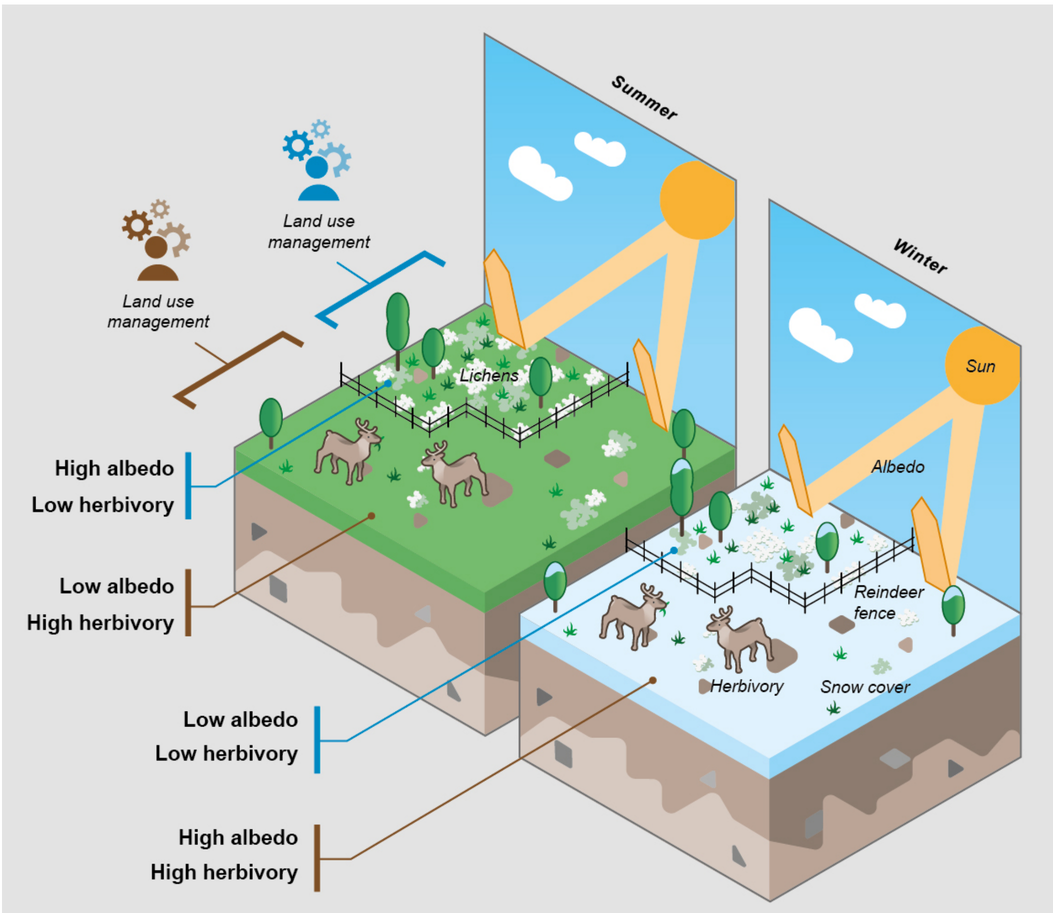

Fig. 1.2. Contrasts in surface albedo and vegetation driven by differing rangeland grazing regimes, with contrasting effects between summer and winter. These exert strong controls over soil temperatures and hence permafrost thaw and carbon release.

Reindeer is a keystone herbivore in circumpolar SESs and a central element for the livelihoods of many Arctic residents. Humans and their semi-domesticated reindeer herds have probably been affecting landscape-level tundra and taiga ecosystem dynamics for two millennia or longer (Krupnik 1993; Forbes et al. 2006; Uboni et al. 2016). The

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vegetation of the Arctic evolved in the presence of herbivores. Reindeer are distributed across most vegetated areas of the mainland tundra biome, a large portion of the northern taiga, and on many Arctic islands (Fig. 1.1a, b). Reindeer depend on shrub tundra, wetlands, and lichen-woodland ecosystems and simultaneously modify them across vast stretches of the tundra biome (Forbes 2010). In Northwest Eurasia, reindeer herding has for centuries been a significant socio-economic activity for sustenance, commerce and culture (Forbes et al. 2006) The scope and intensity of grazing and associated trampling depend on political, socio-economic and cultural factors. Vegetation and soils of Northwest Eurasia have been affected profoundly by reindeer management. Thus, anthropogenic and natural influences are very much interlinked in the SESs comprising our study region. The 1.8 million km^2 reindeer herding region (Fig. 1.1b) consists of tundra and northern forest rangelands for approximately 1.8 million reindeer and constitutes the working environment and cultural landscape for numerous indigenous and local herding communities within four countries. Reindeer numbers have been growing significantly in many parts of Northwest Eurasia during recent decades, while annual variability of reindeer numbers has stabilized (Uboni et al. 2016).

Several feedback loops exist between large-scale reindeer management of the core CHARTER study region (Fig.1.1) and its climate and biodiversity dynamics. Climate impacts on soil temperatures and snow cover vary according to land-use history, in particular in areas with *versus* without semi-domesticated reindeer herds (Forbes et al. 2006; Olofsson et al. 2009). Soil composition, hydrology and temperature, affecting Arctic ecosystems, are in turn affected by local weather and snow conditions, as well as grazing/trampling history (Olofsson & Post 2018). Landscape changes caused by permafrost thaw and subsequent changes in the biodiversity affect reindeer rangeland conditions and patterns of reindeer movement (Macias-Fauria et al. 2012; Forbes & Stammler 2009; Forbes et al. 2010).

Shrubification decreases local and regional albedo (Fig. 1.2 and 1.3) and amplifies warming. The advance of trees and shrubs into the tundra, as well as *in situ* increases in annual growth, increases vegetation height (Bjorkman et al. 2018) and has profound implications for social-ecological and economic dynamics (Macias-Fauria et al. 2012; Shen et al. 2015; Myers-Smith & Hik 2017). Large vertebrate herbivores can negate this woody-plant advance (Olofsson et al. 2009; Speed et al. 2010; Cromsigt et al. 2018). Long-term reindeer management within the region thus affects Arctic albedo in two ways; (1) decreased lichen coverage vis-a-vis grazing and trampling reduces albedo during the summer; and (2) grazing and trampling increase albedo by keeping the vegetation low, i.e. below the prevailing snow cover. This leads to higher albedo during the snow season and delays snow melt (Cohen et al. 2013).

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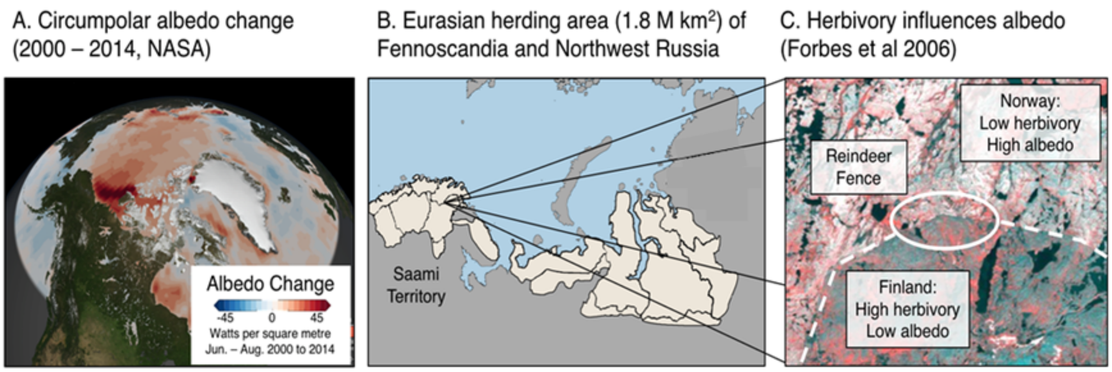

Fig. 1.3. a) Circumpolar albedo change (2000-2014, NASA); b) Eurasian reindeer management area (1.8Mkm^2) of Fennoscandia and Northwest Russia; and c) Herbivory influences albedo (Forbes et al. 2006).

