

## Effects of surface disturbance on the movement of native and exotic plants under a changing climate

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### Abstract

A warming arctic climate may offer both opportunities, for revegetation efforts, and risks, from migrating exotics. With or without climatic change, we cannot expect the chorologies of ruderal plants or even whole plant communities, to remain static. Expansion of corridors and increasing human relocation from southern regions will likely continue to provide a ready source of introduced species. It is well known that human feet, grazing animals, cars and railroads are all capable dispersers of viable plant propagules. Widespread disturbance regimes; such as ungulate grazing, thermokarst activity, oil and gas exploration and pipeline development may assure the availability of a variety of habitat conditions favourable to colonising species. Evidence from current climatic conditions indicates that such disturbance may favour the establishment, maintenance and spread of nascent satellite plant populations in the Arctic.

### Introduction

It is unclear how northern plant communities would respond to climatic amelioration. Several important questions arise regarding this situation. This paper will focus on two of these. First, what is the general status of exotic plant migration in the circumpolar North under the existing macroclimate regime? Second, how might the future differ from the past? Existing empirical data from a number of biogeographically analogous situations can go at least some way towards answering the first question. While there have been far fewer naturalisations at high latitudes than there have been casual introductions, there is a need to verify the preset extent of established exotics. This is particularly the case at the taiga/tundra ecotone, where many such populations may be at or near their northern limits. First, we need to assess the potential risk.

The intensity and extent of anthropogenic surface disturbance are on the increase in virtually all sectors of the circumpolar north. This is just one of several differences from the early Holocene, the period from which much of our retrospective data on plant migration rates is derived (MacDonald, 1992). It is thus apparent that the context for future plant migration will differ from the past. It would be prudent to expect that many northward advancing ecosystems will comprise complements of both 'native' and 'exotic' plants. Although the latter may have evolved in temperate lowlands in conjunction with agriculture (Baker, 1974), many have already become naturalised in boreal and subarctic regions (Porsild, 1932; Dorogostaiskaya, 1975). As in other biomes, the migration of native and exotic plants may often be assisted by humans, as well as domestic and wild animals.

From a management perspective, sustaining current levels of biodiversity cannot be an end in itself. Northward migrating communities, and the multitude of species that characterise them may bring with them undesirable aliens that could potentially increase species richness at several scales. These migrants might be hardy, invasive exotics. Areas of special interest are those undergoing large-scale resource development, such as the Yamal Region of northwest Siberia. There, northward migrating plants would be unimpeded by any natural barriers, as has been the case with the Brooks Range in Alaska (Kubanis, 1980). The question arises, do we need to concern ourselves with such migrations and if so what measures can we take to mitigate against undesirable changes in indigenous biodiversity?

## Discussion

### *Corridors*

In the context of global change, one of the major concerns is our ability to predict the movements of populations and communities. This concern has prompted a debate over the role of corridors in species migration. Corridors have both potential advantages and disadvantages. Among the proven disadvantages listed by Noss (1987) and Hobbs (1992), perhaps the strongest empirical data are those supporting the role of corridors as avenues of successful exotic flora introduction. These data are abundant for ecosystems ranging from tropic (D'Antonio and Vitousek, 1992) to temperate (Mack, 1985) to subarctic and even low arctic (Dorogostaiskaya, 1975; Staniforth and Scott, 1991; Forbes, 1992a). This was not the case in much of boreal North America and Europe before World War II (Raup, 1941; Ahti and Hamet-Ahti, 1971).

Within northern ecosystems, new corridors tend to be constructed by humans and dissect landscapes that are relatively homogeneous. Riparian zones may also serve in this regard. Temperate corridors in contrast are often comprised of strips of native vegetation that connect otherwise isolated remnants within a largely human-modified matrix (Hobbs, 1992). In the case of invading plants, corridors can help to overcome local and geographical barriers to dispersal by providing suitable habitat unlike that of the native vegetation that extends tens or hundreds of kilometres. Typically a number of native plants known as apophytes also benefit from these artificial habitats (Ahti and Hamet-Ahti, 1971; Dorogostaiskaya, 1975). The responses are not consistent, even within a single region. Within northern Finland, for example, roadsides may be colonised by mixtures of native and exotic species (Ahti and Hamet-Ahti, 1971) or entirely by native species (Nenonen and Mansikkaniemi, 1990). In areas of moderate relief significant differences in cover and composition may be apparent on verges and berms (slopes) of varying aspect (Suominen, 1969; Nenonen and Mansikkaniemi, 1990).

