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Consequences of Future Expansion at the Arctic Treeline in Northernmost Norway

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Abstract: Seedlings from eight seed populations of mountain birch (*Betula pubescens* var. *tortuosa*), were transplanted to a site close to the town Vardø, in the Arctic part of the Varanger area in Northernmost Norway, in order to investigate the adaptation to climate change in different birch provenances and the implications for the treeline ecosystem and the local population. A comparable site was established at Kilpisjärvi (500 masl) in Northern Finland close to treeline. Five replicates with 20 plants per replicate were established per site. The Vardø site was partly snow-free, sheltered by a willow thicket, and partly exposed on a ditched peat bog with thick snow cover from a nearby snowfence. Annual measurements were carried out on survival and growth parameters. The preliminary conclusion from this study is that local climate may be more important than the overall climatic variation in the adaptation and reforestation process in Northernmost Fennoscandia. In this process, the subarctic willow and shrub vegetation seems to be an important factor influencing the microclimate and seedling establishment. Species and provenances originating from areas with similar latitudes and climatic conditions as the reforestation area, were most successful. The Varanger area has always been a meeting place between different cultures, i.e., the Sami, Norwegian, Finnish and Russian population. The study indicates that in a changed climate the birch forest area would expand because there will be more willow growth and consequently more safe sites for birch seedling establishment and growth, which would also create a better local climate for the human population. In this process local birch populations that are adapted to a more coastal climate, would have an advantage. Since birch has been shown to be an important resource for all these cultures, this would decrease the level of conflicts between the different groups of stakeholders about the resources in the area.

Key words: Climate, mountain birch, Arctic treeline, socio-ecology.

1. Introduction

The Varanger Peninsula west of the city of Vardø (Fig. 1) and the coastline along the adjoining Varanger fjord, is located in the Arctic-boreal transition area, between 70-71° N and 27-31° E in Northeasternmost Norway. Most of the area is a true Arctic treeless undulating inland plain at 2-300 m altitude, where the highest mountain peak reaches 636 m altitude. The dominant treeline species is mountain birch (*Betula pubescens* var. *tortuosa*) with patches of rowan (*Sorbus aucuparia*) and abundant growth of willow species (mostly *Salix phylicifolia* and *S. glauca*) outside the tree line [1]. In the southern and eastern part of the peninsula there are large areas of wetlands and willow thickets. The mean annual precipitation is in the range of 365-550 mm and mean July temperature is between 9.8 °C and 12.3 °C. The human history of the area goes back 12,000 years, and Varanger was among the first parts of Scandinavia that was deglaciated after the last Ice Age. The first immigrants were hunters and fishers, mostly on the rich populations of reindeer and marine resources (fish, whale and seal), and there are numerous remains of ancient settlements along the coast [2]. These are believed to be the forerunner of what was later defined as the Sami population in the area. However, from about 700 A.C. immigrants from Southern Norway

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started to settle along the coast, where they were living on fishing and fur trade with Russia. The oldest city in Northern Norway, Vardø, at the easternmost coast of the peninsula, was established around Vardøhus castle in 1307, to protect Norway/Denmark from Russian and Swedish influence. Around 1500 the wild reindeer population had decreased to a minimum due to overexploitation, and part of the native Sami population in the area then turned partly to a nomadic life form where they started to keep reindeer as domestic animals, travelling up to 200 km between summer pastures at the coast and winter pastures with lichen (*Cladonia* spp.) in the inland areas. Another part continued their fishing and hunting activities and combined this with a small livestock (usually some sheep and a cow for each family group). Their winter settlements were located in the inner part of the fjord, while the summer settlements were located further out along the seaside [3]. Over-grazing and excessive clear cutting have permanently damaged the ecosystems of the outermost coast of the county of Finnmark more than ecosystems further inland [2]. From the time of Christ to about the end of 1200 A.D. the climate improved again and so did the natural forests. But then the so-called Little Ice Age started and at the same time the human population grew even in the far northeastern coastal regions of Norway. Currently, reindeer herding has been restored several decades ago and has grown to be a viable and prosperous industry. However, climate change with milder winters causes ice formation after thawing periods. This makes the lichen difficult or impossible to reach by the animals [4-6].