Winter icing and ROS events have created lethal grazing conditions for semi-domesticated reindeer herds from Northern Fennoscandia to West Siberia (Forbes et al. 2016; Rasmus et al. 2018; Eira et al. 2018), as well as wild herds in the High Arctic (Hansen et al. 2014). The effects cascade across local and regional SESs dependent on herding but have also motivated development of several coping measures and led to new herding practices, i.e. innovation (Forbes & Stammler 2009; Forbes et al. 2016; Turunen et al. 2016). Socio-economic costs of thawing permafrost are only just beginning to be accounted for but will run into trillions of USD (Yumashev et al. 2019). As the Arctic land-surface continues to change and plant biodiversity shifts with the warming and changing cryosphere, trophic interactions will also change, potentially leading to mismatches between the availability of food resources and the activity and reproduction of species across food webs (Schmidt et al. 2017). These trophic interactions will have far reaching effects across the Arctic, altering the livelihoods of Arctic peoples (IPCC 2014). Thus, a fundamental research gap is the identification of historic, current and future biodiversity trends across trophic levels in in contrasting SES contexts.

Flexibility is repeatedly identified as key to reducing vulnerability in relation to climate change (Rees et al. 2008; Horstkotte et al. 2014) **but there is still little knowledge regarding how land-use flexibility and climate change link to reindeer nutrition and productivity**. The ability to exploit the most nutritious forage resources may be constrained, or facilitated, by both landscape topography and herders' decisions. Integrating herders' decisions, policy developments and local ungulate feeding patterns help us understand tundra rangeland dynamics. Increasing frequent and intense ROS events (Forbes et al. 2016) add complexity since they have substantial immediate and

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short-term effects on reindeer movement and productivity, with concomitant lag effects in the following several years on rangeland vegetation and soils.

Under conditions of rapid anthropogenic global change, maintaining viable SESs for the future requires new approaches (Falardeau et al. 2019). Specific Arctic adaptation strategies are needed both to mitigate and to adapt to challenges brought by changes in the cryosphere (JOIN 2016). The question is not only about biodiversity conservation and optimal management of reindeer herds, but also about developing more sustainable ways for infrastructure development, which tundra pastoralists must navigate (Forbes et al. 2006, 2009). Developing effective strategies under this new paradigm will also require deeper understanding of how SES dynamics have developed through time and how they influence the present actions and perceptions of risk in local communities.

In CHARTER, *we combine data, methods, expertise and evidence from modern ecology, social sciences, anthropology, geography, archaeology, paleoecology, and multiple aspects of climate research to create a Late Holocene/Anthropocene SES synthesis*. Since local communities and other stakeholders have unique ways of understanding the SESs they inhabit, we have already implemented co-design of the research via our long-term indigenous, local and administrative partnerships (see Support Letters as Appendices in Section 5) in core portions of the study region (Fig. 1.4) and further aim for participatory co-production of ways of knowing, co-development of viable adaptation strategies and co-dissemination both during and following the project. It should be noted that in addition to our practitioner partners (i.e. reindeer herders), we will have indigenous scholars engaged intensively at all levels from early career (e.g. doctoral, post-doctoral) to senior researchers. Early career scholars will be employed from part- to full-time depending upon the respective institutions involved (e.g. UHAM, LAY, NTNU). **Utilizing this co-development and strongly participatory approach is a way to avoid inadvertently choosing mitigation policies that have unwanted local and regional side effects**. CHARTER aims to produce research in support of the three-fold EU objectives for the Arctic: high surface albedo during all seasons, high biodiversity, and co-existence of traditional pastoralist-based livelihoods of indigenous populations and local communities (cf. EU's Joint Communication on An Integrated Policy for the Arctic 2016; European Political Strategy Centre 2019; IPBES 2019; IPCC 2019; von der Leyen 2019).

(b) Methodology

To facilitate the adaptive capacity of Arctic communities to changing climate and terrestrial biodiversity, a complex modelling framework is required based on a comprehensive synthesis of existing (albeit dispersed and partly hard-to-access) data on

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the impact of multiple drivers affecting Arctic SESs (Fig. 1.4). Improved understanding of the linked climate/biodiversity/SES dynamics cannot be achieved without transdisciplinary collaboration (Fig. 1.1). In response to these needs, CHARTER **will utilize datasets based on complementary scientific methods: remote sensing products of the terrestrial cryosphere and vegetation will provide a circumpolar overview (WP1)**. *In situ* observational and experimental data address ecosystem processes; such data were mostly collected during previous and ongoing national (e.g. RISES), Nordic (e.g. NCoE TUNDRA, NCoE ReiGN) and EU projects (e.g. TUNDRA, RENMAN, PAGE21, HUMANOR). **These inform biodiversity dynamics in WP2 and local and indigenous knowledge in WP3. WP4 will utilize a broad range of traditional and state-of-the-art paleoecological methods to understand centennial trajectories of herbivore impacts and food-web dynamics. We will combine these data within a modelling framework** that encompasses local-scale process models of snow cover, regional Arctic climate and landscape models of northwest Eurasia, and global earth system models **(WP5)** driven by **narrative scenarios worked out in cooperation with local communities (WP6)**. CHARTER methodology comprises:

1) **Involving** the well-established stakeholder network of CHARTER including reindeer herders, reindeer herding organizations, and representatives of the various local administrative institutions, in synthesizing existing yet dispersed knowledge about the combined action of drivers of change on tundra biodiversity and ecosystem processes. These parties, as well as the relevant government ministries in Finland, and Russia (Yamal), were involved during the initial (Step 1) phase of the CHARTER proposal and many of them have written detailed Support Letters.
2) **Mapping**, analyzing and synthesizing data from a variety of complementary sources including various remote sensing platforms and sensors (i.e. pan-Arctic energy fluxes, terrestrial snow cover extent and snow water equivalent, sea ice concentration from satellites; detection of ROS events using a combination of satellite and atmospheric re-analysis (e.g. ECMWF ERA5) data sets; NOAA circumpolar observation network; permafrost change datasets; land use maps; aerial photos and Unmanned Aerial Systems), field studies and local knowledge; data from long-term herbivory exclosure experiments; national vegetation and ungulate inventories; small rodent trapping; records of significant weather events reported in archives and oral histories; previous local observations on environmental changes; dendrochronological data sets; and multi-proxy sea ice reconstructions.
3) **Collection of data** using latest technology and targeted field experiments including paleoecological data (pollen and non-pollen palynomorphs) from surface samples, peat cores and lake sediments, targeted field work on sub-fossil

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shrub specimens preserved in permafrost, identification of ROS events and their severity by remote sensing, new herbivory exclosures at targeted sites complementing ongoing experiments.

