Risk assessment of non-native seed introduction by visitors to Svalbard

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Introduction

The introduction of non-native species exists as one of the major threats to native ecosystems (Higgins et al. 1999, Chapin III et al. 2000). The impacts of non-native species elsewhere in the world have been costly (Pimentel et al. 2005), and in cases irreversible (e.g. Deckers et al. 2005). High latitude regions as e.g. Alaska were thought to be immune to invasions of non-native plants because of great distances to source populations, relative lack of agriculture, low levels of human disturbance and cold climate. However, recent studies suggest increased vulnerability with increased human activities also in these areas (Carson & Shephard 2007). The number of non-native species established on the high arctic archipelago Svalbard and their impact is relatively low (Elven & Elvebakk 1996, Rønning 1996). Nevertheless, a number of plant species have established, mostly around settlements and areas of human influence (www.svalbardflora.net).

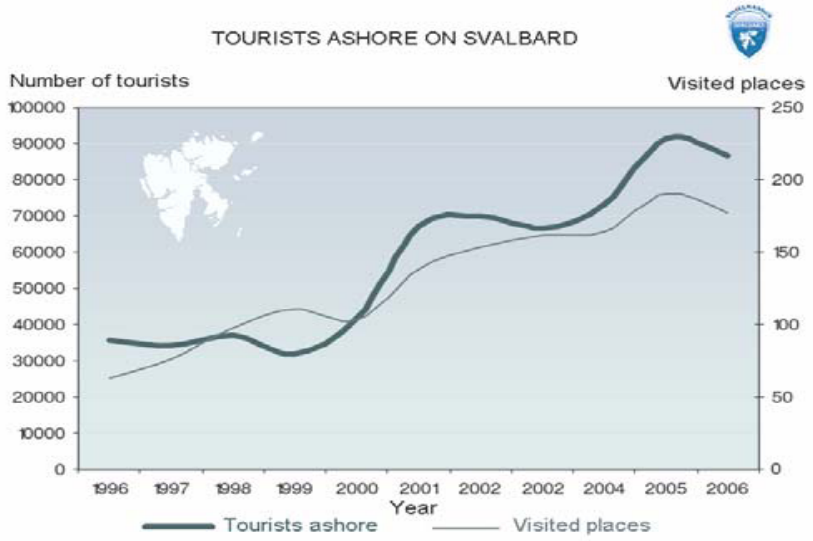

Figure 1: Development of tourism over the past years in Svalbard.

Humans can inadvertently transport and introduce plant seeds to new locations on their clothing and equipment (Whinam et al. 2005). In particular, seeds can collect on footwear and be dispersed over great distances. Both the recent increase in visitor numbers to Svalbard (figure 1), and regional climate warming (Christensen et al. 2007) may increase the risk of new species introduction and establishment to Svalbard. We aimed to assess the increased risk of plant invasions in Svalbard associated with growing visitation to the region and changing climates.

Methods

Visitors arrive to Svalbard via two main modes: by plane, or by cruise ship. As such, we aimed to include visitors from both categories in our study to sample any biological material that may be stuck to their footwear.

a **b**

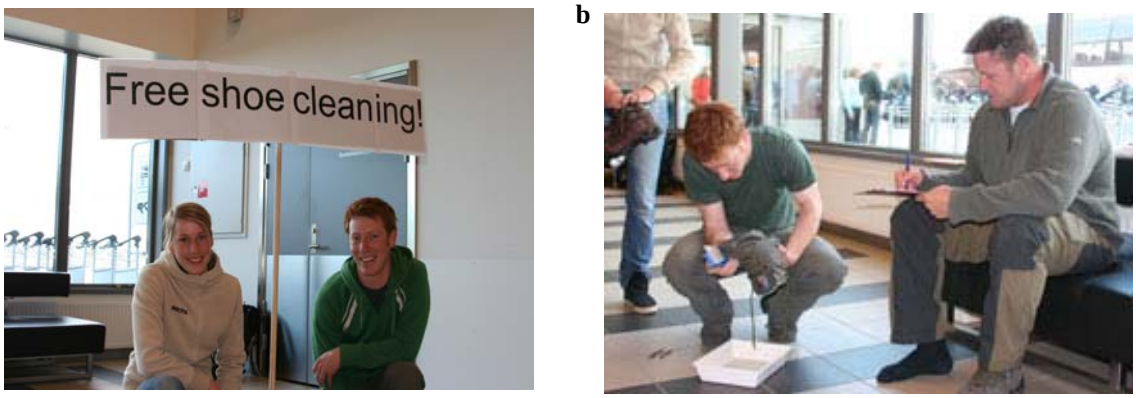

Figure 2a: UNIS students Anika Beiersdorf (right) and Christopher Ware (left) at Longyear airport. **2b:** Christopher Ware sampling boots of a volunteer participating in the study.