The ecosystems of these coastal districts are now characterized by low regrowth due to the harsh climate with an average tetratherm temperature of June, July, August and September just below 8 °C in recent years. However, it should be possible to get an “environmental forest” to survive in the Vardø area, particularly by the present climate change [7, 8], by choosing the right tree species and provenances and by protection and good shelter especially to the young seedlings [9]. This is true especially for the dominant treeline species *B. pubescens* var. *tortuosa*, but also for other low tetratherm temperature requiring deciduous trees like *Populus tremula*, *Prunus padus*, *Alnus incana*, *Sorbus aucuparia*. Re-vegetation of most coastal districts in Finmark county today, therefore, probably will require both shelterbelts, protection of populations from grazing, and species adapted to local climate and soil. Indigenous willows, such as *Salix lanata* and *Salix phyllicifolia* grow rapidly and form natural shelterbelts on the coast, often up to 5 m high. As the willow thickets grow older, hardy genotypes of larger and less wind-tolerant species can be transplanted into the natural shelterbelts formed by the willows (without too strong shading) and in small ditches in the lee of furrowed soil ridges on a mixture of mineral and organic soil [2].

The aim of the present study was (1) to test out by transplantation studies the adaptations in mountain birch provenances to climate at the Arctic treeline in Fennoscandia, (2) to use these findings to predict how the expected future climate changes will affect the Arctic treeline and forest growth and survival, (3) how local communities in Northernmost Fennoscandia (Vardø and Kilpisjärvi) can make use of the birch forest resources under changed climate and land use conditions.

2. Materials and Methods

Seedlings from eight populations of mountain birch (*B. pubescens* var. *tortuosa*), see Fig. 1 and Table 1, were transplanted to a subalpine site in Kilpisjärvi (510 m altitude) and an Arctic site in Vardø (15 m altitude). Fig. 2 shows a view of the Vardø site. In Table 1 the position and altitudes of the seed populations are shown with the mean normal January (t_1) and July temperatures (t_7) in °C. The continentality is determined mainly by the amplitude between t_1 and t_7 [10]. As a result populations from