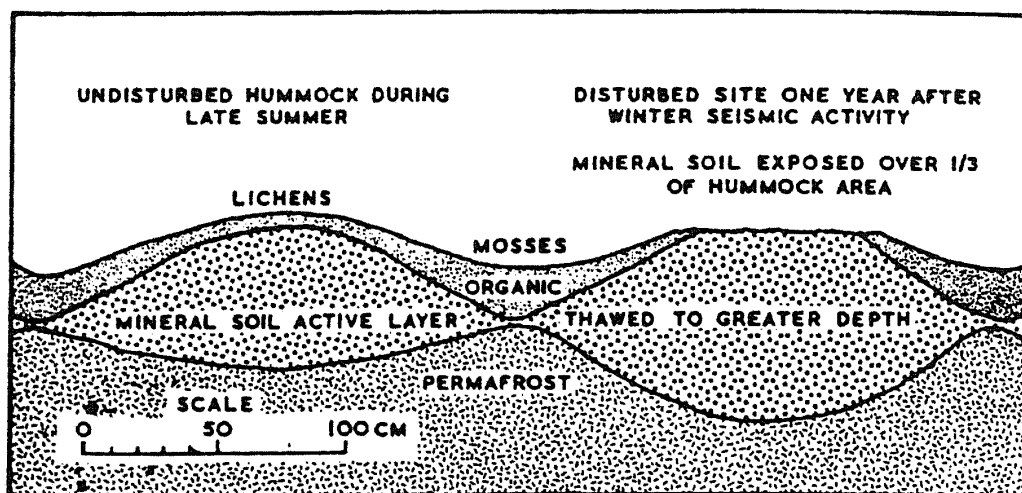
Another major effect of northern roads and railways is the direct alteration of hydrology. A railway or road exerts its maximum influence on the movement of surface water when it is aligned at right angles to the direction of water movement. Subsequent effects of impeded drainage include changes in surface albedo, active layer and permafrost, soil temperature and decomposition, and an increase in aeolian sands and dust (Jeglum, 1975; Walker and Everett, 1987; Forbes, 1992a, c). These processes are strongly interrelated and feedbacks among them are to be expected. In North America, the number of major northern roads increases each year, with several new highways in the planning stages for the western Canadian Arctic (Wray, 1990).

### *Patchy disturbance*

Many plants whether we call them ruderals, apophytes or another name, are adapted to the early or pioneering stage following surface disturbance, Krassilov et al. (1992) have recently noted that in disturbed portions of the Russian Arctic native plant species are being replaced by exotic ruderals, a trend initially observed more than 35 years ago (Tikhomirov and Dorogostaiskaya, 1957). The plants may be newly dispersed to the patch or those that have existed on the site previously in 'mature' communities or merely as viable propagules within the seed bank. Numerous studies have shown that the role of initial floristics (*sensu* Egler, 1954) within a patch is critical during vegetation change in response to disturbance (Pickett and White, 1985; Glenn-Lewin et al., 1992). Patch level disturbance is often neglected in models of global change, yet it is the local scale that is most important in terms of plant establishment. Without establishment there will be no migration.