4) **Back-casting and forecasting climate, cryosphere and biodiversity changes**. Regional climate simulations including coupled vegetation (ICON-CLM/HIRLAM-CLM), the Arctic tundra vegetation dynamics model ArcVeg, Earth System Modelling and model improvements to the BNU-ESM. Simulating historical and future ROS and icing events with various modelling tools.
5) **Co-documentation of different ways of knowing** about weather impacts and terrestrial biodiversity with indigenous peoples and local communities based on both past and newly evolving understandings of the changing environment, ecosystems and climate, using focus groups, recording interviews, participant observation, indigenous ground-truthing, participatory GIS, and ethnoclimatology. In addition, intensive participatory workshops will be held in northernmost Finland, Sweden and Norway, as well as in Yamal, West Siberia, all regions which have already pledged support to CHARTER at several levels.
6) **Contributing to development of planning and policy options** via summary presentations of data and simulations. Planning and implementing management actions with indigenous and local communities, institutional and policy analysis. Assessments of the most promising management options at the local level.

We have given general principles about our engagement with the local and indigenous communities in this plan. Nevertheless, we aim at genuine co-design and co-production of knowledge. Traditional, academic ways to plan research do not work well in this context. We have extensive experience with the methodologies to be used (e.g. participant observation with both active and retired nomadic pastoralists in remote regions). However, the timing of specific events (e.g. participatory workshops), or even expected outcomes for certain tasks, cannot be known yet. These must be co-developed with the stakeholders, once the project actually begins.

a)

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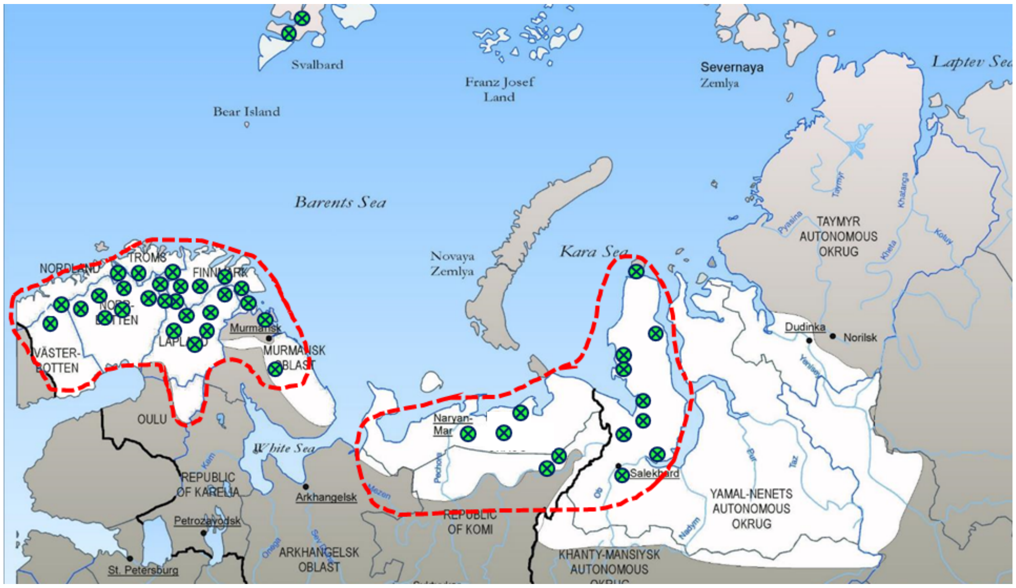

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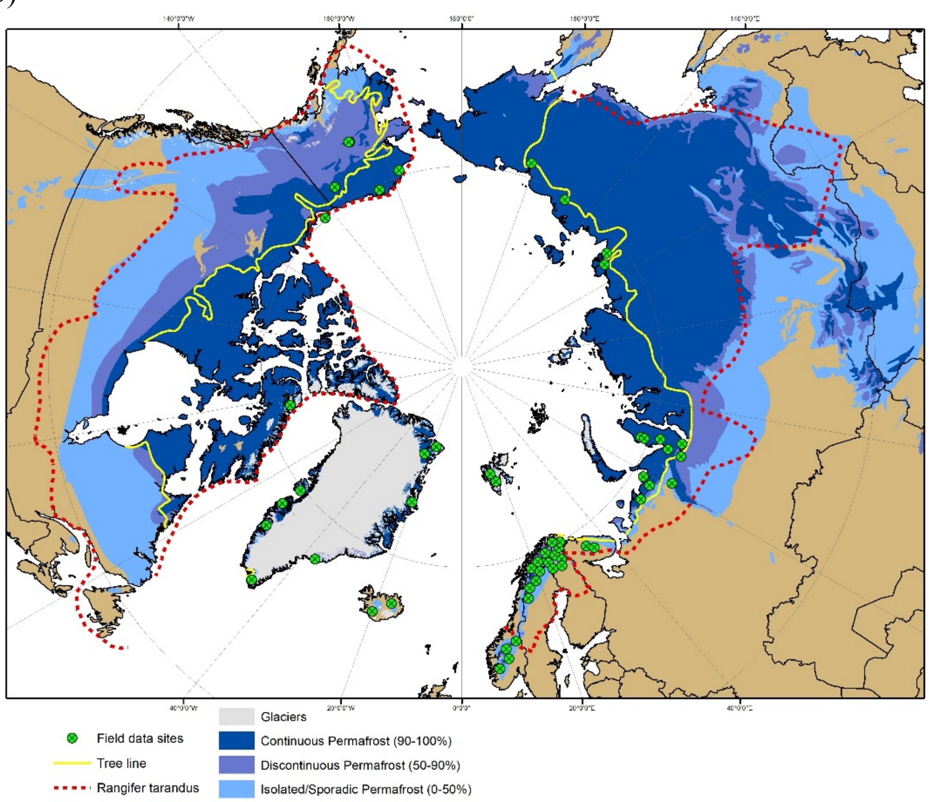

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Fig. 1.4. a) Reindeer herding areas of Northwest Eurasia (in white) comprising the core study region of CHARTER. Focal sub-regions in N Fennoscandia and NW Russia are highlighted (in red). The Barents Euro-Arctic Region is also indicated (black border). Green dots mark the field study sites. b) Circumpolar map of field data sites.

Our focus is on providing policy-relevant, testable and locally applicable results for the next generation, out to the year 2050. To achieve that we will use both sub-daily resolution data and simulation of extreme weather events like ROS and multi-decadal, centennial and millennial data on paleoecological human-environment interactions. CHARTER encompasses the circumpolar terrestrial Arctic, with emphasis on Northern Fennoscandia and NW Russia (Fig. 1.4). It examines the region's diversity of local SESs within and among specific core areas, paying special attention to the Eurasian terrestrial Arctic as being comprised of cultural landscapes developed over centuries, if not millennia (cf. Forbes et al. 2006, 2009; Horstkotte et al. 2017; Fig. 1.4).

