Scandinavian Journal of Forest Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/sfor20

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To cite this article: Göran Bostedt, Johnny de Jong, Hans Ekvall, Anouschka R. Hof, Jörgen Sjögren & Astrid Zabel (2021) An empirical model for forest landscape planning and its financial consequences for landowners, Scandinavian Journal of Forest Research, 36:7-8, 626-638, DOI: 10.1080/02827581.2021.1998599

To link to this article: https://doi.org/10.1080/02827581.2021.1998599

Published online: 15 Nov 2021.

SCANDINAVIAN JOURNAL OF FOREST RESEARCH
2021, VOL. 36, NOS. 7–8, 626–638
https://doi.org/10.1080/02827581.2021.1998599

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An empirical model for forest landscape planning and its financial consequences for landowners

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ABSTRACT
Despite well-formulated goals for environmental protection in the forestry sector, the biodiversity crisis remains. Protected habitats are often small, isolated and lack continuity. We studied forest planning at a landscape scale as a method to increase habitat connectivity, and improve conservation values whilst maintaining high levels of forest production. We assessed the financial impacts of landscape planning for the landowners, and present a fee-fund system to solve unequal burdens among them. As case studies, we used three landscapes along a latitudinal gradient in Sweden. The results demonstrate some variation between the landscapes in terms of the total cost for set asides and large differences in terms of the financial impact per landowner. Our conclusion is that forest landscape planning may be a way forward to improve conservation efforts, but given the variation in financial impacts, we propose to combine landscape planning with economic tools for compensation.

ARTICLE HISTORY
Received 4 January 2021
Accepted 16 October 2021

KEYWORDS
Biodiversity; forest landscape planning; forest protection; financial impacts; connectivity

Introduction

The Agenda 2030 is a plan of action for achieving economic growth while protecting the environment and supporting human welfare (https://sustainabledevelopment.un.org/). It, therefore, sets a global framework for sustainable development. In practice, however, sustainability transitions are often fraught with trade-offs between legitimate but diverging objectives among different dimensions of sustainability (Geijer et al. 2011, 2014). In many cases, reforms are necessary to reconcile the dissenting interests and to design more coherent, and thus sustainable, policies. One example can be found in the forest sector, where global efforts are ongoing to advance forest landscape restoration which aims at integrating forest production and conservation needs in the same landscape. However, meeting the financial demands of such undertakings pose a challenge in tropical as well as in OECD countries (Organisation for Economic Co-operation and Development) (Brancalion et al. 2017; Dawson et al. 2017).

The Convention of Biological Diversity (CBD) is another important process for environmental goals, such as the Aichi targets (United Nations Environmental Programme (UNEP)/CBD/COP 2010). To implement the CBD, the Swedish parliament adopted a set of 16 environmental quality objectives. These provide detailed information on the national conditions deemed necessary for the environmental component of sustainable development in Sweden (http://sverigesmiljomal.se/environmental-objectives/). Formulated already in 1999, the Living Forests objective states that "The value of forests and forest land for biological production must be protected, at the same time as biological diversity and cultural heritage and recreational assets are safeguarded". The Swedish Environmental Protection Agency (SEPA) claims that this objective has not yet been reached, and according to projections, there are currently dim prospects that it will be achieved with existing and approved instruments and measures by its target year 2020 (Naturvårdsverket 2017). The SEPA highlights the need for measures to halt habitat loss and fragmentation while criticizing that current environmental initiatives are insufficient (Naturvårdsverket 2017).

Indeed, Swedish forestry is intensive, enterprises are highly mechanized, and the export-oriented sector is driven by efficiency considerations. Since Sweden is the world's third-largest exporter overall of paper, pulp, and sawn timber, the forestry sector is economically strong, contributing 10% of Sweden's export earnings, and it provides employment especially in rural areas (Swedish Forest Industries 2020). With respect to nature conservation, the proportion of formally set-aside forests in Sweden is limited to 4%, with an additional 5% set aside as part of voluntary agreements (Swedish Forest Agency 2019). As a result, the set asides create a mosaic of small conservation patches within

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a landscape of intensive forestry (Aune et al. 2005; Gustafsson et al. 2010). Areas of high conservation value are however not spread homogeneously across Swedish forest estates. They are rather heterogeneously distributed across forest landscape, i.e. on some estates far more than 5% of the area contains habitat with conservation values, while on other estates, there may be no areas of particular conservation value. The uneven spatial distribution of biodiversity is not unique to Sweden, but rather a typical feature of forest biodiversity all over the world (Pizo and Tonetti 2020; Taylor and Lindenmayer 2020; Zhou and Song 2021). In Sweden, a relatively small part of the forest landscape is protected as nature reserves with full compensation to the landowner, while the majority of habitats with conservation value is supposed to be conserved voluntarily without compensation. This creates an obvious challenge for biodiversity conservation (Michanek et al. 2018).

One possible solution for combining intensive forestry with efficient conservation of biodiversity is landscape planning based on conservation goals and a gap analysis. The objective with forest landscape planning for conservation is not only to identify habitats with high conservation value, but also to increase the functionality of landscapes by restoring and creating new habitats and by giving priority to connected habitats for conservation rather than to small and isolated habitats (Lindenmayer and Hobbs 2007). Further, it includes spatial and temporal aspects such as movements of organisms, connectivity, and continuity (Desmet 2018; Lechner et al. 2017; Nordén et al. 2014; Ruokolainen et al. 2018), and a number of conservation tools may be useful such as set-aside, restoration or conservation management. Landscape planning has been discussed as a way forward for decades within conservation biology (Leitão and Ahern 2002), but seems to be very difficult to realize in practical forestry, and it requires much expertise and a truly interdisciplinary approach (Michanek et al. 2018). Deciding on goals may create conflicts between stakeholders and requires strategies and processes for environmental communication.

Introducing landscape planning that affects many landowners is however tainted with several challenges. Firstly, there are several administrative and legal problems. A forest is almost always owned by someone, who – within legal limits – has the right to decide and plan for their own property. Secondly, there are economic issues that need to be addressed. While most landowners prioritize timber production, some will be intrinsically more motivated to focus on conservation, (e.g. Bostedt et al. 2019). Consequently, there will be differences in costs and benefits among the landowners. In addition, there are scientific issues related to our knowledge about species (habitat requirements, dispersal abilities, etc.) which are necessary to address to create an efficient forest landscape plan. Thus, while landscape planning for conservation in principle may seem like a fairly straightforward approach to improve the connectivity of ecologically valuable areas, actual policy design becomes difficult when landowners are unequally affected by restrictions. Few studies have addressed policy analysis in this area until now, and little is known about financial effects of landscape policy approaches for forest owners (Bell et al. 2016; Parkhurst and Shogren 2007; Parkhurst et al. 2002; Zabel et al. 2018).

