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Geographic Variations in Anthropogenic Drivers that Influence the Vulnerability and Resilience of Social-Ecological Systems

Across the circumpolar North large disparities in the distribution of renewable and nonrenewable resources, human population density, capital investments, and basic residential and transportation infrastructure combine to create recognizable hotspots of recent and foreseeable change. Northern Fennoscandia exemplifies a relatively benign situation due to its current economic and political stability. Northern Russia is experiencing rapid, mostly negative changes reflecting the general state of crisis since the collapse of the Soviet Union. North America enjoys a relatively stable regulatory structure to mitigate environmental degradation associated with industry, but is on the verge of approving massive new development schemes that would significantly expand the spatial extent of potentially affected social-ecological systems. Institutional or regulatory context influences the extent to which ecosystem services are buffered against environmental change. With or without a warming climate, certain geographic areas appear especially vulnerable to damages that may threaten their ability to supply goods and services in the near future. Climate change may exacerbate this situation in some places but may offer opportunities to enhance resilience in the long term.

INTRODUCTION

Evolving over long periods during the Tertiary and Quaternary (1), elements of the boreal and arctic tundra biota have adapted to high variability in climate and other variables, such as herbivory (2). Resilience is expressed at several levels from the individual to the ecosystem (3). Even when entire biomes have disappeared, as in the case of the steppe-tundra of Beringia (2), isolated relics or fragmentary analogues of ancient communities have persisted, albeit in impoverished forms, indicating that some inter-species relationships are resilient in the face of major, long-term environmental change (4).

The range of adaptation among human cultures during the Holocene is similarly impressive. During this period the whaling and reindeer-dependent cultures of Eurasia were undergoing profound changes, partly in response to climate (5). More recently, contemporary cultures of the taiga and tundra zones have experienced intensive outside economic and institutional pressures (6, 7), as well as relatively short-term but significant climate change in some regions (8, 9). Overall, northern indigenous peoples are experts in adapting to shifting conditions (environmental, social, economic) and recognize their own abilities in this regard (7).

Despite this record of resilience and the capacity to buffer against change, northern ecosystems have traditionally held a reputation for being 'fragile' and therefore vulnerable to immediate, long lasting and perhaps irreversible change. The flip side of fragility is ostensibly stability. Yet to some early observers, arctic ecosystems appeared to be so thoroughly affected by the natural disturbance regimes associated with frozen ground that 'stability', as represented by so-called 'climax communities', was simply absent (10). More recent thinking incorporates the disturbance regimes into the theoretical framework of community processes that direct succession and the individualistic responses of species. In this framework, transitions between states are caused by the different disturbance events, and alternative stable states are possible (11).

It is only in the last 35 years or so that concern has been expressed about the ability for humans to have significant impacts on northern ecosystems (12). From the 1970s onwards, anthropogenic drivers have come to be recognized as increasingly critical. Some of the same drivers first identified are still important, in addition to more recently acknowledged threats, such as persistent organic pollutants (POPs) and tourism (13). Other key drivers include changes in fire and ungulate grazing regimes (14–15). Monitoring efforts can be somewhat patchy spatially and temporally, but there is little doubt that the extent of human alteration to arctic and boreal social-ecosystems is growing (16), in part because some of the potential for impacts to accumulate in space and time (17). These cumulative impacts may occur independently of each other, or may be exacerbated through interactions among drivers of change.

As with the recently detected and anticipated climate change (18), the scale and intensity of anthropogenic drivers varies geographically. Certain areas appear especially vulnerable to damages that may threaten their ability to supply goods and services in the near future. In this paper we present an overview of these variations and a discussion of their implications for policy.

GEOGRAPHIC VARIATION IN DRIVERS

Alaska

In Alaska, a strong regulatory framework coupled with a relative lack of widespread ecosystem degradation compared to temperate regions provides a generally positive outlook for the future maintenance of ecosystem integrity. The state's total area is 656 424 mi² (1 056 186 km²). The population of nearly 650 000 includes some 120 000 Alaska Natives. Much of the land is publicly owned, including an extensive network of land under various levels of state and national protection. Nevertheless, population growth, urban expansion, and ever-increasing market demands place pressures on ecosystem resources. The result may be some degree of ecosystem degradation, due to creation of habitat-fragmenting transportation corridors; immediate and long-term impacts of mining and drilling here and in northwestern Canada; and alteration of natural fire regimes. Alaska's resources are also directly and indirectly threatened by climate change.