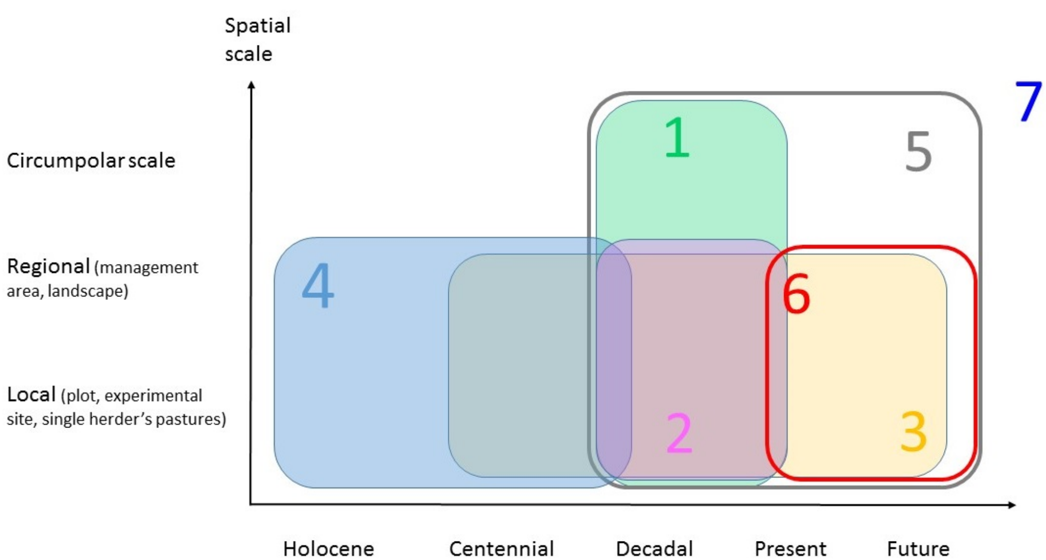

Figure 1.5. CHARTER aims at integrating knowledge across multiple spatial (from local to circumpolar) and temporal (from the late Holocene to ca 2050) scales. Numbers refer to WPs.

By examining pastoralism and other forms of renewable resource use (e.g. fishing, hunting), CHARTER addresses the viability and gender dynamics of Arctic

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communities. Team members' research has shown that land use, gender roles, gender-specific aspirations, demography, and community well-being are closely intertwined (Vladimirova et al. 2018). Socio-economic changes, development of traditional livelihoods and other sources of income all bear out differentially on careers and life projects at the intersection of gender, age, and formal education in northern rural communities. During interviews in the tundra and settlements for CHARTER will follow gender- and age-related ethical guidelines. However, the most preferable data will be collected from both male and female reindeer herders or from people who are involved in day-to-day reindeer herding work and can provide relevant information to understand the different ways of knowing about the tundra, weather events, etc. Age of the respondents should not be grounds for excluding them from the group interviewing, unless the person is too young for giving reasonable answers.

Including both Northern Fennoscandia *and* NW Russia is a key element of the research design. It is impossible to make any generalisations about the Arctic in general, and the Eurasian Arctic specifically, without considering Russia: It hosts the majority of the Arctic land mass; the majority of the Arctic's human population lives in Russia; and Russia features a greater level of biodiversity than other parts of the circumpolar North (CAFF 2019). In particular, both domestic and wild reindeer co-exist within the Russian Arctic, sometimes managed by the same indigenous peoples (e.g., Yamal-Nenets). Thus, research on biodiversity changes in the Arctic must address the situation in Russia – otherwise it will remain far from comprehensive. A considerable part of the scientific literature on climate change and its consequences deals with the North American Arctic, and hinges on the concepts and discourses that have been evolving in that regional setting (e.g., definitions of "indigenous" or "community"). Many of these concepts have developed differently in Russia, and CHARTER research sets out to integrate evidence from this substantial part of the Arctic for advancing our general understanding of biodiversity change.

Our main sites in Russia are located both within (Nenets Autonomous Okrug, Komi Republic) and beyond (Yamal-Nenets Autonomous Okrug) the Barents Euro-Arctic Region (Fig. 1.4). These areas encompass of some the closest connections to Western Europe, based on a shared economic history, ethnic and language continuities (Sámi live also in the Russian part of Lapland; Sámi, Komi and Nenets belong to the Uralic language group – as does Finnish). Nenets are of particular importance because they manage the world's largest and most productive reindeer herds and retain – in the Yamal tundra - long-distance migrations of up to 1200 km round-trip annually (Forbes 2010). Nenets migrate together year-round with their reindeer on both sides of the Ural Mountains, so their ancient and vibrant culture literally straddles the geographic divide between Europe and Asia. In Yamal, the Nenets graze their animals on top of the world's largest untapped gas reserves, which are of crucial importance for European energy markets and consumers. **A proper assessment of the prospects for Arctic terrestrial biodiversity in a changing climate should not stop at the EU border, but rather integrate and reach out to Arctic communities in neighbouring parts of the Eurasian landmass**.

1.4 Ambition

CHARTER will create a unique data-based synthesis informed by stakeholder perspectives of 21st century Arctic change. The policy options we pursue will be driven by co-production of knowledge with local communities, simultaneously accounting for global shifts, including climate change.

CHARTER's analysis will include conceptualization of large herbivores (e.g. reindeer/caribou) as drivers of tundra ecosystem state transitions (e.g. biodiversity, vegetation productivity, land surface albedo, permafrost dynamics, carbon and energy budgets), all based on a combination of empirical, modelled and re-analysis data. Our reconstruction of sea ice dynamics and grazing-vegetation-permafrost interactions will employ a multi-proxy approach.

The holistic simulations will be used as the basis for iterative dialogue with land users during data collection, processing and synthesis. The resulting simulations and pathways are testable and relevant at local scale and may be directly incorporated into existing locally-derived adaptation plans. Stakeholders at individual, community and administrative levels are genuinely involved during all research phases (e.g. development, execution, interpretation, dissemination).

Further, we will expand our team's initial successful attempts at "fingerprinting" ROS events resulting from sea ice degradation which have catastrophic implications for terrestrial SESs (Forbes et al. 2016). Together, the consortium will pursue a breakthrough in our functional understanding of decadal to centennial time scales of sea ice and terrestrial rangeland dynamics. In doing so, we scrutinize the notion of the Arctic as a matrix of potentially ancient cultural landscapes (SESs) and aim at understanding the interaction of renewable resource use and landscape development, assessing past dynamics alongside preconditions for a viable future.

By **addressing how livelihoods based on pastoralism will continue to co-exist in an Arctic characterized by rapid land use and climate change**, CHARTER can **facilitate future biodiversity-oriented conservation projects in the Arctic**. CHARTER will **showcase and serve as a model for what decision makers can actually achieve for future climate and biodiversity adaptation and mitigation** elsewhere on the planet, by

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properly integrating successful and sustainable reindeer management practices that affect vast and potentially sensitive Arctic rangelands.

Given the proposed time depth of CHARTER's research, the consortium will strive to be at the cutting edge of the new revolution in paleoecology (Harrison 2017). The aim is to use large datasets and new analytical tools to understand how biodiversity has changed in the past, how conservation efforts need to take long historical trajectories into account and identify thresholds and tipping points of ecological systems. Genuine breakthroughs are possible also in snow science are possible if new data-model fusion approaches are developed (Boelman et al. 2019). The **combination of decadal and centennial time-scales with present-day studies** of herbivore-vegetation interactions is powerful and innovative. Our application of a high-resolution regional climate model will encompass **local to regional scales** and be understood within **global-scale** climate model scenarios tackling both greenhouse gas climate and socially-derived scenarios.

