An overview of the impacts of climate change on biodiversity in the Barents region, with discussion on potential adaptation measures

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Abstract

This essay presents a brief overview of the current knowledge on the impacts of climate change on biodiversity in the Barents region, with a particular focus on the effects of observed and projected increases of ambient temperatures on abiotic and biotic drivers of biological diversity. Climate in the region has already warmed by ca. 2 °C since the mid-1800s, and further increases by 2…7 °C are projected to take place by the end of 21st century. The observed impacts resulting from current warming are arranged into six main groups: (1) physiological changes, (2) changes in distribution and abundance of species, (3) changes in the composition and structure of plant and animal communities, (4) changes in phenology, i.e. annual timing of biological phenomena, (5) changes in interspecific interactions, and (6) evolutionary changes, i.e. changes in heritable traits from generation to the next. Future changes in the occurrence of species and habitat types have often been assessed using bioclimatic envelope models (BEM). These models predict approximate locations of the suitable future climatic spaces for the species. The realized changes in distributions will, however, depend also on species characteristics such as dispersal ability. Moreover, availability and connectivity of suitable habitats matters, causing strong synergetic impacts between climatic change and habitat availability. Protected area (PA) network is one of the main tools in alleviating the deleterious impacts of climate change on biodiversity. To enhance this role of PA network, new PAs should be targeted into areas where the network is sparse, and adaptive management should to be introduced within the existing PAs to prepare for the impacts of warming climate. However, actions are needed also outside the PA network. For example, forestry practices could be developed to better take into account requirements of species vulnerable to climatic change.

1. Introduction

Global climate change is considered as one of the major threats to biodiversity with accelerating effects by the end of this century. Northern latitudes and the Barents region in particular are no exceptions in these projections (Pereira et al. 2010; Garcia et al. 2014). One of the expected outcomes is the establishment of ‘no-analog’ climate spaces and species communities which have no current counterparts on the earth (Williams & Jackson 2007; Garcia et al. 2014). Moreover, extinction probability of species is predicted to increase synergetically in response to climate change and habitat loss (Travis 2003; Thomas et al. 2004).

There are a number of general reviews presenting overviews of climate change on biological diversity in high latitudes, including the Barents region. The report of Arctic Climate Impact Assessment (ACIA 2005) provides a broad overview of the impacts of climate change in the Arctic, whereas Callaghan et al. (2004) and CAFF (2013) focus primarily on the impacts on biodiversity. All these reviews indicate that the impacts of climate change on biota will be particularly pronounced in the Barents region as the climate is predicted to warm more in the Arctic compared to lower latitudes.

This essay on the impacts of climate change on biodiversity and potential adaptation measures is based on a talk given by the author at the 9th Habitat Contact Forum meeting held in Oulu, Finland during 6th-8th June in 2017. The main goal of this brief overview is to gather information on the impacts of climate on biodiversity and natural habitats based on studies conducted specifically in the Barents region. The overall scope of topic is broad, covering both terrestrial and freshwater, but excluding marine environments. The overview is based on studies published in international peer-reviewed scientific journals, and both empirical case studies as well as general review articles are included.

I will address the following four questions: (1) How has climate changed in the Barents region; (2) What changes have accordingly been observed in nature; (3) What are the predicted future impacts on biodiversity; and (4) Can biodiversity be protected under changing climate, i.e. what adaptation measures could be applicable?

2. Material and methods

Publications were searched from the ‘Web of Science’ publication database by using a combination of key words for topics. These included e.g. ‘climat* change’, name of a study group (taxon) and name of each country included in the Barents region. In addition, papers on the topic were searched using the Google scholar and the same key words that were used in the Web of Science –search.

The research on the impacts of climate change on biodiversity has increased markedly during the last decade. This increase is illustrated in Fig. 1, which presents the number of published papers in the Web of Science –database using the key words ‘climat* change AND biodiversity’ AND ‘boreal’.

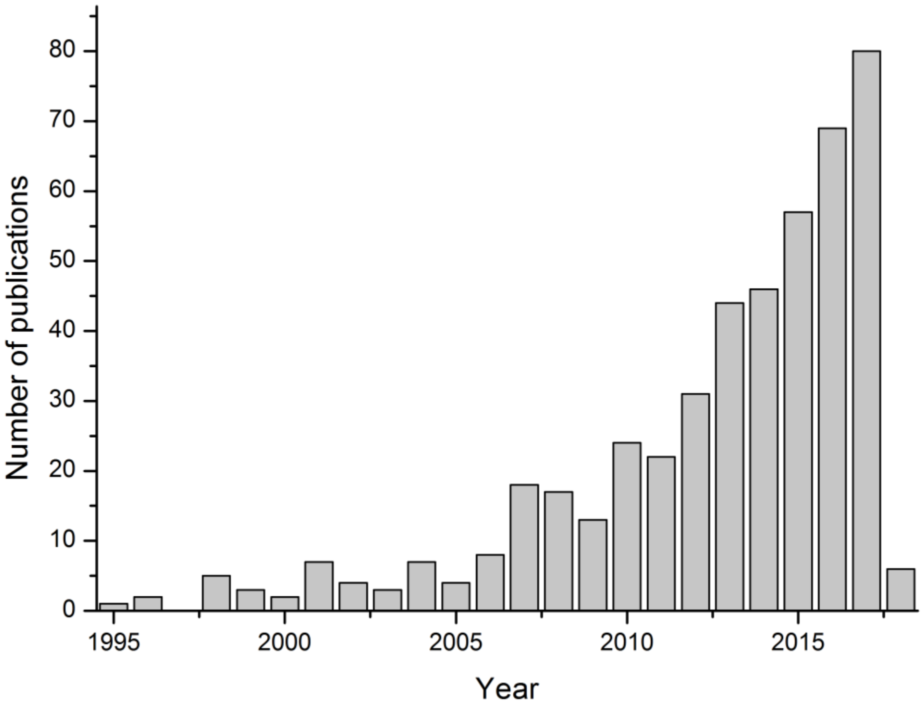

Fig. 1. The number of papers (n = 473) in the Web of Science –publication database based on a search using the key words “climat*change AND biodiversity AND boreal”. [Accessed on 13th February, 2018].

