Forest Ecology and Management 339 (2015) 34–43

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

The development of universal response functions to facilitate climate-smart regeneration of black spruce and white pine in Ontario, Canada

Jing Yang[a], John H. Pedlar[b,*], Daniel W. McKenney[b], Alfons Weersink[a]

[a] Dept of Food, Agricultural and Resource Economics, University of Guelph, Guelph, Ontario N1G 2W1, Canada
[b] Canadian Forest Service, Great Lakes Forestry Centre, 1219 Queen Street E., Sault Ste. Marie, ON P6A 2E5, Canada

ARTICLE INFO

Article history:
Received 3 September 2014
Received in revised form 12 November 2014
Accepted 2 December 2014
Available online 19 December 2014

Keywords:
Climate change
Seed deployment
Seed procurement
Universal response function
Black spruce
White pine

ABSTRACT

Climate change is expected to impact forest growth and survival as tree populations experience climates to which they are not well adapted. However, forest regeneration efforts represent opportunities to introduce genetic material on the landscape that is well matched to future climates. We estimated universal response functions (URF) for two economically and ecologically important tree species in eastern Canada – black spruce (*Picea mariana*) and eastern white pine (*Pinus strobus*). The URF approach models tree growth as a function of both the planting site climate (*i.e.*, environmental effects) and seed source climate (*i.e.*, genetic effects), allowing the growth of any seed source to be estimated at any location. Both species exhibited a relatively weak genetic effect, suggesting modest potential for seed movements to mitigate climate change impacts. The optimal provenance for any given location was not local, but rather located in environments that were approximately 1.5 °C warmer than the planting site; this shift is consistent in both direction and magnitude with that expected due to climate warming since the start of the industrial revolution. Both species exhibited a strong environmental effect with clear evidence for a central climatic optimum. As a result, climate warming is expected to enhance black spruce growth at sites with mean annual temperature colder than approximately 4.5 °C and white pine growth at sites colder than 11 °C. Thus, Ontario white pine populations may benefit from the climate changes projected to occur in the province over the next 50–100 years. For black spruce, populations in southern and central Ontario may experience suboptimal climate conditions over the mid-to-end of the current century. Despite the relatively weak genetic effect, climate-smart seed movements could play a role in maintaining the productivity and genetic diversity of black spruce in these areas. While the URF approach has limitations, this work demonstrates its potential for informing regeneration decisions under climate change.

1. Introduction

Tree species often exhibit adaptive genetic variation along climatic gradients or clines (Morgenstern, 1996 and Rehfeldt et al., 1999). For example, Lu et al. (2003) reported significantly higher cold tolerance in white pine populations from northern Ontario as compared to those from southern Ontario. Similarly, black spruce populations from northern Quebec set their buds in fall at an earlier date than southern populations (Beaulieu et al., 2004). Such variation allows populations to survive and grow well under local climate conditions; however there are also instances in which regenerative materials have shown optimal growth under climatic conditions that differ from their site of origin (*e.g.*, Thomson and Parker, 2008).

Given these strong ties to climate, it is expected that recent and anticipated climate change will have impacts on forest growth and survival. In the long term, species may be able to adapt and migrate in response to climate change, but in the short term locally adapted populations are likely to experience climates to which they are not well adapted (Matyas, 1994, Wang et al., 2006; Leites et al., 2012 and Williams and Dumroese, 2013). Therefore, seed deployment and procurement strategies that are part of a long-term, sustainable reforestation plan may need to be modified to ensure plantations are well matched to future climates (Wang et al., 2006, 2010) while minimizing current risks.

Provenance studies, in which parent material from a range of geographic and climatic origins (or provenances) are grown at one or more planting sites, provide valuable information on patterns of forest genetic variation in relation to climate (Morgenstern, 1996). Here we use the term population to refer to a set of intermating individuals that live in the same area and the terms provenance and seed source to describe the geographic

* Corresponding author.
E-mail addresses: jyang06@uoguelph.ca (J. Yang), John.Pedlar@NRCan-RNCan.gc.ca, john.pedlar@nrcan.gc.ca (J.H. Pedlar), Dan.McKenney@NRCan-RNCan.gc.ca, dan.mckenney@nrcan.gc.ca (D.W. McKenney), aweersin@uoguelph.ca (A. Weersink).

http://dx.doi.org/10.1016/j.foreco.2014.12.001
0378-1127/

and climatic origin of a forest tree population (Morgenstern, 1996). The approaches used by forest geneticists to analyze and summarize provenance data have evolved over time. Simple response functions typically employ a quadratic function to model the relationship between a measured provenance characteristic (*e.g.*, height growth) and climate (*e.g.*, mean annual temperature) – thus illustrating how a given population grows across a range of conditions (Rehfeldt et al., 1999; Wang et al., 2006 and Thomson and Parker, 2008). Alternatively, a simple transfer function shows how a selection of seed sources grow at a particular site (Matyas, 1994; Carter, 1996 and Rehfeldt et al., 1999). These approaches are limited in that they summarize information for only a single seed source or planting site. To address this limitation, transfer functions have been pooled across planting sites to provide insights into seed movements across the range of a species (Rehfeldt et al., 2003 and Andalo et al., 2005). However this approach assumes that all populations respond similarly to climate transfers, which is often not the case. Wang et al. (2010) developed a universal response function (URF) which models provenance growth as a function of both the planting site climate (*i.e.*, environmental effects) and seed source climate (*i.e.*, genetic effects). The URF model allows forest growth in current and future climates to be predicted for any population in any location as a function of the climates at the planting sites and provenance sites, effectively combining the transfer function and response function into a single model.

