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Alien plant species in Svalbard

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Abstract

Increased introductions combined with favorable growing conditions may enhance the presence and increase the success of alien plant species in High Arctic settlements. With global warming, the presence and success of alien plants in Polar Regions might expand beyond the confinement of human settlements and cause problems for native species and ecosystems. Presence and abundance of alien and native vascular plant species were recorded, from chosen study sites, in the Svalbard settlements of Barentsburg and Longyearbyen during the summer of 2011. Soil temperature and soil nutrient concentrations measurements were also conducted in the same study sites. The effect of soil temperature attributes and soil nutrient concentrations on alien and native species were investigated. Further, the effect of alien plant species on the abundance of native plant species was investigated. The results indicated that both high soil temperature and high soil nitrogen concentrations may facilitate alien plants in Svalbard settlements. Further, the results showed that both presence and abundance of alien plant species had a negative effect on native species abundance in the study sites. This may imply that when alien plant species are facilitated, they may constitute a threat to native species abundance in High Arctic settlements.

Introduction

Introductions of alien species is believed to be one of the most serious environmental threats to biodiversity (Sandlund et al. 1999) . Today there are few habitats on earth free of species introduced by humans. Few areas are remote or unique enough to be considered immune against alien introductions (Lonsdale 1999; Mack et al. 2000). Although several species are capable of dispersing naturally to new areas by chance (Alsos et al. 2007; Mack and Lonsdale 2001), human activities, such as trade and agriculture have been strong contributors to species dispersion, both intentionally and accidentally. The risk of further introductions is bound to increase as human activities continue to expand and globalize (Gaston and Spicer 2004; Jenkins 1999; McNeely 2001).

Introduction of alien plants has caused extinction of native species through competition and habitat alteration, such as altered fire regimes, nutrient cycles, energy budgets and productivity. In addition, alien plants constitute a threat to genetic diversity when they hybridize with native species (Lonsdale 1999; Sakai et al. 2001). The threats these species constitute to both native organisms and ecosystems, in terms of numbers, extent and significance, are expected to increase with global environmental changes (Frenot et al. 2001).

Harsh physical environments are believed to act as a constraint on alien plant invasions (Shea and Chesson 2002). The Arctic is an example of such an environment. Low air and soil temperatures, large temperature variations, limited soil nutrients, permafrost and short growing seasons are some of the challenges plants have to deal with at these latitudes (Callaghan et al. 2004; Chapin et al. 1975; Chapin and Shaver 1981; Liska and Soldan 2004). Temperature is especially outlined as one of the most controlling factors for plant germination and diversity in the Arctic (Rannie 1986). In addition of being low, arctic temperature is also known to show large variations to which native plants have adapted (Muller et al. 2011; Rannie 1986). In general, the Arctic is not strongly influenced by alien plants and they are today not considered to be a threat to native species and Arctic ecosystems (Elven and Murray 2011). The absence of invasive alien species in the Arctic may be explained by the aliens not being adapted to the harsh Arctic conditions (Callaghan et al. 2004; Elven and Murray 2011; Liska and Soldan 2004). However, the current climate change may increase the success of alien species in becoming established, and maybe also invasive in the Arctic in the future (Elven and Murray 2011). According to Alsos, Eidesen et al. (2007), several hundred plant species might be able to grow in the High Arctic archipelago of Svalbard if the temperature increase a few degrees. The same applies for Antarctic islands where an increase in temperature is likely to result in higher alien colonization success (Bergstrom and Chown 1999; Frenot et al. 2005).

The vast majority of alien plant species in the Arctic are confined to human settlements or infrastructure (Elven and Murray 2011). In some cases plants have been imported as hitchhikers in industry shipments (mining, railroad, pipelines, etc.), while others have been deliberately introduced as fodder for animals, in re-vegetation projects or for esthetical purposes (Carlson and Shephard 2007; Elven and Murray 2011; Forbes and Jefferies 1999; Hagen 2001; Liska and Soldan 2004). A large range of exotic plants have been reported from High Arctic settlements, including extremes like peas, apple trees and sunflowers (Elven and Elvebakk 1996; Elven and Murray 2011).

Human settlements are believed to provide more favourable environmental conditions for alien plant species, than the surroundings (McKinney 2006). Temperatures within human settlements can exceed those in surrounding areas by several degrees (Collins et al. 2000). This also applies in the High Arctic, where studies have shown higher average temperatures within settlements, compared to the surroundings (Hinkel et al. 2003). Such differences may facilitate the presence and success of alien plants which otherwise not would be able to survive here (Liska and Soldan 2004). In addition, human disturbance (road construction, pipeline, etc.) has been shown to increase soil temperature in disturbed sites (Chapin and Shaver 1981). This could be favourable to alien plants and especially alien graminoid species which are believed to be good colonizers (Forbes and Jefferies 1999; Pysek 1998).