In this study, we propose a new, generally applicable, method to increase habitat connectivity, and improve conservation values, whilst maintaining high levels of forest production by forest planning at a landscape scale. Further, we apply this method to investigate the financial impact on the landowners in three model forest landscapes with a simulated ownership structure, and discuss the potential for a future fee-fund system. Such a fee-fund system could serve as a solution for a sustainability transition in forests that reconciles economic growth, environmental protection and social welfare concerns. Here, the paper builds on the study in Zabel et al. (2018), which proposed the above-mentioned fee-fund system. With this system, forest owners pay a certain fee, and the funds generated through the fee are used to compensate forest owners that are required to set aside land for conservation purposes. Such a policy is theoretically related to refunded emissions payment programs (cf. Fredriksson and Sterner 2005), an environmental policy approach which has been successfully tried in Sweden when equity concerns and political acceptance need to be taken into account.

Figure 1 outlines the logic of the approach proposed in this paper. The status quo described above is depicted in the lower left quadrant of Figure 1. The first step proposed in this paper is to define criteria based on which conservation priorities, i.e. forest areas with high environmental values, can be identified and mapped. This shift is marked by arrow 1 in the figure. Consequently, the financial burden of conservation becomes unequally distributed across landowners because priority areas most likely are heterogeneously distributed. A fee-fund system can then be applied to even-out the financial burden of conservation among forest owners (arrow 2 in Figure 1), ideally restoring horizontally equity in terms of the distribution of costs. The upper left quadrant would resemble a situation with uniformly distributed conservation sites, e.g. a requirement to set aside 10% of each stand's area. Given the variation in economic value, such an area-based solution would result in an unequal distribution of the burden across landowners and would thus be politically difficult to implement.

The aim of this paper is to make an as realistic as possible simulation of the effects of implementing a landscape forest management plan combined with a fee-fund system on biodiversity and on the economy of private forest owners. Key questions are to what extent such a landscape plan is superior to the current Swedish system from a biodiversity point of view, and whether such a system can be self-sustained in the sense that the fee-fund system can finance the loss for forest estates that are required to set aside larger shares of land, or if additional government funding is necessary to achieve the conservation objectives. Our application of forest landscape planning is an advance on prior works that generally use highly stylized or simplified model landscapes. We examine the ecological and economic effects on forest landscapes that reflect the real situation in Sweden, albeit with a simulated ownership structure. We argue that our approach has wide applicability for boreal forest landscapes all over the world.

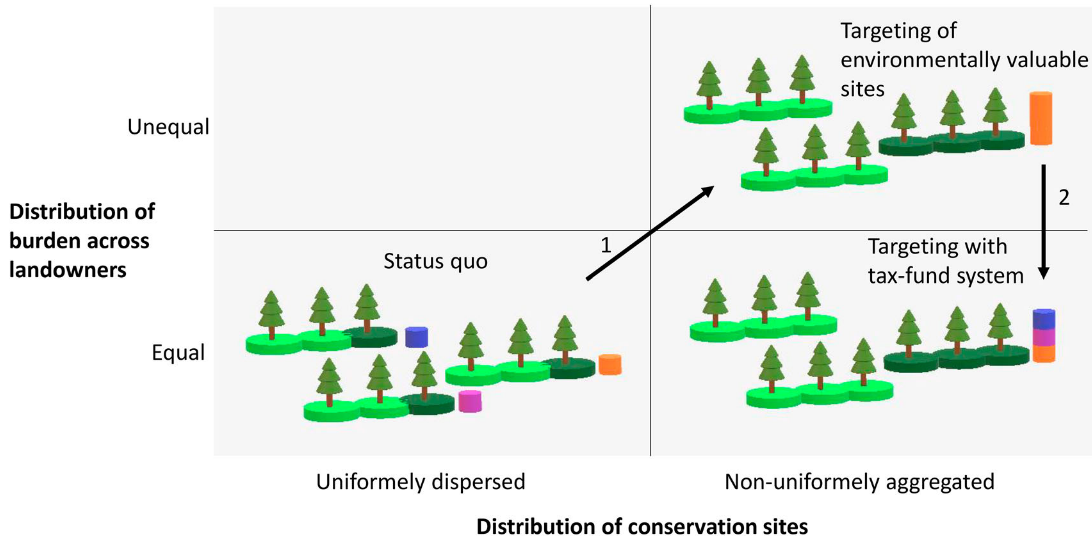

Figure 1. Moving from uniformly dispersed conservation with equal burdens across landowners to targeting with a tax-fund system. (Note: The three "forests" per quadrant represent the estates of three forest owners. The dark green is the conservation area. The colored pillars to the right of the estates represent the owners' monetary burdens).

Methods

Study sites

Three different forest landscapes were selected for the study (Figure 2) to compare the effects of forest landscape planning across Sweden. The landscapes in our study sites are all owned by large forest companies, one in each landscape (SCA AB in Lapland, Holmen Skog AB in Östergötland, Sveaskog AB in Småland). The reason for selecting study sites with one dominating landowner was due to data availability considerations. We then overlaid these study sites with a simulated ownership structure (see below for details). The single ownership of the studied landscapes could influence the results, especially if the owner already implements some kind of landscape approach in the management of their forests, rather than a standwise optimization approach. However, the current forest landscapes in these areas are the results of historical management, and since landscape approaches are a relatively new element in forest management a standwise management has been the most likely approach. Furthermore, ownership can vary over time and since our approach is a demonstration of results of a forest planning, we do not think single ownership has a large effect on the outcomes. One forest landscape was located in northern Sweden (province of Lapland) and two were located in southern Sweden (provinces of Östergötland and Småland).

The three forest landscapes are well distributed from north to south Sweden. The longitudinal distance from the landscape in Lapland to the southernmost landscape in Småland is ~1050 km. That implies large differences in temperature and climate, which means large differences in growth potential. Forests in the southern part of Sweden (Östergötland and Småland) produce twice as much commercial wood compared to Lapland. All three forest landscapes are dominated by Scots pine (*Pinus sylvestris L.*), while Norway spruce (*Picea abies (L.) H. Karst*) is more common in the country as a whole (Swedish Forest Agency 2018a). The proportion of deciduous trees is, compared to current official statistics (Swedish Forest Agency 2018a), notably low for all three forest landscapes. The current age class distribution in all three areas is uneven (Figure 3). The main differences between the landscapes are the occurrence of Lodgepole pine (*Pinus contorta* Douglas ex Laudon) in the north and higher growth rates in the south. Lodgepole pine is an important provider of pulpwood, but only allowed to be grown in the northern parts of Sweden. There is also a difference in the proportion of forested land in each landscape with the highest proportion in Östergötland and the lowest in Småland. In Lapland, the non-forest land cover mainly consists of bogs and lakes, in the south, it consists of fields and lakes. The geographic location of the sites and basic landscape data for each forest landscape are presented in Table 1.

Younger stands up to 39 years old, dominate all three study sites. The tallest bar, age class 30, for Lapland, depends mainly on extensive plantation of Lodgepole pine more than 30 years ago. The age maturity ratio, Age/Rotation, indicates that study site Östergötland (0.64) possesses relatively more mature forest stands than the study site Lapland (0.47).

