Biological Conservation xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Biological Conservation

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

Cost-efficient strategies to preserve dead wood-dependent species in a managed forest landscape

Thomas Ranius [a,*], Anu Korosuo [b,1], Jean-Michel Roberge [c], Artti Juutinen [d,e], Mikko Mönkkönen [f], Martin Schroeder [a]

[a] Dept. of Ecology, Swedish University of Agricultural Sciences, Box 7044, 750 07 Uppsala, Sweden
[b] Dept. of Forest Resource Management, Swedish University of Agricultural Sciences, 901 83 Umeå, Sweden
[c] Dept. of Wildlife, Fish and Environmental Studies, Swedish University of Agricultural Sciences, 901 83 Umeå, Sweden
[d] Dept. of Economics, P. O. Box 4600, 900 14 University of Oulu, Finland
[e] Natural Resources Institute Finland, P.O. Box 413, 90014 University of Oulu, Finland
[f] Dept. of Biological and Environmental Science, University of Jyväskylä, P.O. Box 35, Jyväskylä 400 14, Finland

A R T I C L E I N F O

Article history:
Received 29 June 2016
Received in revised form 7 October 2016
Accepted 13 October 2016
Available online xxxx

Keywords:
Conservation strategy
Discounting
Forest age
Population viability
Prolonged rotation
Time horizon

A B S T R A C T

Negative consequences of intensive forest management on biodiversity are often mitigated by setting aside old forest, but alternative strategies have been suggested. We have compared using simulations the consequences of two of these alternatives — setting aside young forests or extending rotation periods — to that of current practice in managed boreal forest. In all scenarios we applied a constant conservation budget and predicted forest development and harvesting over 200 years. As a proxy for biodiversity conservation, we projected the extinction risk of a dead wood-dependent beetle, *Diacanthous undulatus*, in a 50 km^2 landscape in central Sweden, using a colonization-extinction model. During the first century, setting aside young forest stands rather than old stands increased extinction risk because young stands have lower habitat quality. However, habitat quality of young forests increased as they aged and they were much cheaper to set aside than old stands. Therefore, the strategy allowed a larger set-aside area (within the budget constraint), resulting in lower extinction risk and harvested timber volumes in the second century. Prolonging rotations also decreased the extinction risk but was in the long-term less cost-effective. The most cost-effective strategy in the long-term (200 years) was to set aside a mixture of old and young forest. However, setting aside young stands rather than prolonging rotations or setting aside old stands delays both the benefits (lower extinction risk) and costs (lost harvest volumes), so the optimal strategy depends on the assumed societal values and hence discount rates.

1. Introduction

Intensive forest production has modified forests worldwide, often with strongly negative effects on biodiversity (Secretariat of the Convention on Biological Diversity, 2010). Since maintenance of biodiversity is regarded as an important goal in sustainable forestry, efforts are made to mitigate these effects (Lindenmayer and Franklin, 2002). The underlying policies often aim at maintaining species populations that are viable in the long-term (e.g. in the Swedish Environmental objectives: Anon, 2016). This is often done by establishing set-asides (i.e. conservation areas exempt from timber extraction), typically to protect biodiversity 'hotspots' in order to maximize current species richness within budgetary and other socio-economic constraints (e.g. Virolainen et al., 2000). However, especially in landscapes with little remaining unmanaged forest, such a strategy may result in small and isolated protected areas, often providing poor prospects for long-term viability of some species' populations (Öckinger and Nilsson, 2010). Thus, to evaluate the consequences of conservation strategies on biodiversity, it is important to adopt a long temporal perspective, meaning that more than one rotation should be included, which is typically more than a century in northern forests (Ranius and Roberge, 2011). Furthermore, it is often crucial to recognize that habitats are dynamic, and that suitable habitats for forest species may occur not only in protected areas, but also in managed production forest matrices (e.g. Lindenmayer and Franklin, 2002, Schroeder et al., 2007). Therefore, both species and habitat dynamics as well as both production and set-aside forests should be considered when evaluating effects of conservation strategies on biodiversity in forest landscapes.

In the even-aged forest management systems dominating in many parts of the world, forest stands are harvested by clearcutting and then actively regenerated. In such managed forest landscapes, old forest

* Corresponding author.
E-mail address: thomas.ranius@slu.se (T. Ranius).
[1] Present address: Ecosystems Services and Management Program, International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria

http://dx.doi.org/10.1016/j.biocon.2016.10.017
0006-3207/© 2016 Elsevier Ltd. All rights reserved.

covers smaller areas than in naturally-dynamic forest landscapes (Lindenmayer and Franklin, 2002). This impairs biodiversity, because forests in later successional stages contain structures and species that are rare or absent in younger forests (Lassauce et al., 2013). Therefore, older forests have been traditionally prioritized over younger ones when selecting set-asides (Gustafsson and Perhans, 2010). However, results from two recent analyses suggest that it may be more cost-efficient, in terms of conservation benefits that can be obtained with a given budget, to set-aside young forests (Lundström et al., 2016; Mazziotta et al., 2016). This is mainly because timber products cannot be extracted from young forests for several decades, so they are much cheaper to set aside than mature stands due to their lower economic value. However, the cited studies did not address two factors which must be considered in comprehensive assessments of the consequences of setting aside young forests for biodiversity and forestry: (1) persistence of species' populations and (2) future levels of harvestable timber volumes.

