Journal of Environmental Management 210 (2018) 1–9

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Modified forest rotation lengths: Long-term effects on landscape-scale habitat availability for specialized species

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ARTICLE INFO

Article history:
Received 21 February 2017
Received in revised form
7 December 2017
Accepted 9 December 2017

Keywords:
Aegithalos caudatus
Certhia familiaris
Forest age
Forest rotation
Hadreule elongatula
Tetrastes bonasia

ABSTRACT

We evaluated the long-term implications from modifying rotation lengths in production forests for four forest-reliant species with different habitat requirements. By combining simulations of forest development with habitat models, and accounting both for stand and landscape scale influences, we projected habitat availability over 150 years in a large Swedish landscape, using rotation lengths which are longer (+22% and +50%) and shorter (−22%) compared to current practices. In terms of mean habitat availability through time, species requiring older forest were affected positively by extended rotations, and negatively by shortened rotations. For example, the mean habitat area for the treecreeper *Certhia familiaris* (a bird preferring forest with larger trees) increased by 31% when rotations were increased by 22%, at a 5% cost to net present value (NPV) and a 7% decrease in harvested volume. Extending rotation lengths by 50% provided more habitat for this species compared to a 22% extension, but at a much higher marginal cost. In contrast, the beetle *Hadreule elongatula*, which is dependent on sun-exposed dead wood, benefited from shortened rather than prolonged rotations. Due to an uneven distribution of stand-ages within the landscape, the relative amounts of habitat provided by different rotation length scenarios for a given species were not always consistent through time during the simulation period. If implemented as a conservation measure, prolonging rotations will require long-term strategic planning to avoid future bottlenecks in habitat availability, and will need to be accompanied by complementary measures accounting for the diversity of habitats necessary for the conservation of forest biodiversity.

1. Introduction

Much of the world's timber, wood fibre, and biomass production stems from forests managed with even-aged silvicultural systems. These systems are characterized by the maintenance of a more or less even age structure of trees within forest stands, with one single tree cohort established through regeneration after clearcutting. In such systems, the number of years between two final fellings is referred to as the rotation length. In traditional forest management, the economically optimal rotation length is determined by the financial maturity of a stand in terms of wood production, i.e. the point in time when final felling yields a higher economic value (considering a certain interest rate) compared to letting the stand continue to grow (Nyland, 2002).

However, there is an ongoing trend whereby a range of socio-ecological factors other than financial stand maturity influence decisions about rotation lengths, potentially yielding rotations that are shorter or longer than traditionally used. Shorter rotations have been proposed as a means to decrease the susceptibility of forest stands to expected increases in forest damage in the future (Felton et al., 2017). For example, the leading forest owners association in

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https://doi.org/10.1016/j.jenvman.2017.12.022
0301-4797/

southern Sweden is currently advising its members to shorten rotations by 10–15 years in Norway spruce (*Picea abies*) dominated stands, specifically as a means to reduce climate-associated risks of forest damage (Södra Skog, 2012). Shorter rotations would also yield more frequent opportunities to adapt forest management strategies to future climatic conditions or changed demand for certain wood products, for example by changing tree species composition or genotypes when reforesting the site after final felling. Finally, another driver which may result in shorter rotations is the wish from the industry to get a continuous supply of timber, which may involve harvesting some stands at an earlier age in regions characterized by a paucity of mature forest (Roberge et al., 2016).

At the same time, arguments have also been proposed for prolonging rotations. Longer rotations are expected to provide habitat for many threatened species that are dependent on attributes found in late-successional forest (Dettki and Esseen, 2003; Lassauce et al., 2013; Lindenmayer and Franklin, 2002; Roberge et al., 2016). This is a key conservation issue in several countries where industrial forest management has led to a loss of old-growth forest (Burton et al., 1999; Lindenmayer and Franklin, 2002). Among others, average dead wood amounts are predicted to be higher under longer rotations (Felton et al., 2017; Ranius et al., 2003), with positive implications for saproxylic species. Furthermore, some species are more abundant in older forest because a longer temporal continuity of the tree cover allows more time for local population growth (e.g. Dettki and Esseen, 2003). Longer rotations are also expected to decrease the amount of edges between open areas and forest, thereby potentially reducing detrimental edge effects on forest specialists (Thompson, 1993). In addition to biodiversity benefits, forest managers, environmental NGOs and researchers have raised the possibility to extend rotation lengths as a means of increasing forest carbon stocks for climate change mitigation (Felton et al., 2016). Longer rotations may also enhance the recreational and aesthetic quality of the forest landscape (Gundersen and Frivold, 2008) and may allow for production of larger-sized sawlogs with high economic value.