The state-of-the-art in biodiversity conservation theorizes biodiversity management as a public good based on the inclusion of different ways of knowing (e.g. scientific, indigenous and local knowledge) in order to ensure relevance, legitimacy and credibility. EU initiatives reflect this approach in theory (CCIVE 2017; JOIN 2016) but have seldom achieved it in practice. CHARTER **will provide empirical evidence of how concerns about biodiversity protection, and climate change mitigation and adaptation**, can be integrated across knowledge systems and spatial scales. CHARTER recognizes that biodiversity is a key element that provides services that can reduce the impacts of climate change adaptation on natural and anthropogenic systems. We will approach the integration of biodiversity and climate change adaptation/mitigation from a cross-regional perspective. This integrates varied knowledge systems into a model that provides both regional overview and local relevance, and aim at true integration of local communities and indigenous groups in grappling with the consequences and challenges of climate change and possibilities for mitigation and adaptation through EU and circumpolar policy instruments.

3. Implementation

The project is organised into seven interconnected work packages (Fig. 3.1-1). In particular, the project structure has been planned to 1) link the WPs so that the deliverables contribute to and benefit other WPs and ensure close collaboration, while simultaneously 2) clearly defining each WP's respective responsibility area.

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WP1: Transitions in land cover, biodiversity and cryosphere at decadal time scales

WP1 will improve the capacity to identify biodiversity change and associated reindeer rangeland impacts, as well as how biodiversity and grazing regimes will change in relationship to cryospheric and climate change. Earth observation data and relevant by satellite observable parameters will be linked to ground observation networks. The objectives are:

- Full characterization of Arctic terrestrial environments for relevant observable parameters, including time series covering the last four decades of snow and permafrost properties, rain-on-snow (ROS) events, surface albedo, vascular plants, mat-forming lichens, mosses and biocrusts.
- Quantify biodiversity and rangeland indicator changes at local to regional spatial scales at selected study sites with sufficient ground-level data.
- Establish a pan-Arctic database of decadal scale biodiversity trends. This includes evaluation how local drivers (i.e. sea ice loss, changes in Arctic precipitation) and global drivers (i.e. changes in large-scale atmospheric circulation, anthropogenic warming) drive biodiversity changes.

WP2: Changing grazing regimes and Arctic biodiversity at local and regional scales

WP2 will construct trajectories for key components of Arctic biodiversity using reindeer-vegetation interactions as a central node to understand how climatic drivers together with management regimes modify Arctic SESs with impacts for the livelihood of local and indigenous people. Building upon the current understanding on the impacts of herbivory on tundra ecosystems WP2 will integrate socio-political processes and cascading food-web implications to these trajectories. Changes in the cryosphere in the form of more ground icing and hard snow is detrimental for large and small tundra herbivores with profound consequences for predator communities, leading to changes in food web structure functioning. WP2 will estimate the role of these direct and indirect impacts of major drivers of change on Arctic biodiversity using primarily existing datasets collected on the ground and thus complementing the larger scale trends assessed in WP1. The objectives are to:

- Provide a synthesis based on existing evidence and datasets from previous studies across the Arctic where grazing by different herbivores has been prevented using long-term exclosures or natural experiments, to quantify how herbivore communities affect biodiversity and food-web structure in habitats of varying productivity and contrasting climatic conditions across the Arctic.
- Link large-scale vegetation inventory data in those Arctic countries within the Eurasian semi-domesticated reindeer range where data is accessible to correlate

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ongoing vegetation and biodiversity trends with climatic conditions, the present and the historical local reindeer management practises and data about key herbivores where available, and to build habitat-specific vegetation trajectories under differing reindeer herding regimes.

- Unravel the implications of local reindeer management practises in the context of different climatic regimes and vegetation states across the Arctic for boreal generalist predators and their impact on biodiversity at different trophic levels.

WP3: Socio-economic impacts of Arctic environmental changes on indigenous populations and local communities

One of CHARTER's central aims is "to understand the effects of biodiversity changes on indigenous/local communities and traditional livelihoods, e.g. reindeer herding". WP3 objectives:

- To clarify how environmental changes interact with past and current socio-economic developmental trends in different parts of the Arctic and identify future scenarios in close interaction with indigenous and local communities (O3.1).
- To apply O3.1 to contrasting reindeer-based SESs from northern Fennoscandia and across northwest Russia (O3.2).
- To address O3.1 and O3.2 across the time period extending from approximately 300 BP to the next generation of herders, out to the year 2050 (in line with the modelling of WP5)

WP4 Arctic terrestrial biodiversity changes at centennial time scales

WP4 will focus on i) generating long-term records of key biodiversity variables and ii) studying their spatiotemporal dynamics as related to changes in climate, cryospheric processes, and human agency. Objectives are to:

- Determine the variability of key biodiversity and ecosystem state variables across the terrestrial Arctic ecosystems during the Holocene.
- Study the relationships between these variables and changes in climate, cryospheric processes, and human agency.
- Analyse the temporal stability of these responses, and whether they are in agreement with the more recent observational record (WPs1&2) and state-of-the-art process-understanding of the Arctic System (WP5).

WP5: Designing futures based on systemwide natural and human drivers

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WP5 will i) provide quantitative 'biogeoengineering' scenarios conforming to reindeer management for different types of development futures, and ii) use data-model fusion to produce projections of human-biosphere-climate impacts. In order to address these tasks, close collaboration with WP3 and WP6 will ensure that trans-generationally ethical and societally useful socio-economic and environmental pathways identified in those WPs are explored. Objectives:

- Ascertain how cryospheric changes affect biodiversity under several climate and SES futures.
- Identify and quantify the impacts of changes in animal grazing legislation and practice on Arctic and global climate e.g. via changing the energy budget and carbon storage in the permafrost zone.

WP6: Narratives and policy options for biodiversity and land use to increase resilience of Arctic social-ecological systems

WP6 concentrates on building pathway narratives and developing policy options to offer understandable and relatable information for stakeholders and decisionmakers. WP6 includes participatory stakeholder dialogue to identify current and co-produce new knowledge and identify best practices to design a set of land-use and biodiversity policy options. These should support the development of an Arctic strategy in general and climate adaptation and mitigation in particular.

The pathway narratives are based on an extensive literature review, empirical data and findings from WP3 and WP5, and stakeholder dialogue to engage with local and indigenous knowledge and views of experts. The design of the pathway narratives and policy options is informed by the findings produced in WP3, WP5 and stakeholder interactions: Findings from WP3 (Socio-economic impacts of Arctic changes on indigenous populations and local communities) and WP5 (Building a full-system view of the physical and socio-ecological drivers) will offer crucial qualitative and quantitative input for WP6 activities, and therefore WPs 3,5 and 6 will coordinate their actions closely. Objectives:

- Build biodiversity and land use narrative synthesis based on a scientific and grey literature review as well as policy document and media analysis; concentrating on reindeer grazing and pertinent forms of land use while it controls biodiversity which in turn affects albedo in Fennoscandia and Russian Arctic
- Examine the relations of the stakeholder network of local practitioners, policy and decision-makers, and experts related to land-use and biodiversity policy and governance conducting a social network analysis of these actors. Based on the analysis, key stakeholders can be identified to be invited to workshops to co-design scenarios and develop policy options.