A total number of 129,274 passengers arrived and departed at Longyear airport in 2007 (Årsstatistikk Passasjerer 2007, Avinor 2008). Conservative calculated over four month, approximately 1% of passengers took part in the study. In 2008, over the summer and autumn 260 visitors arriving in the Longyearbyen airport voluntarily participated in our study (figure 2a). Here, they completed a short questionnaire and had their shoes cleaned of any mud, dirt and biological material (figure 2b). Via the questionnaires we collected information regarding the purpose of participants' stay in Svalbard; where they hoped to go during their stay; whether their shoes had been used or cleaned before traveling; and, if they had been used and where. Shoe samples were linked to questionnaires and taken to UNIS laboratories for analysis.

Any seeds present in the samples were collected and identified. For vascular plants, this was mainly to species or genera level. This information was then linked back to individual questionnaires completed by participants. From this, patterns of seed introduction will be identified. The germination of all collected seeds is being attempted in conditions replicating Longyearbyen summer soil temperatures. Bryophytes were also counted but not identified or tested if growth is possible.

In addition to shoe sampling at the airport, the passengers of a cruise ship arriving in Ny-Ålesund also participated in this study. Three hundred passengers scrubbed their shoes on a mat as they arrived at the Ny-Ålesund pier. This provided the only opportunity to sample the footwear of cruise ship tourists; larger ships usually only berth in Longyearbyen following several earlier landings around Svalbard. Thus, samples collected following several prior landings would be likely to carry both seeds from elsewhere and Svalbard. The passengers of smaller expedition ships typically boarded vessels in Longyearbyen and therefore had their shoes sampled at the airport.

Finally, non-native plant surveys were carried out in Barentsburg and Pyramiden. Specimens collected were identified, preserved, and later sent to the herbarium in Tromsø. The results of this survey are in preparation. In Longyearbyen surveys have been carried out previously.

Results

In total 104 of the 260 samples analyzed contained seeds. We obtained a total number of 1098 seeds. In addition, 470 bryophyte parts were recovered from shoes (Table 1). On average each visitor arriving with the plain carried four seeds and two bryophytes resulting in six propagules per passenger. All categories of visitors carried propagules. The largest number of propagules was carried by a scientist (136) having 13 seeds and 123 bryophyte parts attached to his shoes whereas the largest number of seeds (117) attached to a person's shoes was found on a tourist (Table 1). Unfortunately, the information for one sample containing 82 seeds got lost.

The raw data indicate that there are some differences among the categories. However, this will be analysed in more detail to check for possible effect of e.g. sampling date.

Table 1: Summary of shoe sampling carried out at the Longyearbyen airport during the 2008 summer. Information was collected in questionnaires completed by participating visitors at the airport whilst their shoes were sampled for any biological material. The results included below then, are a combination of questionnaire results and the results of shoe sample analysis.

Visitor category	*Number of samples*	*% Samples containing seeds*	*% Pre-cleaned shoes*	*Maximum seeds in a sample*	*Average seeds per passenger*	*Average seeds per contaminated sample*	*Total numbers of seeds*	*Total number of bryophytes*
Tourist	170	41	21	117	4	9	631	148
Scientist	37	46	19	62	6	13	209	175
Student	28	29	22	39	4	12	98	9
Business	19	47	2	25	3	8	59	51
Resident	5	20	0	19	4	19	19	82
unknown	1	-	-	-	-	-	82	5
Total	**260**	**40**	**20**	**-**	**4**	**11**	**1098**	**470**

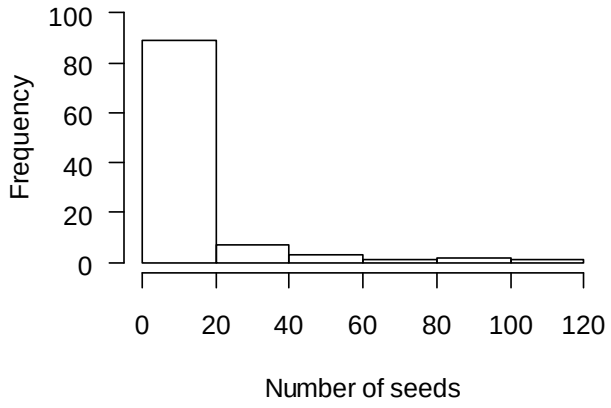

Figure 3: Histogram of number of seeds attached to sampled passenger shoes, Longyearbyen airport summer 2008. Samples with no seeds are excluded n=104.

