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Integrating accessibility and intactness into large-area conservation planning in the Canadian boreal forest

Ryan P. Powers [a,*], Nicholas C. Coops [a], Trisalyn Nelson [b], Michael A. Wulder [c], C. Ronnie Drever [d]

[a] Integrated Remote Sensing Studio, Department of Forest Resources Management, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada
[b] Spatial Pattern Analysis & Research Laboratory, Department of Geography, University of Victoria, Victoria, BC V8W 3R4, Canada
[c] Canadian Forest Service, Pacific Forestry Center, Natural Resources Canada, Victoria, BC V8Z 1M5, Canada
[d] The Nature Conservancy – Canada Program, 506-250 City Centre Ave., Ottawa, ON K1R 6K7, Canada

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ABSTRACT

The creation of large protected areas from naturally functioning ecosystems that are largely without anthropogenic activity is viewed as an important option for maintaining the persistence of biodiversity and for allowing natural ecological and evolutionary processes to continue. Using the Canadian boreal forest as a case study, we demonstrate how biological elements, intact forest landscapes (e.g., dominantly forested areas largely unaffected by recent anthropogenic disturbance); cost (e.g., area and accessibility), and size considerations can be incorporated within spatial conservation planning tools to propose and, following transparent criteria, prioritize potential conservation opportunities within the boreal. We explore the trade-offs between reserve size and different area-based representative targets for three scenarios, two of which preferentially prioritize areas without competing land use. Consistent with other findings, the level of compactness (i.e., reserve size) greatly influences the reserve efficiency. Priority areas restricted to only intact forest landscapes were less flexible and efficient, particularly as target and compactness level increased. Nevertheless, priority areas using accessibility (distance from road and human settlement) as a cost surrogate were able to satisfy a range of conservation targets and compactness levels while remaining remote from human influence. These findings indicate the abundant intact areas within the Canadian boreal provide suitable areas for conservation investment and that this coarse-scale approach is useful for aiding conservation planning.

1. Introduction

It is anticipated that biodiversity across the world's boreal forest will be increasingly threaten by change, including altered disturbance regimes, the variable intensification and the expansion of human activity such as land conversion and resource extraction (e.g., mineral, energy, timber) mostly in Russia and Canada's southern boreal forest extent, and increasing global climate variability (Lee et al., 2006; Cyr et al. 2009; Bradshaw et al., 2009). Although the protection of large intact areas is seen as an important option for conservation efforts (Bradshaw et al., 2009), based on global conservation targets that consider 10–12% a minimum standard (e.g., IUCN, 1993; Coad et al., 2009), the boreal forest is under protected (Schmitt et al., 2009) at approximately 8.5% (Coad et al., 2009).

In Canada, approximately 8.1% (448,178 km^2) of the boreal forest is under some form of permanent protection, with a slight bias towards low productivity environments (Andrew et al., 2011) typically found in the more northern regions or at higher elevations. However, since as much as 80% of the Canadian boreal forest is free of human disturbance and may be considered *de facto* protected (Andrew et al., 2012), a unique opportunity exists for implementing comprehensive conservation strategies. In the North American context, the temperature changes in the boreal ecoregion over the next 60 years (up to 2070) are projected to be relatively minor compared to other regions globally (Beaumont et al., 2011). Similarly by 2100, climate driven changes in the global boreal biodiversity are expected to be less than those triggered by other dominant drivers of change (e.g., land use and nitrogen deposition) in other biomes such as savanna, Mediterranean, and alpine (Sala et al., 2000). The implications for Canada are that protected areas established in the boreal forest under current conditions are likely to retain conservation target contributions and relevancy at least in the short term until such adaptation and mitigation responses are needed. However, it is also important to recognize that the Canadian boreal forest covers an extensive area and that future climate

* Corresponding author. Tel. +1 778 997 3646.
E-mail addresses: rppowers@alumni.ubc.ca (R.P. Powers), Nicholas.Coops@ubc.ca (N.C. Coops), trisalyn@uvic.ca (T. Nelson), Mike.Wulder@NRCan-RNCan.gc.ca (M.A. Wulder), cdrever@TNC.ORG (C. Ronnie Drever).

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induced disturbances will be both highly spatially variable and will have impacts that are difficult to accurately predict. Likewise, expected changes in biodiversity over the next century (up to the year 2100) can also vary greatly, and are sensitive to the degree of interaction between drivers of biodiversity change (e.g., land use, climate, nitrogen deposition, biotic exchange, and atmospheric CO_2) (Sala et al., 2000). Nonetheless, recognition of the conservation potential within the Canadian boreal forest has generated serious debate surrounding the expansion of current protected areas to include substantial new areas, with some initiatives advocating over 50% conservation of the boreal forest (CBI, 2005). As such, designing an expanded comprehensive protected area network that meets current needs should be the priority by way of complementing those protected areas that already exist and providing a basis upon which to build future protected areas as needed.

