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Analysis

Trade-offs and Synergies Between Economic Gains and Plant Diversity Across a Range of Management Alternatives in Boreal Forests

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ABSTRACT

Intensive forest management activities that maximize economic gains could have a negative impact on the ecosystems and generate environmental conflicts, which may in turn translate to poor delivery of ecosystems services. Although plant diversity is positively associated with multiple ecosystem functions, it remains unclear how economic gains influence plant diversity across vegetation strata. We analyzed the relationships between economic gains, assessed as profit, and plant species richness following forest management alternatives (managing rotation age and overstorey composition) for the boreal forests of Canada. We found a hump-shaped relationship between total plant richness and profit, with total plant richness increasing initially, reaching a peak, and then declining with increasing profits. The relationship between profit and plant diversity differed among vegetation strata. Understorey plant richness followed similar trends to total plant richness, but overstorey tree richness increased linearly. The results of path analysis presented management alternatives as major drivers determining profit and plant diversity across vegetation strata. Our analysis indicated that maximum profit ($5000/ha) could lead to 20% loss of total plant species richness. Among the alternatives we compared, we conclude that managing for mixedwood with approximately a rotation of 100 years is an optimal compromise between economic and plant diversity objectives.

1. Introduction

Forest ecosystems provide a diverse range of ecological functions and services to humanity (Millennium Ecosystem Assessment, 2005). As one of the world's most important biogeoclimatic regions (Bradshaw et al., 2009), boreal forests contribute approximately 45% of the global growing stock of timber, fibre, and bioenergy for economic development (Vanhanen et al., 2012). In addition, a more varied forestry in boreal forests decreases the possibilities for spreading of risks under climate change, including mitigation of the increased risks of extensive wildfires, storm winds, harmful fungi and insects (Chapin III et al., 2007; Haas et al., 2011; Felton et al., 2016; Astrup et al., 2018), as well as offer greater opportunities for outdoor life and tourism (Annerstedt et al., 2010; Karjalainen et al., 2010). However, forest management intensification that maximizes economic gains may result in the loss of habitat and biodiversity, i.e., trade-offs between economic gains and biodiversity (Foley et al., 2005; Monkkonen et al., 2014; Frank and Schlenker, 2016). Others, however, have reported synergic (Rana et al., 2017) or lack of relationship between forest biodiversity and economic gains (Steffan-Dewenter et al., 2007; Clough et al., 2011). Across a wide range of management alternatives, the relationships between biodiversity and economic gains tend to be nonlinear (Chan et al., 2006; Steffan-Dewenter et al., 2007). Understanding these potentially nonlinear relationships would help choose management options with limited or no ecological losses while still satisfy economic gains. In boreal forests, economic gains are strongly determined by management intensification involving changes in rotation age and overstorey composition (Chen et al., 2017). However, the relationships between economic gains and plant diversity following forest management alternatives across a diverse range of vegetation strata remain poorly understood.

Plant species diversity is positively linked with multiple ecosystem functions such as the provision of habitat, nutrient cycling, energy flow, and regulating succession (Wardle et al., 2004; Royo and Carson, 2006; Cardinale et al., 2012; Gamfeldt et al., 2013). Diversity can be explored within a small part of the landscape (alpha diversity), spread across the landscape between the ecosystems (beta diversity), and more comprehensive diversity within a region (gamma diversity) (Maclaurin and Sterelny, 2008). Species richness is the most important measure of alpha diversity within a particular area because each species provides