Patchy disturbance is widespread in subarctic and arctic regions. Common anthropogenic disturbance regimes include pedestrian trampling, camping and temporary housing, off-road vehicle traffic and seismic surveys (Figure 1), gravel/sand quarries and mining (Forbes, 1992a, c; 1994, b). The shift from scale-of-impact to scale-of-response can be several orders of magnitude, as with wetlands drained by vehicle ruts. In the High Arctic, as little as a single passage of a tracked vehicle in summer can have catastrophic effects on tundra hydrology when ruts, which may persist for decades, inadvertently channel moisture away from wet sedge-moss meadows (Forbes, 1993c). On northern Baffin Island, the desiccation of wet tundra has resulted in the local extinction of rhizomatous aquatic sedges, *Sphagnum* spp. and other hydric bryophytes. After  $\geq 21$  years this vegetation has been replaced by caespitose graminoids, crustose and fruticose lichens (Forbes, 1993c). Soils of these drained wetlands, as well as mechanically disturbed patches, tend to exhibit higher levels of pH and corrected conductivities than adjacent controls (Forbes, 1993a, b). Such disturbances are characterised by warmer soils and increases in available nutrients (Challinor and Gersper, 1975; Forbes, 1993a). Fine scale patterns of establishment, particularly by bryophytes, are comparable to those observed on natural tundra disturbances that similarly affect substrate chemistry (Jonasson, 1986).

Classification and ordination procedures have revealed linkages between the floristic associations of moderately trampled meadows on Baffin Island and prehistoric Thule dwellings on Devon and Cornwallis Islands, (Forbes, 1994, b). It was demonstrated that increasing intensity of disturbance tends to override geobotanical differences among widely disjunct landscapes. These communities approach what Ellenberg (1988) terms 'azonal' vegetation, i.e. plant communities that appear in approximately the same form in several different climatic zones because they are determined by the same extreme soil factors. One of the most important local effects of such impacts may be the development of a bank of viable seeds that could respond rapidly to future patchy disturbance (McGraw and Vavreck, 1989Y; Parker et al., 1993). For example, the 1986 excavation of one of the archaeological sites on northern Devon Island led to the establishment of abundant seedlings of *Alopecurus alpinus* and *Poa arctica* (Forbes, 1993a). These grasses are believed to reproduce from seed only rarely (Savile, 1972; Bliss and Grulke, 1988).



*Figure 1 Most summer exploration has been banned since the 1970's in arctic North America and since 1988 in northwest Siberia. However, even winter activity can have significant local impacts. With regard to plant establishment there are several important effects among them exposed mineral soils, greater fluxes in soil temperature, and an increase in active layer depth. Source: Crampton (1977). Used with permission of the author.*

### Grazing

Tyser and Worley (1992), working in temperate grasslands, recently presented evidence that "low level" livestock grazing allowed establishment of exotic grasses in otherwise intact stands of native vegetation. In a review of plant invasions, Hobbs and Huenneke (1992) observed that in most plant community types, soil disturbance creates openings for establishment which are often exploited by ruderal species (see also Grubb, 1977). A simulation model by Rejmanek (1989), suggests that the requirement of heavy disturbance for the invasion of native communities by exotic plants may, in fact, apply mainly to competitively inferior species. Tundra is widely viewed as a rangeland resource (Lent and Klein, 1988). Studies have shown that overgrazing of tundra can lead to destruction of non-vascular plants, particularly fruticose and crustose lichens and *Sphagnum* mosses, and subsequent invasion by ruderal native plants (Palmer and Rouse, 1945; Klein, 1987). Pegau (1970) reported recovery of lichens to be incomplete up to 33 years after "moderate damage". In the Yamalo-Nenetsky district of northwest Siberia, 46% of the tundra is utilised as pasture. By 1980, large portions of the Gydan and southern Yamal Peninsulas were showing signs of overgrazing (Vilchek, 1992). Vilchek and Bykova (1992) estimate that the number of domestic reindeer on Yamal is already 1.5 to 2 times greater than the optimum for the region. They also note that ongoing gas and oil exploitation is constantly

reducing the area of tundra suitable for pasture and that grazing pressures are increasing throughout the region.