3. Results

3.1. Observed climate change in the Barents region

Temperature reconstructions show that the annual mean temperature of Finland has risen by 2.3 °C since the mid-1800s (Fig. 2; Tietäväinen et al. 2010; Mikkonen et al. 2014; Ilmasto-opas.fi 2017), and a similar trend has occurred in Norway and Sweden (Norsk Meteorologisk Insittutt 2017, Sveriges Meteorologiska och Hydrologiska Institut 2017). All the three data series show a similar gradual increase in mean temperature that culminated in the warm 1930s, followed by a slight decrease between 1940 and the 1980s and a resumed warming since the last years of 1980s.

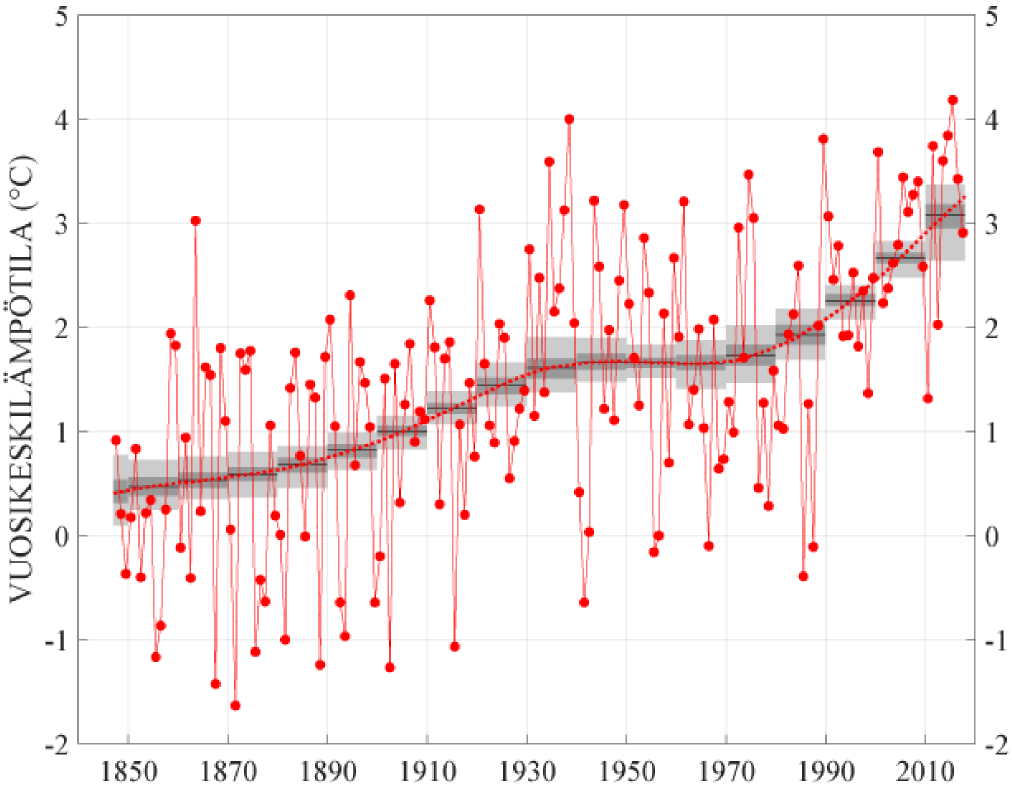

Fig. 2. Annual mean temperature of Finland during 1847-2017 (Source: Finnish Meteorological Institute).

The annual mean temperature of Russia shows a pattern comparable to the Nordic countries, i.e. a rather stable mean temperature between 1935 and mid-1980s, followed by a notable increase since the last years of 1980s (Bulygina et al. 2017). Following the increase in the annual mean temperature, growing season has prolonged and temperature sum (i.e. growing degree days, GDD) has increased across northern Europe (Carter 1998; Linderholm et al. 2008). Similarly, periods of cold winter weather have shortened across northern Fennoscandia during the last century (Kivinen et al. 2017).

Following the increase of ambient temperatures, temperature in freshwater springs has also increased 1.24 °C in Finland and Sweden during 1978-2012 (Jyväsjärvi et al. 2015). Increasing ambient temperatures are also reflected in biogeophysical changes such as the melt of permafrost areas, for example the palsa mires in northern Fennoscandia (Luoto & Seppälä 2003, Luoto et al. 2004).

3.2. Observed impacts on biodiversity

The impacts on biodiversity – both observed and predicted – can be assigned to six coarsely defined main groups (cf. Walther et al. 2002, Parmesan 2006, Rosenzweig et al. 2013): (1) physiological changes, for example changes in primary production and carbon uptake in ecosystems; (2) changes in distribution and abundance of species, for example population expansions of southern species and contractions of northern species; (3) changes in composition and structure of plant and animal communities; (4) changes in phenology, i.e. annual timing of biological phenomena; (5) changes in interspecific interactions; and (6) evolutionary changes, i.e. changes in heritable (genetic) traits from generation to the next.

3.2.1. Physiological changes

A well-known example of physiological changes attributed to climatic warming is the increased biological production across northern latitudes. This phenomenon was first reported by Myneni et al. (1997) for the period 1981-1991. The study by Myneni et al. covered also the Barents region. Recently, Huang et al. (2017) compared the observed velocities of climate warming and increase of biological production in high latitudes, and observed that the velocity of the increase of biological production was less than half of the velocity of climatic warming during the period 1982-2011. This difference was attributed to the effects of limited resource availability and vegetation acclimation processes (Huang et al. 2017). One of the obvious outcomes of the increasing biomass production in high latitudes is the increasing vegetation cover and dominance of woody shrubs in plant communities. Such trends have been reported also in the High Arctic part of the Barents region by Elmendorf et al. (2012) and by Kapfer et al. (2012) on the island of Jan Mayen.

Increasing temperatures not only lead to increasing biological production or faster growth of individuals, but they can also cause increased physiological stress in species adapted to cool climates. For example, a possible result of physiological stress is the decreasing temporal trend in body size of invertebrates as exemplified by high-arctic butterflies in Greenland (Bowden et al. 2015). Such phenomena might be possible also in the Barents region and would require new research. Warming may cause deleterious effects on certain plants, particularly those characterized by a dense growth form. For example, arctic-alpine cushion plants can show lethal physiological changes during the intensified periods of summer heat (Marchand et al. 2005). Climatic warming may also increase respiration in northern peatlands as shown by Dorrepaal et al. (2009), who demonstrated that experimental warming of 1 °C increased respiration rates of peatlands by more than 50%. Such a change would transform peatlands from carbon sinks to carbon sources, thereby accelerating the climate change.