Sixty-five percent of the visitors carried no seeds or bryophytes. Among the 35% of visitors carrying seeds, the majority carried between one and 20 seeds on their shoes. Only a few visitors carry more than 60 seeds on their shoes (Figure 3).

In contrast to the samples collected from visitors arriving at the airport, the average number of propagules found on each passenger's footwear from the cruise ship was low with only 0.067 propagules per participant (Table 2).

Table 2: Summary of shoe cleaning carried out in Ny-Ålesund. Passengers from the cruise ship MV Artemis wiped their shoes on a shoe-cleaning mat as they arrived at the Ny-Ålesund pier during a visit in August 2008. The mat was later vacuumed with a nylon filter fitted to the vacuum nozzle to collect any seeds.

Total participants	*Total number of propagules*	*Average number propagules*
300	21	< 1 per participant

All seeds were indentified to the lowest possible level. Seeds of 18 plant families were introduced attached to shoes (Appendix 1). More than half of the seeds were grass seeds (Figure 4) and at least 17 species of grasses (Poaceae) were identified. Among them were two species which have already established in Svalbard (*Poa annua* and *Deschapsia chespitosa*) and two species known to be invasive in other cold climate habitats: *Poa trivialis* (Antarctica) and *Deschampsia flexuosa* (Alaska). Additionally, two herb species already established on Svalbard were found in the samples: *Polygonum aviculare* and *Ranunculus acris*. Remarkable is the high number of birch (*Betula pubescens*) seeds recovered. All seeds in the category trees (Figure 4) except one seed (*Thuja* spp.) are birch seeds (total 149 seeds).

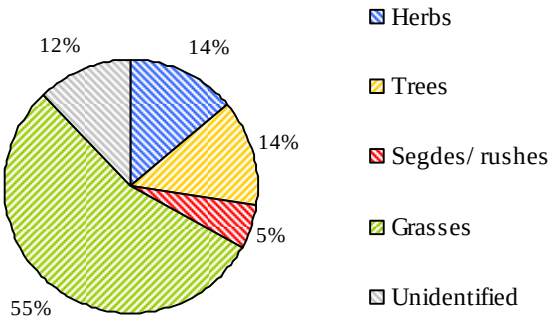

Figure 4: Summary of the obtained seeds sorted into different categories. Only seeds from the study on the airport were included.

Management implications

Based on the analysis so far, we can say that the average of six propagules per person is less then compared to a study undertaken in the Antarctic where they found 15 propagules per person (Whinam et al. 2005). However, in the Antarctic study, clothing and equipment was included in the cleaning and might be a reason for higher seed numbers per person. When accounting the high number of passengers arriving and departing from Svalbard the risk should not be underestimated. The low cleaning rate of shoes reported by visitors (20 %) shows that visitors are not aware of the seeds they might transport with their shoes and clothing.

The low number of propagules collected from the shoes of cruise ship tourists in comparison to the airport sampling results suggests that cruise ship tourists pose a lower risk. However, this difference may be related to the sampling strategy as the cruise tourists only wiped off their shoes on a doormat whereas shoes of visitors were cleaned properly. This suggests that using a doormat will not be sufficient to reduce the introduction of seeds.

The question whether the introduced seeds are able to germinate and establish under the arctic conditions found in Svalbard remains to be addressed. Some of the introduced grass species have closely related species native in Svalbard. A successful establishment of introduced grass seeds might thus pose a considerable risk for Svalbard's flora as hybridization can take place and open for gene exchange between introduced and native species. Moreover, four of species that were found are already introduced to Svalbard (see results) and have managed to establish under high arctic conditions. Especially repeated introductions contain an elevated risk as they may increase genetic diversity and cause new genetic combinations resulting in genotypes better adapted to their new environment (Lavergne & Molofsky 2007, Rosenthal et al. 2008). Germination tests of the seeds are currently done at UNIS to evaluate which species may germinate under temperature conditions found in Svalbard.