Focal species

As focal species, we mostly used species listed in the Habitat directive, annex II, and in the Bird directive (Council Directive 92/43/EEG and 2009/147/EG). We chose our focal species to, together, represent the occurring species assemblage, and each species to (1) be forest specialist, (2) have very specific habitat requirements affected by forestry (such as dead wood, old trees, or swamp forest), and (3) have distribution areas overlapping with our study sites. For the forest landscapes in Småland and Östergötland, 16 species were selected as focal species, and in Lapland, 11 species were selected (Table 2).

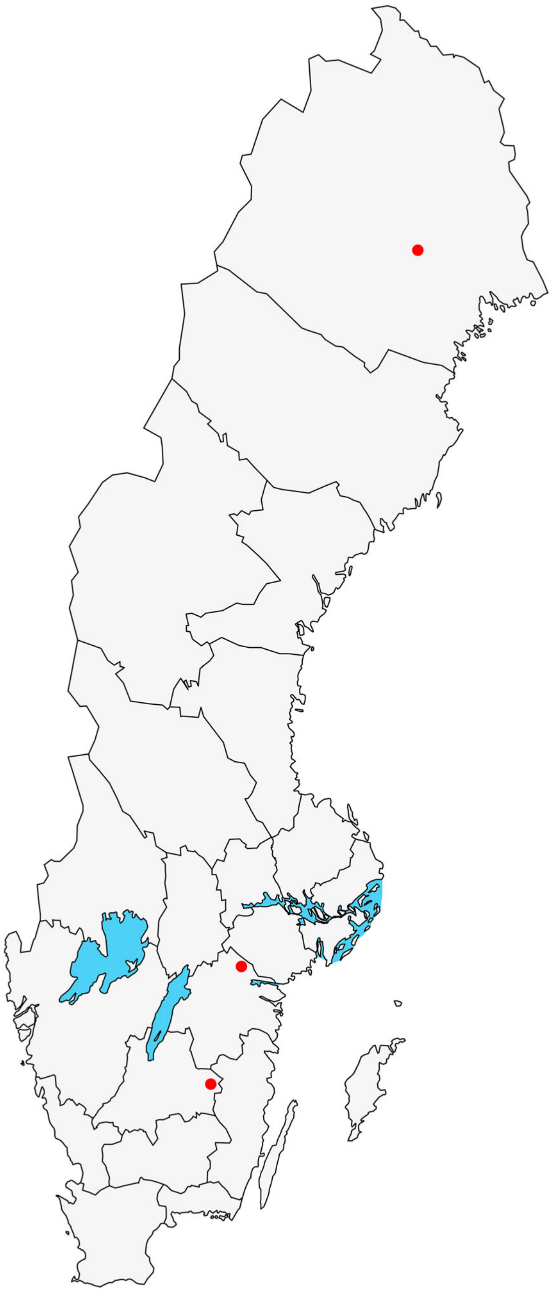

Figure 2. Study areas, indicated by red dots. From north to south: Lapland, Östergötland, Småland.

Spatial prioritization

The spatial conservation planning software Zonation (Moilanen et al. 2005, 2014a) was used to identify (1) which stands should be set-aside to benefit the selected species, (2) which stands should be restored to benefit the selected species by creating more connectivity between suitable sites, and (3) which stands can be harvested with a "normal" harvest strategy. Zonation allows for prioritization of multiple biological features for conservation based on the known or inferred presence of biological features (Moilanen et al. 2014b). Biological features could be species as well as habitat types, ecosystems, and other features. Based on the presence of biological features and user-defined weights of feature importance, in which more heavily weighted features are prioritized over less heavily weighted features, Zonation identifies the areas (on a cell level) that should be prioritized in order to protect the most important features, as defined by the user. When the model starts, every cell is protected. At every iteration, a set number of cells is removed until all cells in the model are unprotected. The first cells to be omitted have the lowest priority for conservation and the last cells to be omitted have the highest priority for conservation. Connectivity can be accounted for in several ways (Moilanen et al. 2014b, see below). The output consists of, amongst others, a map with prioritization hotspots and cold-spots in which each cell has a value ranging from 0 (no priority) to 1 (high priority).

Since the presence/absence of our focal species in our study region is currently not known, we used a number of forest characteristics, presumably reflecting the likelihood of occurrence of our species, as our input features in Zonation (Table 3). We collected data for forest characteristics based on the age of the forest, volume of specific tree species (Silver birch [*Betula pendula* Roth], Norway spruce, Scots pine), woodland key habitat (defined by the Swedish Forest Agency as a forest patch of high conservation value, Swedish Forest Agency 2017a), swamp forest, forest with conservation values (Swedish Forest Agency 2018b), and biotope protection (Table 3). The denseness of the forest (open or dense) was determined in relation to the standing volume in the study site. Cells with a volume larger than average for the area were classified as dense and those with a value lower than average for the area were classified as open. For the area in Lapland, we were also able to obtain data on whether the forest was classified as forest with continuity of crown cover (forests without clear-cuts). Data were collected from the forest companies and available forest statistics from several internet sources (www.skogsstyrelsen.se, www.slu.se, www.naturvardsverket.se). Based on the known ecological requirements of our focal species, combined with our own expert knowledge of the species, we scored the importance of each forest characteristic for the focal species as 0 (not important), 1 (moderately important), and 2 (very important). The final score entered as a weight for the feature in Zonation to create one map of prioritization for all species was based on the sum of the individual scores given to the forest characteristics deemed important for our focal species.

We used the core-area zonation method in which cell removal is done with the aim to minimize the loss of biological features (Moilanen et al. 2014b). To obtain some measure of connectivity between areas of high priority, we used the boundary penalty length (BPL), which penalizes cell removal based on increasing boundary length to produce a more compact reserve network (Moilanen et al. 2014b). After testing several BPL values, we decided to use a small boundary penalty of 0.0001 to obtain some connectivity in the landscape without too much aggregation of cells. The warp function, which decides how many cells are "removed" at a time, was set to 1 (Moilanen et al. 2014b). Based on the resulting prioritization map, we took the median of the cell values per stand to create a stand-level priority map. Stands that had an average cell value of ≥0.90 were assigned to be set-aside for protection, those that had an average value of ≥0.80 but

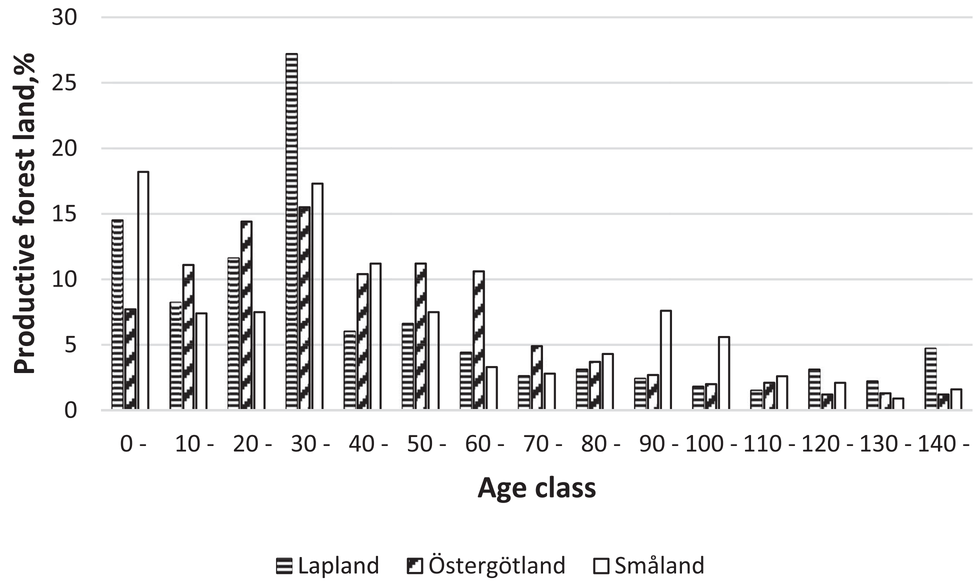

Figure 3. Current age class distribution in the three study sites (Data from forest companies, SCA, Holmen and Sveaskog).