3.2.2. Changes in species distributional areas, abundance relationships and community composition

Northward expansions and positive abundance changes

Studies on distributional and abundance shifts of species have mainly focused on groups with high citizen science interest and high observational background. This is the case particularly with birds and butterflies. In addition, species with high economic value such as forest trees and agricultural and forest pest species have been a subject of research activity in the Barents region.

Several studies have presented evidence for positive trends of overwintering bird populations as well as northward shifts of breeding distributions and abundance patterns in northern Europe and the Barents region (Virkkala & Rajasärkkä 2011b, Lehikoinen et al. 2013b, Virkkala & Lehikoinen 2014, Fraixedas et al. 2015a, Meller et al. 2016, Virkkala & Lehikoinen 2017). Such examples usually represent species adapted to more temperate climates. For example, overwintering ranges of common waterbirds have shifted northeastwards in northern Europe with a velocity correlating with an increase of 3.8 °C of early winter temperatures between 1980 and 2010 (Lehikoinen et al. 2013b). In addition, Välimäki et al. (2016) have presented evidence that density shifts of nesting bird species have been affected by their traits so that long-distance migrants and large species (measured in body mass) have responded more slowly to climate change compared to resident species, short-distance migrants and small bird species.

Butterflies and moths have been focus for intensive studies in northern Europe and the Barents region, and examples of positive population changes and northward range limit shifts in response to recent climatic warming are presented by e.g. Parmesan et al. (1999), Kuussaari et al. (2007), Pöyry et al. (2009), Eskildsen et al. (2013) and Leinonen et al. (2016). For example, Pöyry et al. (2009) reported that northern range limits of Finnish butterflies had shifted on average 60 km towards the north between the periods 1992-96 and 2000-04. Importantly, non-threatened species had shifted their range limits by 85 km but Red-listed species had not shifted their range limits at all. This difference indicates a strong synergetic impact between climatic change and habitat availability. Leinonen et al. (2016) reported that annual species richness of nocturnal moth species in Finland had increased significantly during 1993-2012, probably as a response to the recent warming. This change was strongest in southern Finland and leveled off towards northern Finland (Fig. 3). A possible outcome of warming climate and an example of increasing pest insect populations is the recent increasing trend of defoliation of the Scots pine forests in Finland reported by Nevalainen et al. (2010).

In addition to the pure impact of climate, species characteristics such as adaptation to nitrogen-rich host plants can interact and accelarate positive impacts of climate (Betzholtz et al. 2013, Pöyry et al. 2017). Traits that predict positive responses to climatic warming insects are e.g. adaptation to warmer, more temperate climates, large body size and high dispersiveness, wide nutritional scope or preference on nitrogen-rich food and multivolnism, i.e. the ability to produce several generations during a year (Pöyry et al. 2009, 2017).

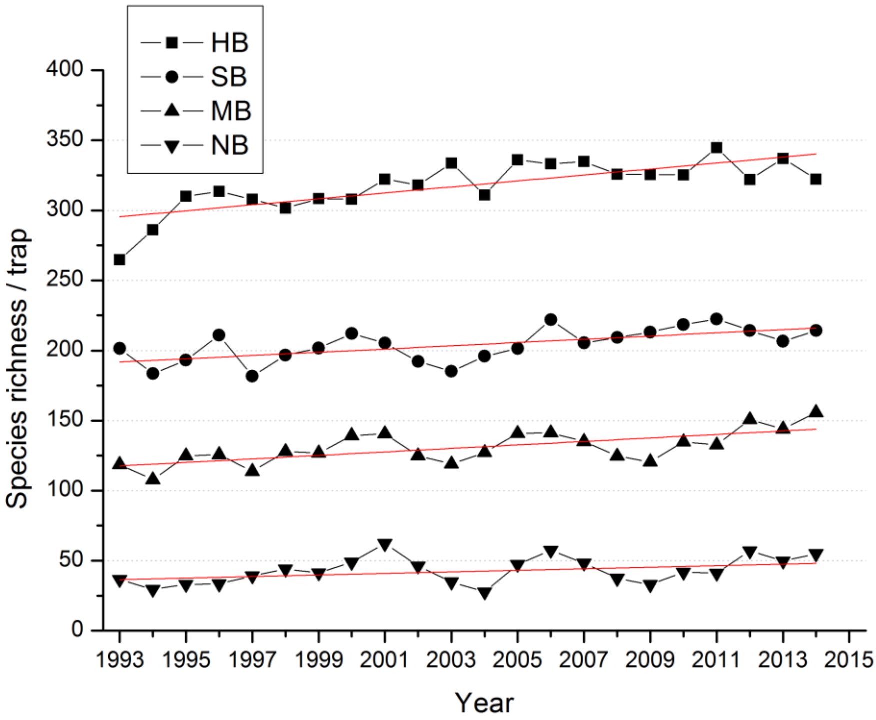

Fig. 3. Mean annual richness of species per trap site in 1993-2012 within latitudinal forest vegetation zones in Finland (Leinonen et al. 2016). Both the temporal increase and latitudinal increase towards the south are statistically significant ($p < 0.001$) according to a liner mixed effect model (LMM). Abbreviations of the forest vegetation zones are: HB – hemiboreal, SB – southern boreal, MB – mid boreal and NB – northern boreal.

Expansion of the northern tree line in northern Fennoscandia has been studied by Juntunen et al. (2002) and Hofgaard et al. (2013). While Juntunen et al. (2002) reported only a modest increase in basal areas of conifers at forest and tree lines, Hofgaard et al. (2013) showed that the birch and pine forest lines had advanced by 156 and 71 m^{-1}, respectively, in northern Norway during the 20th century. Similar observations of advancing tree line were made in the Scandes by Kullman (2001).

Northward retreats and negative population changes

There are less published examples of northward retreats of species with a generally northern distributional pattern and adaptation to cooler climates in the Barents region and elsewhere. This is probably explained by two factors, the smaller detection probability due to the smaller pool of northern species (compared to more southern species) and because the detection of population declines is methodologically more challenging than expansion of new species (Thomas et al. 2006).

