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Assisted migration to address climate change: recommendations for aspen reforestation in western Canada

Laura K. Gray, Tim Gylander, Michael S. Mbogga, Pei-yu Chen, and Andreas Hamann[1]

University of Alberta, Department of Renewable Resources, 751 General Services Building, Edmonton, Alberta T6G 2H1 Canada

Abstract. Human-aided movement of species populations in large-scale reforestation programs could be a potent and cost-effective climate change adaptation strategy. Such large-scale management interventions, however, tend to entail the risks of unintended consequences, and we propose that three conditions should be met before implementing assisted migration in reforestation programs: (1) evidence of a climate-related adaptational lag, (2) observed biological impacts, and (3) robust model projections to target assisted migration efforts. In a case study of aspen (*Populus tremuloides* Michaux.) we use reciprocal transplant experiments to study adaptation of tree populations to local environments. Second, we monitor natural aspen populations using the MODIS enhanced vegetation index as a proxy for forest health and productivity. Last, we report results from bioclimate envelope models that predict suitable habitat for locally adapted genotypes under observed and predicted climate change. The combined results support assisted migration prescriptions and indicate that the risk of inaction likely exceeds the risk associated with changing established management practices. However, uncertainty in model projections also implies that we are restricted to a relatively short 20-year planning horizon for prescribing seed movement in reforestation programs. We believe that this study exemplifies a safe and realistic climate change adaptation strategy based on multiple sources of information and some understanding of the uncertainty associated with recommendations for assisted migration. Ad hoc migration prescriptions without a similar level of supporting information should be avoided in reforestation programs.

Key words: bioclimate envelope modeling; climate change; ecological genetics; reforestation; remote sensing; seed transfer guidelines; seed zones.

Introduction

Climate change is projected to eliminate suitable habitat of many endemic or range-restricted species (e.g., Hannah et al. 2005, Parmesan 2006), which suggests that assisted movement of endangered species outside their historic range may be necessary for conservation purposes (e.g., Millar 2004, McLachlan et al. 2007). However, proactive mass translocation of a wide variety of species to mitigate loss of biodiversity under changing climate is a contentious issue and conflicts with well-established conservation principles (Hunter 2007, Ricciardi and Simberloff 2009). The concept of assisted migration may also be applied to translocation of populations within a species range. Populations within wide-ranging species are usually adapted to local environmental conditions (e.g., Kawecki and Ebert 2004, Savolainen et al. 2007) and maladaptation due to climate change may require population movement to matching habitat in new locations to maintain ecosystem health and productivity. This version of assisted migration, too, has been subject to debate (Marris 2009), and it also conflicts with well-established forest resource management principles and legislation that restrict the movement of seed sources in reforestation programs (e.g., Morgenstern 1996, Ying and Yanchuk 2006, McKenney et al. 2009).

We find it useful to differentiate the movement of species far outside their range for conservation purposes (*assisted colonization*), and population movement within a species range or somewhat beyond the leading edge (*assisted migration*). Under this definition, assisted migration would usually apply to common and widespread species for the purpose of maintaining ecosystem health and productivity, whereas assisted colonization aims at conserving endemic or range-restricted species. Although there are exceptions, this definition largely reflects previous usage of terminology in conservation biology (e.g., Hunter 2007, Hoegh-Guldberg et al. 2008, Ricciardi and Simberloff 2009) and forest resource management (e.g., Millar et al. 2007, O'Neill et al. 2008*b*, McKenney et al. 2009). For both assisted migration and assisted colonization, the contentious issue is the risk of unintended consequences associated with large-scale management interventions as well as a lack of rigorous scientific knowledge to guide the movement of species or genotypes. While predictive habitat modeling and observed biological impacts suggest an obvious general need for assisted migration

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[1] Corresponding author. E-mail: andreas.hamann@ualberta.ca