Several mechanisms determine the invasion success of alien plant species. The intermediate disturbance hypothesis states that while high and low levels of disturbance will allow competitive exclusions, favouring specific species, an intermediate level of disturbance will allow a variety of species to co-exist without outcompeting each other (Connell and Slatyer 1977; Molles 2005). The invasibility of a community is often determined by extant vegetation. Native vegetation in a community may impede or facilitate colonization by new arriving species (Brooker et al. 2008; Shea and Chesson 2002). The competitive dynamics between co-occurring species (e.g. native and alien) are often dependent on available resources, and the species ability to utilize these (Daehler 2003; Davis et al. 2000). Plant communities become more susceptible to invasion when there is an increase of available resources, whereas communities with low resource availability are less likely to see an increase in alien competitors (Daehler 2003; Davis et al. 2000).

Agricultural attempts and re-vegetation projects in Arctic settlements or infrastructure have been known to increase the availability of soil nutrients (e.g. nitrogen), which otherwise are low, especially in High Arctic environments (Dowdall et al. 2005; Forbes and Jefferies 1999; Liska and Soldan 2004). Additions of soil nutrients (fertilizers, domestic animal faeces, etc.) especially in nutrient poor environments, can increase the invasibility of natural communities and improve alien germination and competitive skills (Brooks 2003; Chapin et al. 1986; Hueneke et al. 1990). How soil nutrients affect alien success, may be dependent on both species characteristics and on the amounts and frequency of nutrient addition (Forbes and Jefferies 1999). While some species are dependent on continued fertilization to maintain population presence (Forbes and Jefferies 1999), others may survive many years in sites fertilized only once (Younkin and Martens 1987). Native vegetation can re-colonize sites where aliens have been growing, and the rate of this process is dependent on the alien success (Chapin and Chapin 1980; Forbes and Jefferies 1999).

Where resource availability is scarce, other factors may contribute to alien success. Native plant species can facilitate non-native species in terms of providing shelter, enhancing nutrient and water availability and alter microclimate (Brooker et al. 2008; Cavieres et al. 2005; Maron and Connors 1996). The Stress Gradient Hypothesis suggests that positive interactions between plants may occur when conditions are harsh, and change to negative when conditions improve (Brooker et al. 2008; Maestre et al. 2009). In less stressful environments, alien species success may be favoured.

While environmental factors and resource availability control species interactions, species composition may also be explained by the history of colonization (arrival order). According to Ejrneas, Bruun, et al. (2006) the first species to colonize a new area, may have competitive advantage in impeding the establishment of new arriving species, indicating that the history of colonization may change the outcome of community structure. In Arctic settlements, human influence (re-vegetation projects, animal husbandry, road construction, etc) have affected native plant communities (Carlson and Shephard 2007; Elven and Murray 2011; Forbes and Jefferies 1999; Hagen 2001; Svenning et al. 2001), and may have enabled alien species in colonizing new sites before natives. As the global climate is changing and temperatures increasing, the Arctic may be more susceptible to alien invasion (Elven and Murray 2011). A study of non – indigenous species and the factors restricting them to Arctic settlements, might give an indication on future development, including alien species effects on native vegetation.

By measuring soil temperature, nutrient concentrations, alien presence and abundance, and native species abundance we investigated how soil attributes affects the presence and abundance of alien plant species, compared to native species in two Svalbard settlements. We also investigated alien effect on native species, in terms of presence and abundance. We asked the following questions: 1) Are the presence and abundance of alien plant species in Svalbard settlements limited to areas with high levels of soil nutrients? 2) Do sites with warmer micro climate favour alien species more than native species? 3) Do the alien plant species in Svalbard settlements affect the abundance of native species in sites where both occur?

Methods

Site description

The High Arctic archipelago of Svalbard (74° - 81° and 10° - 30° E) is situated between the north pole, Greenland and the northernmost point of the European mainland, covering about 62 000 km². About 60 % of the archipelago is covered by glaciers, while only 10 % is regarded as suitable for biological production of major importance (Johansen et al. 2009). Around 165 vascular plant species are native to Svalbard (Kålås 2010; Lid et al. 2005). The flora is believed to be mainly a result of past and present long distance dispersal from Greenland and Russia (Alsos et al. 2007). Despite of remoteness and harsh climate, about 60 alien plant species have been recorded in Svalbard settlements (Elven and Elvebakk 1996; Hadac 1941; Liska and Soldan 2004). In the Russian settlements of Barentsburg and Pyramiden, there are several dung heaps, from animal husbandry, and these are expected to contain high concentrations of nutrients and act as a source of introduction. They may also facilitate alien species growth and survival (Elven and Elvebakk 1996; Liska and Soldan 2004). During the 1980s and 1990s re-vegetation projects took place in the settlements of Longyearbyen, Pyramiden and Barentsburg to make the settlements greener for esthetical and recreational purposes. Commercial seed mixtures fertilizers and organic soil were added to selected sites in the settlements (Hagen 2001; Hagen and Prestø 2007). The vegetation of these sites still appears different from the surroundings, especially along the road edges in Longyearbyen and in the central parts of Barentsburg and Pyramiden.

Field survey

In June 2011, 25 transects (à 20 meters) were established in 7 sites (Figure 1) in the two settlements of Longyearbyen (16) and Barentsburg (9). The sites were chosen on the basis of where others had recorded alien plant species (Elven and Elvebakk 1996; Hadac 1941; Liska and Soldan 2004; Rønning et al. 1996). Each transect started in the centre of what was considered to be the source of introduction (e.g. dung hill, road edge, old cowshed), and for every 5 m a plot (1x1m) was established. In August 2011, occurrence and cover of plant species in each plot was recorded with a frame (0.5x0.5 m). Cover of each species in the plots was recorded on a scale from 0 – 5 (0=0%, 1=1-20%, 2=21-40%, 3=41-60%, 4=61-80% and 5=81-100%).