As in studies on increasing population trends, studies on negative population changes and northward retreats of distributions have mostly focused on two groups, birds (Virkkala & Rajasärkkä 2011a, 2011b, Laaksonen & Lehikoinen 2013, Lehikoinen et al. 2014, Fraixedas et al. 2015b, Lehikoinen et al. 2016) and butterflies and moths (Kuussaari et al. 2007, Mattila et al. 2011, Leinonen et al. 2016, Pöyry et al. 2017). As a bird example, Virkkala & Lehikoinen (2014) showed that mean weighted densities of 94 bird species had shifted northwards 1.26 km year^{-1} from 1970s to 2010s, and this change was fastest for northern species. Considering the role of PA network, Virkkala & Rajasärkkä (2011a) showed that northern species decreased most in protected areas situated in southern Finland and southern species increased most in protected areas in northern Finland (Fig. 4). Moreover, for species inhabiting the entire country a clear density shift towards the north was observed. It appears that the migration strategy interacted with distribution pattern so that among northern species both migratory and resident species decreased, whereas among southern species they both increased (Virkkala & Rajasärkkä 2011b).

As a moth example, Leinonen et al. (2016) reported how population sizes of several northern species, which are adapted to boreal climates, have decreased in Finland during the period 1993-2012, corresponding to the expected outcomes of climatic warming.

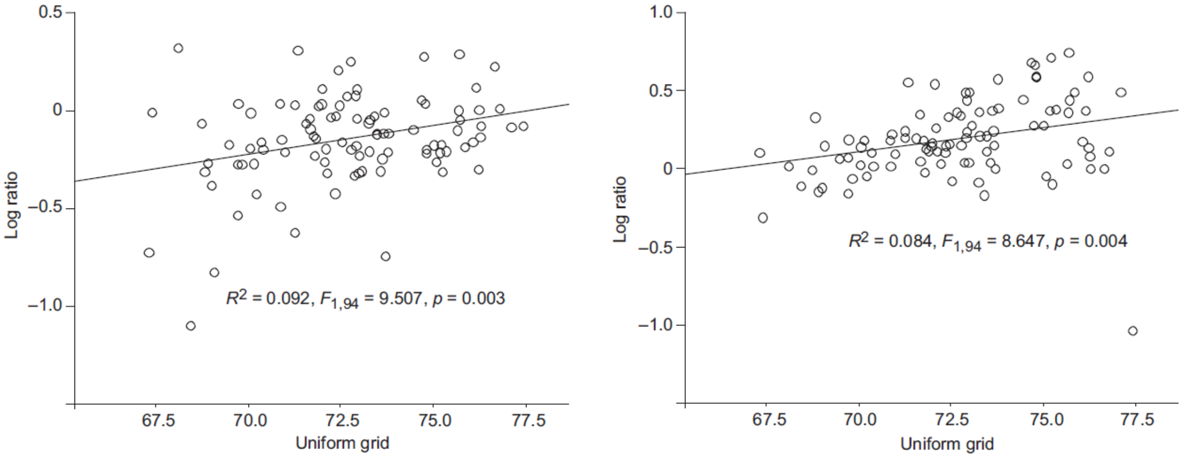

Fig. 4. Population density shifts of northern (left) and southern (right) breeding birds in 96 Finnish protected areas during 1981-2010 based on Virkkala & Rajasärkkä (2011a).

Community composition and structure

Studies on the impacts of climate change on the composition and structure of species communities have focused on a wider set of taxa compared to those focusing on large-scale changes in distribution and abundance of species. This is understandable in the light of the lower spatial requirements of long-term data collection in studies where the aim is to detect community-level changes. Studies on the impacts of climate change on communities have focused on birds (Virkkala & Lehikoinen 2014, Lehikoinen & Virkkala 2016, Välimäki et al. 2016), butterflies and moths (Hunter et al. 2014, Leinonen et al. 2016), vascular plants (Virtanen et al. 2010) as well as invertebrates inhabiting small lakes in the fells (Sorvari et al. 2002) and coastal brackish water plots (Altermatt et al. 2008).

Lehikoinen & Virkkala (2016) showed that the geographic change in the composition of breeding bird communities in Finland has been towards the north - northeast across most of the country, although there was some variation with respect to distributional pattern and breeding habitat type. These overall changes in community composition follow the changes in densities of individual bird species reported by Virkkala & Lehikoinen (2014).

Virkkala & Lehikoinen (2017) studied distributional changes in the whole bird fauna between the bird atlases carried out between 1974-89 and 2006-10. Between these time periods species richness did not change, but the composition of the bird fauna changed considerably with 37.0% of species gaining range and 34.9% of species losing range. Altogether 95.7% of species (225/235) showed changes either in the numbers of occupied squares or they experienced a range shift (or both).

Hunter et al. (2014) studied population dynamics of 80 moth species in a subarctic area in NE Finland during the period of 32 years (1978-2010). They reported that populations of most species were either stable (57 %) or increasing (33 %), but that, perhaps surprisingly, descriptors of population change rate were more negative than positive in a larger proportion of species. Thus about 60% of the studied moth species were predicted to be vulnerable to the impacts of climate warming. Leinonen et al. (2016) reported a general ‘southwesternization’ of moth communities across Finland as a response to the recent climatic warming trend (Fig. 5). This change in community composition is the outcome of simultaneous increase of population sizes of southern moth species and the decline of species with northern distribution pattern.

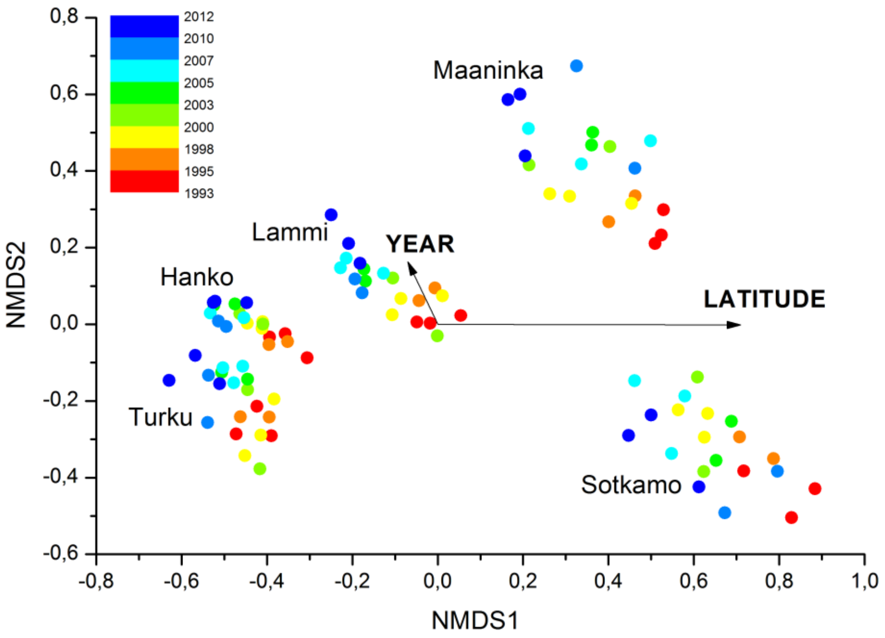

Fig. 5. Change in moth species composition during 1993–2012 at five trap sites in Finland based on a NMDS (non-metric multidimensional scaling) ordination according to (Leinonen et al. 2016). One dot depicts moth species composition in a single year, and dot colour depicts observation year (change from red colour in 1993–95 to blue in 2010–2012).

