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ORIGINAL PAPER

Developing seed zones and transfer guidelines with multivariate regression trees

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Abstract Managing seed movement is an important component of forest resource management to minimize maladaptation of planting stock in forest plantations. Here, we describe a new approach to analyze geographic patterns of adaptive and neutral genetic variation in forest trees and to link this genetic information to geographic variables for the delineation of seed zones and the development of seed transfer guidelines. We apply multivariate regression trees to partition genetic variation, using a set of environmental or geographic predictor variables as partitioning criteria in a series of dichotomous splits of the genetic dataset. The method can be applied to any type of genetic data (growth, adaptive, or marker traits) and can simultaneously evaluate multiple traits observed over several environments. The predictor variables can be categorical (e.g., ecosystem of seed source), continuous (e.g., geographic or climate variables), or a combination of both. Different sets of predictor variables can be used for different purposes: In two case studies for aspen and red alder, we show (1) how latitude, longitude, and elevation of seed sources in a provenance trial can be used to develop simple seed transfer guidelines; (2) how ecosystem classes and elevation as predictor variables can be used to delineate seed zones and breeding regions; and (3) how climate variables as predictors can reveal adaptation of genotypes to the environments in which they occur. Partitioning of genetic variation appears very robust regarding the choice of predictor variables, and we find that the method is a powerful aid for interpreting complex genetic datasets.

Keywords Genetic diversity · Tree improvement · Ecological genetics · Genecology · Aspen · Red alder

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Introduction

Seed zones and seed transfer guidelines are essential tools in reforestation to ensure that seedlings are well adapted to the growing conditions of the planting site (e.g., Morgenstern 1996; Ying and Yanchuk 2006). Using planting stock for reforestation that originates within a restricted geographic area delineated as a seed zone aims at minimizing loss of productivity and forest health issues due to maladaptation. Alternatively, movement of seed can be restricted with seed transfer guidelines, also sometimes referred to as floating or flexible seed zones (Ying and Yanchuk 2006). Transfer guidelines avoid drawing fixed boundaries across continuous genetic clines by specifying a maximum distance and elevation movement from source location to a planting site to avoid maladaptation (e.g., Rehfeldt 1988, 1989).

Generally, there are two conceptual approaches to develop seed zones and seed transfer guidelines. The first aims at *maximizing tree growth* by comparing response functions of different genotypes over multiple test environments. The approach usually employs univariate or multivariate curve fitting techniques to analyze growth and adaptive traits as a function of environmental or geographic predictor variables (e.g., Lindgren and Ying 2000; Raymond and Lindgren 1990; Roberds et al. 1990; Wang et al. 2006b). The second approach aims at *minimizing risk*