<0.90 were assigned to be restored. The stands that had an average cell value of <0.80 were assigned to be harvested.

Financial data and financial calculations

For the financial analysis prices on timber, harvesting and silviculture were obtained from the forest owners associations Norrskog (study site Lapland) and Södra Skogsägarna (study sites Östergötland and Småland). The financial base year was set to 2015 and due to volatility in market prices, applied price levels for 2015 were estimated as the average value for the years 2011–2020. A discount rate of 3% was used for the present value estimations.

Since each forest landscape was dominated by one large landowner, it was easy to obtain forest data for each stand.

Table 1. Descriptions of the three study areas.

	Province		
Landscape characteristics	Lapland	Östergötland	Småland
Central coordinates	N66.2; E20.2	N58.8; E16.2	N56.9; E15.3
Landowner	SCA	Holmen	Sveaskog
County	Norrbotten	Östergötland	Kronoberg
Area of productive forest, ha	6535	7394	7216
Number of stands	1116	4567	3617
Tree volume, m^3sk/ha	60	171	146
Tree volume, mean value/ county, m^3sk/ha	87	179	142
Growth, m^3sk/ha and year	2.9	6.6	5.0
Tree species composition, %			
Scots pine	55	50	66
Lodgepole pine	20	0	0
Norway spruce	17	43	28
Deciduous trees	8	7	6
Age aver, years	47	47	49
Rotation aver, years	101	74	83
Age/rotation	0.47	0.64	0.59
Number of simulated properties	88	255	208
Mean property size, ha	74	29	35
Max–min property size, ha	12–98	1–40	1–52
Number of stands/property	4–24	1–36	1–40
Protected area	0	0	0

However, for the purpose of the current project, we overlaid the stand structure with a simulated owner structure, based on a regular grid of 100 by 100 m in north Sweden and 50 by 50 m in south Sweden, which corresponds to the average property sizes in the respective areas (Swedish Forest Agency 2017b). This simulated landowner structure was then used in all financial calculations.

Stand management

The management of the stands was planned according to the present value maximization using Plan33, a computer program for economic forest management (Ekvall 2014). Here, it is important to emphasize the sequential nature of the analysis. The spatial conservation planning done by Zonation precedes the present value maximization done in Plan33, which is done while taking the Zonation results as given. This means that there is no feedback from the financial analysis back to the selection of conservation sites. This effectively limits the economic analysis to a financial comparison of the Zonation results with the current Swedish forest management, rather than an integrated economic optimization.

The timing of final harvest and the number, type (e.g. size of felled trees in relation to those retained), timing, and intensity of the thinnings were based on the Faustmann model for defining opportunity cost measures. It was assumed that the stands are managed according to normal forest practice. The applied silvicultural system can be defined as even-aged timber management including regeneration measures, intermediate cuttings, and a final clear-cut. Harvest residues from conifers in connection with the clear-cut are piled up for biofuel use. At each clear-cut, 11% of the productive area was assumed to be left as set-aside (Swedish Forest Agency 2019). The notion of normal forest practice can be defined as adopting accepted silvicultural measures and complying with the Swedish Forest Act to achieve production and environmental objectives stated by governmental authorities.

Table 2. Focal species used in each study area.

Species	Study area	Species	Study area
Bryophytes		**Butterflies**	
Buxbaumia viridis	Småland, Östergötland	*Lopinga achine*	Småland, Östergötland
Leucobryum glaucum	Småland, Östergötland	*Parnassius apollo*	Småland, Östergötland
Herzogiella turfacea	Småland, Östergötland	**Terrestrial molluscs**	
Fungii		*Vertigo angustior*	Småland, Östergötland
Phellinus ferrugineofuscus	Lapland	**Bats**	
Lichens		*Myotis nattereri*	Småland, Östergötland
Lobaria pulmonaria	Lapland	*Barbastella barbastellus*	Småland, Östergötland
Vascular plants		**Birds**	
Lycopodium tristachyum	Småland, Östergötland	*Dendrocopos leucotos*	Lapland
Lycopodium zeilleri	Småland, Östergötland	*Dendrocopos minor*	Småland, Östergötland
Cypripedium calceolus	Småland, Östergötland	*Picoides tridactylus*	Lapland
Saproxylic invertebrates		*Perisoreus infaustus*	Lapland
Anthrenochernes stellae	Småland, Östergötland	*Poecile cinctus*	Lapland
Lucanus cervus	Småland, Östergötland		
Osmoderma eremita	Småland, Östergötland		
Boros schneideri	Lapland		
Xyletinus tremulicola	Lapland		
Agathidium pulchellum	Lapland		
Pytho kolwensis	Lapland		
Stephanopachys substriatus	Lapland		
Stephanopachys linearis	Lapland		

Initially, it was assumed that over the last 20 years, the forest in each study site was tended complying with prescriptions stated by the certification organization Forest Stewardship Council (FSC). This implies setting-aside at least 5% (we have in fact assumed a 5.1% set-aside area according to statistics from the Swedish Forest Agency (2019), of each stand's area for the benefit of increased biodiversity. Furthermore, the FSC prescribes measures that increase the volume of dead wood (Coarse Woody Debris, CWD), such as creating high stumps, avoid felling snags and dying trees, save nest trees, etc.

Table 3. Forest characteristics and weights given to each characteristic in Zonation. The "weight" signifies the user-defined importance of the feature, in which more heavily weighted features are more important to conserve than less heavily weighted features. The final weight of a feature as shown in the table is the total sum of weights, i.e. importance, of the feature for each focal species.

Forest characteristics	Weights Lapland	Weights Småland and Östergötland
Forest with nature values	18	28
Biotope protection	18	28
Swamp forest	4	17
Average age >60	1	2
Average age >100	6	14
Average age >120	18	24
Volume scots pine >50%	5	6
Volume Norway spruce pine >50%	11	6
Volume silver birch >50%	8	19
Key habitat	18	28
Continuity forest	14	NA

The mandatory set-aside area of 11% at each final-cut, and the optional set-aside area of 5.1% (FSC) eventually resulted in a total set-aside area of between 11 and –16.1% for each landscape in Sweden.

