Ecological Economics 148 (2018) 92–102

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

Conservation Costs of Retention Forestry and Optimal Habitat Network Selection in Southwestern Germany

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ARTICLE INFO

Keywords:
Conservation planning
Habitat connectivity
Forest reserves
Minimum area
Retention forestry
Opportunity costs

ABSTRACT

Promoting the maintenance of biodiversity in managed forests should take into account economic efficiency of conservation plans. Therefore, novel economic valuation schemes must be developed in order to support conservation programs and mitigate biodiversity loss. Here, we assess the economic implications of retention forestry practices and create a habitat network in a mixed-montane forest in Southwestern Germany. We applied a simulation-optimization approach for i) evaluation of retention forestry practices applied in the region, ii) creation of forest reserves with a minimum eligible area for biodiversity conservation and establishing a connecting corridor with minimum cost, and iii) allocation of deadwood islands inside the connecting corridor with minimum cost. The average opportunity cost arising from retention forestry practices amounted to 1795 EUR/ha by leaving a minimum deadwood volume of 35 m^3/ha and 2.5–5 habitat trees/ha. The optimized plan for establishing a habitat network would reduce the net present value (NPV) of forest management between 3.7% and 4.2%, and the novel design for the allocation of deadwood islands would impose a marginal reduction (< 1%) to the NPV. We conclude that the creation of a habitat network for biodiversity conservation can be realized with the minimum trade-off to forest management profitability.

1. Introduction

Safeguarding the provisioning of multiple ecosystem goods and services is a major goal of modern forest management. In this context, biodiversity plays a major role, as it directly affects ecosystem functioning and productivity (Liang et al., 2016) and, thus impacting ecosystem value (Isbell et al., 2009). Moreover, several key forest processes are dependent on forest biodiversity, such as pollination, decomposition and nutrient cycling (Thompson et al., 2009). Despite the evident importance of forest biodiversity for human well-being, it has been decreasing at an alarming rate due to anthropogenic influence (Wilson et al., 2005). Approaches aiming to mitigate this trend have been gaining attention in the past decades and the creation of mechanisms related to valuation of ecosystem services, institutional changes and conservation planning have contributed to the implementation of policies targeting biodiversity conservation (Chan et al., 2006).

One of the most relevant policies aiming to benefit forest biodiversity is the implementation of retention forestry practices. Retention forestry emerged as an instrument for balancing biodiversity conservation and production objectives, contributing to the provisioning of multiple goods and services inherent to forest ecosystems (Mori and Kitagawa, 2014). It was developed initially in North America as a response to the simplification of forest landscapes, promoting the inclusion of structural retention into forest management (Gustafsson et al., 2012). Retention forestry has been mostly applied in Boreal forest ecosystems with successful outcomes, helping to mitigate negative impacts from forest harvesting activities (Fedrowitz et al., 2014). In temperate forests the applications have been more limited, but there is an increasing interest in such practices for conservation purposes. Nevertheless, as increasing biodiversity protection usually implies a reduction of revenues from wood production (Bergseng et al., 2012), analyzing the cost of conservation programs is crucial for the implementation of public policies, as it provides a basis for compensation schemes (Hily et al., 2015; Schöttker et al., 2016).

Although retention forestry has shown effective results for biodiversity conservation, its integration with other conservation policies, such as conservation planning, may increase the effectiveness of the conservation strategies. Conservation planning refers to the creation of

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https://doi.org/10.1016/j.ecolecon.2018.02.013
Received 15 August 2017; Received in revised form 15 December 2017; Accepted 20 February 2018