Sorvari et al. (2002) documented a distinct change in the diatom assemblages of Arctic lakes, probably as a response to the 20th century warming in northern Fennoscandia. Similar changes were observed also in chrysophytes and zooplankton, and thus entire lake ecosystems were affected. Altermatt et al. (2008) followed communities of rock pool – inhabiting crustaceans of the genus Daphnia at the Baltic coast during 1982-2006. They observed an increased colonization rates among the study species in response to warming summer temperatures,

Phenological changes and their ecological consequences

The impacts of climate change on phenology, i.e. the timing of natural phenomena, has been a subject of intensive research activity in the Barents region. Trends in timing of plant bud burst and flowering have been studied by Karlsson et al. (2003), and Holopainen et al. (2013). While no trend in birch bud burst were observed in either Abisko or in Kevo in northern Fennoscandia during 1920-2002 (Karlsson et al. 2003), Holopainen et al. (2013) derived a phenological index based on timing of phenological events of nine plant species and showed an advancing trend in phenology during the recent decades in northern Finland. Lappalainen et al. (2008) studied phenological trends of 31 plant and animal species in central Finland. These authors documented advancing phenological trend in five animal species including an ant, a frog and three bird species. As an example of phenological changes in insect populations, Pöyry et al. (2011) and Leinonen et al. (2016) showed an increasing trend in the occurrence of moth multivoltinism, i.e. the ability of producing more than one generation during a season, across Finland during twenty years (1993-2012). This increase is connected with the increasing annual thermal sum that occurred during the study period.

Timing of spring migration and nesting of breeding birds have been subject to in-depth examination in several papers (Ahola et al. 2004, Vähätalo et al. 2004, Jonzen et al. 2006, Rainio et al. 2006 and Meller et al. 2013). For example, Ahola et al. (2004) reported an advancing trend in spring arrival dates for the pied flycatcher (*Ficedula hypoleuca*) during 1970-2002, but no trend was observed in mean egg-laying dates. Jonzen et al. (2006) showed that the advancing trend was particularly strong in long-distance migrants arriving northern Europe in springtime during 1970-2004.

One particular aspect in studies of phenological changes has been year-to-year variation in North Atlantic Oscillation (NAO) that crucially affects winter temperatures and spring phenology across northern Europe. Positive phase of NAO (large difference in average surface air pressure between the Icelandic low and the Azores high) has been shown to be linked with northwards shifting of bird overwintering areas and timing of spring migration becoming earlier (Ahola et al. 2004, Vähätalo et al. 2004, Lehikoinen et al. 2006, Rainio et al. 2008). A positive impact of NAO has also been documented in the phenology of forest vegetation, i.e. bud burst (Lappalainen et al. 2008).

Some studies conducted in Central Europe have documented that timing of the nesting period of birds and the availability of their food (consisting mainly of insect larvae feeding on leafs of deciduous trees) have shifted earlier but with different velocities (Visser & Both 2005). This phenomenon, coined as 'trophic mis-match', may cause difficulties in food availability, and consequently lead to a decreasing reproductive rate in some bird species. The topic has been subject to very intensive research in northern Fennoscandia (e.g. Ludwig et al. 2006, Laaksonen et al. 2006, Lehikoinen et al. 2009, Lehikoinen 2011, Lehikoinen et al. 2011, Saino et al. 2011, Vatka et al. 2011, Vatka et al. 2014, Terraube et al. 2015, Vatka et al. 2016, Valtonen et al. 2016), but hitherto these studies have produced only little evidence for the occurrence of trophic mis-matches between bird nesting and food availability in northern environments. Also it can be expected that such temporal mis-matches would disappear by time as species adapt to new conditions.

Changes in species interactions have also been suggested to have led to dampening of herbivore cyclicity observed recently particularly in northern parts of Europe (Cornulier et al. 2013). However, similarly as with the trophic mis-matches, widely applicable general conclusions may be difficult to develop.

Evolutionary changes

Only few studies have focused on evolutionary (i.e. genetically inheritable) changes caused by climate change. An obvious reason for this scarcity is methodological difficulty, as documentation of evolutionary changes requires not only direct prove of genetic changes but also often experimental studies on species characteristics that are affected by the genetic change. Studies on the topic have hitherto focused on changes in timing of bird migration and reproductive success (Jonzen et al. 2006, Ahola et al. 2009). Ahola et al. (2009) showed that selection on egg laying date did not change in great tit (*Parus major*) during the period 1953-1994 in spite of increasing spring temperatures. However, there was a selection for early laying with high breeding-time temperature and high breeding density. Yet no trend in egg laying date was observed during the study period. By contrast, the advancing date of spring arrival by several breeding bird species has been suggested to be affected by evolutionary changes (Jonzen et al. 2006).

3.3. Predicted climate change and its impacts on biodiversity

According to the most recent climate change projections, annual mean temperature in the Barents region is predicted to increase ca. 2…7 °C by the end of the 21st century, depending on emission scenarios and general circulation models (GCM) used in the prediction (Fig. 6; IPCC 2013, Ruosteenoja et al. 2016).

