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Development and assessment of regeneration imputation models for National Forests of Oregon and Washington

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ABSTRACT

Imputation models were developed to predict seedling regeneration density and composition on National Forest System (NFS) lands in Oregon and Washington. The models were based on Forest Inventory and Analysis and Pacific Northwest Regional NFS Monitoring data. Individual models were developed based on broad forest plant association groups (FPAGs) with all model development and analysis conducted in R using a most similar neighbor-like imputation approach. Model performance was evaluated based on bias, mean absolute deviation, root mean-squared error (RMSE), and error rate in correctly predicting the total presence or absence of any regenerating species regardless of species (Total ER). Low to moderate RMSE ($\leq$7400 regeneration stems ha^{-1}) and low to moderate Total ER ($\leq$50%) were observed for 25 out of 58 FPAG-specific models. The regeneration imputation models produced in this study represent a large first step towards developing flexible, expandable, and adaptable regeneration models that can be easily incorporated into existing growth models like the Forest Vegetation Simulator.

1. Introduction

Seedling regeneration processes are integral components of forest stand dynamics and recovery following disturbance (Oliver and Larson, 1996, Crotteau et al., 2014) and can have significant influence on the outcome of growth model simulations, especially in forests dominated by natural regeneration (Weiskittel et al., 2011). Managers use these growth models to evaluate the potential effects of alternative treatments and these models are especially useful when site-specific information concerning treatment effects is lacking or unknown. However, not all growth models include regeneration components and many often leave this component to the user to provide as an input over time (Weiskittel et al., 2011). One reason for the lack of a regeneration component is that seedling regeneration (hereafter "regeneration") is stochastic in nature and influenced by a wide variety of factors, many of which are not easily measured or observed (Weiskittel et al., 2011). It has also been noted that accurate prediction of regeneration can be complicated in areas composed of multiple tree species, numerous age cohorts, or with high structural complexity (Oliver and Larson, 1996, Ek et al., 1997). This is particularly true for the Forest Vegetation Simulator (FVS; Dixon, 2013), which is the standard growth model used by the US Forest Service and many other agencies throughout the United States and Canada.

The US Forest Service has developed regional variants of FVS across the United States and other organizations have developed regional variants for Canada (e.g., Lacerte et al., 2006). Yet, while FVS has become the growth model of choice for many public land managers, particularly federal land managers in the western Unites States, tools for automating natural regeneration remain limited or absent within the modeling process. At present, introducing natural regeneration automatically into an FVS simulation is only available for two geographic variants. For regional variants which cover the Northern Rocky Mountains, a model developed by Ferguson et al. (1986) and later extended by Ferguson and Carlson (1993) is available. This regeneration model predicts the expected density, size, species, and survival rate of seedlings following a disturbance, and makes use of stand characteristics that include site preparation methods and the residual species composition of the surrounding area. A similar model is available for coastal Alaska (Ferguson and Johnson, 1988). For all other geographic regions, the user must specify the density, size, species, and survival rate of expected seedlings.

At present, the user-specified approach is the only option available to managers using FVS in the Pacific Northwest where forests can range from single-species dominated stands to complex multi-cohort, multi-