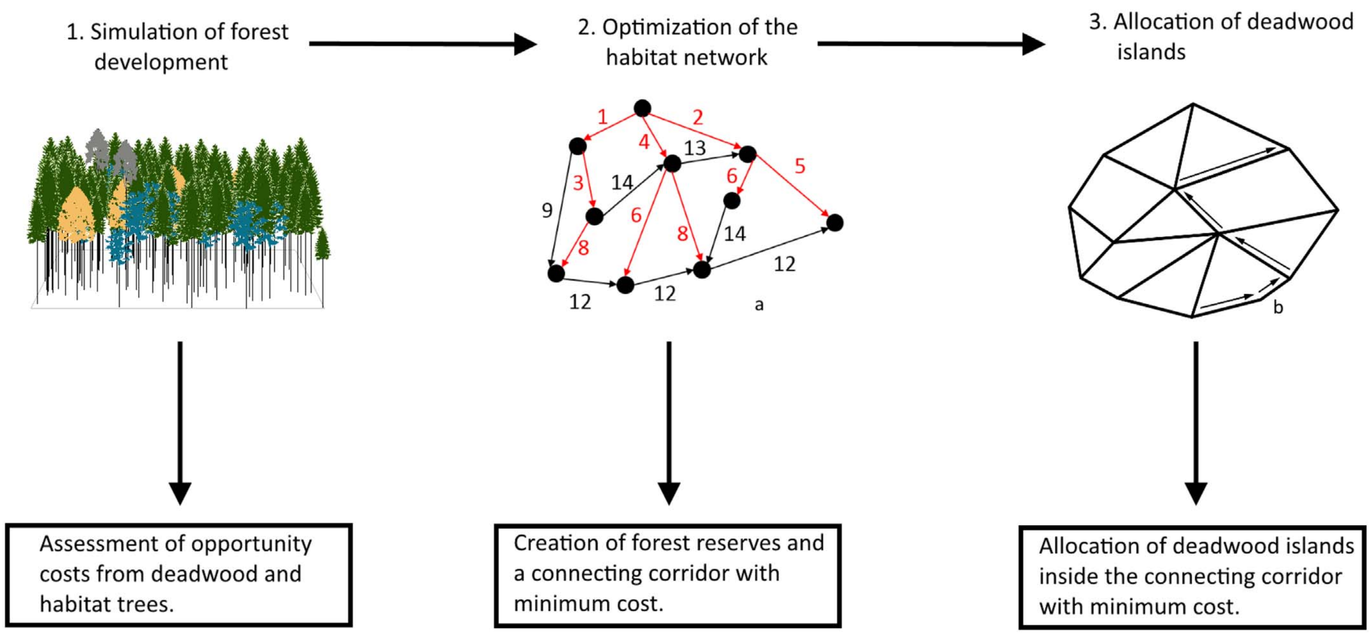

Fig. 1. Steps of the analysis conducted for defining the opportunity costs of retention forestry practices and conservation planning actions (sources: [a] https://commons.wikimedia.org/wiki/File:Minimum_Bottleneck_Spanning_Arborescence_(MBSA).png; [b]https://commons.wikimedia.org/wiki/File:Simplex-description-en.svg).

forest reserves, setting aside forest areas from management, thus preserving habitat and benefiting biodiversity (Ranius et al., 2016; Wilson et al., 2005). The creation of forest reserves is essential, as managed forests are usually unable to provide adequate conditions for several species, particularly specialists depending on large amounts of deadwood and old-growth forest habitats, e.g. birds and saproxylic organisms (Gossner et al., 2016). When designing conservation plans, however, one must consider that the spatial features of the reserves, namely their connectivity and area, may affect the success of the conservation efforts. Connected landscapes facilitate population mobility and gene flow, promoting the persistence of specialist species (Coulon et al., 2004; Stevens et al., 2006; Wang et al., 2008). In addition, landscape connectivity promotes the provisioning of ecosystem services through the transport of matter and biodiversity protection (Mitchell et al., 2013). Hence, it is expected that connected forest reserves show increased stability and integrity and a higher capacity for promoting population persistence (Saura and Pascual-Hortal, 2007). Moreover, observing a minimum area for forest reserves is warranted, as larger forest patches usually display higher species richness and higher probability to maintain functioning ecosystem processes compared to smaller ones (Crist et al., 2005).

There is a rich literature on the creation of connected landscapes and forest reserves. These studies include spatial relationships between stands into forest planning, usually adopting approaches related to graph and network optimization. Mixed Integer Linear Programming (MILP) and heuristic methods have been widely applied in spatial planning studies and the creation of old growth forest patches (e.g. Borges et al., 2017; Fotakis et al., 2012; Tóth et al., 2009). Connectivity problems have been mostly addressed through network optimization, applying adaptations from commodity flow problems (e.g. St John et al., 2016), optimization of connectivity indices (e.g. Ayram et al., 2016; Loro et al., 2015) and graph theory (e.g Foltête et al., 2014; Lechner et al., 2015).

The spatial allocation of forest reserves and the cost associated with retention forestry practices are essential aspects to be considered by decision-makers when managing forest resources. Forest land must fulfill multiple purposes and conservation must be harmonized with production of raw materials, recreation, climate regulation and other objectives (Margules and Pressey, 2000). These objectives are often conflicting and there is a need for an efficient allocation of productive and protected forest areas across the landscape. In this sense, a common rationale when considering the creation of forest reserves is achieving conservation goals with minimum cost. Therefore, it is crucial to consider that forest stands and productivity classes are heterogeneously distributed over the landscape and it is necessary to take into account individual management units' characteristics in the decision-making process (Naidoo et al., 2006).

Although models for creating forest reserves and connected landscapes have been proposed, the simultaneous creation of forest reserves with minimum area and a connecting corridor still has not been considered. Additionally, a comprehensive economic evaluation of retention forestry practices in temperate mixed forests is still missing. In this context, the objectives of this study were to answer the following questions: i) what is the cost arising from retention forestry practices applied in temperate mixed mountain forests? ii) how can we integrate the creation of forest reserves and connecting corridors in a strategic forest planning model? and iii) what is the cost of allocating deadwood islands to promote specialist species in the landscape?

We simulated the Business-as-Usual (BAU) management regime applied in Southwest Germany applying the individual tree, distance-dependent forest growth model Sibyla (Fabrika, 2005). For each stand we computed the value of deadwood generated during the simulation period, as well as the value of selected crop-trees as a proxy for habitat trees, establishing the cost related to retention forestry practices. Habitat network selection was carried out through a forest Net Present Value (NPV) optimization, including the cost related to the establishment of forest reserve borders according to the reserve's perimeter. We included minimum area constraints by implementing ring inequalities (Carvajal et al., 2013) and simultaneously applied an adaptation of the classical Single Commodity Flow problem (Chwatal and Raidl, 2011) in order to connect forest reserves. We then assessed the costs related to this habitat network by comparing the NPV obtained when the creation of new forest reserves and a connecting corridor were taken into account, with the NPV obtained under the baseline scenario, where the habitat network creation was not imposed.

2. Material and Methods

To tackle our research questions, we conducted a 3-step analysis (Fig. 1). Initially, we simulated the forest development under the BAU