Journal of Environmental Management 180 (2016) 366–374

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Discussion

Optimal conservation resource allocation under variable economic and ecological time discounting rates in boreal forest

Adriano Mazziotta [a, b, *, 1], Federico Montesino Pouzols [c, d, 1], Mikko Mönkkönen [b], Janne S. Kotiaho [b], Harri Strandman [e], Atte Moilanen [c]

[a] *Center for Macroecology Evolution and Climate, Natural History Museum of Denmark, University of Copenhagen, Copenhagen, Denmark*
[b] *Department of Biological and Environmental Science, University of Jyvaskyla, Jyväskylä, Finland*
[c] *Department of Biosciences, University of Helsinki, Helsinki, Finland*
[d] *Rutherford Appleton Laboratory, Science & Technology Facilities Council, Harwell Oxford Campus, UK*
[e] *School of Forest Sciences, University of Eastern Finland, Joensuu, Finland*

ARTICLE INFO

Article history:
Received 9 May 2015
Received in revised form
11 February 2016
Accepted 24 May 2016
Available online 1 June 2016

Keywords:
Clear-cut
Complementarity
Conservation planning
Forest management
Habitat restoration
RobOff software

ABSTRACT

Resource allocation to multiple alternative conservation actions is a complex task. A common trade-off occurs between protection of smaller, expensive, high-quality areas versus larger, cheaper, partially degraded areas. We investigate optimal allocation into three actions in boreal forest: current standard forest management rules, setting aside of mature stands, or setting aside of clear-cuts. We first estimated how habitat availability for focal indicator species and economic returns from timber harvesting develop through time as a function of forest type and action chosen. We then developed an optimal resource allocation by accounting for budget size and habitat availability of indicator species in different forest types. We also accounted for the perspective adopted towards sustainability, modeled via temporal preference and economic and ecological time discounting. Controversially, we found that in boreal forest set-aside followed by protection of clear-cuts can become a winning cost-effective strategy when accounting for habitat requirements of multiple species, long planning horizon, and limited budget. It is particularly effective when adopting a long-term sustainability perspective, and accounting for present revenues from timber harvesting. The present analysis assesses the cost-effective conditions to allocate resources into an inexpensive conservation strategy that nevertheless has potential to produce high ecological values in the future.

1. Introduction

In a world dominated by human impacts, where habitat degradation is reducing the space suitable for species, there are different alternatives to protect land when economical resources are limited (Polasky et al., 2008; Mönkkönen et al., 2011). Given the importance of habitat area and quality in conservation (Hodgson et al., 2011), taking two extremes, we can set-aside small selected areas of high quality habitats or we can set-aside as much area as we can, caring less for quality. In the former case we usually assume high habitat quality for species in these selected core areas; in the latter case we create a bigger reserve network that may compensate lower average habitat quality by increased area. Conceptually for boreal forest, setting aside large areas of presently lower quality habitat can be a long-term winning strategy, for at least three reasons. First, those areas will follow natural succession and improve in their quality through time. Second, the economic loss required to set aside this network may be much lower, thereby reducing conflict with stakeholders. This is assuming that lower habitat quality is correlated with lower economic value, as is the case specifically for the boreal forests in Fennoscandia that are focus of this study (Mönkkönen et al., 2014). Finally, choosing a few sites of high habitat quality (and high cost) can result in lower than expected long-term benefits: areas can be damaged by natural or human disturbance; a small protected area is likely to be unable to maintain spatial population dynamics leading to delayed extinctions via the extinction debt (Kuussaari et al., 2009). As a contrary

* Corresponding author. Center for Macroecology Evolution and Climate, Natural History Museum of Denmark, University of Copenhagen, Universitetsparken 15, Building 3 DK-2100 Copenhagen, Denmark.
E-mail addresses: adriano.mazziotta@snm.ku.dk, a_mazziotta@hotmail.com (A. Mazziotta).
[1] Equal first authors.

http://dx.doi.org/10.1016/j.jenvman.2016.05.057
0301-4797/

argument, many species simply cannot survive outside high-quality late successional habitats, implying that such habitats must be included in any successful conservation area network (e.g., Hodgson et al., 2009; Mönkkönen et al., 2011).

In favor of protecting large conservation area networks is the species-area relationship, which states that there is a positive relationship between the area of a site and the number of species found on it. This relationship is one of the most general patterns observed in ecology (Rosenzweig, 1995). On the other hand, empirical observations show that species extinctions follow habitat loss, although often with a considerable time lag (Kuussaari et al., 2009). This implies that a conservation strategy opting for good quality habitats can maintain viable populations in the short term, but isolation and the small aggregate area of the sites could reduce the survival of populations in the long term. Both theory and practice suggest that successful conservation must aim at a balance between area and mean habitat quality (Hodgson et al., 2011).

