Using Available Information to Assess the Potential Effects of Climate Change on Vegetation in the High Arctic: North Billjefjorden, Central Spitsbergen (Svalbard)

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Abstract We review the available data that can be used to assess the potential impact of climate change on vegetation, and we use central Spitsbergen, Svalbard, as a model location for the High Arctic. We used two sources of information: recent and short-term historical records, which enable assessment on scales of particular plant communities and the landscape over a period of decades, and palynological and macrofossil analyses, which enable assessment on time scales of hundreds and thousands of years and on the spatial scale of the landscape. Both of these substitutes for standardized monitoring revealed stability of vegetation, which is probably attributable to the harsh conditions and the distance of the area from sources of diaspores of potential new incomers. The only evident recent vegetation changes related to climate change are associated with succession after glacial retreats. By establishing a network of permanent plots, researchers will be able to monitor immigration of new species from diversity ‘hot spots’ and from an abandoned settlement nearby. This will greatly enhance our ability to understand the effects of climate change on vegetation in the High Arctic.

Keywords Alien plants · Arctic · Biodiversity hot-spots · Climate change · Macroremnants · Plants

INTRODUCTION

In the Arctic, increasing temperatures, increasing levels of CO₂, glacial retreat, and permafrost thaw are effects of climate change that may cause changes in vegetation, including shifts in species range, biodiversity loss, changes in dominance, altered biomass production and invasion of new species (Callaghan et al. 2004; Prach and Walker 2011). Although the list of references recording the impact of climate changes on

biota in the Arctic is enormous (Parmesan 2006; Thuiller et al. 2008), reports are rare from conditions which were not experimentally manipulated and for which comparative data describing past vegetation composition, biomass production or plant distribution are available, and methods of assessment are repeatable (Callaghan et al. 2011). As a consequence, determining how the vegetation has changed over decades at specific locations is difficult. A monitoring scheme on detection of the impact of climate change on biota in Arctic has only recently been proposed (Elvebakk 2005b), and therefore we should use all available sources of information to assess the possible impact of climate change in contemporary ecosystem studies. To outline a framework for assessing climate change impact on plants when results from standardized monitoring are lacking, we present the case of North Billjefjorden (central Spitsbergen, Svalbard) (Figs. 1, 2, 3).

KEY PROCESSES AND AVAILABLE METHODS FOR THEIR MONITORING

On the local scale, we can expect changes in several vegetation characteristics in response to climate change (Fig. 4). The species pool of the area could change because of immigration of plant species new to the area, either as a consequence of human activity or as a consequence of natural migration from arctic biodiversity ‘hot spots’. The characteristics of resident species may change in terms of biomass production, phenology or fecundity, resulting in changes in competition and in extreme cases resulting in extinction. Finally, changes in abiotic conditions and plant productivity may affect the activity of herbivores and soil microbial communities (Callaghan et al. 2004; Elvebakk 2005b).

Each of these processes can be monitored using different methods. The methods are well known and have been

Fig. 1 Broader geographic context of the studied area. **a** European Arctic, **b** Svalbard, and **c** west coast of Spitsbergen Island, the largest island of the Svalbard archipelago. The area under study (see Fig. 2)

is depicted by the shaded rectangle. Source: <http://maps.grida.no/go/graphic/arctic-map-political>

validated by long use in the monitoring of vegetation dynamics (Walker and del Moral 2003). These include direct methods such as vegetation mapping, phytosociological relevés, checklists, biomass assessment, etc. (Table 1). Indirect methods can also be used, and these include analysis of preserved pollen and macrofossil spectra in organic sediments and growth characteristics recorded on perennial parts of plants (dendrochronology and herbchronology) (Table 1). All of these methods have been used in various studies focused on the effects of climate change on plant species or vegetation in different parts of the Arctic (see references in Table 1).

AVAILABLE DATA FOR THE TARGET AREA AND THEIR EVALUATION

Of the possible methods listed in Table 1, only a few have been recently applied to our study area: an old vegetation map with species lists, phytosociological relevés, photographs, and palynological and macrofossil data. Consequently, for the key processes depicted in Fig. 4, we only have information on the species pool and vegetation structure at the spatial scales of plant communities and the landscape, and in time scales of decades to thousands of years.

