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REVIEW PAPER

Biodiversity Conservation in Swedish Forests: Ways Forward for a 30-Year-Old Multi-Scaled Approach

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Abstract A multi-scaled model for biodiversity conservation in forests was introduced in Sweden 30 years ago, which makes it a pioneer example of an integrated ecosystem approach. Trees are set aside for biodiversity purposes at multiple scale levels varying from individual trees to areas of thousands of hectares, with landowner responsibility at the lowest level and with increasing state involvement at higher levels. Ecological theory supports the multi-scaled approach, and retention efforts at every harvest occasion stimulate landowners' interest in conservation. We argue that the model has large advantages but that in a future with intensified forestry and global warming, development based on more progressive thinking is necessary to maintain and increase biodiversity. Suggestions for the future include joint planning for several forest owners, consideration of cost-effectiveness, accepting opportunistic work models, adjusting retention levels to stand and landscape composition, introduction of temporary reserves, creation of "receiver habitats" for species escaping climate change, and protection of young forests.

Keywords Conservation planning · Cost-effectiveness · Key habitat · Matrix · Reserve · Tree retention

INTRODUCTION

Nature conservation efforts have traditionally been concentrated to certain areas, while the remaining land has been used for production. An integrated approach to provide various ecosystem services on the same land, including both nature conservation and production, has emerged as a main guiding principle for sustainable land-use only lately, in the twenty-first century (Millennium Ecosystem Assessment 2005).

Already several decades ago, an integrated model was introduced in Sweden, with incorporation of conservation measures into the production forest landscape, i.e., the matrix, and with a new component of voluntary commitment of the forest owners. Main measures since then have been for the forest owners to leave single trees and tree groups on clear-cuts, in contrast to before when logging resulted in very large tree-less areas, and to set aside whole stands or parts of stands. This model was developed in parallel with the emergence of the "new forestry" concept of the Pacific North-West of North America (Franklin 1989). It is today practiced in, e.g., NW USA (Aubry et al. 2004), Canada (Work et al. 2003), Tasmania (Baker et al. 2009), Finland (Vanha-Majamaa and Jalonen 2001), Norway (Sverdrup-Thygeson and Birkemoe 2009), Estonia (Lõhmus and Lõhmus 2010), Lithuania (Lazdinis et al. 2007), and is at the experimental phase in, e.g., Argentina (Martínez Pastur et al. 2009). The new approach in Sweden was legally established in 1978 with the launch of a new forest policy, and further manifested in the subsequent forest policy of 1994, in which it was stated that equal emphasis should be given to production and environmental issues. The model was further consolidated in 1998 when Sweden was the first nation to adopt a national certification standard within the Forest Stewardship Council (FSC) system.

A fundamental assumption of the integrated conservation model is that biodiversity is best promoted with a multi-scaled approach (Lindenmayer et al. 2006), i.e., that conservation actions are most efficient if they are taken at different spatial levels. There is a trade-off between focusing on conservation measures within the matrix or protection of reserves. For species depending on natural forest characteristics, the importance of reserves decreases with increasing matrix quality, and vice versa. The balance between the matrix and reserves varies depending on the habitat demands and life-history traits of a species (Fig. 1).

Sweden is in a late stage of forest transition (Mather 1992) from a natural state to whole-covering industrial use, with large-scale, mechanized clear-cutting starting more than 50 years ago. Today, more than 90% of the productive forestland is managed more or less intensely with largely similar practices irrespective of ownership, i.e., by the about 50% small private forest owners (<50 ha forestland), 40% large forest companies as well as by the 10% other forest owners. Soil preparation, regeneration with the indigenous conifers *Picea abies* and *Pinus sylvestris*, pre-commercial thinning and thinning are part of the forest management standard. The industrial forestry has resulted in more homogenous forest stands and landscapes with considerably lower amounts of deadwood, old trees and other properties of importance to biodiversity, compared with natural forest landscapes.

The multi-scaled approach is expanding globally in boreal and temperate (Lindenmayer et al. 2006) as well as tropical forests (Fimbel et al. 2001). Thus, it is important to evaluate one of the pioneer examples, to elucidate strengths and weaknesses but also to identify and discuss potential future developments. We focus mainly on conditions in the boreal part of Sweden, and exemplify with research mostly from the Nordic countries. We describe how expanded spatial planning and more dynamic approaches would improve the efficiency of the multi-scaled model. We also stress the need for more flexible and innovative strategies, to counteract an otherwise likely future impoverishment of biodiversity due to intensified forestry and climate change.