Management programs

On each simulation, each stand was treated by one of four different management programmes, MP1 (current applied certified forestry), MP2 (set-aside), MP3 (restore), or MP4 (harvest) (Table 4). The outcome of each management program is optimized on stand level according to the Faustmann rule. The chosen management program is affected by four main control variables: Set-aside area, broadleaf proportion, complying with FSC standard and biofuel harvesting. The first management program, MP1, is a simulation of current applied certified forestry in Sweden. In the second management program, MP2, the whole stand area is set-aside. In the third management program, MP3, 20% of the productive area is set-aside and on the remaining 80% broadleaf management is conducted. Finally, MP4 means an intensive forestry focused on maximum profit for the forest owner.

Scenarios

Three different scenarios have been simulated in the forest landscape. Each scenario consists of one to three different management programs.

1) The first scenario, called Maximum Timber Production (TPmax), is dedicated to intensive timber production across the entire landscape, which means harvesting pulpwood, saw timber, and biofuel assortments and with none or limited consideration to nature values or conservation goals. The objective of this management is to maximize the owner's profit. For scenario TPmax, MP1 (Table 4) was applied throughout the entire forest landscape. Although this scenario was the guiding principle for foresters before 1980, it is nowadays forbidden by current Swedish forest legislation. The scenario serves merely as an interesting comparison of the effects of a pure profit-maximizing forest management.
2) In the second scenario, called "Certified forestry" (CF), the forest owner complies with both the general conservation measures in The Swedish Forest Act and the regulations stated by FSC. For scenario CF, MP2 is applied throughout the entire forest landscape. This scenario can be considered as the base with which other scenarios are compared.
3) The third scenario, called "Landscape planning" (LP), is characterized by extensive considerations for conservation and biodiversity improvement. Within this scenario MP1, 3 or 4 are used based on the results from the Zonation calculations. Each stand in the landscape is assigned a Zonation value between 0.00 and 1.00. A Zonation value larger than or equal to 0.90 implies the use of MP2, a Zonation value larger than or equal to 0.80 directs to MP3, and finally a Zonation value lower than 0.80 points to MP4.

Table 4. Applied management programs.

Management programme	Management objectives	Control variables: Set-aside area, %	Broad leaf proportion objective, %	Comply with FSC rules	Area used for harvesting biofuel, %
MP1	Certified forestry	11.0 + 5.1	–	Yes	83.9
MP2	No management	100	–	No	0
MP3	Increasing the proportion of dead wood and broadleaf	20	75	No	80
MP4	Intensive forestry	0	–	No	100

For each scenario, calculations over a time span of 200 years are made. Every 5 years, the change in important forest characteristics such as standing volume, proportion of tree species, harvest composition, the volume of CWD, age class distribution, etc., are estimated. Changes over time are finally reflected in the estimated present value of the forest.

Results

Landscape planning

As described in the section study sites, there are some differences between the study sites and this is reflected in the result from the landscape planning (Figures 4 and 5, Table 5). There are no large differences between the forest landscapes in the proportion of areas with high conservation values (varies from 5.0 to 6.6). However, in south Sweden (Östergötland and Småland), the area is divided into a very large number of small patches. Concerning patchiness, Östergötland is the most extreme forest landscape, and about 98% of the patches are smaller than 5 ha, and no patches are larger than 10 ha. This is also reflected in the landscape planning; in Lapland and Småland, forest-sites with high conservation values are more aggregated, while these sites are patchier in Östergötland. With our model, a less fragmented forest landscape (larger patches) result in higher proportion of set-aside, and higher connectivity.

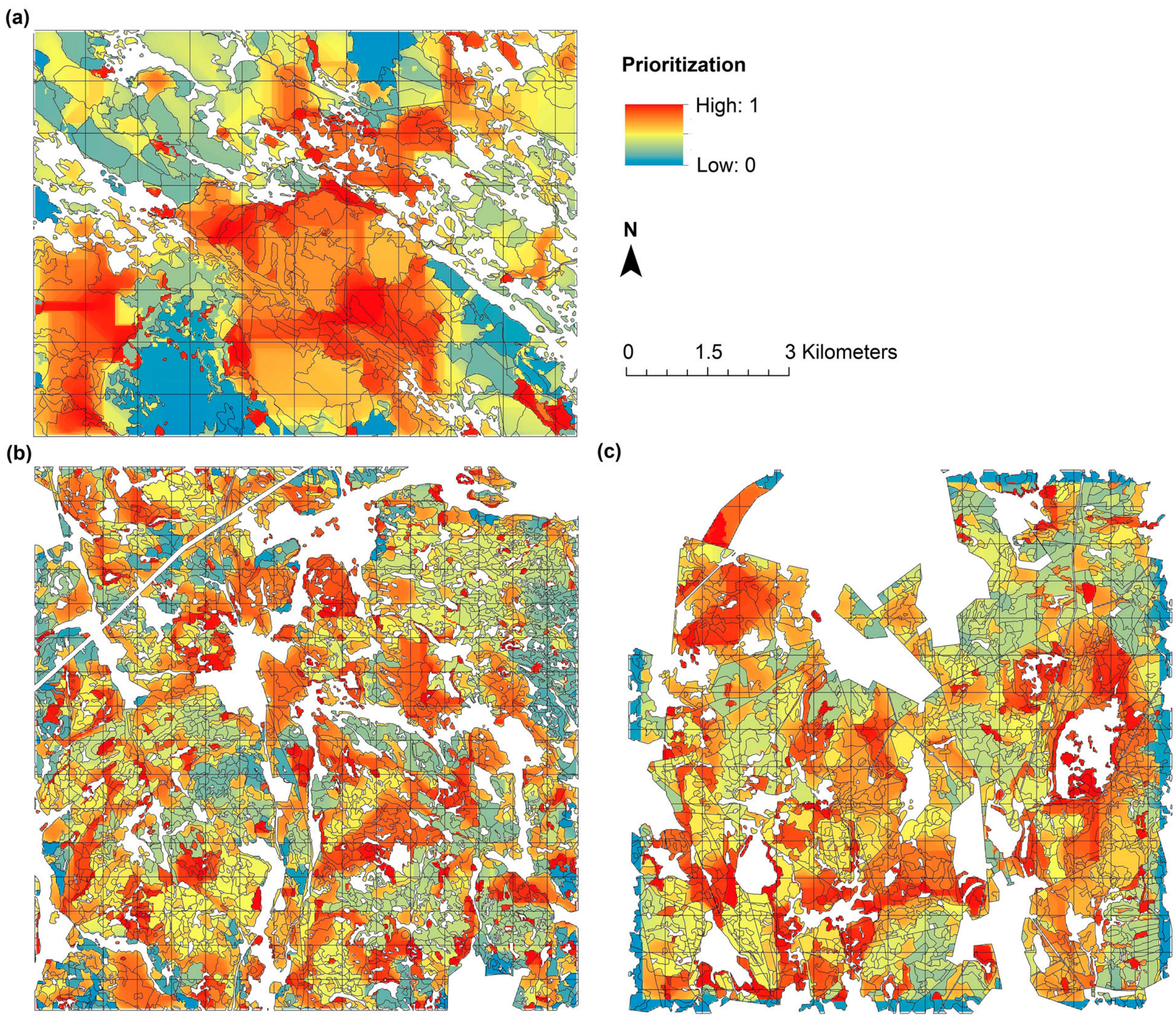

Figure 4. Prioritization maps for (a) Lapland, (b) Östergötland, and (c) Småland.