Fig. 2 A map of the studied area. 1 repeated mapping of vegetation near Brucebyen; 2, 3 Sampling of organic sediments for microfossil analyses. *Sites where succession after retreating glaciers was studied. Adapted from Rachlewicz et al. (2007), with permission

Recent and Short-Term Historical Records

Vegetation studies from the first half of the twentieth century are available from the studied area. Walton (1922) described the vegetation of salt marshes in the adjacent Adolfbukta, and some additional information was also provided by Summerhayes and Elton (1923), who studied the fauna of the Brucebyen area (Adolfbukta) (Fig. 5). The work by Walton was followed up by a study by Dobbs (1939), who aimed at repeating the mapping carried out by Walton and established a basis for further studies of vegetation succession on a raised beach. Besides mapping, he also used transects with sampling plots, whose locations unfortunately cannot be determined, making resampling impossible.

On the other hand, the study by A.M. Acock, who worked in the area at the same time as Dobbs (summer seasons of 1936 and 1937), clearly identified the study area so that his findings and subsequent findings for the specific location could be compared. The same strip of land (2042 × 521 m; at the settlement of Brucebyen; latitude 78°38' N, longitude 16°45' E) that was surveyed by Acock (1940) in 1936–1937 was studied again in 2008 using the same methods (for details, see Prach et al. 2010); vegetation was mapped again and species lists were compiled again. The mapped area stretched from the sea coast to the foothills of steep mountain slopes. The lower part of the mapped area was formed by the more or less stabilised substrate of old maritime terraces, which originated from a rising of the land, and by siltation from streams running

Fig. 3 The Petuniabukta area, view from the west coast. Photo by Jan Kavan

Fig. 4 Factors that affect vegetation and vegetation characteristics and that could be affected by climate change. *Lines with arrows* denote changes in the regional and local species pool; *large hollow arrows* denote interactions with other trophic levels (herbivory, decomposition), environmental factors (climate, mineral nutrients), and human influence; the *large hatched arrow* denotes changes in competitive hierarchy, seed availability, and clonal growth

down from the hills. Several permanent and periodic pools were located here. The upper part of the mapped area was formed by unstabilised fluvial sediments and screes (talus cones) that have been in some areas heavily silted by numerous permanent or periodic streams that often

changed their courses. Here, we only present results from the stabilised lower part. For a complete survey, see Prach et al. (2010).

The earlier and current vegetation patterns are compared in Fig. 6. The maps are clearly similar, and the small changes that are evident may have been caused by differences between mappers and other methodological factors. Acock (1940) found 46 vascular plant species and 43 bryophytes. The new study failed to find seven of the vascular plant species listed earlier, but found six new species, all of which occurred very rarely in the mapped area and their presence can be of random character. The new study failed to find eight bryophytes listed earlier but found 34 new species. The higher number of bryophyte species recorded in 2008 can be simply attributed to the presence of a bryophyte specialist in the team.

Thus, established late successional vegetation at this site has not exhibited evident changes since 1937, except as affected by local erosion or by disturbance by factors other than climate change. On-going vegetation succession that is directly related to climate change, however, is evident in the forelands of the retreating glaciers (Matthews 2008). As documented by Rachlewicz et al. (2007), a rather fast retreat of glaciers is occurring around North Billjefjorden. The distance from the present front of some glaciers to the Little Ice Age (LIA) moraine is about 2 km. We made vegetation records (60 in 2009) at various distances

Table 1 Sources of information that can be used to assess the effect of climate change on vegetation in the High Arctic

	Sources of information	References	Time scale (years)	Parameter	Spatial scale
Historical records	Vegetation maps, photographs, check lists, phytosociological relevés	Prach et al. 2010; Daniëls et al. 2011	70	Species pool, plant cover, vegetation units, species composition	Landscape
	Permanent quadrats, transects, etc.	Wilson and Nilsson 2009; Hill and Henry 2011	20	Vegetation composition on microscale, biomass production, plant traits, phenology, fecundity	Community
	Satellite imagery, aerial photographs	Sturm et al. 2001; Myneni et al. 1997	20	Shrub and trees cover	Landscape
	<i>Indigenous knowledge</i>		30	Shrub and tree cover, berry production	Landscape
Retrospective methods	Macrofossils	Birks 1991	100–8000	Species pool	Community, landscape
	Pollen profiles	Rozema et al. 2006; Van der Knaap 1987, 1988, 1990, 1991	100–11 000	Species pool	Community, landscape
	Dendrochronology, herbochronology, lichenometry	Rozema et al. 2009	50 - 100	Plant growth	Plant individual & community

Sources of information in **bold** are available in the studied area and source of information in *italics* is not relevant for the studied area

