Forest Ecology and Management 321 (2014) 94–104

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Quantifying connectivity using graph based connectivity response curves in complex landscapes under simulated forest management scenarios

Bevan W. Ernst *

Thompson Rivers University, 900 McGill Road, Kamloops, BC V2C 0C8, Canada

ARTICLE INFO

Article history:
Available online 16 August 2013

Keywords:
Landscape connectivity
Forestry
Biodiversity conservation
Landscape ecology

ABSTRACT

The maintenance of habitat connectivity is promoted as a method of biodiversity conservation in forest management. Graph based metrics have demonstrated efficacy at deriving landscape scale connectivity metrics from habitat maps. The response of a graph-based connectivity metric to changes in the size of gaps considered to fragment habitat is proposed as a method of quantifying the impacts of changes in landscape composition on connectivity across a range of spatial scales. The parameters that describe this relationship are proposed as indices to quantify changes in the amount, fragmentation and spatial dispersion of habitat in a landscape. Systematic manipulations of landscape structure demonstrated response curve sensitivity to the impacts of forestry that are predicted by the literature to affect habitat connectivity. The response to controlled manipulations of landscape structure was used to guide an examination of the efficacy of distributing habitat reserves as corridors to mitigate the impacts of forestry on landscape connectivity. I conclude that the parameters that describe the relationship between spatial scale and the probability of connectivity index values can be used to compare the impacts of alternative forest management strategies on landscape connectivity, distributing conservation areas as corridors resulted in minimal benefits to landscape connectivity, and that the benefits of corridors were further reduced when natural disturbances were included in model simulations.

1. Introduction

Modern forest management is focused on the conservation of biodiversity and habitat values while maintaining timber resources (Eriksson and Hammer, 2006; Fischer et al., 2006; Hoberg and Malkinson, 2012). Anthropogenic impacts to habitat distribution affect the ability of species to disperse between habitat patches, hence the maintenance of habitat connectivity is widely recommended as a method of promoting ecosystem resilience and biodiversity in landscapes subject to disturbances (Brudvig et al., 2009; Fischer and Lindenmayer, 2007; Lindenmayer et al., 2008; Taylor et al., 1993). Careful attention should be paid to maintaining an appropriate spatial pattern of retained mature forest habitat during harvest planning to avoid unnecessary losses of biodiversity in forested landscapes, as many species are known to rely on this habitat type (Raphael et al., 2001). In British Columbia (BC) the distribution of mature forest habitat in a landscape is managed by controlling the amount of forest that can be harvested, the spatial distribution of harvesting, and by excluding harvest from old growth management areas (OGMA) (Forest Practices Board, 2012). Despite being a frequently recommended management strategy, there are no accepted standards for the measurement of connectivity or its application to forest management strategies (Kindlmann and Burel, 2008; Laita et al., 2011; Lindenmayer and Fischer, 2007).

To have value as a tool to guide forestry management, a connectivity metric should reflect the accepted principles of landscape connectivity, be sensitive to the impacts of forestry, and be logistically feasible to apply to large spatial areas. Landscape connectivity is widely cited and defined as "the degree to which the landscape facilitates or impedes movement among resource patches." (Taylor et al., 1993). This definition highlights the differences between landscape connectivity, where the degree to which landscape structure impedes movement is quantified, and patch connectivity, where movement between specific habitat patches is quantified (Tischendorf et al., 2003). From the perspective of forest management, the resource patches of greatest interest are ecologically mature forest habitats (Spies et al., 2006) and the goal is to distribute forest harvesting to maintain the connectivity of mature forests to mitigate the impacts of harvesting on metapopulation dynamics. Metapopulation persistence is enhanced through increased connectivity by minimizing the impediments to immigration/

* Address: 670 MacKenzie Ave., Kamloops, BC V2B 3V8, Canada. Tel.: +1 250 318 6929.

E-mail address: bevan.ernst@gmail.com

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.07.033

emigration between patches and allows the re-colonization of areas that have experienced extinction of local populations (Hanski and Ovaskainen, 2003). Although connectivity plays an important role in metapopulation dynamics, it can only facilitate movement among otherwise productive populations, and cannot be expected to maintain biodiversity if other aspects of habitat are not managed concurrently.

The primary factors that facilitate or impede movement between patches of habitat within a landscape are the amount of a specific habitat type, how fragmented it is and the spatial dispersion of habitat patches (Lindenmayer and Fischer, 2007; Long et al., 2010; Tischendorf et al., 2003). The fragmentation of habitat reflects the number of separate patches a given amount of habitat is divided into, and the spatial dispersion of habitat describes the distance between fragmented patches. Commercial forestry impacts North American landscapes by reducing the amount of mature forest habitat (Spies et al., 2006) and fragmenting the remaining forest patches with road networks through the landscape to allow for the extraction of the harvested timber (Houle et al., 2010; McGarigal et al., 2001). Larger amounts of suitable habitat increase landscape connectivity by increasing the pool of potentially connected habitat. For a given amount of habitat, fragmentation into a greater number of patches is considered to decrease the connectivity of available habitat (Blaschke, 2006; Saunders et al., 1991; Zuckerberg and Porter, 2010). Increasing the distance between fragmented patches further decreases landscape connectivity (Anand et al., 2010; Hinam and Clair, 2008; Tischendorf et al., 2005).