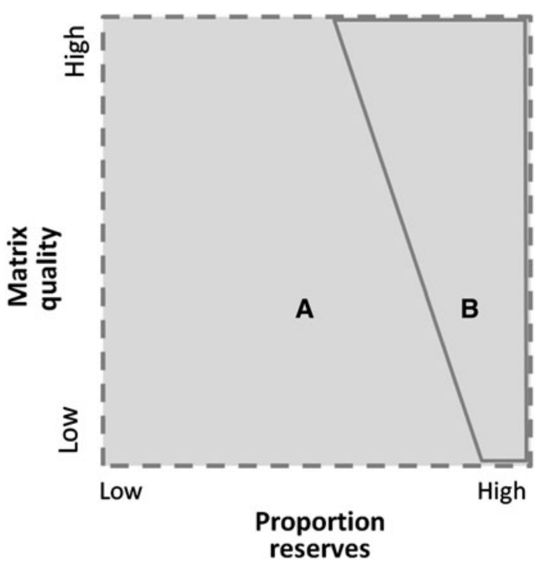

Fig. 1 Trade-off between matrix quality (production forests) and proportion of reserves. The figure represents a sphere of landscapes with a specific mix of matrix quality and proportion of reserves. Species have varying survival possibilities in the sphere depending on their degree of habitat specialization and life-history traits. For instance, generalist species, like A, can survive in any combination of matrix quality and proportion of reserves. For specialist species, like B, which depend on large areas with coherent old forest with natural forest characteristics, and which have poor dispersal ability, reserves are essential even if matrix quality is relatively high

THE MULTI-SCALED SYSTEM

Different Levels and Responsibilities

The multi-scaled model can in principle be divided into any number of scales, but for clarity we here distinguish three levels (Fig. 2). At all three, a major conservation action is to set aside trees for conservation purposes, from single ones up to clusters comprising areas of thousands of hectares. The lowest level includes individual trees and tree patches up to about 0.5 ha. The medium level embraces parts of stands and whole stands from above 0.5 ha up to about 15–20 ha, and the large-scale level includes sizes above that. The forest owner is responsible for the lowest level and the state for the largest, while responsibilities for the medium level are mixed.

Tree Level

At the smallest spatial scale, dead and live trees are left in most harvested stands. About 5 m^3 of deadwood is left on

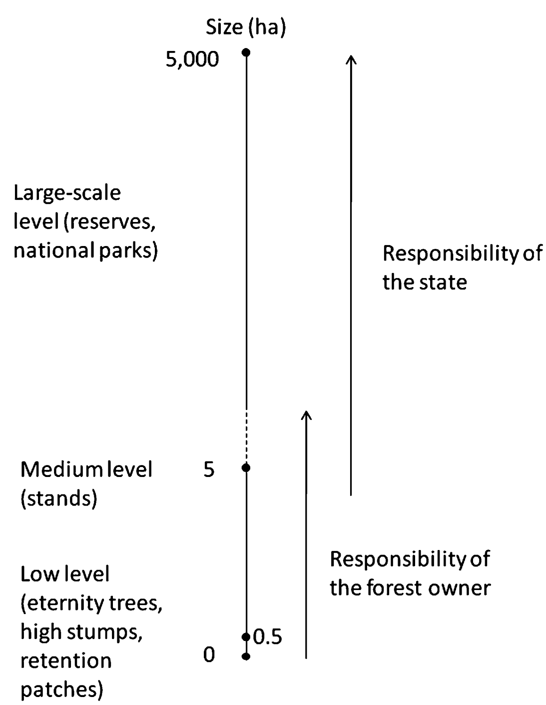

Fig. 2 The Swedish multi-scaled forest conservation model with divided responsibility between forest owners and the state

average per hectare, as logs, snags, or as artificially created high-stumps (Swedish Forest Agency 2008). The average number of live conservation trees retained (often called "eternity trees") is 7 ha^{-1}, although the level in FSC-certified forest should be at least 10 trees. The trees are either retained solitary or in patches of about 0.01–0.5 ha, free-standing on the clear-cuts or as buffer zones to streams, lakes, or mires (Fig. 3). The conservation efficiency of retained trees and deadwood has been the focus of numerous studies, including a recent review (Rosenvald and Lõhmus 2008). A number of these studies have been conducted in the Nordic countries. Several of them demonstrate that retained deadwood often hosts a species composition different from that on similar substrates in closed forests with more species associated with open, sun-exposed habitats (Kaila et al. 1997; Sippola et al. 2002; McGeoch et al. 2007). Retained structures may, therefore, constitute a dynamic, changing habitat important for species adapted to natural disturbances (Lindhe and Lindelöw 2004; Lindhe et al. 2004). Furthermore, a "life-boating" objective of retained forest patches may be applicable to many species, but true interior species may not be able to persist (Matveinen-Huju et al. 2006; Perhans et al. 2009). For both deadwood and retained live trees, long-term studies of their conservation efficiency and importance on the landscape scale are largely lacking (Rosenvald and Lõhmus 2008). At the stand level, however, studies indicate that the number of trees retained today is too low and that a higher level of retention more efficiently would meet conservation objectives (Toivanen and Kotiaho 2007; Söderström 2009).