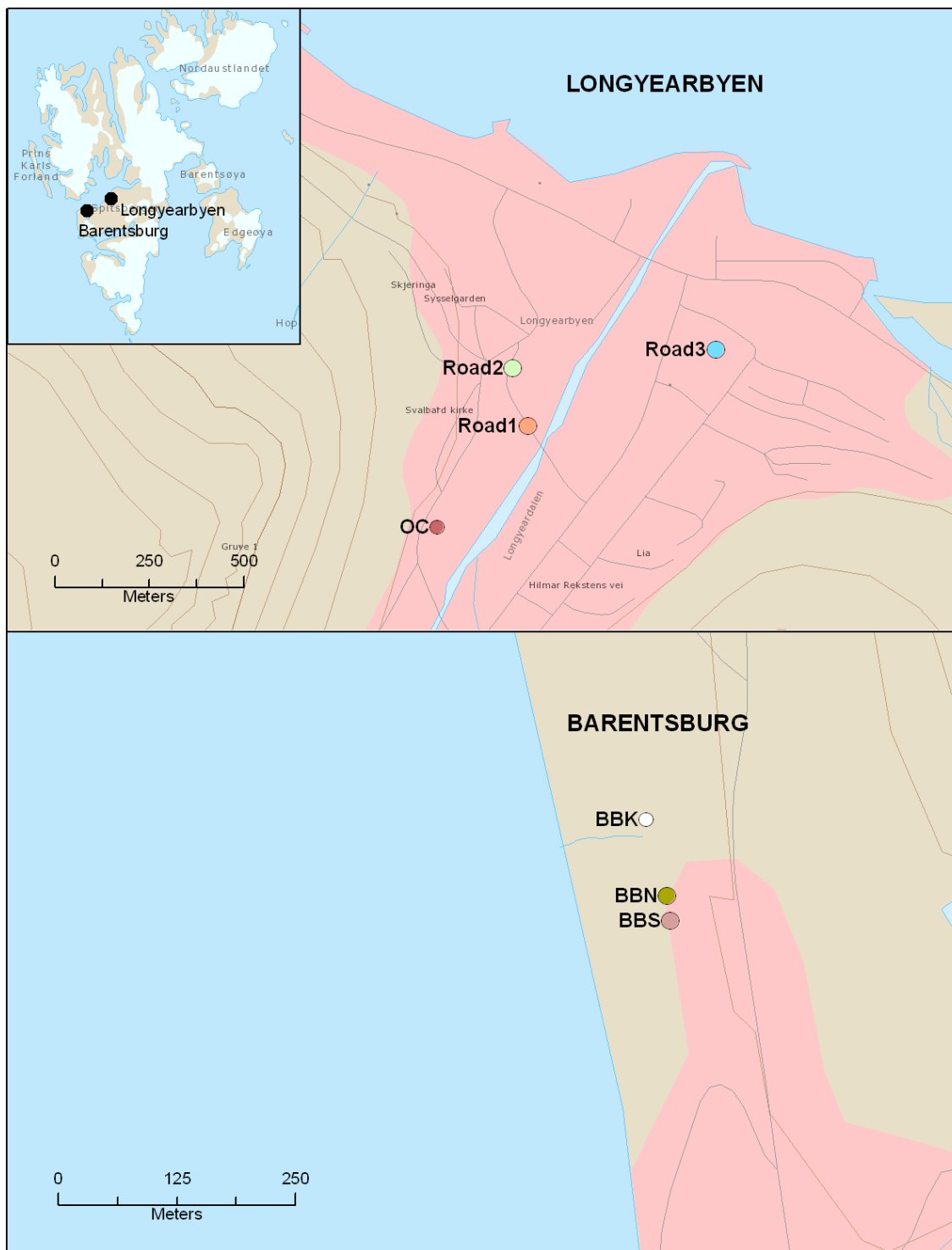


Figure 1 The eight study sites in the Svalbard settlements of Longyearbyen and Barentsburg. The colours and the names/abbreviations indicate the locations of the sites in the focal settlements. In addition of the three road sites in Longyearbyen the following abbreviations means: OC = Old cowshed, BBK = Barentsburg control, BBN = Barentsburg north and BBS = Barentsburg south.

Soil nutrient and temperature recordings

Plant Root Simulators (PRS)TM – probes were inserted in the top 5 cm of the soil to measure the nutrient flow in the soil from mid June to mid August. The PRS – probes consisted of two types of probes, measuring cation and anion concentrations by absorbing ions from the soil over a membrane. Two nutrient probes were buried in each of the four corners of the plots. For the nine transects in Barentsburg, only one pair of probes were buried in the soil, in the upper left corner of each plot. When removed, the nutrient probes were cleaned with demineralised water in the lab and sent to Canada for analyzes at Western Ag Innovations. For each probe, ions were extracted by the use of 17.5 ml of 0.5 mol/l HCl. Determination of inorganic nitrogen (NH₄⁺ -N and NO₃⁻ - N) were done by colometry, using a Technicon Autoanalyzer II (TIC 1997). Total nitrogen concentration was based on the colometry measurements of NH₄⁺ -N and NO₃⁻ -N, and presented as micro grams/10cm²/burial length.