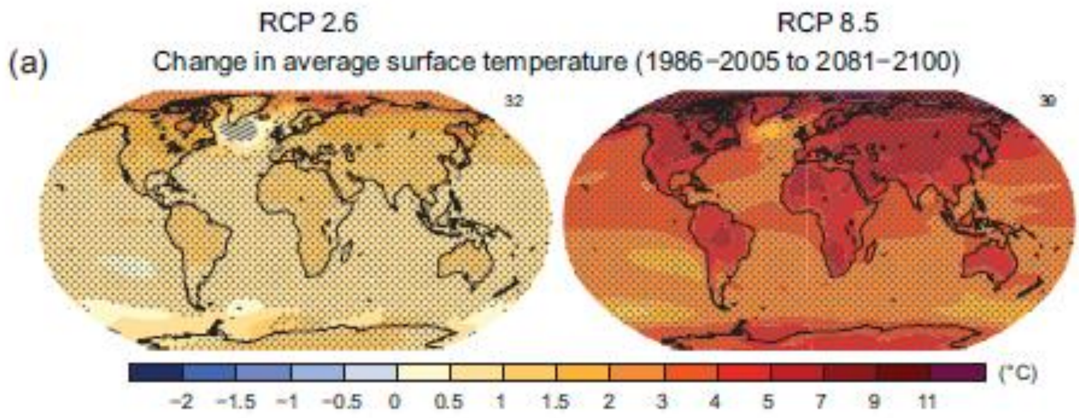

Fig. 6. Predicted change in the annual mean temperature on earth by the end of 21st century according to two contrasting emission scenarios, RCP 2.6 and RCP 8.5 (IPCC 2013).

The increase in ambient temperature is predicted to be most pronounced during winter months, but more modest during summer months (Fig. 7; Ruosteenoja 2016). Precipitation is predicted to increase, particularly during winter months. Frequency of extreme events of precipitation is also predicted to increase.

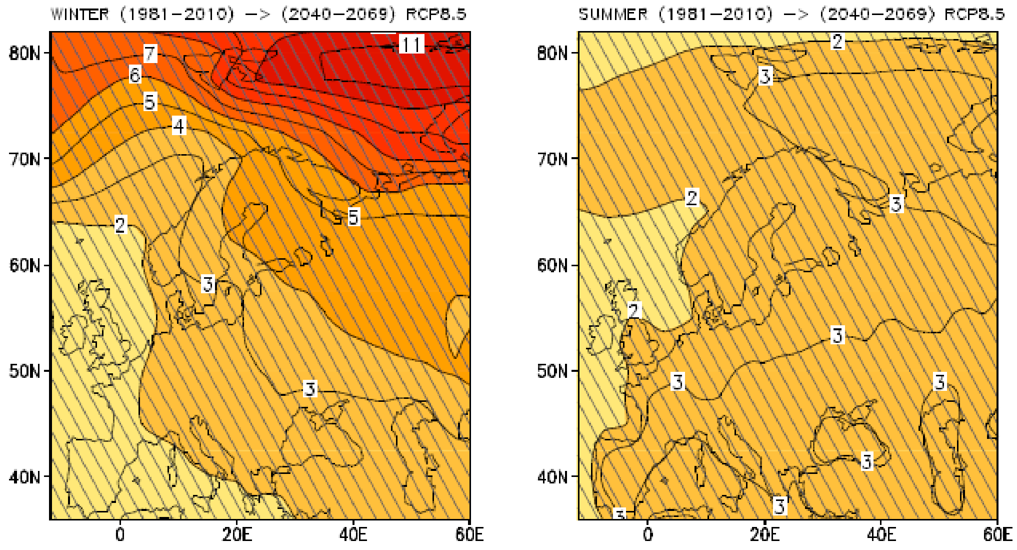

Fig. 7. The predicted change in winter (left) and summer (right) temperatures across Europe by the mid-21st century according to the emission scenario RCP 8.5 (Ruosteenoja 2016).

The projected changes in temperatures and precipitation will have a strong impact on both abiotic and biotic factors regulating natural phenomena. An obvious outcome of increasing ambient temperatures is the lengthening of growing season (Carter 1998) and increase in annual thermal sum (Ruosteenoja et al. 2011). According to Carter (1998) the growing season would lengthen ca. four weeks by the 2050s, while Ruosteenoja et al. (2011) predicted that by the end of 21st century the growing season length would increase by 40-50 days and the thermal sum (i.e. growing degree days) would nearly double compared to the baseline period 1971-2000. A major expected outcome of increasing temperatures in the Barents region is melting of polar sea ice so that the Arctic Ocean could be ice free during summer months within some decades (see https://www.globalchange.gov/browse/multimedia/projected-arctic-sea-ice-decline). This is considered likely if global warming exceeds ca. 2 °C (Stroeve et al. 2012, Screen & Williamson 2017).

Warming winter temperatures are predicted to lead to a decrease in soil frost during winter (Venäläinen et al. 2001). One outcome of this change would be an almost complete end of land surface processes that are known to be crucial in maintaining vegetation diversity in the arctic and subarctic regions (Aalto et al. 2014, 2017). Another example of geomorphological changes is melting of permafrost and particularly the palsa mires in the Barents region (Fronzek et al. 2006, 2010, 2011). This is predicted to have deleterious impacts on populations of several northern wetland bird species for which palsa mires are important breeding habitats (Luoto et al. 2004).

Jyväsjärvi et al. (2015) has shown that temperature in freshwater springs increased 1.24 °C in Finland and Sweden during 1978-2012. Furthermore, they predicted that an increase of an extra one degree will have major impacts on the composition of bryophyte and macroinvertebrate communities inhabiting spring habitats.

Distributional changes based on bioclimatic envelope modelling

There has been very active research on the projected changes of species distributions by using the bioclimatic envelope modelling (BEM) in the Barents region. These models fit the current distribution of species to multiple climatic variables, and then predict the future suitable climatic space and potential distributional area by using climatic projections (Heikkinen et al. 2006). Such studies have focused on different taxa, including vascular plants (Sætersdal et al. 1998, Svenning & Skov 2006), butterflies (Mitikka et al. 2008, Eskildsen et al. 2013) and birds (Virkkala et al. 2008, 2010). Sætersdal et al. (1998) modelled occurrences of more than 1500 vascular plant species and predicted that species richness would increase on average by 26% per 75-km grid square in response to warming climate. This increase would be strongest in southern parts of boreal and alpine zones of Fennoscandia. Virkkala et al. (2008) focused on the future ranges of 27 northern breeding bird species and they concluded the ca. two thirds of them are susceptible to major range contractions. Thus, species richness of northern breeding birds is expected to decline in the region (Fig. 8).

