Recent Changes in Vegetation

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Vegetative Boundaries

In northern latitudes, there is a series of vegetation and plant life form boundaries that are associated with temperature (Figure 1). They generally move northwards as climate becomes warmer although advance is not expected to be uniform, in part due to differences in individual species response. The latitudinal treeline is the most obvious one, and is associated with the isotherm for July mean monthly temperature of about 11° C. North of this boundary, one finds the shrubline, and further north, the tundra becomes completely devoid of woody plants. Along this latitudinal gradient, the height of the vegetation decreases, the complexity of the plant canopy is reduced and the biodiversity generally decreases. There also tends to be a decrease in the carbon annually captured by photosynthesis and an increase in albedo (i.e. the incoming solar radiation reflected from the land surface). As the latitudinal distribution of plant life forms are associated with climate, vegetation zone dynamics and shifts in their composition are considered one of the major processes that will respond to a warming Arctic (Callaghan et al., 2004a).

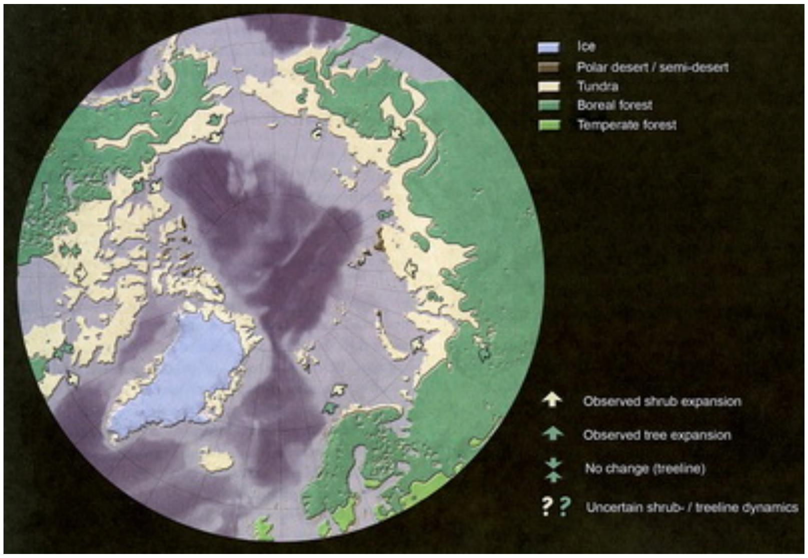

Figure 1. Observed arctic vegetation dynamics (modified from Kaplan et al., 2003 and Callaghan et al., 2005).

Recent vegetation dynamics observations across the Arctic show that, in general, shrubs have become more abundant and taller. A study in northern Alaska (Tape et al., 2006) showed that both larger and smaller shrub species have increased in size, abundance and extent over the last 50 years. As well as increasing in size and filling in empty patches, the shrubs were colonizing new areas (Figure 2). Results do vary regionally. For instance, Shvartsman et al. (1999) pointed to a decrease in shrubs along the Pechora River in western Russia (66.1° N, 57.1° E) between 1960 and 1983, a change they attributed to an increase in trees. Preliminary results from Lantz & Henry (unpublished data, Tape et al., 2006) showed a recent expansion of the shrub cover on the Canadian Mackenzie River delta (69.1° N, 135.1° W). In the Northwest Territories (65.1° N, 111.5° W), P. Grogan (personal communication, 2005; Tape et al., 2006) observed an increase in shrubs on floodplains and stream channels, whereas in Labrador (58.1° N, 72.1° W), Payette (2006) found that alder had increased in conjunction with a northward migration of the treeline.