In total 120 temperature loggers (NexSens DS1922T micro T Temperature Logger) were programmed to measure soil temperature every hour for the same period as the nutrient probe insertions. The temperature loggers were buried approximately 2 cm under the soil surface next to the nutrient probes in the upper left corner of the plots. In one of the sites in Longyearbyen, temperature was only measured in two of four transects due to shortage of temperature loggers. To form a uniform dataset we decided to use data from 13.06.2011 (programmed start of measurements) to 07.08.2011 (collection of the first loggers). From this dataset average soil temperatures and average max – min temperatures (temperature variations) were calculated.

Supplementary recordings

Supplementary, we recorded alien plants findings, both in and outside the study sites. We were on a constant lookout for alien plants throughout the fieldwork in Svalbard and visited different locations in the two study settlements as well as Pyramidene, and abandoned Russian settlement. Alien plant findings were documented with photos.

Statistical approach

To test if there were significant differences in plots where alien species were present/absent (binary response variables), concerning soil nitrogen concentration, average soil temperature, average max – min temperature (temperature variation) and native species abundance, we applied a Generalized Linear Mixed Effect Model (GLMM) with binomial error structure by use of the lme4 package software (R Development Core Team 2011). Variables explaining dependence of plots (study sites, transects within sites and distance within transects) was entered as random effects. We tested all combinations of random effects. The best models, fitted with maximum likelihood, were chosen on the basis of AIC values (Burnham and Anderson 2004; Crawley 2007). Soil nitrogen concentration, average soil temperature, average max – min temperature and native species abundance was entered as fixed explanatory variables, with models fitted with restricted maximum likelihood.

To test for significant relations between alien species abundance, native species abundance, nitrogen soil concentration, average soil temperature and average max – min temperature, a Spearman rank correlation test

was applied. This non parametrical test was chosen on the basis of some of our data not being normally distributed. Independence of plots was justified by a distance of 5 meter between them.

All statistical analysis were done in R software (R Development Core Team 2011).

Results

Of eight assessed study sites, only five was inhabited by alien plant species and were included in the further analysis. Three sites were situated in Longyearbyen and two in Barentsburg. The sites in Longyearbyen were all road edge sites, while the sites in Barentsburg were both located in dung heaps. Of the 544 nutrient probes buried in the two settlements, 24 (12x2) could not be found or not used due to technical uncertainties (16 in Barentsburg and 8 in Longyearbyen). Of the 90 temperature loggers, 21 were missing or could not be used due to technical uncertainties (13 from Barentsburg and 8 from Longyearbyen). In one of the study sites in Longyearbyen, one plot could not be located.

The two settlements, Barentsburg and Longyearbyen, differed concerning environmental variables (Table 1) and growth substrate. While the Barentsburg sites (dung heaps) consisted of rich organic soil and rich vegetation, the sites in Longyearbyen were dry, contained less soil nitrogen and had partly scarce vegetation. Due to these differences, it was decided to treat the two settlements separately for further analysis.

Table 1 Attributes of soil nitrogen concentration, soil temperatures and vegetation cover measurements in study sites, Longyearbyen and Barentsburg

	Longyearbyen	Barentsburg	Longyearbyen	Barentsburg	Longyearbyen	Barentsburg
	Nitrogen	Nitrogen	Temperature	Temperature	Vegetation cover	Vegetation cover
	(mg/cm ²)	(mg/cm ²)	(°C)	(°C)	(%)	(%)
Average	1.5	3.1	8.7	7.2	52	62
Maximum	2.7	11	31.5	21.5	95	100
Minimum	0.5	0.3	0.5	0.5	6	11
Standard error	0.07	0.53	0.24	0.3	3.04	2.85
Measurements	56	32	42	27	59	40

Plant recordings in plots

In total 24 vascular plant species, 7 alien and 17 native were identified within the plots. About 30 % of the plots in Barentsburg and 40 % of the plots in Longyearbyen included alien species. Six alien plant species were recorded in the Barentsburg sites. Alien herbs, *Rumex longifolius*, *Ranunculus acris*, *Ranunculus repens*, *Epilobium montanum*, and the grass species *Deschampsia cespitosa* and *Poa pratensis*, were recorded within the plots. Alien species occurred in all transects. Native species were present in all plots and were more abundant than the alien species (Figure 2). Two alien grass species (*Festuca rubra* and *Poa pratensis*) were recorded in Longyearbyen. Red fescue (*Festuca rubra*) were more abundant than Smooth meadow grass (*Poa pratensis*) and was found in all transects in the three study sites. The alien grass species in Longyearbyen were, with one exception, only found in the first three plots closest to the source of introduction (road edge). The cover of native species in Longyearbyen, and vegetation cover in general, increased as alien abundance decreased (Figure 3).