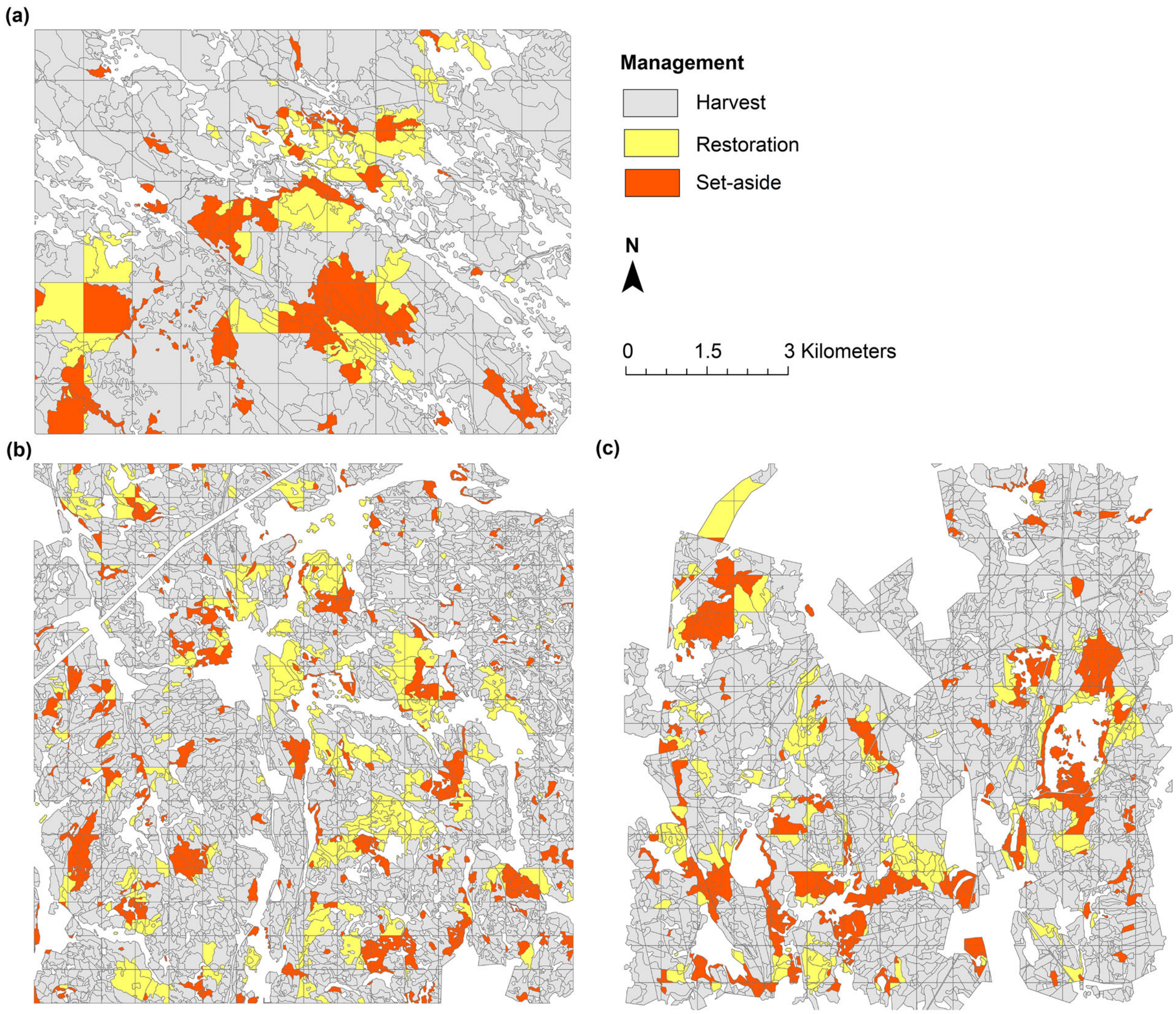

Figure 5. Stand-level priority map for (a) Lapland, (b) Östergötland, and (c) Småland.

Financial calculations

The three scenarios, TPmax, CF, and LP, were compared with respect to variables related to conservation value. In Table 6, some stand characteristics are presented, which are of great importance when assessing factors that improve the conservation value (Ranius et al. 2005). The figures in Table 6 refer to simulated average stand characteristics from year 0 to year 200. Furthermore, Table 6 also shows to what extent the present value is affected by applied conservation efforts.

Comparing the three scenarios, some evident results emerge. Generally, scenario CF generates more set-aside area, volume coarse woody debris, old trees, and spruce. Scenario LP increases the proportion of deciduous trees more efficiently. Although the CF scenario seems to produce more old and dead trees, one has to have in mind that scenario LP increases the connectivity between valuable conservation sites dramatically. As expected, scenario TPmax generates the lowest conservation values and the highest profits for landowners.

When the transition from the CF scenario to the LP scenario takes place, forest owners will face losses or gains. These losses or gains are presented as changes in the property present value of timber production (Figure 6, Table 7).

The most costly management program to undertake in the Landscape scenario (LP) is MP2, i.e. setting-aside the entire stand for improved biodiversity. The area of forest land managed according to MP2 is calculated by Zonation and reflects an assumed minimum area set-aside needed for the survival of focal species. The area MP2 in relation to total area is estimated to 12.4% for Lapland, 9.5% for Östergötland, and 12.6% for Småland. Furthermore, the relative present value of latent timber production on areas designated for MP2 varies a lot. In the study site Lapland, very financially valuable stands are set-aside (relative present value 1.63) but in Östergötland, the set-aside area consists of average stands (relative present value 0.99). Significantly lower values for both set-aside area and present value of the set-

Table 5. Proportion of areas with high conservation values based on Zonation, and size distribution.

Landscape	Prop. of areas with high conservation values (%)	Number of patches <5 ha	Number of patches >5 ha	Number of patches >10 ha
Lapland	6.3	50	24	6
Östergötland	5.0	297	6	0
Småland	6.6	235	20	2

Table 6. Average stand characteristics, simulated over a time span of 200 years.

Study site	Scenario	Area of set asides, %	Volume of coarse woody debris,m^3/ha	Share of stands aged >120 years, %	Share of deciduous stands, %	Present value, relative to CF scenario, %
Lapland	TPmax*	0	3.9	0.1	4.9	21
	CF**	16.1	11.9	15.5	4.3	–
	LP***	14.8	11.1	14.8	8.3	−9
Östergötland	TPmax	0	5.6	0	7.8	19
	CF	16.1	18.5	15.7	6.6	–
	LP	12.3	16.1	12.2	11.6	3
Småland	TPmax	0	4.2	0	8.0	19
	CF	16.1	15.4	15.4	7.2	–
	LP	14.7	14.2	14.5	10.6	−3

*This scenario is dedicated to intensive timber production across the entire landscape, which means harvesting pulpwood, saw timber and biofuel assortments, and with none or limited consideration to nature values or conservation goals.
**This scenario complies with both the general conservation measures in The Swedish Forest Act and the regulations stated by FSC.
***This scenario is characterized by extensive considerations for conservation and biodiversity improvement based on the results from the Zonation calculations.

aside for Östergötland indicate lower management costs that are more easily balanced by proceeds from larger areas managed by the MP4, or intensive forestry program (Table 8).