Grazing, effects from snow geese and lemmings can be locally significant in terms of community structure and functioning (Jefferies et al., 1992). In both the Low and High Arctic it has been observed that lemmings respond quickly to patchy nutrient additions (Schultz, 1969; J. Svoboda, 1991, pers. comm.). On northeast Baffin Island, *Dicrostonyx groenlandicus* continue to graze and nest preferentially on and adjacent to small Inuit homesites abandoned  $\geq 21$  years ago and on adjoining trampled ground. The Inuit residences were occupied for  $\leq 6$  years (Forbes, 1993a). The vegetation of these sites fits the pattern described by McKendrick et al. (1980) for Alaskan lemming grazing, and fertilisation. Such impacts are strongly associated with an increased importance of graminoids and decreased importance of lichens. These responses may be related more to the initial human impact than to subsequent grazing. However the annual deposition of lemming faeces remains significantly greater on the disturbed patches and almost certainly contributes to higher nutrient concentration measured in plant tissues (Forbes, 1993a). Similar responses were observed on Devon Island and indicate that even low intensity disturbance associated with transient arctic settlement may have lasting impacts on local plant establishment and grazing patterns.

There are many other disturbance regimes important in northern forest and tundra regions which will only be mentioned here. These include logging, peatland drainage, dust from settlements, deflation of soils and anthropogenic fires. Several of these are of regional importance in North America, Fennoscandia and northern Russia (Gorham, 1991; Yevseyeva, 1987).

### *Adaption of migrating plants*

Evidence from a variety of experimental studies indicates that we may expect an individualistic response to climatic change among native arctic flora (Chapin and Shaver, 1985; Henry et al., 1987). Among non native plants, it is known that certain introduced annuals may overwinter (*Capsella bursa-pastoris*) or function as perennials (*Poa annua*) at higher latitudes (Ahti and Hamet-Ahti, 1971; Dorogostaiskaya, 1975; Walton, 1975). However, a perennial life history is not a prerequisite for persistence in the Arctic. This is evident in the cases of *Chenopodium album* in northern Alaska and *Hordeum jubatum* on southern Baffin Island (Kubanis, 1980; Aiken, 1989). It has been demonstrated that introduced ruderals may mature and disperse viable seeds in the Arctic (Rønning, 1970; Dorogostaiskaya, 1975; Kubanis, 1980).

Holten (1993) has argued for the systematic marriage of native northern plant distributions using a grid net system, with climatic variables. I would add that non-native plants need to be given similar treatment. Plants that have already become naturalised in high latitude ecosystems in one part of the world should be considered prime candidates for successful establishment and spread in other areas with similar climatic regimes. Site specific studies, such as those by Staniforth and Scott (1991) and Wein et al. (1993), are useful in this context. They have taken advantage of older, detailed inventories of ruderals and have attempted to determine the extent of persistence and spread by previously introduced populations. Long-term observations at the population level contribute greatly to an understanding of the degree of adaptation among non-native taxa.

In a discussion of tundra disturbance and succession, Bliss (1990) proposed five reasons why European weeds are not likely to assume importance in arctic communities. He listed the long photoperiod, short growing season, low temperature, and low soil nutrient and water content as strong barriers to the invasion of southern ruderals. However, the latter four factors would be directly or indirectly affected by a changing climate. Bliss notes that the introduced grasses *Festuca rubra* and *Poa pratensis* have successfully maintained populations in the Low Arctic for >12 years. Recently, factorial greenhouse experiments with *P. pratensis* in Norway demonstrated that an ecotype from 69°N had higher relative growth rates and developed two to three times as many rhizomes as ecotypes from southern Norway (61°N and 59°N). Although complete flowering and heading was limited by low temperatures, the long summer days tended to augment rhizome formation (Aamlid, 1992). These results indicate that, at least for genetically diverse southern taxa, the long photoperiod does not pose a barrier to poleward dispersal (see also Kubanis, 1980). Conversely, it may even enhance the vegetative maintenance of satellite populations established from seed.