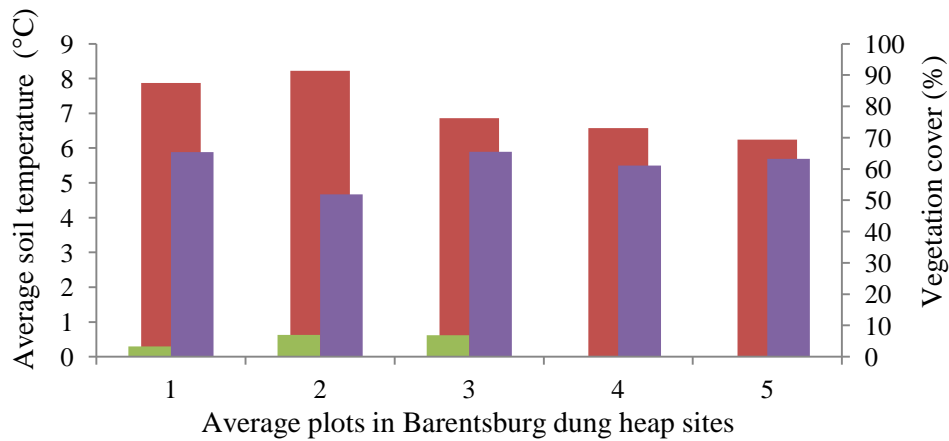


Figure 2 Average temperature (red column), average vegetation cover (blue column) and average alien vegetation cover (green column) in Barentsburg dung heap sites

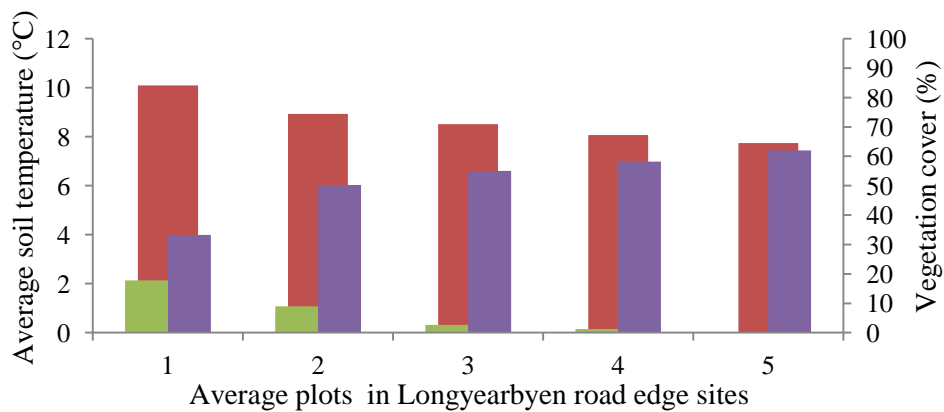


Figure 3 Average temperature (red column), average vegetation cover (blue column) and average alien vegetation cover (green column) in Longyearbyen road edge sites.

Supplementary recording of alien species

In the supplementary search for alien plants within the settlements, 16 alien species were identified (Appendix), including the ones already mentioned from the study sites. The majority of the alien plant species (12) were found in Barentsburg close to an old cowshed and in the central parts of the settlement. In Longyearbyen we identified 6 alien species, two of them already found in Barentsburg. In Pyramiden we found 4 alien plant species. All of these had already been found growing in Barentsburg or in Longyearbyen. All alien species, except *Polygonum aviculare ssp. aviculare*, were perennial. One alien species, *Taraxacum sect. ruderalia*, had visible seeds, both in Barentsburg and in Pyramiden. It was especially abundant in Barentsburg.

Soil nutrient availability and plant species

The results showed that the soil nitrogen availability in the Barentsburg sites was more than two times larger than in the Longyearbyen sites (Table 1). Neither in Barentsburg nor in Longyearbyen did plot with and without alien species presence differs significantly in soil nitrogen concentrations (Table 2). There were no significant correlation ($Rho = 0.22$, $p = 0.20$) between alien plant species abundance and soil nitrogen concentration in Barentsburg (Table 3). Neither did native species show any significant results in Barentsburg (Table 3). In Longyearbyen however, the results showed a significantly positive correlation ($Rho = 0.32$, $p = 0.016$) between alien species abundance and nitrogen soil concentration. The abundance of native species in contrast decreased significantly with soil nitrogen concentration ($Rho = -0.32$, $p = 0.015$) showing an opposite correlation pattern in comparison to alien species abundance in Longyearbyen.

Soil temperature attributions and plant species

Temperatures measurements from the two Svalbard settlements showed in average a higher soil temperature in Longyearbyen than in Barentsburg. This also applied for maximum soil temperature (Table 1). There were no significant differences in average soil temperature ($p = 0.705$) or max – min temperature ($p = 0.215$) between plots where alien species were present or absent in the Barentsburg sites (Table 2). In Longyearbyen, alien plant species tended to occur in sites where average soil temperature was relatively high ($p = 0.085$). There were no significant differences between plots with alien species presence or absence, concerning temperature variation (max – min temperature) in Longyearbyen (Table 2).

