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Understanding spatial and temporal Douglas-fir fertilizer response in the Pacific Northwest using boosted regression trees and linear discriminant analysis

K.M. Littke[a,*], J. Cross[b], R.B. Harrison[a], D. Zabowski[a], E. Turnblom[a]

[a] University of Washington, School of Environmental and Forest Sciences, Box 352100, Seattle, WA 98195, United States
[b] Stand Management Cooperative, Box 352100, Seattle, WA 98195, United States

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ABSTRACT

Fertilizer response of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantations can vary considerably throughout the Pacific Northwest due to differences in soil and site productivity. In this study, we calculated significant two-, four-, and six-year cumulative volume growth response per tree due to urea fertilization on 71 Douglas-fir installations using a paired *t*-test. To understand the biogeoclimatic factors affecting fertilizer response, climate, location, soil, and productivity predictor variables were used in boosted regression tree (BRT) and linear discriminant (LDA) analyses to produce models that could predict significant regional response to fertilization. The ability to predict significant volume response decreased with time since fertilization (71–37% from 2 to 6 years), yet installations that were predicted to respond in all years of BRT models had similar response to significantly responding installations (> 5000 cm^3/yr). The most common predictors of volume response in both model types and all measurement periods were high elevation (> 400 m), low-moderate site index (< 42 m at 50 years), and cold winter temperatures (< 4.4 C). The Oregon (OR) Klamath Mountain region contained the greatest coverage of predicted volume response. The Middle Cascade Mountains also had large areas predicted to respond, but in this study OR installations responded better than Washington (WA) installations. The Coast Range, Olympic Mountains, Puget Trough, and Northern Cascade Mountains were predicted to have very little response. This study demonstrates the spatial relationships between climate, soil, and productivity variables that indicate fertilization response across the coastal Pacific Northwest.

1. Introduction

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is native to the Pacific Northwest and is the most-commonly utilized forest plantation species across the region (Franklin and Dyrness, 1988). It grows on many of the diverse soil types within the region, but with varying levels of productivity due to distinct soil parent materials with different soil depths, textures, and nutrition (Steinbrenner, 1979; Miller et al., 1989; Turner et al., 1979; Kruckeberg, 1991; Littke et al., 2011; Littke et al., 2014a; Littke et al., 2016).

The maritime climate of the Pacific Northwest yields a dry, warm summer, but with variation from north to south and west to east (Franklin and Dyrness, 1988). Along with differing water availabilities in the region, there are large differences in soil nitrogen (N) (Littke et al., 2014a). Previous observations of relationships between soil N and response to fertilization in the Pacific Northwest suggest that N is the most limiting nutrient and is predictive of inherent forest productivity. For example, forest floor and soil carbon to nitrogen (C:N) ratio (Peterson et al., 1984; Edmonds and Hsiang, 1987), soil mineralizable N (Shumway and Atkinson, 1978), total soil N content (Hopmans and Chappell, 1994), and foliar N concentration (Turner et al., 1988) have all been used to predict response to N fertilization with some success. Also, an ability to locate forests with low soil N availability is important for forest plantation management in order to improve and sustain forest productivity (Powers et al., 2005).

Although prediction of fertilizer response through site and soil variables has been investigated in the Pacific Northwest in the past, only around 50% of fertilizer response variation has been explained by these models (Peterson et al., 1984; Edmonds and Hsiang, 1987; Turner et al., 1988; Miller et al., 1989; Carter et al., 1998). Boosted regression tree models (BRT), a combination of machine learning and regression tree models, were used in Littke et al. (2014b) for predicting fertilizer

* Corresponding author.
E-mail address: littkek@uw.edu (K.M. Littke).

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response with similar variables as in previous research and were able to explain more of the variation in fertilization response and over a larger area than in previous investigations (Edmonds and Hsiang, 1987; Miller et al., 1989).

BRT models are usually formed with binomial data and allow prediction of areas with favorable species distributions (Leathwick et al., 2006; Elith et al., 2008). To avoid overprediction in BRT models, it is recommended to use stochastic sampling, which results in slightly different results with each model run and difficulties in transferring models and results for other uses. In contrast, linear discriminant analysis (LDA), which also uses binomial data, produces a much simpler model that analyzes the behavior of both the responders and non-responders, rather than explaining the behavior of responders alone. The results from LDA models have the potential to better capture the different predictors affecting responders and how they differ from non-responders.