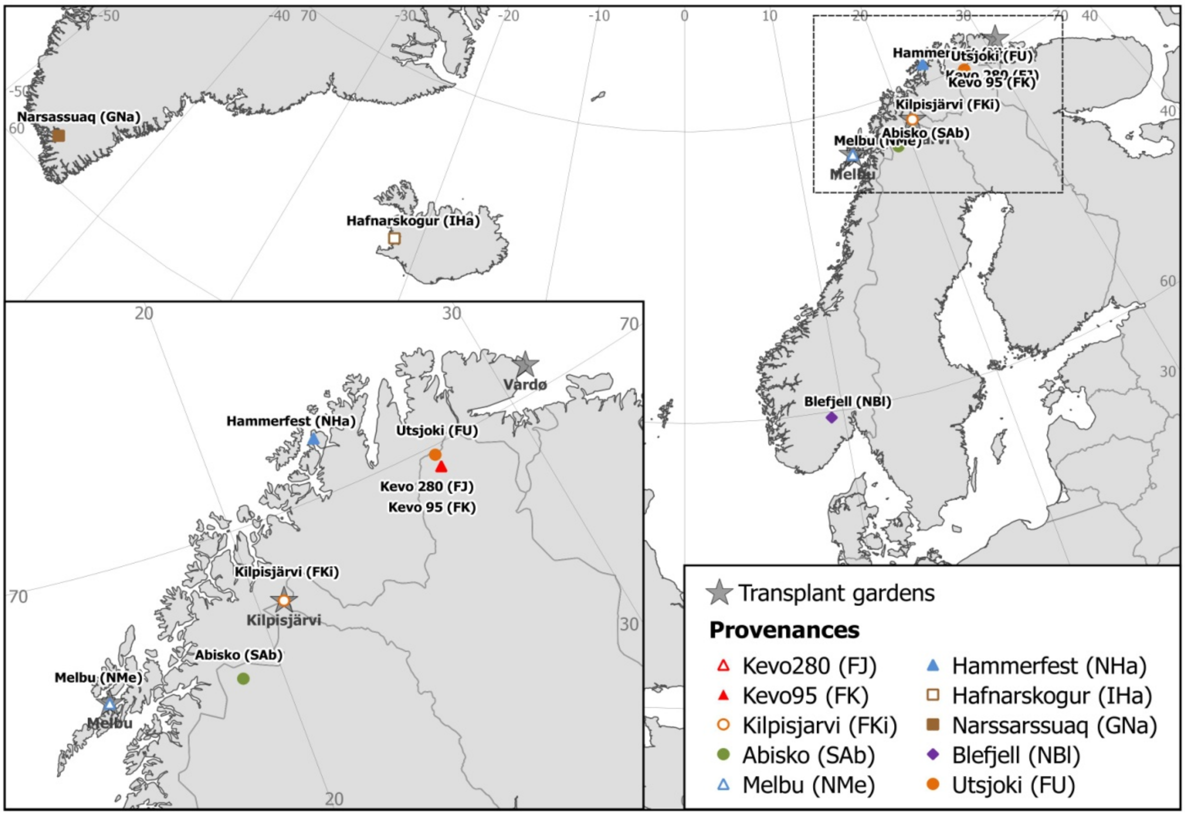

Fig. 1 Location of the transplanted gardens at Vardø and Kilpisjärvi .
The map also shows the location of mountain birch provenances transplanted to Vardø and Kilpisjärvi. The Varanger Peninsula is located just west of the city of Vardø. See also Table 1.

Table 1 Origin of seed populations (1-10) and location of the Vardø transplant garden (11) with continentality, altitude (m), position (latitude and longitude) and mean January (t_1) and July (t_7) temperatures (°C) during 1961-1990.

No.	Population	Continentality*	Altitude (m)	Latitude (° N)	Longitude (° E)	t_1 (°C)	t_7 (°C)
1	Kevo 280 (FJ)	+	28	69.8	27.0	-12.1	11.8
2	Kevo 95 (FK)	+	95	69.8	27.0	-13.6	13.3
3	Kilpisjärvi (FKi)	+	500	69.0	20.8	-10.6	11.2
4	Abisko (SAb)	+	360	68.3	18.8	-10.3	11.4
5	Melbu (NMe)	-	40	68.5	14.8	-1.0	13.1
6	Hammerfest (NHa)	-	70	70.7	23.7	-5.5	12.3
7	Hafnaskogur (IHa)	-	20	64.5	-21.9	-0.3	10.2
8	Narsassuaq (GNa)	-	70	61.2	-45.4	-3.3	7.0
9	Blefjell (NBl)	+	750	59.8	9.2	-5.6	13.5
10	Utsjoki (FU)	+	200	69.9	27.0	-12.8	12.5
11	Vardø	-	13	10.3	31.1	-4.3	9.1

*The localities are classified as oceanic (-) when the difference between t_7 and t_1 is below 20 °C and (+) elsewhere [10].

Utsjoki (FU), Kevo (FJ and FK), Kilpisjärvi (FKi) and Abisko (SAb) are classified as continental and those from Narsassuaq (GNa), Hafnarskogur (IHa), Blefjell (NBl), Melbu (NMe) and Hammerfest (NHa) as oceanic (cf. Fig. 1). The seedlings were raised in the greenhouse at University of Tromsø, and transplanted in 2002 to the Vardø and Kilpisjärvi sites as five replicates with 1 m^2 plots and 20 plants per population and replicate [10]. The results from this extensive long time study were recently analyzed and published [9].

Fig. 2 View of the Arctic Arboretum in Vardø September 2010.
In front the cold and wet birch replicates, in the background to the left is the warm and dry replicate, sheltered by the willow thicket and the conifer plantation behind.