Fig. 5 Brucebyen (Adolfbukta), the houses served for accommodation of numerous scientific expeditions in first half of the twentieth century. Photo by Jan Kavan

between the LIA moraine and the present front of five glaciers and compared the records with those from an ‘old’ tundra just outside of the LIA glaciation (Figs. 2, 7). We

are aware that distance is only an approximate substitute for the real age of a community because glaciers do not retreat at a constant speed (Rachlewicz et al. 2007). We

Fig. 6 Acocck's map (a) redrawn from 1936 (Acocck 1940) and the map from 2008 (b). 1 low cover of *Dryas octopetala*; 2 *D. octopetala* with *Carex misandra*; 3 *D. octopetala* with *Carex rupestris*; 4 moss vegetation with *Carex subspathacea*, including *Eriophorum*

scheuchzeri swamps; 5 marginal stream vegetation usually with *Dupontia psilosantha*; 6 no vegetation; 7 permanent water bodies. The mapped area spans 1021 × 521 m. Adapted from Prach et al. (2010)

found that the succession is clearly unidirectional. Significant variability is evident only in the initial stages, when random events often influence the species composition (Walker and del Moral 2003). Then, new species typical of the old tundra gradually appear, and the last of them is *Carex rupestris*, which occurs only in the oldest successional samples. The only species from the old tundra that is not yet present after more than 100 years of succession is *Cassiope tetragona*, a distinct species of the climax tundra in the area (Elvebakk 2005a). We can conclude that in the extreme environmental conditions of the High Arctic, succession is not represented by any species turnover, as is usually the case (Walker and del Moral 2003). All species recorded in the successional stages were also present in the neighbouring old tundra. We can tentatively expect that under climate warming, the colonisation of such deglaciated terrains may be a little faster than without climate warming, but the same species in the same sequence will probably participate. We do not expect participation of species alien to the area in the harsh environment of the glacial fronts.

Retrospect Methods

Palaeoecological investigations of organic deposits and sediments from tundra lakes provide data for reconstruction of vegetation response to past local events. The arctic sediment records are unique in that this area was protected from human impact until recent times. The area of Billefjorden was completely deglaciated about 11 200–11 300 years before present (BP) (Szcucinski et al. 2009), at the beginning of the Holocene, and there is no evidence for large-scale re-glaciation since then. Ice-core records together with pollen and marine mollusc data indicate that the climate from 9500 to 4000 years BP was approximately 1–2°C warmer than today (Rozema et al. 2006; Svendsen and Mangerud 1997). This warm period was confirmed in a study of macrofossils (Birks 1991), which inferred a warmer climate 8000–4000 years BP with denser and more luxuriant vegetation than today and with species not currently occurring in the area. In a core from Lake Skatdjorna (Fig. 1), leaves of *Salix herbacea* were found in deeper layers (between ca. 5500–2500 years BP) (Birks 1991).

Fig. 7 Foreland of Ragnar glacier deglaciated since Little Ice Age. Photo by Karel Prach

Recently, the occurrence of this species has been restricted to the southern part of the Svalbard archipelago (Rønning 1996). The wider distribution of the species in the past was also indirectly confirmed by our finding of leaves of a hybrid between *Salix herbacea* and *S. polaris* in a core from Petuniabukta (Fig. 1, Bernardová unpubl.).

Gradual cooling accompanied by glacier expansion began about 2800 years BP and culminated in the LIA dated to 700–100 years BP (Elverhoi et al. 1995; Szczucinski et al. 2009). In pollen profiles, a decrease in species richness during the LIA was observed (Rozema et al. 2006; Van der Knaap 1987, 1988, 1990, 1991), although the vegetation composition according to pollen and macrofossil analyses on Svalbard was rather stable in that time. Hyvarinen (1970) found an assemblage of vegetation that resembled the current assemblage of vegetation in a core dated to 11 000 years BP from basal sediments in north Svalbard. Also, our preliminary data from a 27-cm-deep core obtained from a lake near Scottedytta (Petuniabukta) show a stable vegetation with *Salix polaris* and *Dryas octopetala* since the first colonisation of the substrate, dated to 5800–5700 years BP.