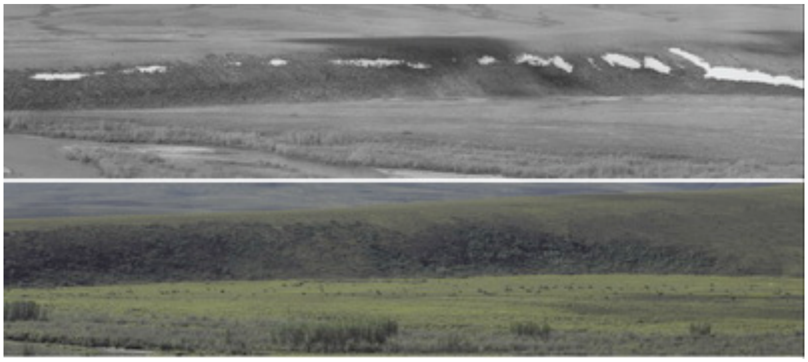

Figure 2. Large shrubs have colonized a river terrace that was virtually free of large shrubs in 1949. The new shrubs are more than 2 m high. In the foreground are poplar trees. Photo from the Chandler River located at 68° 25.14' N, 161° 15.24' W: 7/4/1948 and 7/29/2001. (Tape et al., 2006).

Other evidence of widespread change of vegetation in the tundra regions come from trends in tundra greenness as detected by satellites. The Normalized Difference Vegetation Index (NDVI) is a measure of greenness derived from reflectance of the surface in the red and near-infrared channels. If the climate warms, higher NDVI values might be expected to shift northward. Earlier global studies of NDVI changes indicated a general pattern of increased NDVI in the region between 40-70° N during the period 1981-1999 (Myneni et al., 1997, 2001; Zhou et al., 2001; Lucht et al., 2002). Stow et al. (2004) noted the largest NDVI increase for the period 1982-1999 in northern Russia (north of 65° N, between 70 and 140° E), the North Slope of Alaska, and parts of northern Canada and Scandinavia. Studies of the NDVI in the tundra area of northern Alaska indicate an increase of 17% in NDVI values in this region. A follow-up to this study shows linear trends in Arctic tundra vegetation greenness over the period 1982-2005 as positive over Eurasia (Yamal) and North America, as observed with NOAA AVHRR satellite. Although general trends of greening were observed, there are different magnitudes between the tundra biome in Eurasia and North America. For instance, in the region south of 70 degrees north, the rate of change is +0.58%/yr over the North American Arctic compared to +0.34%/yr over the Yamal Arctic.

More recent studies based on the 1981-2005 AVHRR record show that there is not a simple linear positive trend in NDVI across all of the North corresponding to warmer temperatures (Goetz et al., 2005, Bunn et al., 2007). Eighty-eight percent of the northern high latitudes show no significant deterministic trend in satellite-derived NDVI values. Nine percent of the areas show increased NDVI, while 3% indicate a decline. In the forested areas, 6% of the areas show a decline while 4% indicate an increase; whereas, in the tundra and other shrubby areas, 1% show a decline, while 6% reveal an increase in NDVI. The increasing NDVI values in the tundra areas is thought to be primarily caused by increasing density of shrubs, while the decline of NDVI in the forested areas is attributed to increased moisture stress (Bunn et al., 2007).

Treeline dynamics are also complex. Although most arctic areas report a recent advance of this vegetation boundary, there are considerable inertia effects in some areas. For example, a broad-scale study by Lloyd (2005) revealed a treeline advance occurring throughout three separate regions of Alaska. Although treeline advance was detected at all locations, the timing of the advance varied by more than a century among regions. Besides timing, the spatial scale of the advance also varied among sites.

Several large scale studies in northern and eastern Canada making use of both macro-fossil tree remains and remote sensing data, revealed a long-term stability of the treeline ecotone during the past 2000-3000 years (Lavoie & Payette, 1996; Masek, 2001; Payette, 2006) (Figure 1). Recently, the treelines in the forest-tundra areas of Quebec have risen slightly either through establishment of seed-origin white spruce *Picea glauca* or through height growth of stunted spruce already established on the tundra hilltops. However, invasion of tundra and alpine areas by trees occurred only gradually and seems seriously hampered by local topographic factors as well as by harsh wind-exposure conditions (Gamache & Payette, 2005; Payette, 2006; Caccianiga & Payette, 2006).

