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Interactions between macroclimate, microclimate, and anthropogenic disturbance affect the distribution of aspen near its northern edge in Quebec: Implications for climate change related range expansions

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ABSTRACT

Policy to address the shifting tree species distributions anticipated in coming decades requires a sound understanding of how forests respond to environmental change. Using a combination of remote sensing, geographic information systems (GIS) analysis, and ground-based techniques, we explored the environmental factors associated with the distribution and abundance of trembling aspen (*Populus tremuloides* Michx.) across regional gradients near its northern range limit in northwestern Quebec, Canada. Although not regionally abundant, aspen is the main deciduous tree species in this conifer-dominated landscape. Regionally, the ~51,200-km^2 study area has very few settlements or roads, and little industrial resource extraction. Most of the region is inaccessible to humans except by foot or water travel. We utilized Landsat Thematic Mapper images from 2010 and 2011, and a robust collection of ground reference data developed from aerial photography, supported by field verification (vegetation sampling) where access permitted, to construct a thematic map of 11 land cover classes. The map highlights the spatial distribution of aspen, which represents only 0.3% of the study area. Map validation indicated an overall mapping accuracy of 74%, and the aspen predicted class was determined to be over 77% accurate. The regional-scale distribution of aspen stands ⩾0.5 ha within the study area shows two patterns: (1) a shift toward greatest abundance on south-facing aspects with increasing latitude; and (2) a highly clustered pattern with a strong signal of concentration in areas of human activity. These patterns suggest that aspen range expansion due to climate warming will vary with topographic and other microclimatic factors (i.e. be a function of climate change interacting with landscapes) and that anthropogenic activities have the potential to influence future aspen abundance independently of climate. Forest management policies concerned with changing forest composition in these northern landscapes should recognize the potentially important role of human activity in driving the abundance of aspen.

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1. Introduction

With growing evidence that climate change is substantially affecting forest processes, structure, and function, determining appropriate responses to such issues is increasingly critical, and rests on the ability to predict how different tree species will respond to future climates over the entire range of their distributions (Potter et al., 2013). While models have generally used coarse-scale climatic data to predict future distributions, increasing attention has been paid to the importance of microclimatic factors in determining species' responses to environmental change (Gillingham et al., 2012; Potter et al., 2013; De Frenne et al., 2013; Harwood et al., 2014). As Potter et al. (2013) point out, our ability to predict future distributions will be significantly enhanced by understanding how species respond to fine-scale environmental variation as well as that occurring over larger spatial scales.

Trembling aspen (*Populus tremuloides*; hereafter referred to as aspen) is the most widely distributed tree species in North America. Aspen is exceptionally successful at adapting to different habitats, growing in a wide range of climates and soils, and playing ecological roles from aggressive pioneer to self-replacing climax species (Perala, 1990). This wide distribution and ecological amplitude

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make aspen useful as model species to demonstrate how local factors such as topography, landform, natural disturbance and human activity may interact with each other and with larger scale factors to determine species distribution at regional scales. This is particularly true in the largely intact boreal region of western Quebec (Ricketts, 1999), where aspen grows close to its northern range limit, climatic variation may have strong ecological effects, and human disturbance is sparse, reducing confounding factors that may obscure underlying dominant forces driving observable patterns across landscapes (Parmesan and Yohe, 2003).

Aspen has been identified as a keystone species in many parts of its range, and is an important feature of conifer-dominated boreal forest (Hustich, 1966; St. Clair et al., 2013). Aspen presence is a significant driver of biodiversity (Cavard et al., 2011). Considering that northern Canada is predicted to experience considerable warming (Johnston et al., 2009), studies of aspen populations near their northern distributional limits can help inform modelers and decision-makers about the factors contributing to successfully established northern populations of aspen.

Populations of trees near their range edges generally consist of scattered individuals and stands with depressed vigor that are often more vulnerable to environmental stressors than are those in the center of their range (Hoffmann and Blows, 1994; Gaston, 2003, 2009). However, contrary to this common pattern, trembling aspen occurs in uncharacteristic abundance near the northern edge of its range in the area east of James Bay in western Quebec, Canada (Parisien and Sirois, 2003). This unusual distribution presents an opportunity to investigate range-boundary related determinants of distribution and abundance for a tree species of significant economic and ecological importance using a multiple-scale approach (Bartos, 2000; St. Clair et al., 2013).