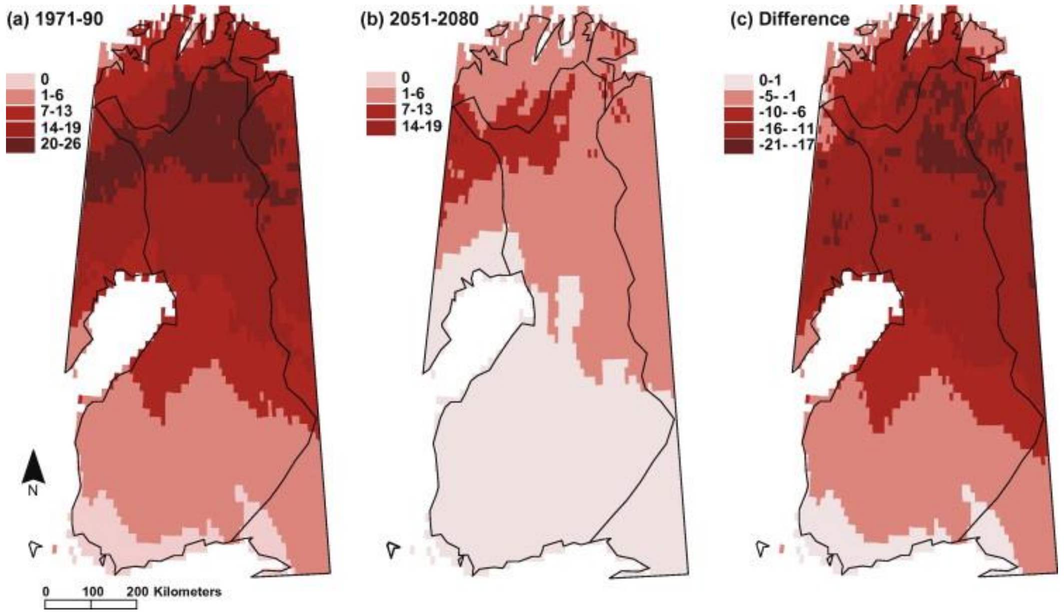

Fig. 8. Predicted decrease of species richness of northern breeding between 1971-90 and 2051-80 in Finland and adjacent areas based on bioclimatic envelope modelling (Virkkala et al. 2008).

BEMs are a methodology that can be applied relatively easily and quickly to predict changes in the suitable climatic space of species. However, the realized distributional changes will depend on, for example, species traits such as dispersal ability as well as availability and connectivity of suitable habitats (e.g. Bateman et al. 2013). There are a number of empirical examples documenting how the habitat availability affects the ability of species to shift their ranges in response to changing climate. Examples of such studies have focused on birds (Lehikoinen & Virkkala 2016, Välimäki et al. 2016) and butterflies (Pöyry et al. 2009, Eskildsen et al. 2013). Also the survival probability of species populations is affected by stochastically occurring adverse weather events. For example, Piha et al. (2007) showed how the impact of prolonged drought in 2002 had particularly negative impacts on Anuran populations in homogenous agricultural landscapes.

The uncertainties discussed above indicate that in order to predict how species distributional changes will realize under climatic change, we need modelling tools that combine information about the availability of suitable habitats and species dispersal ability (Bateman et al. 2013). One such model family is the dynamic population models (e.g. Bocedi et al. 2014) that have been applied to model, for example, butterfly distributional changes within the current network of habitats (Heikkinen et al. 2014, 2015). According to the modelling studies by Heikkinen et al. (2014, 2015), possibilities of grassland habitat specialist butterflies to shift their ranges in response to warming climate appear to be low in the existing agricultural landscapes of Fennoscandia compared to species with a higher supply and thus higher connectivity of suitable habitats.

Adaptation possibilities to protect biodiversity

Protected area (PA) network is often suggested as the main adaptation tool in alleviating the impacts of climate change on biodiversity (e.g. Hannah et al. 2007). Previous research has indeed shown that PAs can maintain higher species richness and maintain populations of species of conservation concern better than the surrounding economically utilized areas (Gillingham et al. 2012, Thomas & Gillingham 2015). They can also act as stepping stones for species that are shifting their ranges towards cooler regions in response to warming climate (Thomas et al. 2012).

Studies on the importance of the PA network in the Barents region have almost exclusively focused on birds as the study group (e.g. Virkkala & Rajasärkkä 2012, Virkkala et al. 2013b, Virkkala et al. 2013a, Virkkala et al. 2014b, Virkkala 2016). For example, Virkkala et al. (2014b) studied changes in species richness of 90 breeding bird species of conservation concern in the Finnish PAs. They showed that bird species richness of this species group decreased almost uniformly between 1970s and 2000s in birds inhabiting forests, bogs and Arctic mountain heaths across three latitudinal zones (Fig. 9). Increasing trends of species richness were observed only in marshand birds and forest birds within the northern boreal zone. These observed changes between 1970s and 2000s were in all cases to the same direction with predictions produced using bioclimatic envelope models for the period 2051-2080 (Virkkala et al. 2013b). Interestingly, average species richness of these 90 bird species was higher within the PAs compared to surrounding areas (Fig. 9), and this difference remained between the periods suggesting that protected areas may slow down adverse impacts of climate change on bird populations (Virkkala et al. 2014b).

Furthermore, PAs has been shown to support communities with a lower community temperature index (CTI), i.e. consisting more of bird species adapted to cooler climates in PAs compared to surrounding areas (Santangeli et al. 2017). Although the CTI has increased in both PAs and the surrounding areas, the difference between them has remained from the 1970s to 2000s. Therefore, their study also supports the observation that PAs can to some extent also buffer against deleterious impacts of warming climate on species communities.