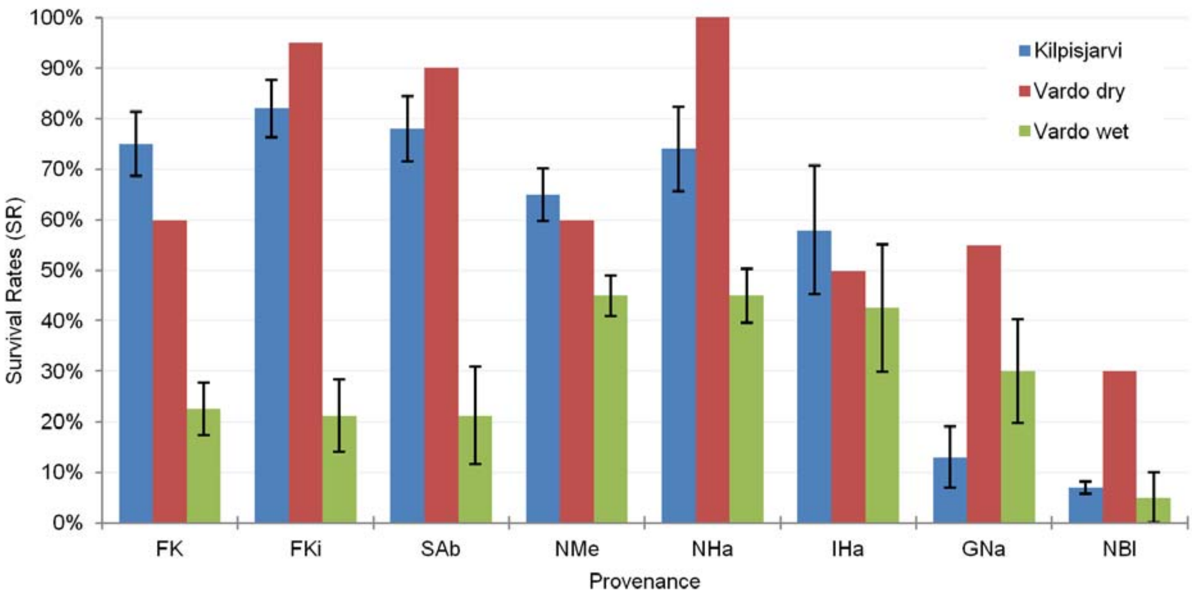

Fig. 3 Mean survival rates (%) with confidence limits 2010-2014 in birch seedlings from birch provenances (cf. Table 1 and Fig. 1) at the cold and warm parts of the Vardø site and in Kilpisjärvi.
See Table 1 for acronyms and locations of seed populations. Two provenances (FJ and FU) were not included in this study.
Source: Ref. [9].

3. Results and Discussion

3.1 Birch Ecology

Recently, the extensive dataset of transplanted birch at the Vardø and Kilpisjärvi site (Fig. 1) was analysed statistically [9]. The survival rates during 2010-2014 at Vardø and Kilpisjärvi (planted in 2002) are shown in Fig. 3. At the Kilpisjärvi site there was a strong latitudinal effect where the three southernmost populations (NBl, GNa and IHa) were less successful than their northern relatives, but also a certain effect of different oceanity. At the Vardø site, the northern oceanic plants from Hammerfest (NHa) were the most successful in terms of survival rates at both sites. It was also found that measurements on total living height partly confirmed the results of the survival rates, but with generally much lower growth rates in the plants growing at the Vardø site than at the Kilpisjärvi site, in agreement with summer temperatures (Table 1).

On the other hand, a clear difference was found in survival rates at Vardø between the two different parts of the site [9], illustrating the effect of different snow cover and growing season [11]. In this respect the three continental populations (FK, FKi, SAb) seemed to be most sensitive. Negative height increments due to dieback were found in all populations at the four cold and wet plots (Skre, unpubl.). In terms of survival rates and height increment (Fig. 3), the warm and dry plot at the Vardø site was comparable to the Kilpisjärvi site [9].

It is interesting to notice that plants from Iceland (IHa) showed relatively high survival rates in spite of its southern origin (cf. Table 1). This adaptation may be partly climatic [12] but also as a result of inbreeding with *B. nana* [13, 14].

The present study supports studies on birch ecology as influenced by climate change [5, 9, 10, 15-17] indicating the following:

(a) Climate change with milder winters and longer growing season, as well as increasing precipitation may favour mountain birch plants adapted to an oceanic climate, which are less sensitive to frost than continental populations. This strongly indicates that mountain birch would be a good indicator for such changes in the future. As expected, the various birch provenances seem to be best adapted to survive and grow in the climate of their origin, while transplantation to a different climate, makes the plants less adapted. Plants with high demands for dormancy breaking [18], i.e., southern and oceanic provenances would have an advantage [19], since also spring frosts caused by premature dehardening would be more common [12].

(b) The present results seem to indicate that in addition to climate, land-use change like overgrazing by reindeer and abandonment of farmland is an important driver of change [20-22]. The frequent insect attacks by geometrid moths are also related to climate change. Increased reindeer grazing as well as insect attacks would be expected to slow down treeline advance as stated by Neuvonen et al. [23] and Jepsen et al. [24], while reduced reindeer grazing would enhance treeline advance [23]. The study also indicated that large differences in survival and growth responses may occur locally, as shown in the Arctic Vardø transplant garden. The preliminary conclusion from this study is that local climate may be equally important as the overall climatic variation in the adaptation and reforestation process in Northernmost Fennoscandia. In this process, the subarctic willow and shrub vegetation seems to be an important factor, influencing the microclimate and seedling establishment. Different snow and temperature conditions are the main selective factors, and the Northern Hammerfest population (NHa) seemed to be most successful at this site. Finally, birch plants growing close to treeline seem to be subjected to frequent frost damages causing dieback of annual shoots and negative height increment.