- Compile and analyze the relevant qualitative (based on O6.1-O6.2, WP3) and quantitative data (WP 5) for the co-development of land use and biodiversity narratives and policy options that support Arctic adaptation and mitigation strategies and increase resilience of Arctic local communities and livelihoods
- Co-design land-use and biodiversity narrative scenarios and related policy options with stakeholders. This includes co-production of knowledge for climate adaptation and mitigation strategies, with indigenous and local actors. Co-design began already during the Step 1 CHARTER proposal with several indigenous partners, but during the main project will take place mainly in participatory workshops, and will be discussed towards the end of the project in common learning events such as world cafés, and town hall events
- Work together with cross-cutting themes and WP7 to help with decision-maker interaction, dissemination, and developing Arctic strategy

WP7: Management and dissemination

WP7 will ensure the effective coordination and management of the project by making sure that it is smoothly executed and fully complies with the proposal. The management structure will ensure that EU requirements for reporting are met, whilst being as lightweight as possible. All aspects of the project's management are covered and coordinated by this WP: planning, administrative, financial, legal, contractual, and reporting. Together with WP6, WP7 will ensure visibility of the project to the scientific community, local communities, and decision makers through variety of communication and dissemination activities. WP7 will support CHARTER exploitation through coordinating the cross-cutting themes "Tools and data for Arctic Strategies", and "Public dialogue
on the Arctic". Management and communication & dissemination objectives:

- Ensure efficient and effective overall management of the project, including Financial and Legal matters (IPR) to achieve the project's objectives, milestones and deliverables - all in a timely manner and with the highest quality level.
- To ensure gender, IPR and ethical issues are addressed, in line with guidance from the EU. Ensure that the consortium follows its contractual obligations and that the project complies with all national and international legal requirements.
- To monitor progress of the activities and ensure communication between partners and work packages
- Interface with the EU. Including, ensuring funding is distributed, financial records are maintained and financial reports generated.

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- Carry out reporting (continuous, periodic and financial) procedures with the consortium
- Strengthen the project's impacts and promote its results through communication, dissemination and exploitation of the research results together with WP6, ensuring a persistent and long-lasting visibility of the project activities and outcomes
- Create and maintaining communication channels for the project stakeholders to facilitate a smooth flow of information, research materials and results, as well as internally within the consortium.
- To coordinate the communication of CHARTER partners and work packages with different stakeholder groups, and to create awareness of questions related to the project among the general public, stakeholders/end users like local Arctic communities, decision makers and scientific community.

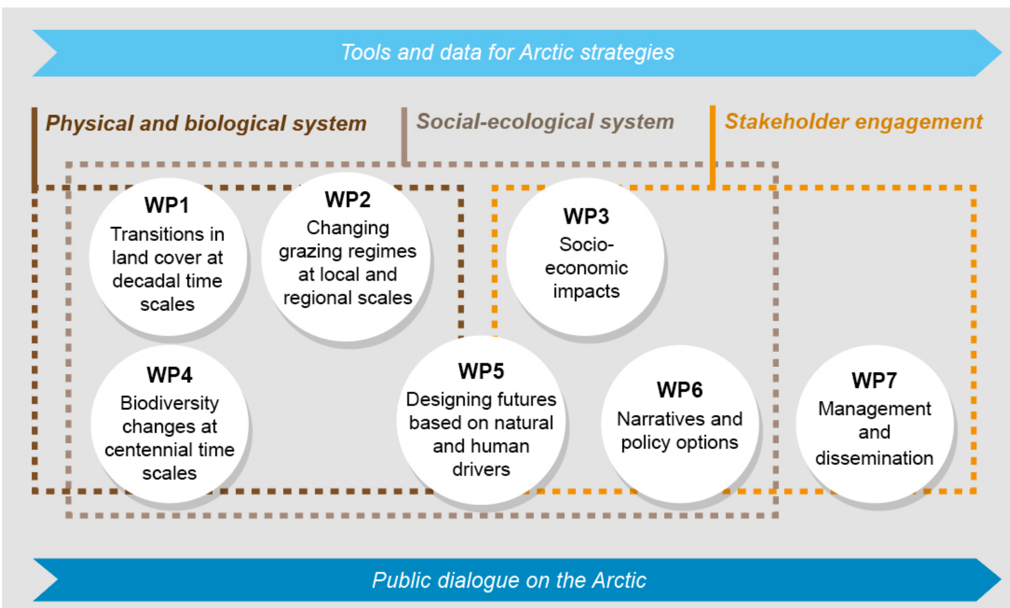

Figure 3.1-1. CHARTER WP-structure

Consortium as a whole

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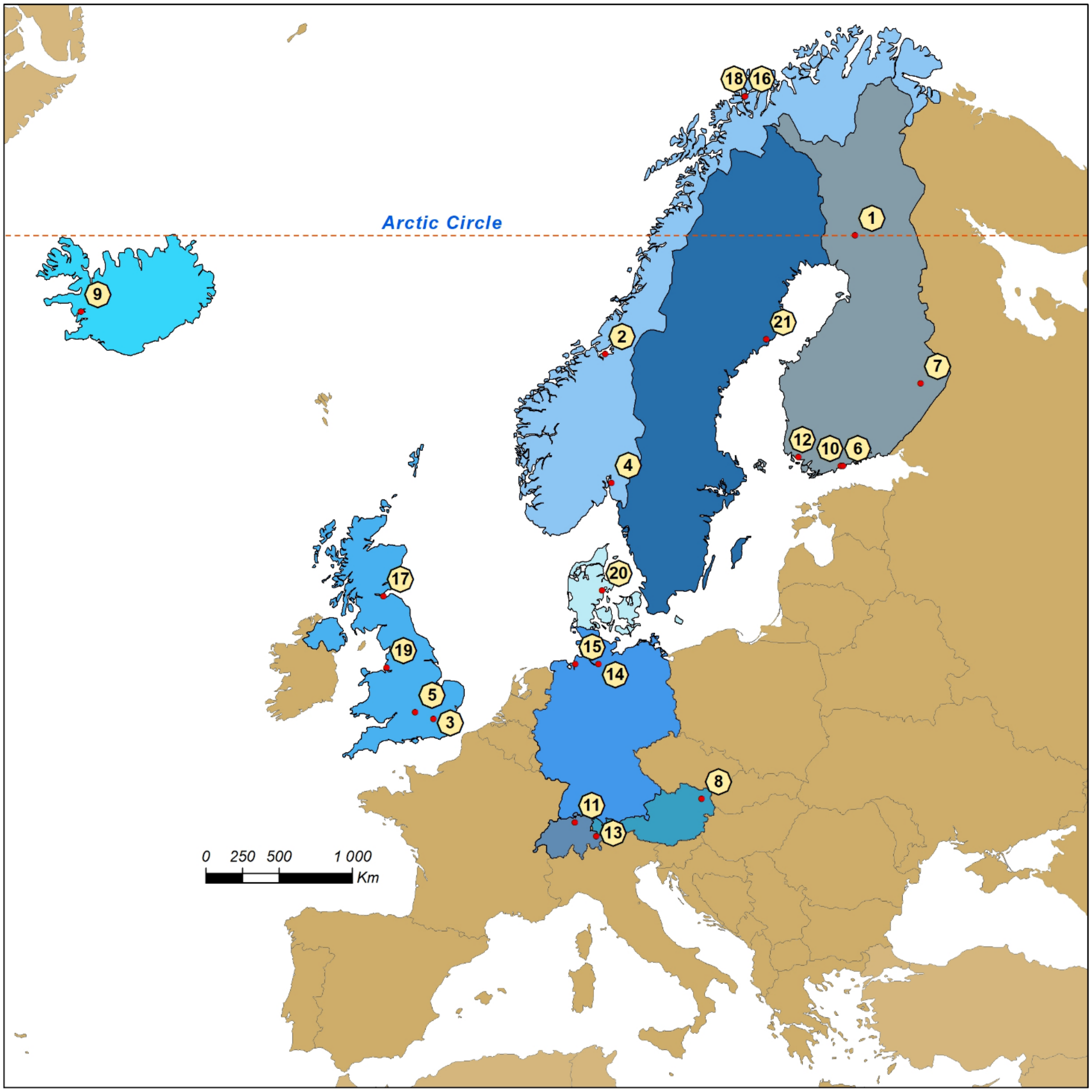