In general, the abundance of deciduous trees decreases markedly from the south toward colder climates in the north (Brown et al., 1996). For aspen in Quebec we have a general idea from Payette (1993) and others (Little, 1971; Foster and King, 1986; Ritchie, 2004) that the greatest abundance occurs in the southern part of the boreal forest (~48°N latitude), although extensive stands can occur as far north as 52°N latitude, particularly around southern James Bay. Aspen's northern boundary in Quebec approximates the 13 °C July isotherm near the forest-tundra ecotone (Halliday and Brown, 1943; Hustich, 1966; Maini and Cayford, 1968), with small isolated stands occurring as far north as 56°N latitude in Quebec (Ritchie, 2004). The modeled maximum northward extent in western Quebec is reported to be between 55°N latitude (Chuine and Beaubien, 2001; Worrall et al., 2013) and ~58°N latitude (Morin et al., 2007), however, aspen's realized distribution and abundance in the northern part of its range in western Quebec remains unclear due to the remoteness and inaccessibility of the region (Ritchie, 2004). In addition, given changing climate, the latitudinal envelope in which deciduous trees decline in abundance and exhibit other signs of climatic stress is uncertain and in flux.

Although the effect of latitude on temperature regimes clearly plays an important role in the distribution of boreal deciduous trees, the relationship is not simple. For example, extensive young aspen stands occur in the Old Factory Lake (OFL) watershed (52.8°N latitude), where the terrain changes from relatively flat to rolling hills with large rock outcrops. OFL is approximately 500 km north of the species' center of abundance in Quebec, and is near the transition from closed forests to lichen woodlands (Payette, 2001). The majority of aspen stands in the OFL watershed are regenerating from a major fire in 1989 (Lavoie and Sirois, 1998), but include small clusters of 75–85 year old (30–40 cm diameter at breast height) aspen trees, presumably established following a previous fire. The oldest aspen core collected and dated from the study area was 114 years old. The older stands in OFL watershed appear to be well-established, productive historical forests. Despite being near their northern range limit, they are not sparse peripheral populations, nor are they new populations that have established following construction of the highway in 1971 (Salisbury, 1986).

The presence of robust aspen stands near the species' presumed northern boundary raises questions about what factors other than regional climate may be influencing the distribution and abundance of aspen. Topographic influence is suggested by the aspen stands in the OFL area. Topographic complexity may play a role through providing warm microsites with direct effects on aspen growth (Landhäusser and Lieffers, 1998) and indirect effects on the movement, intensity, and landscape pattern of fire (Foster, 1983; Heinselman, 1996) – all of which affect vegetation composition (Foster et al., 1998). Human-caused disturbances such as road construction and forest management practices that expose mineral soils have been associated with aspen expansion (Fortin, 2008; Landhäusser et al., 2010; Laquerre et al., 2009).

The objectives of this study were to (1) document aspen's current distribution across a latitudinal gradient in the northwestern boreal forest of Quebec, and (2) determine the degree to which patterns that can be linked to local factors are expressed in the regional distribution. We hypothesized that the three main factors controlling the abundance of aspen in that area are macroclimate, microclimate, and anthropogenic driven disturbance. Based on these hypotheses we expected to see (1) aspen abundance decrease systematically with increasing latitude, (2) aspen more strongly favoring warmer microclimates with increasing latitude, and (3) a spatial correlation between aspen abundance and landscape features associated with human activity.

2. Methods

2.1. Study area – James Bay area

The James Bay area, as defined by our study boundaries, occupies an area of ~51,200 km^2 in the northern boreal forest zone of western Quebec from 76.5°W to 79.1°W longitude, and 51.1°N to 53.9°N latitude (Fig. 1). It lies within the Taiga Shield East Ecozone (Brandt, 2009). Situated in the Canadian Precambrian Shield, the underlying rock is granite and gneiss (Stockwell, 1970), and the soils are typically podzolic on mesic sites, with organic fibrisols in the poorly drained areas (Ritchie, 2004). Bedrock geology has a strong influence over many of the landscape characteristics such as relief, surface roughness, drainage pattern, vegetation pattern, and soil development because large areas of the shield are exposed, with little or no mantle of unconsolidated materials (Ritchie, 2004).

The area is affected by cold, dry arctic air from the north during the winter and by warm, moist air originating from the south during the summer; these result in long and cold winters and short and warm summers. Less than 10% of the study area contains isolated patches of permafrost (Heginbottom et al., 1995). The mean annual temperature ranges from −1 to −3 °C from south to north (Environment Canada, 2002), with little to no east–west temperature gradient within the study area (NOAA/ESRL, 2014; Kalnay et al., 1996). In the south, the average growing season lasts 140 days with 1100 degree-days ⩾ 5 °C as compared to 120 days and 600 degree-days ⩾ 5 °C in the north (Environment Canada, 2002). Total precipitation varies from 868 to 684 mm from south to north, with about one-third falling as snow (Hutchinson et al., 2009). It is important to note here that there is only one weather station (La Grande Rivière station) with enough weather data to obtain interpolated-based climate estimates (30 years or more) for the study area; most weather stations in the area have less than 10 years of weather data (Rapaic et al., 2012). Huang et al. (2010)