Discussion

Our simulations for three forest landscapes in Sweden provide case study insights that are relevant to the larger debates on forest landscape restoration planning and forest restoration finance.

The results show high variation between study areas. For example, in south Sweden, spatial prioritization was more fragmented with a number of small patches of high conservation priority, while the areas with high conservation priority were more aggregated in the north. The conservation value of areas, and the distribution of such areas, depends on many factors, such as historical forest management, topography, natural distribution of habitats (e.g. lakes, bogs, and fields), production capacity, etc. The financial analysis revealed substantial differences between the regions. While the Lapland and the Småland areas cannot support a self-sustaining fee-fund system, the Östergötland area could. There are several plausible explanations for the outcomes of our case study landscapes to differ. The first is that – as mentioned earlier – our computations were conducted sequentially, i.e. the selection of conservation areas with the Zonation software was done first and the financial analysis second, while taking the Zonation results as given. This means that there was no feedback from the financial analysis back to the selection of conservation sites, and thus this approach lacks scope for any optimization to minimize environmental-economic trade-offs. Trade-offs between socio-economic factors and biodiversity conservation are, however, important to consider. Zonation can in fact account for data regarding the spatial distribution of socio-economic factors such as costs of land and management, opportunity costs, and willingness to sell land (Moilanen et al. 2014b). We did not have such data available and therefore did not consider them; in real-life applications of our approach, we would advocate accounting for such socio-economic factors. More advanced possibilities to account for trade-offs between socio-economic factors and biodiversity conservation need further investigation.

A further reason for the differences in the results between the three forest landscapes are likely to be due to the correlation between conservation value and market value of forest stands. Conservation will inevitably be costly, when this correlation is strong because the stands with the highest opportunity cost will be selected for set-aside (Zabel et al. 2018). Moreover, differences in the heterogeneity of the landscapes are likely to play a role. Our approach is based on protecting all habitats above a specific quality threshold. Consequently, the conservation area, and the cost for conservation will vary between landscapes. In Lapland and Småland, financial self-sufficiency is more difficult to achieve because stands with relatively low economic value have to compensate for the foregone income opportunities of far more valuable forest stands. In Östergötland by contrast, the difference in economic value between the stands is far less pronounced.

Methodology-wise, there are a number of different approaches to landscape planning available (Carroll et al. 2010; Lindenmayer and Hobbs 2007; Taylor et al. 2017). Which method to use depends mainly on goals and data availability (Bartuszevige et al. 2016). If there is a conservation goal, landscape planning is often based on some indicator species (e.g. species of conservation interest) and the quality of the plan might depend on the knowledge we have of these species, such as distribution, movements, habitat requirements, etc. (Khosravi and Hemami 2019). In our study, the data input was limited to GIS-layers available on different websites, and to data collected by the landowners. Important data such as abundance of dead wood, forest structure, and species occurrence were lacking. To be able to add such data, fieldwork is required. Therefore, our results may not reflect the real conservation values of the stands. Furthermore, we used a simulated ownership structure which did not reflect true ownership. However, ownership may vary to a large extent in space and over time and with that costs and benefits per owner. We can therefore motivate our using a simulated ownership as a functional approach. The main advantage of using the model in our study is to get an overview and to cover large areas with relatively little economic input, but it should ideally be followed by fieldwork and a process to involve stakeholders.

One critical decision, which affects model outcome, is how the limit for high conservation values in Zonation is set, i.e. above which priority rank in Zonation are conservation

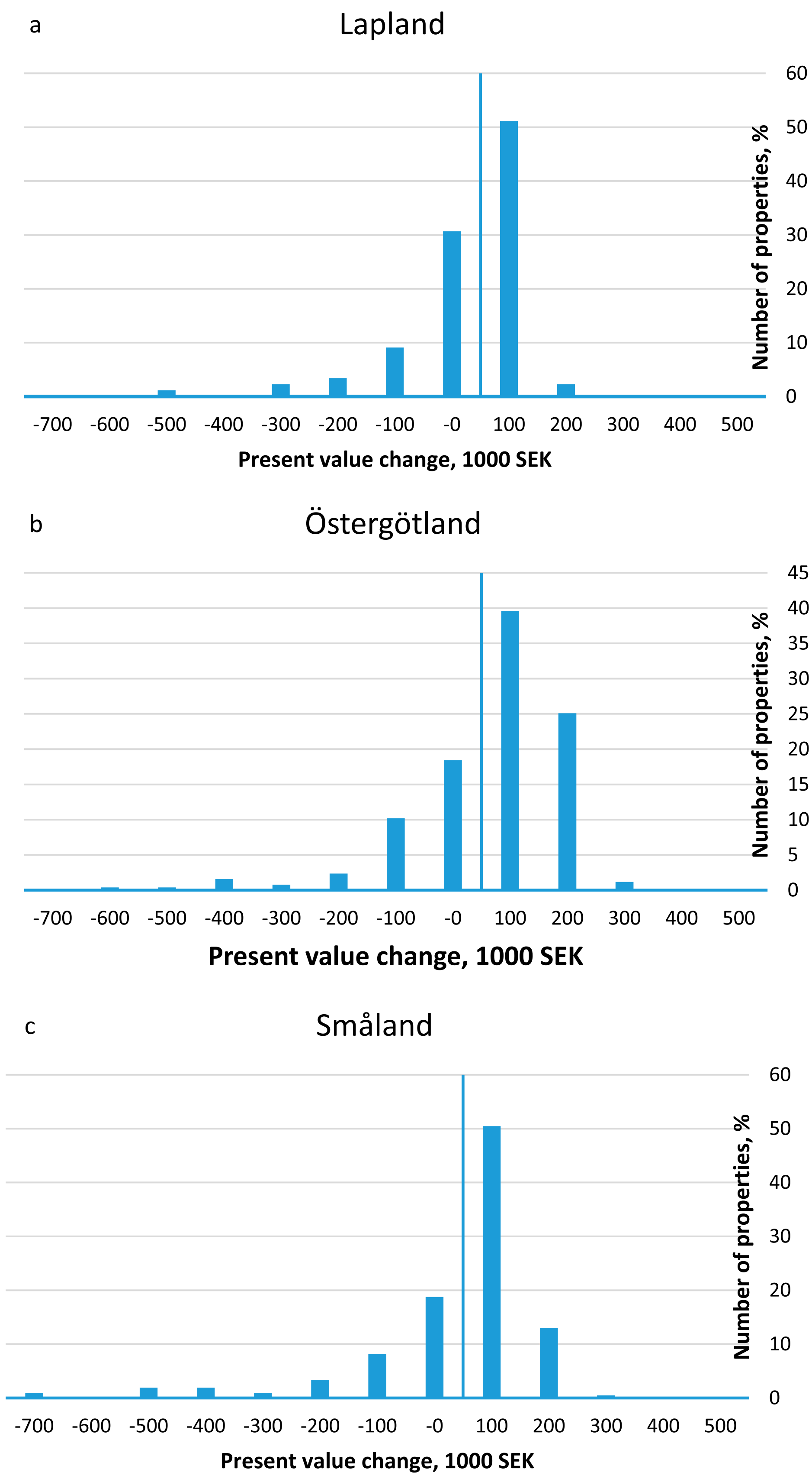

Figure 6. The difference in present value change (1000SEK) for the properties between scenario FC and scenario LP in (a) Lapland, (b) Östergötland, and (c) Småland. (1 SEK ≈ 0.11 EUR, average 2015).