Figure 3.3.1. The CHARTER consortium

Our consortium comprises 21 funded institutions from 6 EU-member countries and 3 non-EU countries, as well as non-EU partners (USA, Russia, China), which will utilize non-EU funding instruments and various forms of in-kind support (i.e. super-computer access for modelling, unpublished datasets etc.). The consortium is relatively large. The main reason for this in order to grapple successfully with the great complexity embedded within specifics of the Cryosphere call. Requesting in-depth research on drivers and implications of changing Arctic biodiversity and climate would be challenging enough in a standard purely biophysical call. However, by adding impacts on indigenous populations and local communities and asking for analyses of combined human and natural influences, the Cryosphere call has itself drastically reduced the potential pool of research teams globally, much less within the EU, able to successfully tackle these questions at the relevant diversity of spatial and temporal scales, ranging from decades to millennia and from individual herding households and districts to entire regions. Our consortium is carefully assembled with several aims in mind: (1) **depth and breadth of Arctic field and/or lab experience**, regardless of career stage or gender; (2) proven ability to work successfully and disseminate findings in **truly interdisciplinary teams**; (3) ability to **bring relevant existing biodiversity/cryosphere/socio-cultural datasets** to the table from previous or ongoing national, Nordic, EU and internationally funded projects; (4) ability to enable analyses of **complex social-ecological datasets** across local, regional and circumpolar scales; (6) ability to engage intimately and ethically with **indigenous and local communities**; (7) strong ambition to manage risks and succeed; and (8) last but not least, collegiality.

Literature cited (CHARTER members in bold, or article marked with * if among the authors):

Allemann, L., and Dudeck, S. 2017. Sharing Oral History with Arctic Indigenous Communities: Ethical Implications of Bringing Back Research Results. Qualitative Inquiry, 1077800417738800.
Anderson, D. (2000). *Identity and ecology in Arctic Siberia: the Number One reindeer brigade*. Oxford: Oxford University Press.
Anderson, D., et al. (2019). Animal domestication in the high Arctic: Hunting and holding reindeer on the Yamal peninsula, northwest Siberia.
Journal of Anthropological Archaeology 55: 101079. *
Barnosky, A. D., et al. (2017). Merging paleobiology with conservation biology to guide the future of terrestrial ecosystems. *Science*, *355*(6325), eaah4787.*
Belshe, E. F., et al. (2013). Tundra ecosystems observed to be CO2 sources due to differential amplification of the carbon cycle. *Ecology letters*, *16*(10), 1307-1315.
Berkes, F. (2012). Implementing ecosystem□based management: evolution or revolution? *Fish and Fisheries*, *13*(4), 465-476.
Bjorkman, A. D., et al. (2019). Status and trends in Arctic vegetation: Evidence from experimental warming and long-term monitoring. *Ambio*, 1-15.
Bjorkman, A. D., et al. (2018). Plant functional trait change across a warming tundra biome. *Nature*, *562*(7725), 57.*
Boelman, N. T., et al. (2019). Integrating snow science and wildlife ecology in Arctic-boreal North America. *Environmental Research Letters*, *14*(1), 010401.
CAFF (2019). Arctic Biodiversity Assessment, https://www.caff.is/assessment-series/arctic-biodiversity-assessment
CCIVE (2017). *Climate change, impacts and vulnerability in Europe 2016: An indicator-based report*. EEA Report No 1/2017. European Environment Agency, Luxembourg, 424 pp.
Cohen, J., et al. (2013). Effect of reindeer grazing on snowmelt, albedo and energy balance based on satellite data analyses. *Remote Sensing of Environment*, *135*, 107-117.*

Crate, S., et al. (2017). Permafrost livelihoods: A transdisciplinary review and analysis of thermokarst-based systems of indigenous land use. *Anthropocene*, *18*, 89-104.*
Cromsigt, J. P., et al. (2018). Trophic rewilding as a climate change mitigation strategy? *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1761), 20170440.
Crowther, T. W., et al. (2016). Quantifying global soil carbon losses in response to warming. *Nature*, 540(7631), 104.
Daniels, S., & Endfield, G. H. (2009). Narratives of climate change: introduction. *Journal of Historical Geography*, *35*(2), 215-222.
EC (2012). Innovating for sustainable growth. A bioeconomy for Europe. European Commission. https://publications.europa.eu/en/publication-detail/-/publication/1f0d8515-8dc0-4435-ba53-9570e47dbd51
EC (2015). EU Press release: https://europa.eu/rapid/press-release_SPEECH-15-5243_en.htm
EC (2018). A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0673&from=EN
Elmendorf, S. C., et al (2012). Plot-scale evidence of tundra vegetation change and links to recent summer warming. *Nature Climate Change*, *2*(6), 453.*
EU's Joint Communication on "An integrated policy for the Arctic" (2016). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016AR4295&from=EN
European Political Strategy Centre (2019). Walking on thin ice: A balanced Arctic Strategy for the EU https://ec.europa.eu/epsc/sites/epsc/files/epsc_strategic_note_issue31_arctic_strategy.pdf
Falardeau, M., et al. (2019). A novel approach for co-producing positive scenarios that explore agency: case study from the Canadian Arctic. *Sustainability Science*, *14*(1), 205-220.
Forbes, B. C., & **Stammler**, F. (2009). Arctic climate change discourse: the contrasting politics of research agendas in the West and Russia. *Polar Research*, *28*(1), 28-42.
Forbes, B. C., et al. (Eds.). (2006). *Reindeer management in northernmost Europe: linking practical and scientific knowledge in social-ecological systems* (Vol. 184). Springer Science & Business Media.
Forbes, B. C., et al. (2009). High resilience in the Yamal-Nenets social–ecological system, West Siberian Arctic, Russia. *Proceedings of the National Academy of Sciences*, *106*(52), 22041-22048.*
Forbes, B.C. (2010). Reindeer herding. In: *Arctic Biodiversity Trends 2010: Selected indicators of change*. CAFF International Secretariat, Akureyri, Iceland, pp. 86-88. ISBN: 978-9935-431-28-8
Forbes, B. C., et al. (2010). Russian Arctic warming and 'greening' are closely tracked by tundra shrub willows. *Global Change Biology*, *16*(5), 1542-1554.*
Forbes, B. C., et al. (2016). Sea ice, rain-on-snow and tundra reindeer nomadism in Arctic Russia. *Biology letters*, *12*(11), 20160466.*
Frost, G. V., Epstein, H. E., Walker, D. A., Matyshak, G., & Ermokhina, K. (2013). Patterned-ground facilitates shrub expansion in Low Arctic tundra. *Environmental Research Letters*, *8*(1), 015035.
Grosse, G., et al. (2016). Changing permafrost in a warming world and feedbacks to the Earth system. *Environmental Research Letters*, *11*(4), 040201.
Harrison, S.P. (2017). *Pages Magazine* 25, 96-97.
Hole, G. M., & **Macias□Fauria**, M. (2017). Out of the woods: Driftwood insights into Holocene pan□Arctic sea ice dynamics. *Journal of Geophysical Research: Oceans*, *122*(9), 7612-7629.
Horstkotte, T., Sandström, C., & Moen, J. (2014). Exploring the multiple use of boreal landscapes in northern Sweden: The importance of social-ecological diversity for mobility and flexibility. *Human Ecology*, *42*(5), 671-682.
Horstkotte, T., et al. (2017). Human–animal agency in reindeer management: Sámi herders' perspectives on vegetation dynamics under climate change. *Ecosphere*, *8*(9), e01931.*
Huang, J. et al. (2017). Recently amplified Arctic warming has contributed to a continual global warming trend. *Nature Climate Change*, doi:10.1038/s41558-017-0009-5
IPBES (2019). Report of the Plenary of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on the work of its seventh session, https://www.ipbes.net/system/tdf/ipbes_7_10_add-1-_advance_0.pdf?file=1&type=node&id=35245
IPCC (2014). *Climate Change 2014 – Impacts, Adaptation and Vulnerability*: Part B: Regional Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report. Cambridge: Cambridge University Press. doi:10.1017/CBO9781107415386
IPCC (2019). Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, https://www.ipcc.ch/report/srccl/
JOIN (2016) *Joint Communication to the European Parliament and the Council: An integrated European Union policy for the Arctic*. JOIN (2016) 21 final. 27 April 2016, Brussels. 17 pp.
Krupnik, I. (1993). *Arctic Adaptations: Native Whalers and Reindeer Herders of Northern Eurasia*. University Press of New England.
Loranty, M. M., & Goetz, S. J. (2012). Shrub expansion and climate feedbacks in Arctic tundra. Environmental Research Letters, 7(1), 011005. doi:10.1088/1748-9326/7/1/011005
Loranty, M. M., et al. (2011). Tundra vegetation effects on pan-Arctic albedo. *Environmental Research Letters*, *6*(2), 024014.
Macias-Fauria, M., et al. (2012). Eurasian Arctic greening reveals teleconnections and the potential for structurally novel ecosystems. *Nature Climate Change*, *2*(8), 613*.
Miller, P. A., & Smith, B. (2012). Modelling tundra vegetation response to recent arctic warming. *Ambio*, *41*(3), 281-291. doi.org/10.1007/s13280-012-0306-1