The same species as frequently found in our sampling on Svalbard have already established as non-native species in other cold climate habitats in the world. If this ability to establish is taken as an indicator for likelihood of establishment on Svalbard, *Poa*

trivialis and *Deschampsia flexuosa* have probably the highest potential to establish in Svalbard as both species have a bi-polar distribution. *Poa trivialis* has for example established in continental Antarctica (Frenot et al. 1999) and is one of the most invasive species worldwide. *Deschampsia flexuosa* is present in high latitude regions in north-east Canada and south Greenland (Hultén & Fries, 1986). Less potential to establish has *Betula pubescens* which grows successfully in south Greenland (60º16'N) but suffers considerable under stress (Kuivinen & Lawson, 1982). The number of non-native plants growing around Svalbard settlements indicates the ease with which plants can be introduced and also the capacity for many species to survive in the Svalbard climate.

The issue of seed introduction–management at airports is not unique to Svalbard. In Australia, New Zealand and when flying to Antarctica, shoe cleaning is mandatory at airports and inspections are made. Moreover, education has worked effectively to reduce the number of propagules humans transport. Over a several year period, hiking shoes used by scientists visiting Antarctica went from being one of the most contaminated items of clothing to one of the cleanest following an awareness campaign.

Summary

In this study shoes from airplane passengers at Svalbard's airport and shoes from cruise ship passengers were cleaned and analyzed for biological material. In particular seeds and parts of bryophytes were recovered and determined. Analysis revealed a high number of seeds and bryophyte parts transported by different categories of passengers. At least 41 plant species belonging to 18 plant families were transported on shoes to Svalbard. Even species were obtained being introduced earlier posing an elevated risk for non-native plant expansion.

Acknowledgement

We would like to thank the Svalbard Environmental Protection Fund for giving us the opportunity to carry out this research. Whilst the results of the study are still yet to be finalized, preliminary conclusions suggest that further research would benefit a more comprehensive risk assessment.

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Appendix

Appendix 1: List of all identified seeds collected from visitor shoe sampling at the Longyearbyen airport, Svalbard, over summer 2008.

Family	Genus	Species	Number of seeds
Asteraceae			1
	Taraxacum spp.		1
		Taraxacum officinalis	11
Betulaceae		*Betula pubescens*	149
Brassicaceae			2
	Erucrastrum spp.		1
	Isatis spp.		7
		Nasturium microphyllum	22
Caryophyllaceae			3
	Cerastium spp.		1
		Cerastium brachypetalum	7
		Cerastium glomerata	12
		Saponaria ocymoides	1
Cupressaceae	*Tuja* spp.		1
Cyperaceae	*Carex* spp.		17
		Carex aucutiformus	1
Ericaceae	*Vaccinium* spp.		3
Fabaceae		*Astragallus glycyphyllos*	1
		Madicago falcata	1
Juncaceae			4
	Juncus spp.		8
		Juncus effusus	30
Liliaceae			2
Papaveraceae			1
	Papaver spp.		2
Plantaginaceae		*Plantago major*	28
Poaceae			116
	Agrostis spp.		5
		Agrostis stolonifera	21
		Alopecurus pratensis	6
		Ammophilia arenaria	4
	Bromus spp.		2
		Bromus hordeaceus	4
		Calamagrostis pseudophragmites	2
		Dactylis glomerata	3
	Deschampsia spp.		2
		Deschampsia ceaspitosa	3
		Deschampsia flexuosa (synonym: *Avenella flexuosa*)	98
	Festuca spp.		9
		Festuca lemanii	1
		Festuca rubra	1
		Holcus lanatus	1
	Hordeum spp.		2

		Lolium perenne	2
		Phleum pratense	2
	Poa spp.		34
		Poa annua	52
		Poa festuca	13
		Poa trivialis	217
		Trisetum flavescens	3
Polygonaceae			1
		Polygonum aviculare	12
	Rumex spp.		1
		Rumex crispis	1
Ranunculaceae			1
		Ranunculus acris	4
		Trollis japonica	1
Rosaceae	*Geum* spp.		1
		Geum macrophyllum	1
Scheuchzeriaceae		*Triglochin maritimum*	18
Scrophulariaceae	*Veronica* spp.		3
Unidentified			134
Total			**1098**

Appendix 2: List of all identified seeds collected from cruise ship passenger shoe sampling during the landing of passengers from the MV Artemis at Ny Ålesund, Svalbard, in August 2008.

Family	**Genus**	**Species**	**Number of seeds**
Cyperaceae	*Carex* spp.		4
Fabaceae			1
Jungaginaceae		*Triglochin maritimum*	4
Poaceae			5
	Alopecurus spp.		1
	Poa spp.		1
Unidentified			3
Total			**19**