There were no significant correlation between alien abundance and average soil temperature ($Rho = -0.11$, $p = 0.580$) or max – min temperature ($Rho = -0.23$, $p = 0.231$) in Barentsburg (Table 3). Native species abundance however, was negatively correlated with average soil temperature ($Rho = -0.41$, $p = 0.005$) and average max – min soil temperature ($Rho = -0.41$, $p = 0.003$). In Longyearbyen, alien species abundance increased with average soil temperature ($Rho = 0.44$, $p = 0.002$, Table 3, Figure 3), while native species abundance decreased ($Rho = -0.42$, $p = 0.005$). Native species decreased significantly with average max – min temperatures ($Rho = -0.34$, $p = 0.025$) in Longyearbyen, while there were no significant correlations between alien species abundance and max – min temperatures (Table 3).

Alien and native species relations

In plots with alien species present, native species was significantly less abundant than in plots without alien presence (Table 2). In Barentsburg the average abundance of native species increased by 9 % (Table 2) in plots where alien species was not present ($p = 0.028$). In Longyearbyen native abundance was almost twice as large (Table 2) in plots with alien species present, compared to plots without any alien species ($p = 0.008$). Native species abundance decreased significantly with alien species abundance in both Barentsburg ($Rho = -0.41$, $p = 0.008$, Table 3) and Longyearbyen ($Rho = -0.66$, $p < 0.001$, Table 3).

Table 2 Average values, standard error, number of measurements (n) and test results (p value) of GLMM comparing the differences in soil nitrogen, average temperature, average max – min temperature and native abundance between plots with and without alien presence in the two Svalbard settlements.

Barentsburg	Presence	n presence	Absence	n absence	Difference (p value)
Nitrogen concentration mg/cm ²	4.22 ± 1.26	8	3.06 ± 0.53	31	0.248 ^{ns}
Average temperature °C	7.1 ± 0.59	8	7.2 ± 0.30	27	0.705 ^{ns}
Max-min temperature °C	8.1 ± 0.91	8	9.3 ± 0.68	27	0.215 ^{ns}
Native abundance %	46 ± 3.44	12	55 ± 2.89	40	0.028*
Longyearbyen					
Nitrogen concentration mg/cm ²	1.68 ± 0.11	24	1.45 ± 0.07	50	0.132 ^{ns}
Average temperature °C	9.6 ± 0.38	20	8.4 ± 0.22	38	0.085 ^(*)
Max-min temperature °C	12.7 ± 1.17	20	10.9 ± 0.62	38	0.281 ^{ns}
Native abundance %	16 ± 4.42	24	30 ± 3.04	59	0.009**

ns=>0.1, (*) = 0.05 – 0.1, * = <0.05, ** = <0.01, *** = <0.001

Table 3 Spearman rank correlation coefficients between nitrogen concentration (N concentration), average soil temperature (Average T), average temperature variation (max – min T), alien abundance (A abundance) and native abundance (N Abundance) in the two Svalbard settlements.

Barentsburg	N concentration	Average T	Max-min T	A abundance	N Abundance
N concentration (mg/cm ²)	1				
Average T (°C)	-0.23 ^{ns}	1			
Max-min T (°C)	-0.04 ^{ns}	0.66***	1		
Alien abundance (%)	0.22 ^{ns}	-0.11 ^{ns}	-0.23 ^{ns}	1	
Native abundance (%)	-0.08 ^{ns}	-0.41**	-0.41**	-0.41**	1
Longyearbyen					
N concentration (mg/cm ²)	1				
Average T (°C)	0.30 *	1			
Max – min T (°C)	0.35*	0.77***	1		
Alien abundance (%)	0.33*	0.44**	0.18 ^{ns}	1	
Native abundance (%)	-0.33*	-0.42**	-0.34*	-0.66***	1

ns=>0.1, (*) = 0.05 – 0.1, * = <0.05, ** = <0.01, *** = <0.001

Discussion

Effects of soil nutrients on plant species in Svalbard settlements

High soil nutrient concentrations were expected to facilitate and accommodate alien species in Svalbard settlements, as this has been known to accommodate alien plants species in other human influenced parts of the High Arctic (Forbes and Jefferies 1999). In Barentsburg, where soil nitrogen concentration was high and several alien species were recorded, soil nitrogen was especially expected to have a facilitating effect on alien plants. The statistical analysis however, did not show any importance of soil nutrients (nitrogen) for the presence of alien species in any of the settlements. Neither did alien abundance prove significant in Barentsburg when correlated to soil nitrogen concentrations. The lack of significant results in Barentsburg, concerning both alien presence and abundance, may relate to an overall high nutrient concentration in all plots. This indicates that soil nutrient concentration was not a limiting factor here.

In Longyearbyen, where soil nutrient levels were lower than in Barentsburg, alien abundance was positively correlated to soil nitrogen, which in turn might imply that alien species in Svalbard settlements are favored by soil nutrient concentration. Native species abundance was not favored by soil nutrients. Several experimental studies have shown similar results, favoring alien species when an increase of nutrients are added to nutrient poor soil (Aber et al. 1989; Chapin et al. 1986). As native species are adapted to relatively nutrient poor conditions in Arctic environments (Dowdall et al. 2005; Liska and Soldan 2004), they may possess poorer competitive qualities than alien species when soil nutrient availability increases (Brooks 2003; Chapin et al. 1986).