The objective of this research was to compare the BRT and LDA model statistics and outputs for two, four, and six year cumulative fertilizer response in Douglas-fir plantations. The model outputs will then be examined spatially over the Pacific Northwest to identify regions with the potential for fertilizer response.

2. Materials and methods

2.1. Site description

Beginning in 2008, the University of Washington Stand Management Cooperative, a cooperative of forest product companies, universities, and government agencies, installed paired-tree installations (blocks) in 71 Douglas-fir plantations extending from northern Vancouver Island to southern Oregon to characterize site and soil characteristics that might predict Douglas-fir response to fertilization (Fig. 1). Installations were established over four years on a range of physiographic regions (USGS, 1946), latitudes, longitudes, elevations, and slopes based on availability from government agencies and forest product companies (Table 1).

Each installation covered 1.1 hectare and contained 24–48 plot-tree Douglas-fir on a 15-m grid (Littke et al., 2014c). Plot-trees were individual dominant or co-dominant Douglas-fir surrounded by a 5-m radius treatment area (81 m^2). Plot centers were skipped if the understory changed species changed, if the overstory was dominated by species other than Douglas-fir, or if the slope or aspect changed in the stand. Before treatment, each plot-tree was measured for diameter at

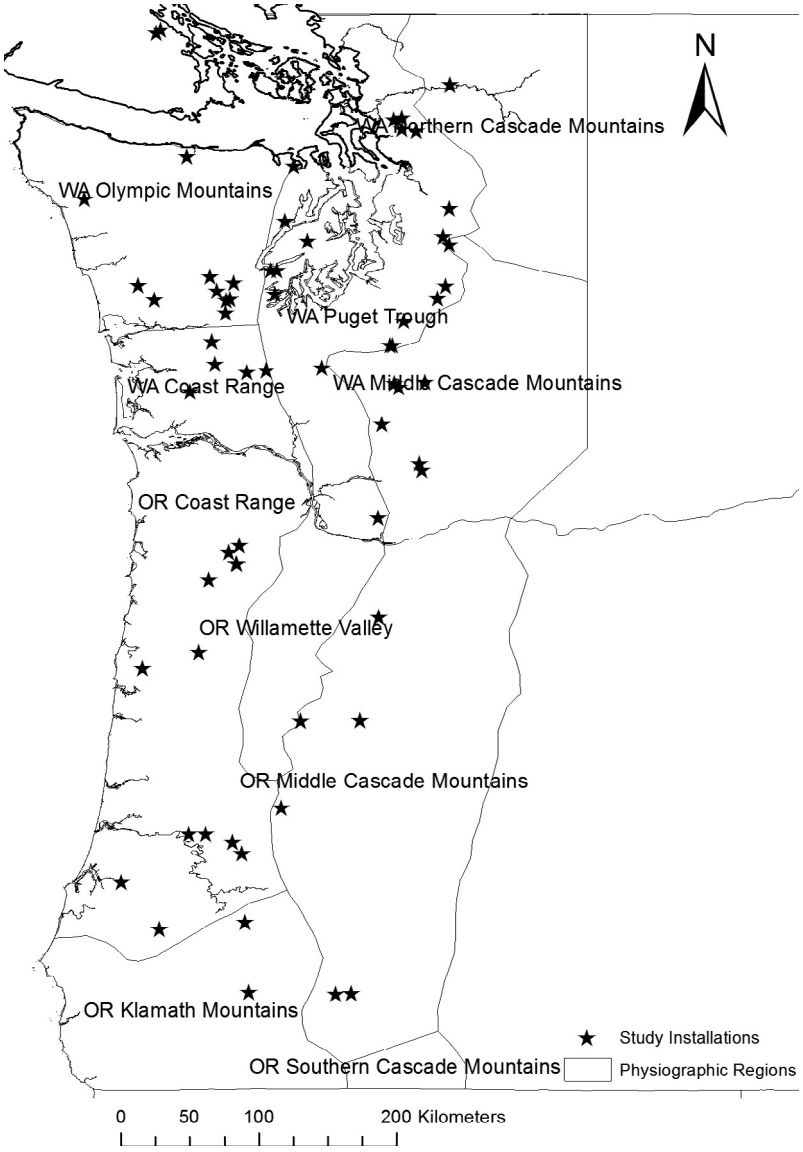

Fig. 1. Location of Stand Management Cooperative paired-tree fertilization installations in the Pacific Northwest. Physiographic regions are shown to describe regional differences in climate and fertilizer response (USGS, 1946).

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