In this study, we evaluate the long-term effects of modified rotation lengths on habitat availability for forest-reliant species. Using a large landscape in Sweden, we combine simulations of forest stand development under different rotation lengths with knowledge of species' requirements for a range of forest types, to project future habitat availability for four specialized species: one insect (*Hadreule elongatula*; Coleoptera: Ciidae) and three bird species (the hazel grouse *Tetrastes bonasia*, long-tailed tit *Aegithalos caudatus* and treecreeper *Certhia familiaris*). To account for the functionality of the habitat (*sensu* Angelstam et al., 2003), we take into account the habitat needs of the species not only in terms of the internal characteristics of the forest stands, but also in terms of the wider spatial distribution of habitat. We predicted that (1) species requiring older forest would benefit from extended rotations and be negatively affected by shortened rotations, while species dependent on young forest would display the opposite response; (2) the relative values of the different rotation scenarios in terms of habitat provision would be consistent through time; and (3) the magnitude of the forecasted effects of modified rotations on habitat provision would be dependent on the spatial scale encompassed by the habitat models (i.e. whether or not the models include the landscape neighbourhood in addition to stand-scale requirements).

2. Materials and methods

2.1. Study landscape

Our study landscape consists of about 24,000 ha of forestland composed of 5911 stands. It is located in south-central Sweden, at the transition between the south boreal and hemiboreal vegetation zones (about 50 km northeast of the city of Örebro; 59-60°N, 15°E). Elevation is about 100–150 m and the topography is characterized by low flat ridges with till and boulders, interspersed by peatlands. Two conifer species dominate the forest: 59% of the standing volume consists of Scots pine (*Pinus sylvestris*) and 34% of Norway spruce. The most common deciduous tree species are the two birches *Betula pendula* and *B. pubescens*. Two dwarf-shrubs, bilberry (*Vaccinium myrtillus*) and lingonberry (*V. vitis-idaea*), dominate the forest floor vegetation. The area is characterized by a long history of logging. Iron mining, relying on charcoal production from wood, occurred in the region already in the 13th century, expanded during the 14th-15th centuries (Bindler et al., 2011), and continued until the later parts of the 19th century. Since the 1950s the forest has been managed for timber and pulpwood production using even-aged management, which involves clearfelling followed by soil scarification, tree planting, pre-commercial thinning, and one or several commercial thinnings during stand growth. The current age-class distribution of the forest is skewed towards younger age-classes (Fig. 1), which is typical for this part of Sweden.

2.2. Forest stand data

We obtained forest stand data from two different sources. The largest part of the study landscape (87% of the productive forest area) belongs to a single forest owner: the state-owned forestry company Sveaskog. For their part of the landscape, we used data from the stand register, which included standing volume, proportions of different tree species, stand age, stand height, and site productivity. For the parts of the landscape which belonged to other owners (13% of the area), we used the segmented version of kNN Sweden (year 2005), which is derived from a combination of satellite images and field plot data from the Swedish National Forest Inventory (Reese et al., 2003). This database contains information about the standing volume of different tree species, stand age and stand height. For the areas where kNN Sweden was the only data source, we estimated site productivity using site index equations based on stand age and height.

2.3. Simulation of future forest development and rotation scenarios

We simulated different management activities (i.e. pre-commercial thinning, commercial thinning, final felling and stand regeneration) and projected forest stand development in the study landscape over a planning horizon of 150 years divided into five-

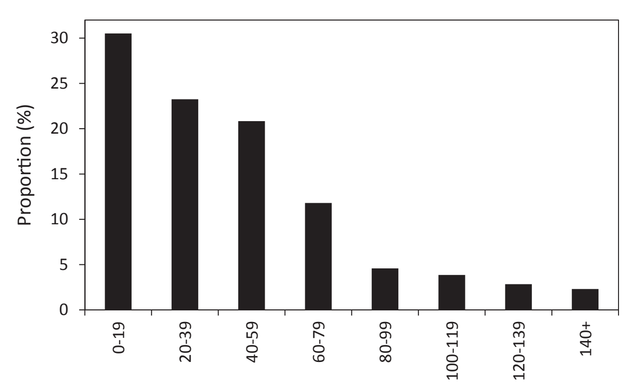

Fig. 1. Initial age-class distribution of the forest stands forming the study landscape in south-central Sweden.