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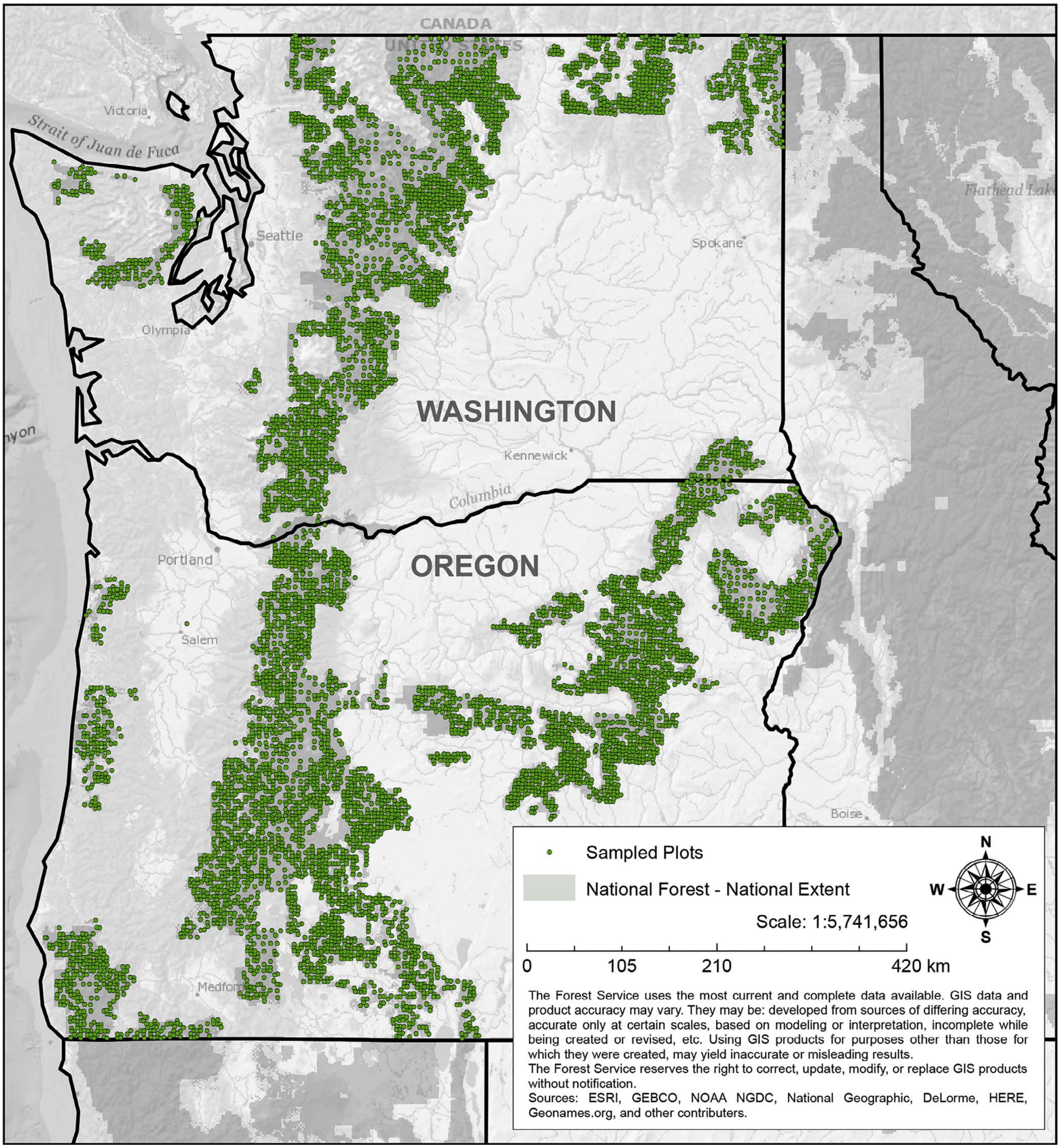

Fig. 1. Study area map illustrating the approximate location of all FIA and PNW subplots included in this study (green circles) from Oregon and Washington states in the Pacific Northwest region of the United States. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

species stands. The need exists for natural regeneration models that can be easily incorporated and automated into FVS, and that also cover the broad range of forested ecosystems found throughout the Pacific Northwest. Ideally, any models developed need to be implementable when data is restricted to the information most commonly collected by land managers; that is data captured in standard inventories (e.g. common stand exams) or permanent plots (e.g. Forest Inventory and Analysis, FIA).

Regeneration, and thus recruitment, can be modeled in many ways (see chapter 9 in Weiskittel et al., 2011 for a review), including regression based approaches, such as zero-inflated Poisson or negative binomial models. Recent examples where zero-inflated Poisson or negative binomial models have been successfully applied to model recruitment and regeneration include Fortin and DeBlois (2007) for forests of southern Québec, Li et al. (2011) for Acadian forests of southern Québec and Maine and the nearby study of Crotteau et al. (2014) for forests of northern California. Imputation methods are an alternative to classic regression techniques for modeling regeneration (Ek et al. 1997, Froese et al. (2003), Hassani et al. 2004). Imputation in this context is an estimation technique where missing or non-sampled measurements (such as regeneration) from one target stand are replaced with measurements or observations from another reference stand belonging to