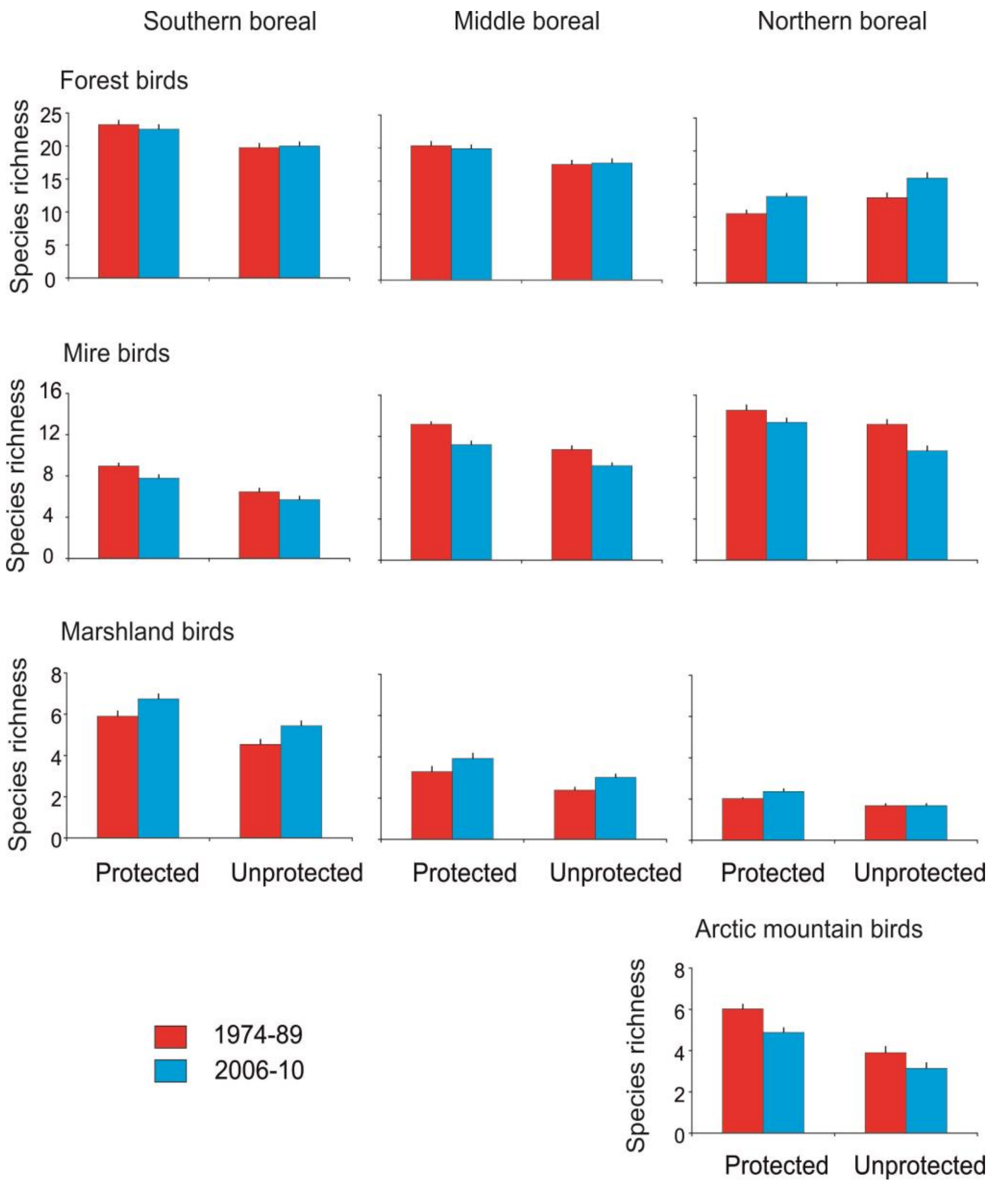

Fig. 9. Changes in the richness of 100 bird species of conservation concern between 1970s and 2000s within the Finnish protected areas (PA) according to Virkkala et al. (2014b). Results are shown for four habitat types (forests, mires, marshlands and Arctic mountain heats) and three latitudinal forest vegetation zones (Southern, Middle and Northern boreal).

A key problem in functionality of the PA network is the current geographically uneven distribution of the PAs (e.g. Virkkala & Rajasärkkä 2007, Virkkala et al. 2013a, b). They are often situated in unproductive and economically secondary, remote areas. This is the situation also in large parts of the Barents region (Fig. 10).

Fig. 10. Protected area (PA) network in the Barents region. (Source: http://www.bpan.fi/en/gallery/maps/)

Therefore, new PAs – when founded – should be situated in more productive areas (e.g. Virkkala et al. 2013b). Selection of new PAs should additionally be based on two criteria: (1) areas with high topographic and microclimatic variation are better buffered against the deleterious impacts of warming climate (e.g. Lenoir et al. 2013), and (2) new PAs should be situated in clusters, i.e. in proximity to other PAs to assist species dispersal and movement between areas (Cabeza & Moilanen 2001, Thomas et al. 2012). Considering the velocity and scale of impacts by climatic change on biodiversity, significant enlargement of PA network is probably not possible under present resources and new measures are needed both within the PAs and in the surrounding landscape matrix.

Within PAs, new measures of adaptive management are obviously needed under changing climate (e.g. Heller & Zavaleta 2009, Lawler et al. 2010). Potential actions of habitat management may be outlined according to three main principles: (1) do not intervene (i.e. laissez-faire), (2) intervene and try to slow down the changes and (3) intervene and try to facilitate the changes caused by warming climate. In the first option, role of a nature conservationist is merely that of an observer recording changes that occur within (and outside) PAs. This role may be considered insufficient considering the high amplitude of pressures affecting biological diversity worldwide (Pereira et al. 2010). Therefore, implementation of the two other options may be necessary (Heller & Zavaleta 2009). An example of management actions that aim at slowing down adverse impacts of warming climate is the use of grazing animals, such as reindeer in northern Fennoscandia, to prevent overgrowth of the Arctic mountain heaths by scrub vegetation (Olofsson et al. 2009). At the other end, management actions may be needed to assist species with poor dispersal abilities by using translocations of individuals to areas that have become climatically suitable due to increasing temperatures (e.g. Thomas 2011). Such measures of ‘assisted colonization’ are still often considered controversial (e.g. Pykälä 2017) and may not be possible to implement over large number of species. However, in situations where a species is predicted to lose its previous climatic space and possibilities for dispersal are weak, assisted colonization may turn out to be an important adaptation measure (Hällfors et al. 2017).

Management actions confined to the PAs cover a small proportion of land and therefore, actions affecting the entire landscape matrix are also needed (Heller & Zavaleta 2009). One option is to build corridors connecting the existing PAs which could support dispersal of individuals and eventually species (Pouzols & Moilanen 2014, Snäll et al. 2016, Tainio et al. 2016). Another option is to develop improved land uses which better acknowledge requirements of species and habitat types that are particularly vulnerable to the impacts of warming climate. In the Barents region, a key land use driver affecting species and habitat types across large scales is forestry. Thus, by developing forestry practices towards maintaining dead wood and variable stand ages with mixed forests and continuous cover forestry would also increase the availability of suitable habitats for several forest specialist species. This would help to increase the adaptive capacity of forests that are utilized economically (Kellomäki et al. 2001, 2008, Mazziotta et al. 2015).

In conclusion, large-scale changes in the constitution of biological communities will occur by the end of 21st century in the Barents region. There are measures that may help alleviating the deleterious impacts of warming climate on species and habitat types adapted to cool climates, but it is unlikely that such actions could completely prevent adverse trends. Therefore, extinction of certain species and habitat types in the region may be unavoidable.

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