CONCLUSIONS FROM AVAILABLE DATA

Repeated vegetation mapping and species lists did not reveal any vegetation changes to be unambiguously related to climate change in the past 100 years. The only evident vegetation change that has occurred as a consequence of climate change is represented by succession after glacier retreat. Vegetation on the isolated and climatically extreme archipelago seems to be resistant to climate change (see also Jónsdóttir 2005 for Svalbard, and Körner 2003 in general). The area seems to be not easily invaded by new species, and shifts in the ranges of native species are also restricted compared with the continental Arctic (Thuiller et al. 2008). Thus, vegetation in the observed time and spatial scales and with the methods used seems to be rather stable. However, fossil records from the area indicate that changes in the past have led to more diverse and luxurious vegetation in warmer periods and extinction events in colder periods, although the magnitude of the changes was not large, as indicated by pollen and macrofossil analyses.

RISK ASSESSMENT AND MONITORING PRIORITIES

Vegetation in an area of about 100 km² near Petuniabukta (the northernmost part of Billjefjorden) was recently mapped by Prach et al. (unpubl.). The northernmost occurrence of the *Cassiope tetragona* heath on old maritime terraces was noted here (see also Elvebakk 2005a), and monitoring of its potential changes at the boundary of its occurrence may be useful. Close to the studied area, there are two potential sources of diaspores for arrival of new species: the former settlement of Pyramiden (Fig. 8), which has several introduced species (Liška and Soldán 2004), and ‘hot spots’, which are characterised by a favourable microclimate and substratum (Fig. 9) hosting several species that could potentially spread with climate change (Elvebakk 2005b). Alien plant species or genotypes were introduced into Pyramiden when hay was imported from the northern edge of Eurasia (Murmansk region) and used for livestock during the last decades of the twentieth century (Liška and Soldán 2004). The ‘hot spots’ usually occur under ‘bird cliffs’ and are enriched by nutrients and characterized by higher insulation and protected against strong winds. Another potential source of diaspores is the regular boat service during the summer, which brings about 30 tourists per day to the former settlement (Wichmann et al. 2009; Hall et al. 2010).

All three sources of diaspores (past arrivals due to large-scale movement of materials, biodiversity ‘hot spots’, and current arrivals due to tourism) should be taken into account when assessing the risk of biological invasion and when setting targets for monitoring. The main potential for invasion probably lies with past arrivals because those introduced species are already surviving in the region, and climate change could help them spread (Hellmann et al. 2008; Essl et al. 2011).

For a more precise and detailed evaluation of potential vegetation changes in the future, we need to establish permanent quadrates, make regular check lists of the local flora, repeatedly map the vegetation of the area, and assess the potential for invasion by new species or the spread of already established aliens or their genes via hybridization with local congeners.

Small-scale permanent plots enable detailed observations of biomass production, phenology and small-scale patterns inside plant communities. The possibilities of herb and dendrochronology, which may provide insight into the past and contemporary growth of individual plants and their populations (see Rozema et al. 2009), should be explored. Given the evident resistance of vegetation in this area to climate change, we should only expect to see change, if change occurs, over relatively long periods (several decades or more). Our recent research in the area of northern Billjefjorden can be seen as a first step to such

Fig. 8 Pyramiden, Russian mining settlement abandoned in 1998. Photo by Jan Kavan

Fig. 9 Rare plant species *Polemonium boreale* in Skansbukta—biodiversity ‘hot spot’ located south to studied area. Photo by Jan Kavan

long-term, standardized monitoring. The climatically extreme central Svalbard is an area of the Arctic that is suitable for the establishment of site that could be part of a worldwide network of sites used to monitor the response of ecosystems to ongoing climate change.

SIGNIFICANCE OF THE STUDIED AREA IN THE REGIONAL CONTEXT

Although the area that we have used as an example for our review is only a tiny fraction of the area of the whole Svalbard archipelago (Figs. 1, 2), it is a useful model area for risk assessment because it shares key characteristics with other similar areas on Svalbard:

- (1) It has research facilities with a tradition of research, which enables the systematic monitoring of vegetation similarly like other settlements (Ny Ålesund, Longyearbyen, Barentsburg) or permanent or seasonal scientific bases in the area (Hørnsund, Kaffiøyra, Petuniabukta) (Fig. 1).

- (2) It was affected by large-scale human activities connected with changes in environment (including changes in terrain disposition, hydrological regime, nutrient enrichment or contamination of soil by pollutants, and import of organic material with diaspores of plants and animals) similarly like other settlements or mines (Ny Ålesund, Longyearbyen, Pyramiden, Barentsburg, Grumant, Sveagruva) (Fig. 1).
- (3) It is affected by unregulated tourism and similarly like other settlements located in the Isfjord area connected by tourist cruisers (Longyearbyen, Pyramiden, Barentsburg) (Fig. 1).

Effect of climate change on flora and vegetation, if any, should be observable first on such places.

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