Myers-Smith, I. H., et al. (2011). Shrub expansion in tundra ecosystems: dynamics, impacts and research priorities. *Environmental Research Letters*, *6*(4), 045509*
Myers-Smith, I. H., & Hik, D. S. (2018). Climate warming as a driver of tundra shrubline advance. *Journal of Ecology*, 106(2), 547-560.
Myers-Smith, I. H., et al. (2019). Plant traits inform predictions of tundra responses to global change. *New Phytologist*, *221*(4), 1742-1748.
Natcher, D.C. et al. (2007). *Arctic Anthropology 44*, 113–126. ISSN 0066-6939
NESH 2002: Den nasjonale forskningsetiske komité for samfunnsvitenskap og humaniora (NESH) 2002. Samisk forskning og forskningsetikk. (https://www.etikkom.no/globalassets/documents/publikasjoner-som-pdf/samisk-forskning-og-forskningsetikk-2002.pdf)
Niittynen, P., et al. (2018). Snow cover is a neglected driver of Arctic biodiversity loss. *Nature Climate Change*, *8*(11), 997.*
Nilsson, A. E., et al. (2019). Towards improved participatory scenario methodologies in the Arctic. *Polar Geography*, 1-15.*
Normand, S., et al. (2013). A greener Greenland? Climatic potential and long-term constraints on future expansions of trees and shrubs. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *368*(1624), 20120479.*
NSF 2018: Interagency Arctic Research Policy Committee (IARPC) 2018. Principles for Conducting Research in the Arctic. (https://www.nsf.gov/geo/opp/arctic/conduct.jsp#one).
Olofsson, J., & Post, E. (2018). Effects of large herbivores on tundra vegetation in a changing climate, and implications for rewilding. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 373(1761), 20170437.
Olofsson, J., et al. (2009). Herbivores inhibit climate-driven shrub expansion on the tundra. *Global Change Biology*, *15*(11), 2681-2693.
Pearson, R. G., et al. (2013). Shifts in Arctic vegetation and associated feedbacks under climate change. *Nature Climate Change*, 3(7), 673-677.
Phoenix, G. (2018). Arctic plants threatened by winter snow loss. *Nature Climate Change*, *8*(11), 942.
Pointner, G., et al., T. (2019). The role of lake size and local phenomena for monitoring ground-fast lake ice. *International Journal of Remote Sensing*, *40*(3), 832-858.*
Rasmus, S., **Kivinen**, S., & Irannezhad, M. (2018). Basal ice formation in snow cover in Northern Finland between 1948 and 2016. *Environmental Research Letters*, *13*(11), 114009.*
Rees, W. G., et al. (2008). Vulnerability of European reindeer husbandry to global change. *Climatic Change*, 87(1-2), 199.*
Regjeringen (2016). *Kjente ressurser – uante muligheter*. Biookonomi Strategi, https://www.regjeringen.no/contentassets/32160cf211df4d3c8f3ab794f885d5be/nfd_biookonomi_strategi_uu.pdf
Schmidt, N. M., et al. (2017). Interaction webs in arctic ecosystems: Determinants of arctic change?. *Ambio*, *46*(1), 12-25.
Schoolmeester, T., Gjerdi, H.L., Crump, J., Alfthan, B., Fabres, J., Johnsen, K., Puikkonen, L., Kurvits, T. and Baker, E., 2019. *Global Linkages – A graphic look at the changing Arctic* (rev.1). UN Environment and GRID-Arendal, Nairobi and Arendal. www.grida.no
Seddon, P. J., et al. (2014). Reversing defaunation: restoring species in a changing world. *Science*, *345*(6195), 406-412.
Sugita, S. (2007). Theory of quantitative reconstruction of vegetation I: pollen from large sites REVEALS regional vegetation composition. *The Holocene*, *17*(2), 229-241.
Sokolov, A. A., et al. (2016). Emergent rainy winter warm spells may promote boreal predator expansion into the Arctic. *Arctic*, 69(2), 121-129*
Speed, J. D., et al. (2010). Experimental evidence for herbivore limitation of the treeline. *Ecology*, 91(11), 3414-3420.
Uboni, A., et al. (2016). Long-term trends and role of climate in the population dynamics of Eurasian reindeer. *PloS one*, 11(6), e0158359.*
Vladimirova, V., & **Habeck,** J. O. (2018). Introduction: feminist approaches and the study of gender in Arctic social sciences. *Polar Geography*, *41*(3), 145-163.
von der Leyen (2019). A union that strives for more. My agenda for Europe. *Political guidelines for the next European Commission* 2019-2024.
Ylänne, H., & **Stark**, S. (2019). Distinguishing Rapid and Slow C Cycling Feedbacks to Grazing in Sub-arctic Tundra. *Ecosystems*, 1-15.*
Yumashev, D., et al. (2019). Climate policy implications of nonlinear decline of Arctic land permafrost and other cryosphere elements. *Nature Communications* 10: 1900 https://doi.org/10.1038/s41467-019-09863-x