(c) Future predictions [24] for the Varanger region indicate an annual temperature increase of 2.1-6.7 °C (depending on the scenario used) comparing 1971-2000 with 2071-2100, and 11%-17% increase in annual precipitation. These scenarios towards a more oceanic climate along the coast of Northern Scandinavia, are associated with increased risk of insect attacks [25]. Polycormic birch with high degree of inbreeding with *B. nana* would then have an advantage [26]. Similarly, oceanic birch provenances (IHa, NMe, NHa) would be expected to expand at the expense of continental relatives (FKi, FK, SAb) because they are more adapted to spring frosts [8]. Similar relationships may be used to predict future changes on species level. Scenarios of future forest in Northernmost Norway indicate reduction of the continental lichen rich alpine heaths, and such changes will have consequences for the reindeer grazing system, as the predicted changes will lead to a decrease in the vegetation types that have high winter grazing accessibility for reindeer [27].

3.2 Mountain Birch as a Socio-Ecological Factor in Northernmost Norway

The birch forest has traditionally been used by the Sami for different purposes [28], i.e., firewood heating, building material and handicrafts, and is a valuable resource for the aboriginal Sami population, but has also been very important for the Norwegian settlements along the coast [2]. As a result, large areas along the eastern coast of the Varanger Peninsula were deforested.

The Varanger area has always been a meeting place between different cultures [29], but during the last centuries, there have also been many conflicts between the different cultures and life forms in the Varanger area, i.e., conflicts between Sami reindeer herders and Norwegian and Finnish ("kvenish") sheep farmers about summer pastures and birch forests.

The central part of the Varanger Peninsula is since 2006 a national park area, where construction and roadbuilding activities are restricted because of the wildlife and vegetation [29]. Altogether, this mixture and interactions between different cultures and life forms make the Varanger Peninsula a very good example of commitment of local communities to their environment, including the relationship and partnership between different stakeholders about sharing resources and ecosystem services. The main traditional products from the farmers in the area are sheep and cattle meat and milk products, while the reindeer herders produce reindeer meat and handicrafts, e.g., hide, carved reindeer horn and birch wood products. The sheep and reindeer husbandry in the study area is providing a number of ecosystem services, like landscape protection and biodiversity, and preserving cultural and spiritual values, as well as income and employment. During the recent decades, the economy has gradually changes from primary to secondary sector activities like agrotourism (small restaurants, farm shops and hotels) where tourists can stay overnight with breakfast, taste local food and buy locally produced handicrafts, as well as perform guided tours and hiking trips in the national park and along the coast for recreation, and visits to bird cliffs and fishing villages.

4. Conclusions

In birch (*B. pubescens* var. *tortuosa*) a clear difference was found in survival rates and dates of budbreak after 10 years between the four cold and wet plots and the sheltered and dry replicate, illustrating the effect of different snow cover, microclimate and soil properties. The study showed that survival rates (Fig. 3) at the dry Vardø plot were comparable to Kilpisjärvi, in spite of lower July mean temperature (Table 1) and much higher than at the cold and wet part. The inland provenances from Northern Fennoscandia (FK, FKi and SAb) were much more successful at the dry site and in Kilpisjärvi than at the wet and cold Vardø site. The two southernmost provenances (NBl and GNa) were least successful at the continental subalpine site in Kilpisjärvi, while at the cold and wet part of the Vardø site the birch seedlings from the northern coastal populations (NHa, IHa and NMe) were most successful. The preliminary conclusion from this study is that local climate may be equally important as the overall climatic variation in the adaptation and reforestation process in Northernmost Fennoscandia. In this process, the subarctic willow and shrub vegetation seems to be an important factor, influencing the microclimate and seedling establishment. Species and provenances originating from areas with similar latitudes and climatic conditions as the reforestation area, seem to be most successful.

These studies on traditional sustainable and balanced use of ecosystem services by different stakeholders/cultures, e.g., reindeer herders, sheep farmers, local enterprises [30], indicate how to make use of them in a sustainable way in an Arctic environment and how possible conflicts between user groups have been solved in a successful way. The present study seems to indicate that in a future climate with extended birch and willow growth along the Arctic coast of Norway, balanced use of grazing areas by sheep farmers and/or reindeer herders would be easier to achieve, and with better grazing conditions, good relationship between reindeer herders and conservationists and ecotourism in the national park area in the inner part of Varanger Peninsula, would also be expected. However, because the lichen is a limiting factor for reindeer grazing in winter, the changed climate would represent a challenge for reindeer herders, and compensation measures like strict population control and/or supplementary winter food would be necessary. In this respect, the increased birch and willow growth would represent a valuable resource—not only for reindeer herders, but also for sheep farming, sustainable tourism and the well-being of the local population.

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