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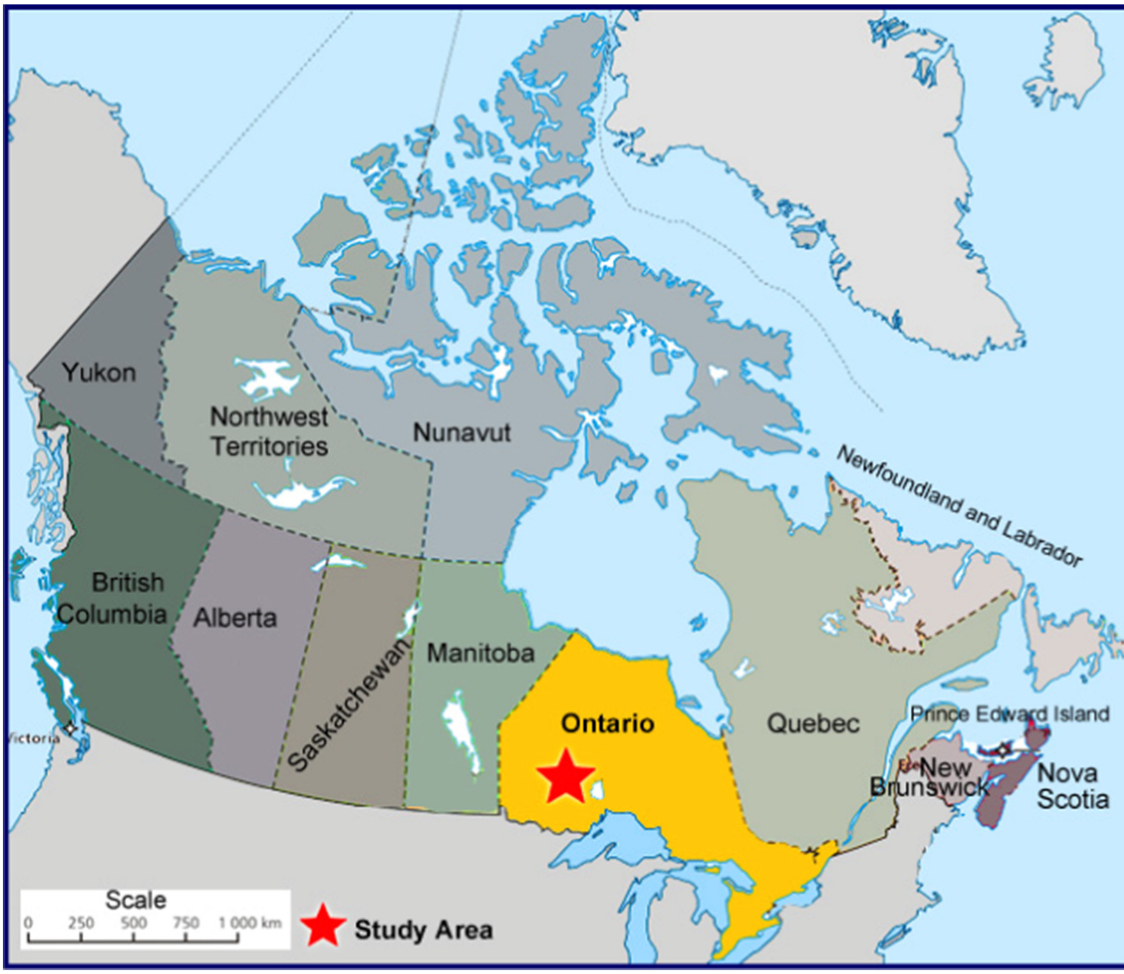

Fig. 1. The location of the study area within the map of Canada.

unique ecosystem functions and services at the stand level (Hector and Bagchi, 2007). Overstorey tree species composition not only determines the economic value of forest products (Mathey et al., 2009), but also influences understorey diversity through availability and variability of resources such as light and soil nutrients (Hart and Chen, 2006; Barbier et al., 2008; Reich et al., 2012; Kumar et al., 2017b). Although accounting for a small fraction of total ecosystem biomass, understorey vegetation including shrub, herb, bryophyte, and lichen species contributes substantially to total forest plant diversity and to a variety of ecosystem functions (Nilsson and Wardle, 2005; Gilliam, 2007; Gilliam and Roberts, 2014; Zhang et al., 2017).

Forest management alternatives for the boreal forest, including different rotation ages and overstorey tree species composition goals, affect economic gains (Chen et al., 2017), as well as plant diversity (Hart and Chen, 2008; Bartels and Chen, 2015; Bartels et al., 2017; Kumar et al., 2018). The choice of rotation age influences the economic value of product mix, because biomass available for harvest tends to increases with rotation age (Liski et al., 2001; Asante and Armstrong, 2012). However, extending the rotation age may not be economically optimal because aging can result in tree mortality and lower net biomass production, reducing timber available for harvest (Luo and Chen, 2011; Chen and Luo, 2015; Brecka et al., 2018). On the other hand, plant diversity tends to increase initially with increasing stand age, but tree mortality increases with older stands, which results in more dead wood that has been identified as a crucial component for large parts of boreal forest plant diversity (Kumar et al., 2017a). Moreover, vegetation requires time to colonize the available resources following disturbances; declines in plant diversity in older stands occur as a result of reduced resource availability and increased interspecific competition (Grime, 1973; Reich et al., 2012). However, plant diversity and stand age relationships could also differ among plants of different life history traits, or between vascular and non-vascular plants (Hart and Chen, 2006, 2008; Kumar et al., 2017b).

Similarly, overstorey species composition (broadleaf, mixedwood, and conifer) — often regulated by regeneration method (natural or artificial) at the stand initiation stage — affects economic gains (Chen et al., 2017), as well as plant diversity (Barbier et al., 2008; Hart and Chen, 2008; Kumar et al., 2017b). Economic gains differ due to the resultant forest products mix of broadleaf and conifer species because the products made from coniferous wood generally have better market value in the Canadian forest sector than those made from broadleaved wood (Chen et al., 2017). On the other hand, the relative proportion of broadleaved and coniferous trees in the overstorey may also affect plant diversity in the understorey as a result of different resource conditions (light and nutrient availability) (Barbier et al., 2008; Bartels and Chen, 2010, 2013; Kumar et al., 2017b). An increased conifer proportion would decrease the overstorey and shrub plant diversity, or vascular plant diversity, because of less resource availability (Hart and Chen, 2006; Barbier et al., 2008). However, an increased conifer proportion would increase non-vascular species diversity because coarse woody debris and thick forest floor layer in coniferous stands favor the establishment of mosses and lichen species (Legare et al., 2005; Startsev et al., 2008; Bartels and Chen, 2013).

Although previous studies have tested the effect of stand age and overstorey composition on economic gains (Chen et al., 2017) and understorey plant diversity (Reich et al., 2012; Kumar et al., 2017b),