Table 7. Present value change over the simulated forest estates, resulting from a transition from the CF* to the LP** scenario.

	Study site		
	Lapland	Östergötland	Småland
Share of properties with decreasing present value, %	47	34	36
Share of properties with increasing present value, %	53	66	64
Average loss for properties with decreasing present value, SEK/Property	−46,000	−41,000	−58,000
Average gain for properties with increasing present value, SEK/Property	20,000	58,000	41,000
Average loss for property with largest decrease, SEK/ha	−5,300	−16,600	−19,600
Average gain for property with largest increase, SEK/ha	1,500	8,900	4,000
Average net change in present value over all properties, SEK/ha	−350	580	−480

*This scenario complies with both the general conservation measures in The Swedish Forest Act and the regulations stated by FSC.
**This scenario is characterized by extensive considerations for conservation and biodiversity improvement based on the results from the Zonation calculations.

values considered high? Field evaluation is likely needed to make a correct decision, and one should expect different thresholds for different species and habitats. The choice of indicator species may also have an impact on the result. However, some groups of species (or guilds) have similar requirements and can be combined (Lechner et al. 2017), and by using different guilds instead of species, the species selection will be less important. For example, species requiring late successional habitats (old-growth forests) can be lumped together, as well as species requiring early successional habitats (e.g. forests disturbed by fire). There are many different decisions one has to take to parameterize settings in software like Zonation. For instance, using the Additive Benefit Function rather than the Core-Area Zonation function, using different BPLs, warp functions, and above-mentioned thresholds all have an effect on the outcome. Also, the choice of conservation planning software itself may have an impact on the outcomes. Marxan (Ball et al. 2009) is, for instance, another freely available conservation planning software that provides decision support in conservation planning such as the creation of protected area networks. Delavenne et al. (2012) compared these two widely used conservation planning softwares and found that the parameterization of the software itself had a greater effect on the output than the choice of software. Furthermore, whilst Marxan produced more efficient results, Zonation produced results with higher connectivity. The choice of which software to use should therefore depend on the overall aim of the landscape planning. Since our work was aimed to demonstrate an approach, we did not do a thorough sensitivity analyses. However, in real-life applications of our approach, one should consider doing such a sensitivity analyses to get a better understanding of the different possible outcomes based on decisions made in the simulation process.

Concluding remarks

In Sweden, the government decided on an environmental goal for forestry already in 1993. At the political level, this goal is meant to be of equal importance as the production goal. Later on, the environmental goal was further developed and specified within the national environmental goal "Living forests". However, after almost 30 years, the environmental authorities conclude that we are not close to reaching the goals (Naturvårdsverket 2017). Some measures have been successful, i.e. the volume of dead wood is increasing as well as the area of old forests, and the environmental considerations have improved in connection to final cutting (Swedish Forest Agency 2018a). However, the forest landscape is still extremely fragmented (Aune et al. 2005; Svensson et al. 2019). A number of species requires connectivity and long continuity of suitable habitats at the landscape level. Today, a relatively large proportion of the red-listed forest species belongs to this group (Kouki et al. 2001; Nordén et al. 2014). Fragmentation, which may cause extinction debts (Hanski and Ovaskainen 2002), is due to a large number of privately owned small properties, and all landowners are obliged to take the same environmental considerations in combination with forest production.

Concerning the potential for a fee-fund system, the presented results give a mixed result. A fee-fund system can sometimes have opportunities to function as a self-financed policy alternative in the sense that forest estates that gain financially from landscape planning can finance the foregone income of estates that must take a larger responsibility for conservation. But as our results show, the costs of implementing the landscape approach cannot always be covered within the studied forest landscapes. In this regard, the result of this, more in-depth analysis, is consistent with the simplified analysis presented in Zabel et al. (2018), as well as findings from other parts of the world that conclude that landscape planning in private lands is essential to achieve cost-effectiveness (Niemeyer et al. 2019). In this paper, we do not take a stand in the issue whether a self-sustained solution is intrinsically better, we are merely interested if such a solution is possible. It can be argued that supporting the fund through general tax money would improve vertical justice, by sharing the socio-economic costs of conservation between forest owners and

Table 8. Zonation values affect the distribution of management programs for the Landscape scenario.

		Landscape					
		Lapland		Östergötland		Småland	
Zonation value	Management program	Area, %	Relative present value/ha	Area, %	Relative present value/ha	Area, %	Relative present value/ha
≥0.90	MP2	12.4	1.63	9.5	0.99	12.6	1.21
≥0.80	MP3	12.2	1.12	13.5	0.89	10.4	1.24
<0.80	MP4	75.4	0.87	77.0	1.02	77.0	0.93

the rest of society. As mentioned, a fee-fund system is related to refunded emissions payment programs (cf. Fredriksson and Sterner 2005), an environmental policy approach which has been successfully tried in Sweden for NO_x abatement.

The problem with fragmentation due to the long history of forest management and the need for improved connectivity is urgent in forests all over the world (Lewis et al. 2015; FAO and UNEP 2020). We conclude that sustainable forestry in which conservation and production is combined, requires a systematic and strategic process. We have demonstrated for real Swedish forest landscapes that landscape planning is a possibility to improve conservation efficiency, and the method is relevant in any fragmented forest. That landscape planning is unquestionably better from a biodiversity conservation standpoint is clear from our results, but the present value of the forest landscape may increase or decrease compared to the present way of combining forestry with conservation. Furthermore, the impact per landowner will vary considerably, which highlights that landscape planning must be combined with economic tools to compensate landowners. Our presented method could in a next step be further improved by applying it on real species occurrences and also on more species than the ones we have used. We see great potential in developing this method by, e.g. applying integrated optimization.

Acknowledgements

This study was supported by the Swedish Environmental Protection Agency, and was part of a larger project "Landscape planning to promote biodiversity and a varied forestry". Forestry data were delivered from the forest companies Holmen Skog AB, Sveaskog AB and SCA AB. We thank our colleagues Maria Forsberg and Gabriel Michanek who also worked within this project for valuable discussions and support. We further thank two anonymous reviewers for useful suggestions on an earlier version of this manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Swedish Environmental Protection Agency: [Grant Number DNR 15/243].

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