### *Other factors*

Climate is just one of several factors influencing the northern range limits of introduced and native vascular plants (Lindsay, 1953; Young, 1971). Even with increasing temperatures under a warming scenario, myriad other factors and interactions among factors will come into play. More snow melting later and radically different snow-free period may effect plant flowering, and seed production (Kudo, 1991; Wookey et al., 1993). Soil development is likely to lag behind any changes in climate and will thus effect the establishment of new populations (Perry et al., 1992). Even local disturbances can cause an increase in pH and stimulate the uptake of nutrients in otherwise oligotrophic soils (McKendrick et al., 1980; Forbes, 1993a, b). Holzner (1978) noted that before communities of European weeds reach their northern range limits they tend to show a preference for calcareous soils, while in their optimal climatic region they are indifferent to this factor. Soil preferences are also evident for certain elements of arctic-alpine and non-arctic floras (Fernald, 1907; Marie-Victorin, 1938).

It has been argued that there are two basic types of plant distribution-saturation and isolated introductions (Hanski, 1982a). In a study of 250 'anthropochorous' plants in Russian Karelia, Hanski (1982b) suggested three causes for patchy species distribution: the northern geographic boundary of the species may run through a given area; the prevalence of patches of 'suitable' versus 'unsuitable' soil; and population dynamic processes. The example of southern ruderals establishing first in villages and then spreading with disturbance is not uncommon and illustrates the potential importance of nascent foci (Moody and Mack, 1988). Once established beyond treeline, populations of potentially invasive plants are literally a step or two ahead of more southerly and ostensibly northward migrating plants. A soil development lag may favour site capture by more ecologically plastic southern exotics over migrating elements of the native flora.

With even moderate warming, we might expect an increase in thermokarst and other thermal erosion, particularly in ice-rich permafrost regions like northwest Siberia (Parmuzin and Shamanova, 1986). If this were the case, we could expect an increase in the number of patches,

both small and large, with exposed mineral soils. Presumably these patches would be colonised mostly by pioneering native and exotic ruderals. Even without a warming climate, the extent of disturbed surfaces is likely to increase as exploitation of previously undeveloped areas continues. Peters (1990) is one of the few to acknowledge that habitat destruction due to human activities will prevent many species from colonising new habitats when their old become unsuitable during climatic warming.

The regional scale of habitat destruction in northwest Siberia, including the Yamal Peninsula, was recently summarised by Vilchek and Bykova (1992). They observed that plant cover is already completely destroyed over 450km<sup>2</sup> within gas and oil fields and 1800km<sup>2</sup> along the main pipelines. They estimate the total area of destroyed vegetation to be about 2500km<sup>2</sup>. Based on the Tyumen Oblast's present plans, they assert that the area of explored gas and oil fields will increase to 16,200km<sup>2</sup> and the portion with completely destroyed vegetation will increase to 5500km<sup>2</sup>. These figures do not include the further degradation that is expected to occur due to overgrazing by reindeer.

## Conclusions

Disturbance is important because it produces patches of bare ground that permit seedling establishment. Human impact is more extensive within tundra and taiga ecoregions now than at any time in the past. Contemporary natural and anthropogenic disturbance regimes are bound to have a significant effect on northward migrating plants under a warming climate. Plant migration depends on many factors, including, the availability of suitable habitats as well as the ability of propagules to reach those habitats. Interaction among different natural and anthropogenic disturbance regimes may enhance invasions. The dynamic chorology of both native and exotic elements of the arctic flora is cause for much more than casual concern. The ability of the fauna to adapt to a changing climate will depend in large part on the ability of suitable forage, with direct and indirect effects potentially manifest throughout the terrestrial food web.

I have attempted here to draw attention to some of the disturbance regimes that affect most tundra ecosystems in the circumpolar North. The importance of these processes needs to be addressed in contemporary models of climatic warming. I have emphasised patch dynamics because, beyond dispersal it is the local scale which is critical for successful plant establishment and, ultimately, migration. As human populations in subarctic and arctic regions continue to expand, there are bound to be concomitant increases in surface disturbance associated with human activities of all kinds. According to Vitousek (1992), "there is a reasonably strong consensus among terrestrial ecologists that for the next several decades, land use is likely to be the most certain and the most significant component of global change, followed by changes in the composition of the atmosphere". It would be prudent to expect that this statement will hold true for major portions of the increasingly accessible Arctic.

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