In 1980, the United States passed the Alaska National Interest Lands Conservation Act, a sweeping law that established 104.3 million acres (42.2 million ha) of protected federal land units in Alaska (19). These include National Parks, National Wildlife Refuges, National Conservation Areas, National Recreation Areas, National Forests, National Wild and Scenic Rivers, and land in the National Wilderness Preservation System. Each of these designations has its own complex set of rules and regulations, some of which allow extensive resource development and others almost none. In sum, they are intended to provide for human uses such as recreation, subsistence and sport hunting, and economic gain (19). However, they also include preservation of "extensive unaltered arctic tundra, boreal forest, and coastal rainforest ecosystems"; provision for "the maintenance of sound populations of, and habitat for, wildlife species of inestimable value to the citizens of Alaska and the Nation, including those species dependent on vast relatively undeveloped areas"; and maintenance of "opportunities for scientific research and undisturbed ecosystems" (19).

ANILCA has arguably done more to ensure boreal and arctic ecosystem integrity than any other single action, decision or policy in any other nation or state. However, it does not control all of Alaska's land, or predict every eventuality. Its interpretation has not always been clear, and it has been criticized and attacked in dozens of legal challenges for being either too restrictive to economic expansion, or not strict enough in its protection of resources (20–22). ANILCA's existence has also been used as a rationale for opposing conservation strategies on other federal lands, as well as on state and private lands.

Ninety million acres (36 million ha) of land in Alaska is owned by the state of Alaska (23). Some of this state land is privately leased or managed, while most is managed by the state. At the state level, there is strong political pressure in favor of resource extraction and construction of transportation corridors. Logging, mining, oil and gas development, and other resource development have been permitted even in seemingly protected areas. For example, in 2002, a lease was granted to a private company to explore for natural gas in Minto State Game Refuge. The debate over whether or not to allow oil drilling in the Arctic National Wildlife Refuge has become increasingly contentious since the mid-1990s, and there is great economic and political pressure to develop a new gas pipeline, perhaps in cooperation with neighboring Canada (24). In addition, the state regularly sells land, including remote parcels, into private ownership. Although such parcels may not have large direct impacts on overall ecosystem health, fragmented land ownership and remote development could have indirect impacts by significantly altering fire management strategies.

It is difficult to predict how alterations in natural fire cycles may affect the boreal region of Alaska, because fire is governed by a complex system of feedback loops between public policy and behavior, climate, and forest vegetation (25). However, almost half the land area of interior (subarctic and boreal) Alaska is governed by a 30–60 year fire cycle that burns highly flammable black spruce and *Sphagnum* muskeg (26). Current fire management suppresses fires near populated or developed areas, a policy that would tend to increase the amount of late-successional flammable vegetation on the landscape (25). Thus we can hypothesize that as human settlements and developments become more ubiquitous and far-flung across the state, the effects of fire suppression disturbance regime patterns and ecosystem dynamics will increase.

Climate change also will undoubtedly alter fire patterns, as well as affecting other aspects of ecological integrity and resilience. Alaska is already experiencing severe environmental stress directly attributed to climate change (27) and has warmed approximately 2°C in the past 40 years (28, 29). An unprecedented outbreak of bark beetles *(Dendroctonus rufipennis)* in the past 10–12 years killed over 2.3 million trees on the Kenai Peninsula, where the beetles are thought to have previously been cold-limited (30). Warming trends also appear to be causing increases in forest fire intensity and severity. Over the course of the 21st century, as much as the top 30 feet of discontinuous permafrost is predicted to melt, along with a complete or almost complete loss of Arctic sea ice (27, 31).