Rotations are sometimes prolonged in managed forest in order to promote biodiversity (Lassauce et al., 2013). This increases amounts of habitats for species that require structures associated with old trees and large-diameter dead wood (Jonsson et al., 2006; Lassauce et al., 2013), especially if the prolonged rotations are not accompanied by extra thinnings (Roberge et al., 2016). Thus, prolonging rotations increases landscape-scale habitat availability for various taxa that might otherwise be threatened (Jonsson et al., 2006; Juutinen et al., 2014; Mönkkönen et al., 2014). Moreover, prolonged rotations increase the length of the temporal window when conditions are suitable for these species, which may strongly improve their persistence by favorably changing the relationship between colonization and extinction rates (Keymer et al., 2000). However, we are not aware of any published analysis of prolonging rotations' effects on colonization-extinction dynamics and hence population persistence.

The aims of this study are to elucidate the long-term biodiversity consequences of setting aside young forests and prolonging rotations in managed forest landscapes, including hitherto neglected effects on population persistence and levels of harvestable timber volumes. By projecting forest development and population dynamics over 200 years in a managed forest landscape in central Sweden, and comparing outcomes with those of a scenario with no conservation efforts, we evaluate the following four strategies for conserving biodiversity: setting aside old stands, young stands, or mixtures of old and young stands, and prolonging the rotations. We consider three responses: timber production (i.e. the total harvested volume of trees), habitat availability, and population persistence of a focal species. The budget, in terms of net present value of timber (NPV), is kept constant in all scenarios. The focal species is a previously red-listed beetle, *Diacanthous undulatus*, which inhabits dead wood. Its population persistence is projected using a colonization-extinction model that we developed from presence/absence data collected in the considered landscape. *Diacanthous undulatus* occurs both on clear-cuts and in old (managed and unmanaged) forests, but 10–60 year-old managed forests offer little or no habitat for the species. Hence, by using this focal species we acknowledge that both managed and unmanaged forests, and young as well as old forests, may be important for the conservation of forest species. Since the species model used is dynamic, the outcome reflects not only habitat availability but also effects of colonization-extinction dynamics.

2. Methods

2.1. Study landscape

The simulations were based on data collected in the Delsbo area, central Sweden (62° N, 16° E). We used *D. undulatus* (formerly *Harminius undulatus*) occurrence data collected in 68 forest stands in a 28 km × 28 km block of land including a 4 km wide buffer zone (Schroeder et al., 2007). Our predictions of species persistence and forest production considered a 7.071 km × 7.071 km (i.e. 50 km^2) area located within that block of land. Most (80%) of the Delsbo area is covered by productive forests (i.e. forests with annual wood volume growth exceeding 1 m^3 ha^{-1}). The landscape is typical for the Swedish boreal region, with Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten) being the dominant tree species. The height above sea level varies from 140 m to 530 m. Currently, most forest stands in the area are constituents of the first generation of even-aged forest created by clear-cut harvesting. The average volume of dead wood in the managed stands is 13.8 m^3 ha^{-1}, about twice as high as the Swedish average (Ekbom et al., 2006). The industrial forest owners (Holmen Skog AB and Bergvik Skog AB) have been FSC-certified since the late 1990s, and thus follow the requirements to set aside ≥5% of the forest land at the scale of whole stands (Forest Stewardship Council, 2010).

2.2. Study species

Diacanthous undulatus is a representative of the species-rich insect community dwelling under bark of dead wood, which is negatively affected by reductions in the amount of dead wood due to forestry (Jonsell et al., 1998). It was previously classified as near threatened (NT) on the Swedish red list (Gärdenfors, 2010), but its status has recently been changed to least concern (LC) (Swedish Species Information Centre, 2015). It is a predatory beetle occurring in dead wood from both coniferous and deciduous trees (Nilsson and Baranowski, 1996) in unmanaged forest, old managed forest, and clear-cuts (Schroeder et al., 2007). In managed forest landscapes, this species seems to occur as habitat-tracking metapopulations, since (i) local populations can go extinct both due to stochastic events in small populations and habitat patches becoming unsuitable (during a rotation, a managed forest stand will have periods of both suitability and unsuitability for the species), (ii) the probability of occurrence increases with the time since the stand became suitable, which suggests a dispersal limitation, and (iii) predictions from a habitat-tracking metapopulation model were significantly correlated with the current occurrence patterns (Schroeder et al., 2007).

The information about current populations of *D. undulatus* used in this study was drawn from a presence/absence dataset obtained from a field study carried out during 2001–2003, described in detail by Schroeder et al. (2007). A stratified sampling design was applied, which means that data was collected from randomly selected forest stands of the following categories: clear-cuts (20 stands), old managed forest (28 stands), set-asides (10 stands) and nature reserves (10 stands), while beetle data were impossible to collect from young managed forests simply because there was too little dead wood with bark (and hence breeding substrate) to sample. Briefly, the presence/absence of *D. undulatus* larvae was assessed by peeling bark from dead wood objects (diameter >10 cm, both downed and standing and belonging to different tree species), sieving the material, and extracting larvae (if present) in Tullgren funnels. Use of this method ensures that any detected members of the species must have originated from reproduction in the stand. If available, 1 m^2 of bark from 10 dead wood objects were sampled per stand, otherwise as many as possible. We assessed presence/absence at one time for each stand; the species was present in 15 stands out of 68.

2.3. Modelling stand development and optimizing stand management

We modelled forest development and management using tree growth, regeneration and mortality functions implemented in the forest planning tool Heureka PlanWise (Wikström et al., 2011), where the simulation and optimization settings can be modified to represent a multitude of different goals in forestry. Here we optimized NPV for each forest stand by comparing the outcomes for a range of management programs, each consisting of a sequence of treatments (planting,