In western Canada, which is experiencing a similar warming and prolonging of the growing season as Alaska (Chapin et al., 2005; Stafford et al., 2000), white spruce is currently invading the southern exposed alpine areas, but north-facing slopes have only experienced a densification (+40 - 65%), (Danby & Hik, 2007), fig.1.

Recent-most investigations in northern Europe report a significant sprouting of seedlings and saplings high above the treeline (Kullman, 2002; Löffler et al., 2004; Dalen & Hofgaard, 2005; Kullman & Kjällgren, 2006; Truong et al., 2007; Van Bogaert, unpublished data) as well as important treeline ecotone densification processes (Tømmervik et al., 2004; Hållmarker, 2002; Figure 1). In the southern Swedish Scandes Mountains (63.1° N, 12.2° E), the mountain birch treeline (*Betula pubescens* ssp. *tortuosa*) rose on average by about 75 m in elevation during the last century (Kullman, 2001, 2002, 2003), while in northernmost Europe (Sweden) the altitudinal increase rate of the treeline is estimated on 0.5 m yr^{-1} or 40 m per °C summer temperature increase (Callaghan et al., 2004b; Figure 3). However, Dalen and Hofgaard (2005) studied recent treeline conditions across northern Europe and came to the conclusion that regional differentiation needs to be considered. In the southern and northern Scandes mountains (Dovre 62.2° N, 9.4° E; Abisko 68.3° N, 18.9° E resp.) the treeline was in a rejuvenating and possibly expanding state, while in northernmost Europe (Finnmark, Norway 69.7° N, 24.0° E) a receding treeline was observed. Most likely the latter observation is related to a decrease in the length of the growing season due to higher winter precipitation (Høgda et al., 2001) and a higher number of reindeer (Ims and Kosmo, 2001).

Figure 3. Forest growth in northern Sweden between 1906 (top) and 1986 (Emanuelsson, 1987). Attribution is difficult: temperature has increased but land use has also changed. The Sami camp in the early 20th century no longer exists and the intensity of land use has decreased.

During the past century, considerable treeline shifts have been reported from the Russian sub-arctic. Both southern and Polar Ural mountain areas have noted a rising treeline within the past century: 60 to 80 m, and 20 to 40 m respectively (Moiseev & Shiyatov, 2001, 2003; Shiyatov et al., 2005). The forested area in northeastern European Russia (Katenin, 2004; personal communication, 2007) and the world's northernmost forest range of Ary-Mas in northwest Siberia have also expanded displacing tundra patches at a rate of 3-10 m per year (Kharuk et al., 2006). Even though data from Russia are still rather scarce and inaccessible (Figure 1), there is also knowledge about contrasting dynamics. For instance, Lapenis et al. (2005) found that during the past 50 years the fraction of leaves and needles has decreased in the vast northern taiga zone of Siberia, where the climate has become warmer, but drier. Additionally, Russia is rather densely populated at the tundra taiga transition zone, causing some large-scale southward treeline recessions due to human activities (Vlassova, 2002). Therefore, attribution is complex and uncertain, and is likely to change from location to location.

Fire and insect outbreaks are inherently connected to the boreal forest and changes in these regimes may alter forest type, structure and extension dramatically (i.e. McCullough et al., 1998; Stocks et al., 1998; Karlsson et al., 2004; Tenow et al., 2004; Juday et al., 2005). Additionally, since the 1950s, growth responses of treeline trees to climate seem to diverge more and more (Lloyd & Fastie, 2002; Wilmking et al., 2004, 2005; Driscoll et al., 2006; Pisaric et al., 2006) challenging both our understanding of climate change responses and climate reconstructions.

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