Fennoscandia

In general, Fennoscandia is subject to extensive and often intensive land use and ecosystem fragmentation relative to much of the boreal zone in Russia and North America. For Norway, Sweden and Finland, boreal forests and forestry are an important source of economic wealth (32). The northernmost provinces of these countries cover an area of some 237 000 km^2 and retain a population of 526 000 despite losing significant numbers since 1990 (33). While forests here are highly managed for pulp and timber, they are also subject to a number of competing and often conflicting uses. There is concern that the sustainability of ecosystem resources is already threatened by this intensive use and that future policy changes may be ineffective in maintaining resilience (34).

Part of the problem is the lack of an agreed structure to monitor the effectiveness of management strategies and questions about the efficacy of current monitoring protocols. One example comes from the availability of arboreal lichens, an important source of winter food for reindeer (*Rangifer tarandus*). Such lichens are plentiful within the canopies of older coniferous forests but are typically scarce or even absent in clearcuts and the young and medium-aged regenerating stands which characterize large portions of Lapland. A recent inventory of arboreal lichens conducted by one of the regional reindeer herding districts (35) found significantly fewer lichen resources than reported for the same areas by satellite survey. This is not surprising, given the scales of resolution of the different methods, but the fact that the lichen resources tend to be overestimated by satellite surveys, which form the foundation for the government's reindeer management policy, results in distrust of official statistics at the local level.

Lapland's ground lichens have also been greatly reduced in recent decades (36) through a combination of more intensive reindeer management and 'double' use (summer and winter) on some areas. This results in both winter consumption and summer trampling of lichens. This has been coupled with incremental encroachment on reindeer 'pasture' resources by diverse land uses such as forestry, hydropower, mining and tourism (34, 37). Here again, disagreement over the root causes of the problem, invariably characterized as 'overgrazing' with most of the blame attributed to the practices of the reindeer herders, means that long-term solutions are delayed or avoided while ecosystems continue to degrade under the synergistic effects of multiple and overlapping land uses (34, 38).

In Russia, renewable and nonrenewable resource management has been somewhat chaotic since at least the breakup of the Soviet Union, and arguably long before that. Fennoscandia presents a relatively benign situation by comparison, due to its economic and political stability since World War II, as well as a strong regulatory framework concerning environmental management. However, this can create a perception that the major problems are now behind us, and so threatening adaptive management. The aforementioned example of contemporary reindeer management points to the lack of cooperative management of natural resources in northernmost Europe. Co-

management is defined as a shared decision-making process, formal or informal, between a government authority and a user group for managing a species of fish, wildlife, or other resources. Ideally, co-management serves to incorporate elements of scientific and local or 'traditional' knowledge to sustain viable pools of resources that may, in turn, secure the livelihoods that depend on them. In practice, there are great difficulties in actually integrating the two types of knowledge (39), although there are instances in North America of different user groups and scientists each benefiting from information derived from the other source (40).

Russia

The high-latitude territories of Russia from the middle taiga to the High Arctic occupy more than half of the nation's land area but contain less than 6% of the country's population of 145 million. The boreal and arctic belt stretches for more than 6000 kilometers along the Arctic Ocean and spans distinct physiographic, biotic and socio-cultural provinces. These areas serve as homelands for about 185 000 persons from more than 30 indigenous nations of the so-called 'small numbered peoples of the North' (41). The immense mineral and renewable resources of the combined European and Siberian sectors predestine increasing anthropogenic pressure. Development of the resources has created not only specific anthropogenic drivers that influence the vulnerability and resilience of social-ecological system here, but has also contributed substantially to the Russian mentality and national character. The current state of socio-ecological systems in Russian high latitudes is a legacy of its previous history. A substantial part of European Russia, ca. 135 million ha, was transformed to agriculture from 1790 to 1914 (42). Major impacts were also manifest under the unique socioeconomic experiment during the Soviet era (1917–1991). Official policy of rapidly populating and developing remote northern territories led to significant transformation of the land *via* the spread of new industries (e.g. forestry, mining/smelting, petroleum development) and associated transportation infrastructure (roads, railways, powerlines, etc.). Even the collectivization of reindeer herding led to profound shifts in land management. The post-Soviet era of the last 15 years has also witnessed dramatic changes; the period of transition to a new political and economic organization of Russian society and the state. Yet, despite significant human impacts in select areas, the region as a whole still remains the least transformed area of the Northern Hemisphere.