Here we develop URFs for two economically and ecologically important tree species in eastern Canada – black spruce (*Picea mariana*) and eastern white pine (*Pinus strobus*). For this effort, we employ range-wide provenance data from trials established over several decades by various research organizations. This is one of the first studies to apply the URF approach to tree species in eastern North America and our findings should provide valuable information to forest managers regarding seed movements of these important forest species under climate change.

2. Methods and materials

2.1. Description of provenance and climate data

Black spruce provenance data was obtained from remeasurements on a portion of the Canadian Forest Service's (CFS) long-term black spruce provenance trial, which originally incorporated 202 populations across 34 test sites in Canada and the United States (see Selkirk, 1974 for details). The remeasurements were carried out in 2003 (33 years of age from seed) and involved measuring height and DBH of all surviving trees at each test site (see Thomson et al., 2009 for details). In total, 192 provenances at 18 test sites in Canada and one test site in Minnesota were measured (Fig. 1). Mean height values for each provenance at each test site were generously provided by Dr. William Parker at Lakehead University.

White pine provenance data were obtained from two sources. The first was a provenance trial initiated by the United States Department of Agriculture (USDA) in 1955 at 13 test sites in the northeastern United States and two in Ontario, Canada (see King and Nienstaedt, 1969 for details). Regional remeasurements of these test sites were reported at age 16 for 10 test sites in the northeastern U.S. (Demeritt and Kettlewood, 1976); at age 16 for three test sites in Maryland (Genys, 1983, 1987); and at age 28 for two test sites in southern Ontario (Abubaker and Zsuffa, 1990). The second source for white pine data was a provenance trial initiated by several cooperating agencies in 1964 (Wright et al., 1979). This trial included 41 seed sources from the southern Appalachian region that were planted at one or more of 11 test sites located between 37.1 and 44.5 °N and 79.7 and 95.9 °W. Height growth was measured at ages ranging from 7 to 11 years depending on the test site (Wright et al., 1979). In total, information for 26 test sites and 195 provenances were obtained from these studies (Fig. 2).

For white pine, height measurements needed to be standardized to a consistent age before using them to develop a URF. To do this, we employed published height-age equations that were developed in the same geographic region as the test site being standardized. For example, for each provenance and test site reported in Abubaker and Zsuffa (1990), we substituted the height and age values measured at 28 years of age into a height-age equation for white pine in Ontario (Payandeh, 1991) and solved for site index. This metric indicated how well a seed source was growing at a site and identified a trajectory through time for that seed source. Once the site index for each provenance at each test site was determined, that site index value was substituted into the height-age equation and the equation was solved for 16 years of age (see

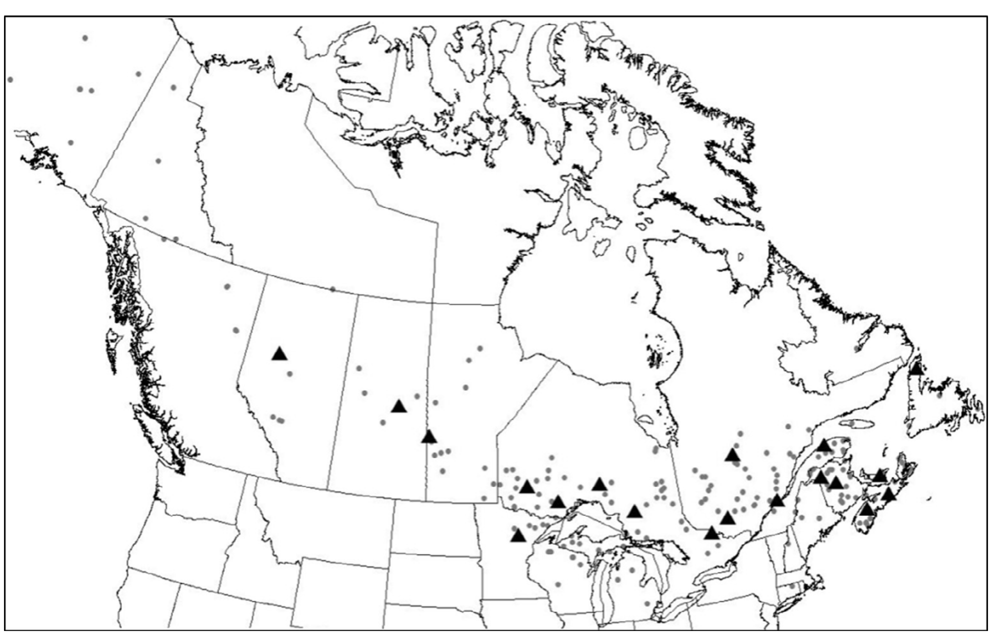

Fig. 1. Location of the black spruce planting sites (black triangles) and provenances (gray circles) used in the current study.