In human disturbed sites, studies have shown that native vegetation may re-colonize at faster rates where there are no repeated additions of nutrients (Chapin and Chapin 1980). Continued additions of fertilizers and seeds may on the other hand facilitate alien success and decrease the rate of native establishment (Forbes and Jefferies 1999). Dependent on how large concentrations of nutrients that are present and available for plants in the Barentsburg dung heaps, it is possible that alien species here will continue to thrive in the years to come. In Longyearbyen on the other hand, there are no dung heaps supplying soil nutrients and native re-colonization may therefore be faster here as shown for similar sites in the Arctic (Chapin and Chapin 1980; Forbes and Jefferies 1999). There were however few signs of native colonization in plots where alien grass dominated in Longyearbyen. Given that the focal sites in Longyearbyen were established during the 1990s, they are still considered to be relatively young (Hagen 2001) which may be an explanatory factor for the lack of native re-colonization. Native species may however establish in the future.

Effects of soil temperature in facilitating alien species

Low temperatures and large temperature variations are both climatic factors limiting plant growth and diversity in Arctic environments (Muller et al. 2011). These factors are also believed to impair alien species presence and success in the Arctic (Callaghan et al. 2004; Elven and Murray 2011). The presence of alien species did not seem to be affected by the variations in temperatures, as there were no significant differences between plots with and without alien presence in neither of the settlements. Given that temperature variations are stressful for plants

(Körner 2003) and that native species are better adapted to Arctic conditions including large temperature variations (Jonsdottir 2005), one would expect native species to tolerate temperature variations better than alien species. Surprisingly native species abundance showed a negative correlation to max – min temperature, suggesting lower abundance in plots with high temperature variation. This unexpected result may be explained by factors like low sample size, experimental design and site attribute.

Average soil temperatures in Svalbard settlements were expected to be higher in plots where alien plants were growing (Liska and Soldan 2004), since temperature increases have been shown to facilitate alien plant species in harsh environments (McKinney 2006). Results from Longyearbyen indicate that temperature might act as an accommodative factor, as average temperature in plots with alien presence were marginally higher than plots without alien presence. However, this simply states whether a species is present or not, and does not reflect on its success in expansion or dispersal. Studies have shown that several non- native species to the Arctic are able to germinate in Arctic temperatures (Trudgill et al. 2000; Ware et al. 2011). Additionally, several alien plants have been known to germinate in Svalbard settlements without being able to produce flowers or seeds (Elven and Elvebakk 1996; Liska and Soldan 2004). Even though temperatures in the Arctic settlements may be sufficient for alien plant germination (facilitation of alien presence) it might still not be high enough to promote establishment and expansion in terms of seed production and dispersal. Only one alien species with visible seeds was recorded during the fieldwork in 2011.

However, in addition to facilitating alien presence, the results showed that alien species abundance increased with average temperature in Longyearbyen which might indicate that temperature is favoring alien success in the Svalbard settlements. Interestingly, native species were not favored in neither of the settlements when temperature increased. This might imply that higher temperature increase the competitive advantage of aliens over native species. Species adapted to warmer environments have been shown to be favored by an increase in temperature (Thuiller et al. 2007), whereas native species which are adapted to colder climates may have poorer responses compared to alien species (Callaghan et al. 2004; Verlinden and Nijs 2010). In Longyearbyen, alien grasses were confined to plots close to road edges, consisting of dry gravel. Disturbances like road construction have been shown to increase soil temperature in sites due to better drainage and removal of vegetation and organic mat (Chapin and Shaver 1981; Forbes and Jefferies 1999). In addition, temperature increase has been shown to be particular high where the vegetation cover is incomplete (Chapin and Shaver 1981; Hernandez 1973) as seen in Longyearbyen. Since alien species were dominating in these plots, this may support aliens as better competitors when temperatures are favorable. Even though temperature may favor alien success, slow re-colonization rates by native species must not be disregarded as an explanatory factor for the dominance of alien plant species in the Longyearbyen sites. As the Arctic may be more susceptible to alien colonization, as a result of an increase in temperature (Alsos et al. 2007; Elven and Murray 2011), we might expect to see similar patterns as discovered in Longyearbyen in other parts of the Arctic.

Alien and native species interaction in High Arctic settlements

The outcome of interactions between alien and native species in Svalbard settlements could have been both positive and negative, depending on factors like the level of disturbance, available resources and environmental

conditions. In study sites with an intermediate level of disturbance, both alien and native species can co-exist while sharing the same niche (Connell and Slatyer 1977). Positive interactions may also be the outcome if natives plants facilitate aliens by giving shelter or accumulating nutrients from the soil (Brooker et al. 2008). Results from both settlements however, showed that alien species presence and abundance had a negative effect on native abundance. These results indicate that neither intermediate level of disturbance nor facilitation by natives accommodates alien plant species, as these theories would have called for a positive relationship (Brooker et al. 2008; Molles 2005).

The outcome of species interactions is often determined by resource availability and the species ability to utilize these resources (Davis et al. 2000). The negative relationship between alien and native plant species might indicate that alien species in Svalbard settlements are better at utilizing available resources than native species. This is supported by the results from Longyearbyen, regarding alien and native abundance and soil nutrient concentrations. Further, temperature may have a positive effect on alien species competitive ability (Callaghan et al. 2004; Verlinden and Nijs 2010), as alien species in Longyearbyen seemed to be favored by higher soil temperatures while native species in both settlements were negatively correlated to higher temperature.