Forestry

By one recent estimate, some 26% of world's remaining intact forest is in Russia, and a major part of these areas is situated in Siberia (43). About half of the logging during the 1950–1990s was concentrated in the European north (44). According to official sources, the Annual Allowable Cut, an ostensibly sustainable norm of harvest, has never been exceeded in the European north. Clearcut logging has been concentrated along roads in the most productive and commercially valuable stands (45), although cutting in the less productive forests of far northwest Russia has had a notable impact (46). Such 'local overharvest' was estimated to be 800 million m^3 during the 1960–1990s (45). At the same time, mitigation strategies were minimal or absent so impacts from the unregulated use of heavy machinery and melting of permafrost led to further ecological degradation on these lands. This practice substantially reduced the future prospects for, and commercial quality of, regenerating forests. The end results were often short-lived forestry enterprises with overall negative social consequences, such as abandoned settlements and roads, weak social infrastructure, and poor living conditions. After harvest and fire, less accessible stands were typically left to regenerate naturally. Over the last four decades about 15 million ha of coniferous forests have therefore been replaced, either by deciduous species that are generally not commercially utilized (47), or anthropogenic tundra (46). In a recent review of conditions at the northern forest-tundra ecotone, Vlassova (46) concluded that because of such anthropogenic pressures the forest border in many heavily developed regions had been displaced 40–100 km to the south since 1959. On the other hand, large areas of forest were also re-planted during this period, with a peak of 0.7 million ha yr^{-1}, and restored areas exceeded those of harvested or destroyed forests. This, as well as high natural regeneration capacity of boreal forests, resulted in a significant increase of forested areas in Russia (80 million ha), although a portion of this value must be attributed to more accurate inventories of remote northern forests (47).

The latest survey of forest tracts > 50 000 ha indicates that the northern regions of European Russia contain only one seventh of Russia's European forests. However, these comprise the last large, intact, forested landscapes of Europe; the major part of intact Russian forest landscapes remains in Asia with a total area of 289 million ha (47). Significant anthropogenic changes in the forests east of the Urals began only after the mid-19th century. At that time the state encouraged migration into, and transformation of, new lands for agriculture. Use accelerated rapidly in West Siberia and along the Trans-Siberian railroad. The colonization of these new territories was accompanied by an initial acceleration in the frequency of forest fire. Then, from 1961 to 1990 areas of burnt forests has decreased about twofold, in part due to official policies related to the protection and re-planting of forests. Thus, in spite of serious shortcomings in forest exploitation during the last four decades of the Soviet era, overall forest governance was rather satisfactory (47). More recent increases in the amount of northern forests burned annually are attributed partly to climate change (14, 48).

The heavy economic and social crisis of the last 15 years has significantly affected life all across Russian society, but the most serious decline has been observed in high latitude regions. Apart from the recent surge of foreign investment in the petroleum industry (24), financing and intensity of exploration of most natural resources had decreased nearly tenfold. In particular, the Soviet-era forest industry was diminished *via* outmigration, and neglect and abandonment of infrastructure, such as logging roads. The production of wood products dramatically decreased over the entire country. In 1998, timber and pulp harvests were ca. 22.0% of those in1988 (49). Vulnerability is highest in remote forest settlements where logging and forestry-related employment are the main sources of livelihood.

As in the Far North, outmigration from forestry-based communities generates social problems for those who remain behind. Residual populations, including many elderly, disabled and unskilled labourers, rely on the surrounding ecosystems as major sources for their survival: fishing, hunting, gathering berries and mushrooms, and vegetable gardens (towards the south). Illegal harvesting of hardwood forests and poaching of wildlife and privately or state-owned semi-domestic reindeer herds are believed to occur over large regions, although there are no reliable statistics on these practices (50–52). The strongest reductions in human population have been reported in the northernmost administrative regions of Russia. According to official data, in 1990–1995 population declines ranged from 8–9% in Murmansk Oblast and Sakha Republic to 40.7% in Kamchatka.