Plotting the response curve of Pascual and Hortal's (2007) probability of connectivity index (PCRC) to changes in the spatial scale of a theoretical disperser is proposed as a method of quantifying landscape connectivity for biodiversity conservation. A similar technique has been previously applied (Laita et al., 2010) to examine the impacts of habitat reserves on landscape connectivity. The probability of connectivity index is a graph-based metric calculated using the Conefor software package (CS), developed to address the conceptual deficiencies in other connectivity metrics (Pascual-Hortal and Saura, 2006; Saura and Pascual-Hortal, 2007; Saura and Rubio, 2010; Saura and Torne, 2009) Graph theory is a method of describing the distribution of habitat as a network of nodes which may be connected by links (Minor and Urban, 2008; Zetterberg et al., 2010). Each node and link are assigned numeric values based on the value of each node and the strength of each link so that the emergent properties of the entire network can be quantified (Minor and Urban, 2007). Distinguishing how the different aspects of habitat distribution impact landscape connectivity is challenging as the factors of habitat amount and habitat distribution are correlated (Smith et al., 2009). In controlled systematic manipulations of simple landscape scenarios the asymptote, intercept, and interaction parameters of a generalized logistic function that describe a PCRC were demonstrated to respond independently to changes in the amount, fragmentation and spatial dispersion of a focal habitat (Ernst, Review Pending). The specificity of response of each parameter to a specific type of landscapechange allows for the conflicting and correlated influence of habitat amount, fragmentation and spatial dispersion to be compared between alternative landscape management scenarios. A similar pattern of response in complex landscapes would indicate that these parameters can be used to assess how forestry impacts landscape connectivity. A PCRC quantifies the degree that changes to a landscape impact connectivity based on a range of dispersal capabilities, rather than focusing on the multitude of stochastic and deterministic factors that will affect the dispersal of focal species but may not accurately reflect impacts to other species (Lindenmayer et al., 2002). Rather than attempting to manage a landscape on a species by species basis, this approach quantifies the changes in the distribution of a focal habitat type in the landscape relative to a starting condition or desired management state. By examining the patterns of habitat-connectivity from all spatial scales, impacts that might otherwise be undetected from a species-specific examination will be observable, and results will better reflect the Taylor et al. (1993) definition of landscape connectivity: "the degree to which the landscape facilitates or impedes movement among resource patches.".

Comparisons of complex ecosystem simulation models were used to: (a) determine if PCRC demonstrated the same patterns of responses to manipulations of habitat amount, fragmentation and dispersion in complex landscapes as were observed in simple landscapes, (b) assess if PCRC can be used to reflect impacts of forestry predicted by the literature, and (c) apply those responses to compare the efficacy of alternative forest management strategies to promote connectivity in a landscape subjected to both natural and anthropogenic disturbance regimes. Independent parameter responses to controlled manipulations of the amount fragmentation and dispersion of habitat, as induced by rates and distribution of harvest, will indicate that PCRC demonstrate the same sensitivities in a complex landscape that were observed in simple landscapes. A negative response to the presence of roads networks, increased rates of harvest, and dispersed patterns of harvest are expected based on the predicted connectivity impacts of forestry on forest dependent species assemblies. Decreased fragmentation and dispersion indices would indicate that distributing OGMA as corridors achieved the goal of minimizing losses of landscape connectivity associated with forestry.

2. Methods

Landscape scenarios were created for a 110,000 ha study area dominated by coniferous forest located approximately 125 km north of Kamloops, BC (51°52′30.92″N, 119°36′16.78″W). The landscape is composed of forests of the Engelmann Spruce-Subalpine Fir and Interior Cedar Hemlock zones outlined in the Biogeoclimatic Ecosystem Classification system used in BC for ecosystem classification (Lloyd, 1990). Current forest conditions were assigned a vegetation class based on species and age information derived from the BC Forests and Range Vegetation Resource Inventory (BC Minsitry of Forests, Lands, and Natural Resource Operations, 2012). This inventory delineates the landscape based on a range of habitat characteristics including tree species composition, stand age, and crown closure. These factors are used to define forest stands as part of the timber harvest land base or as non-contributing areas where forestry is not economically or operationally feasible. These initial conditions were used to develop landscape scenarios where alternative harvesting strategies were applied over a simulated 50 year period. To do this the Tool for Exploratory Landscape Scenario Analyses (TELSA) was applied. TELSA is a spatially-explicit landscape simulation model designed to project ecosystem conditions, incorporating the influence of forest harvesting, natural disturbances, and succession (Kurz et al., 2000). This model has been previously employed as a method of estimating the impacts of management strategies and natural disturbances on forest ecosystems in BC (Klenner et al., 2000; Klenner and Walton, 2009). The TELSA model was used to create scenarios where the connectivity impacts caused by roads, changes to the amount and distribution of harvest, natural disturbances, and OGMA could be assessed and compared to the current landscape connectivity.

2.1. Roads

Different combinations of habitat amount and distribution, as outlined below, were assessed with and without the presence of