Given that the alien introductions in the study sites in Svalbard is a result of human activities executed several years ago (Elven and Elvebakk 1996; Hagen 2001; Liska and Soldan 2004), the negative effect of alien species over native abundance might have been induced by a low level of disturbance in the focal areas. When disturbance levels are low, plant communities will eventually be inhabited by species that are effective competitors, either due to their effective use of available resources or due to having an effective competition interference (Connell and Slatyer 1977). Alternatively, an area with a high level of disturbance could have favored species that are able to colonize new sites and complete their life cycles between frequent disturbances (Connell and Slatyer 1977; Molles 2005). The alien grass species in the Longyearbyen sites were introduced during the 1980s and 1990s (Hagen 2001), and still dominate the plots in which they were introduced. This might indicate that these sites have low or moderate levels of disturbance and that this may have influenced the species composition.

Another factor that might explain some of the alien success in Svalbard settlements is the order of colonization (Ejrnaes et al. 2006). In the study sites in Barentsburg we recorded both alien herbs and grasses, while in Longyearbyen only alien grass were recorded. Grasses are regarded as good colonizers and have been introduced to areas all over the world (Frenot et al. 2001; Pysek 1998). The success of alien grass in Longyearbyen, in terms of both presence and abundance, might be explained by their colonization history. Being the first species to colonize a new area, as a result of intentional human seeding (commercial seed mixtures), may have given the grass species a competitive advantage in comparison to native species. As extent vegetation may impede or facilitate new arriving species (Daehler 2003; Ejrnaes et al. 2006), the success of Red fescue, and partly Smooth meadow grass, in utilizing available resources, may have impeded native species in colonizing road edges in Longyearbyen. This may also apply in Barentsburg where alien grass also have successfully colonized areas, most likely due to human activities such as animal husbandry (Elven and Elvebakk 1996; Liska and Soldan 2004).

Conclusion

This study demonstrates that alien plant species confined to human settlements in Svalbard might be facilitated by higher levels of soil nutrients and warmer micro climate compared to native species. Further, these factors might be increasing the alien species competitive abilities over native species as alien plants have been shown to affect native species in a negative way. This suggests that alien plant species are competing with native species over available resources in Svalbard settlements. Even though alien species are only confined to human settlements and infrastructure, this may change if the Arctic experience and increase in temperature as a result of global warming. Combined with an increase of seed influx, the patterns seen in Svalbard settlements may also apply in other parts of the Arctic.

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Appendix

Characteristics of alien plant species recorded in the Svalbard settlements of Barentsburg, Longyearbyen and Pyramiden in August 2011. The origin (Eu = Europe, As = Asia, NA = North America and Af = Africa) and the characteristics (taxon, family and life history) is based on the species description in Norsk flora (Lid et al. 2005). Abundance is described based on alien plant presence, amounts and distribution in field and ranged from low to high.

Taxon	Family	Locality	Life history	Origin	Abundance
<i>Achillea millefolium</i>	<i>Asteraceae</i>	Barentsburg	Perennial	Eu,As	High
<i>Agrostis canina</i>	<i>Poaceae</i>	Barentsburg	Perennial	Eu,As,NA	Low
<i>Anthriscus sylvestris</i>	<i>Apiaceae</i>	Barentsburg	Perennial	Eu,As,Af	High
<i>Barbarea vulgaris</i> var. <i>Arcuata</i>	<i>Brassicaceae</i>	Barentsburg/Pyramiden	Perennial	Eu,As	High
<i>Cerastium fontanum</i>	<i>Caryophyllaceae</i>	Longyearbyen	Perennial	Eu,As	Low
<i>Deschampsia cespitosa</i>	<i>Poaceae</i>	Barentsburg/Pyramiden	Perennial	Eu,As	Medium
<i>Epilobium montanum</i>	<i>Onagraceae</i>	Barentsburg	Perennial	Eu,As	High
<i>Festuca rubra</i>	<i>Poaceae</i>	Longyearbyen	Perennial	Eu,As	High
<i>Poa pratensis</i>	<i>Poaceae</i>	Barentsburg/Longyearbyen	Perennial	Eu,As,NA	Medium
<i>Polygonum aviculare</i> ssp. <i>Aviculare</i>	<i>Polygonaceae</i>	Longyearbyen	Annual	Eu,NA	Low
<i>Ranunculus acris</i>	<i>Ranunculaceae</i>	Barentsburg/Longyearbyen	Perennial	Eu,As	High
<i>Ranunculus repens</i>	<i>Ranunculaceae</i>	Barentsburg	Perennial	Eu,As	Medium
<i>Rumex longifolius</i>	<i>Polygonaceae</i>	Barentsburg	Perennial	Eu,As	Medium
<i>Taraxacum sect. ruderalia</i>	<i>Asteraceae</i>	Barentsburg/Pyramiden	Perennial	Eu,As	High
<i>Trifolium repens</i>	<i>Favaceae</i>	Longyearbyen	Perennial	Eu,As,Af	Low
<i>Urtica dioica</i>	<i>Urticaceae</i>	Barentsburg	Perennial	Eu,As,Af	High