Considering economics, the net present economic value of an area is combination of the revenue it can produce now and the time discounted revenue it could produce through time. Because future benefits are uncertain, future revenue is usually valued less than immediately available revenue. In contrast, the ecological value of the same area across time can be interpreted from different perspectives. From a utilitarian perspective, the area should have a higher ecological value at present, because the pleasure derived from the presence of biodiversity can only be fully appreciated at the present (Fuller et al., 2007). The conservation perspective assumes a higher ecological value to an area if it can ensure future persistence of species. These two perspectives base their rationale from alternative perceptions of nature as a balance or a flux (*sensu* Ladle and Gilson, 2009). From the sustainability perspective, transmitting ecological values to future generations is the key (Child, 2011).

The choice of the planning horizon or time window for evaluating ecological benefits is a key issue for conservation. Both economic and ecological benefits are dynamic: the former depend on the time an area provides valuable goods; the latter depend on the time the area is suitable for species of interest. Both are mediated through time by biological processes and are conditional on management taken (or lack of it) in the area. Consequently, it becomes necessary to jointly investigate the economic and ecological value of an area through time. However, future benefits of conservation may not be discountable in the same way as are economic values (Gollier, 2010; Kula and Evans, 2011; Guéant et al., 2012; Overton et al., 2013). Based on a logical scrutiny of economic discounting, Philibert (2003) argued that irreplaceable and non-reproducible environmental assets should be given a value growing over time at a pace close to the economic discount rate. A high net present value of future environmental benefits justifies increased immediate investment into conservation (Philibert, 2003). Future high net present value of biodiversity is amplified by the capacity of biodiversity to beget more biodiversity on longer time scales, if protected from factors causing decline (Overton et al., 2013). Long time spans (centuries) are justified in the evaluation of conservation benefits and ecological values, because these benefits are produced by functioning ecosystems and ecological processes and structures that take a long time to establish but can be lost very quickly due to human disturbance.

In Fennoscandia, intensive timber extraction has led to decline of forest biodiversity, and there is a recognized need to expand forest conservation (Brumelis et al., 2011). Here, we investigate optimal allocation of resources between three alternative actions in boreal forests. First, our baseline is business-as-usual commercial forest management. Our second alternative is typical forest conservation enacted via setting aside of mature stands, which offers relatively high immediate ecological quality but with high per-area cost. The third alternative is setting aside of much larger areas of clear-cuts, which presently hold low economic and ecological value. Per-area costs of protecting clear-cuts are much lower than that of mature stands. The question becomes, can clear-cuts support enough ecological value through time to make them a viable complement for mature stands? While clear-cuts currently host few structures of biodiversity importance (Lundström et al., 2011), they can provide habitats for many species if they are allowed to develop via natural succession, including natural accumulation of dead wood (e.g. Junninen et al., 2006; Eräjää et al., 2010; Rudolphi and Gustafsson, 2011; Swanson et al., 2011). They can even host an equal or greater number of species than old-growth forests (e.g. Pykälä, 2004; Selonen et al., 2005).

The analysis done here was implemented using RobOff, a recently released software intended for the investigation of uncertain consequences of alternative (conservation) actions in different environments through time (Pouzols and Moilanen, 2013). A structurally similar analysis could be replicated for other areas or environments with different environmental response functions.

2. Methods

2.1. Outline

We first used a stochastic forest growth simulator (SIMA; Kellomäki et al., 1992) to simulate forest growth in three different habitat types under different management scenarios. From the simulated stands we estimated how economic returns from timber harvesting and habitat suitability indexes (HSI) for six focal species develop over three centuries. Time discounted economic and ecological returns were used to produce response functions that are basic building blocks of the next step, optimal cost-effective allocation of alternative actions using the RobOff framework and software (Pouzols et al., 2012; Pouzols and Moilanen, 2013). This analysis integrates species-specific responses to actions in different environments, uncertainty around these responses, costs of actions, availability of habitats suitable for different actions, and economical and ecological time discounting (Moilanen et al., 2009).

We compared three alternative management scenarios, Business-As-Usual (BAU), set-aside and protect as mature stand (SA), and clear-cut following set-aside and protect (CC + SA). By mature stands we do not mean mature old growth forests but commercially managed forests that have reached the mean diameter allowing clear cut. In Fennoscandia, mature old-growth-forests are available for conservation in very small areas only, and all of them naturally are first priority for conservation. In BAU, stands are managed according to the current widespread standard management recommendations. Since BAU has been developed for the needs of commercial forestry, we can assume that it approximates long-term revenue that is economically optimal. BAU represents a baseline for our primary comparison, which is between SA and CC + SA. In both set-aside scenarios (SA and CC + SA), natural succession was assumed to follow; in CC + SA after the forest first has been cleared during the first 30 years. This time span reflects the fact that the mature managed stands are cut earlier on more fertile soils (like OMT) and later on less fertile soils (like VT). Our chosen time frame, 300 years, corresponds to about four rotations, and is sufficient for a clear-cut to reach the status of an old growth forest stand. Even if stands managed with CC + SA scenario may be of low ecological quality in the beginning they will improve in quality through time. Details of management practices are provided in appendix S1.