Systematic conservation planning (Margules and Pressey, 2000) focuses principally on finding cost-effective solutions to conservation problems by achieving conservation targets for the least cost. Cost of conservation can be assessed in a variety of ways, financial or otherwise, including area in reserve or costs related to acquisition, management, transaction, damage or forgone opportunities (Naidoo et al., 2006). To date, most research in conservation planning has focused on issues around ensuring adequate representation of at-risk species or representation of biodiversity elements including habitat types, species assemblages, and ecosystems. (Church et al., 1996; Cabeza and Moilanen, 2001; Onal and Briers, 2006). One approach to ensuring biodiversity is represented in conservation planning is to use environmental domains (i.e., coarse-filter, ecological regionalization) to provide an indication of the types of environmental conditions present in the landscape. These domains should in theory represent the range of species diversity that can be supported by the landscape (Mackey et al., 1988; Belbin, 1993, 1995; Trakhtenbrot and Kadmon, 2005). The environmental domain approach has been successfully applied in a number of studies for different environments, such as in Australia where environmental domains produced from a continental classification (Mackey et al., 2008) provided biological data in spatial conservation prioritization studies (Carwardine et al., 2010; Klein et al., 2009a,b). This approach was also applied by Coops et al. (2009) to highlight the most unique domains across Canada with 40 and 14 level classifications.

Recently, the attention of conservation planning has shifted towards incorporating spatially explicit information about economic costs (Faith et al., 1996; Stewart and Possingham, 2005; Richardson et al., 2006; Schneider et al., 2011), by informing on a key limiting factor which has been shown to increase the effectiveness and efficiencies of conservation initiatives (Naidoo et al., 2006). For instance, Schneider et al. (2011) investigated the incorporation of spatial distribution of biological data (coarse-filter) and economic costs (foregone resource opportunities) in conservation planning to determine any conservation gain and found that the efficiency of conservation solutions is improved by minimizing cost across all ecosystem representation targets.

Biological and cost considerations may not be sufficient by themselves to ensure the long-term persistence of biodiversity at regional and continental scales (Soulé and Sanjayan, 1998; Possingham et al., 2000). For example, whether protected areas are capable of supporting broad-area and long-term ecological processes and withstanding change largely depends on their size and wilderness quality (Soulé et al., 2004). Over time, the dynamic nature of the Canadian boreal forest may alter the landscape structure of protected areas. Consequently, size represents an important reserve design consideration for incorporating natural disturbance (Baker, 1992); whereby a minimum reserve size or dynamic area (Pickett and Thompson, 1978) could be used help perpetuate the viability of species and ecological processes. Thus, in the interest of maintaining biodiversity, it is beneficial to judiciously consider three key aspects; biological representativeness, the size and quality of the protected areas as well as cost considerations when planning conservation investment (Klein et al., 2009b).

Based on the three considerations outlined above, and with recent conservation initiatives in mind, we provide a case study of conservation planning for the Canadian boreal forest. We apply spatial conservation planning tools to assess three scenarios with varied levels of reserve sizes and different conservation targets for environmental domains and at-risk species. Two of the approaches preferentially prioritized areas away from human influence (i.e., wilderness), and one prioritized intact forest landscapes. We then evaluated the trade-offs between reserve size and relative reserve costs associated with the establishment of large reserves (i.e., >6480 km^2), that expand by 10% intervals from a minimal target of 15% to areas that encompasses a more substantial 25% and 35% of the boreal forest. To meet our objectives we (i) determined if there was any conservation efficiency (i.e., reduced relative reserve cost) gained by using an accessibility cost surrogate instead of an area cost surrogate which has typically been used in past conservation planning efforts, (ii) evaluated how reserve compactness influences relative reserve cost and total area, and (iii) examined the effects of using the accessibility cost surrogate and forest landscape intactness on the areas selected for conservation.

2. Study area

The study area is the Canadian boreal forest ($\sim$5.37 million km^2) as described by Brandt (2009) excluding the southern transitional hemiboreal subzone (includes much of British Columbia), which is considered temperate in North America and not formally recognized as boreal (Brandt, 2009). Situated primarily in the northern latitudes, the region is principally forested ($\sim$58%) and dominated by cold tolerant forest types within the genera *Larix*, *Abies*, *Picea* or *Pinus* as well as *Betula* and *Populus* (Brandt, 2009). Water features such as lakes and rivers, as well as wetlands are also common throughout the boreal forest (Wulder et al., 2008). Stand replacing fire is the dominant natural disturbance on the landscape (Hely et al., 2001).

3. Data

3.1. Environmental domains and species distribution data

We used two suites of data to represent biodiversity: environmental domains and distributions for 16 at-risk species. Environmental domains (Fig. 1a) were generated in a previous study (Powers et al., 2013) by classifying the boreal forest into 15 domains based on productivity, seasonality (snow cover), and land cover similarity. Seasonal greenness (Coops et al., 2008), a vegetation productivity index, was the most important indicator for discriminating among the environmental domain groups. Spanning from east to west along latitudinal gradients, the 15 domains represent regions of environmental uniqueness with spatial and attribute detail that is appropriate for large area conservation planning (Coops et al., 2009). The five northernmost domains are dominated by open shrub vegetation and can be characterized as having high seasonality and low productivity environments. In contrast, the 8 southern domains have a relatively low seasonality and high productivity and are dominated by coniferous and mixed forest. The two central domains are mostly coniferous forest and open shrubland and experience relatively moderate productivity and seasonality.