Medium-Scale Level

The medium-scale level, corresponding to the normal range of stand sizes, has been given considerable attention in Swedish conservation. There are at least three reasons for this. First, the long history of logging in the country, with almost all forestland being affected by forestry operations, has implied that only small remnants with natural forest characteristics remain. Second, a large national inventory of so-called key habitats was executed in the 1990s and early 2000s. A key habitat is a forest area, often equal in area to a stand, with large importance to the flora and fauna, and with a high probability to host red-listed species (Fig. 4). More than 80,000 key habitats with a mean size of 5 ha have been mapped in the survey (Swedish Forest Agency 2008), co-ordinated by the Swedish Forest Agency, using indicator species, forest structures as well as information on forest history. There is no general protection of the key habitats, but the state has the possibility to formally protect some of them, and also to support conservation-oriented management through voluntary agreements with the land owners. The key habitat concept has later been adopted by other countries like Norway, Finland, Estonia, Latvia, and Lithuania. Several research studies have been performed to evaluate whether key habitats are indeed core areas for red-listed species, with some studies confirming this hypothesis, at least for certain areas (Gustafsson 2002; Junninen and Kouki 2006) and others rejecting it (Sverdrup-Thygeson 2002; Hottola and Siitonen 2007). Third, a voluntary commitment of certified forest owners is to set aside at least 5% of their forestland for conservation; and such areas often have this medium-scale size. More than 1 million ha of forestland are currently set aside this way (Swedish Forest Agency 2008).

Large-Scale Level

About 4% of the productive forestland in Sweden is protected but only 1% in the lowland, which constitutes 90% of all land. The largest protected forested area here is circa 5000 ha and about 20% are larger than 100 ha (Statistics Sweden and Swedish Environmental Protection Agency 2008). As in many other countries (Scott et al. 2001), the nature reserves in Sweden are skewed toward low-productivity areas (Fridman 2000) (Fig. 5). An environmental target set by the parliament in the early 2000s was that the protected area should double until the year 2010. This meant that another 900,000 ha should be protected, with the state being responsible for 400,000 ha through purchase of land or other compensation to forest owners, and a majority of these conservation areas belong to the large-scale level. The voluntary set aside areas of certified forest owners contribute to the additional 500,000 ha. The state protection is lagging behind much due to the time-consuming administrative process, whereas the forest owners have reached their goal. Although research has been done on the conservation quality of reserves compared to non-reserved forest (Esseen et al. 1996; Junninen et al. 2006), perhaps surprisingly, no studies in the Nordic countries have attempted to evaluate the importance of large protected areas as such. This makes it hard to assess their importance to plant and animal species in relation to other types of conservation areas and to production forests.

Pros and Cons of the Multi-Scaled Model

One evident feature of the multi-scaled model is the large emphasis on small-sized conservation areas, even down to individual trees. Ecological niche theory (Elton 1927; Hutchinson 1978) supports the efficiency of mixes of different sizes of conservation areas. Life history traits and ecological traits (like reproductive rate and dispersal rate (Fahrig 2001)), habitat demands, and interactions with other species vary enormously between species and, accordingly,

Fig. 3 Logged area where trees of aspen *Populus tremula* (foreground) and a tree group of Norway spruce *Picea abies* (in the distance) have been retained to promote biodiversity. Photo: Lena Gustafsson

Fig. 4 Sign informing on a key habitat ("Nyckelbiotop"), i.e., an area of special importance to red-listed species. Photo: Lena Gustafsson

so do their area demands. Furthermore, the non-linear species-area relationship (Rosenzweig 1995) implies that small areas have higher species richness in relation to their size than large areas, and since there is a variation in species composition between areas, i.e., beta diversity sensu Whittaker (1972), species richness at the landscape level will be higher with many small areas compared to few large, given equal total area. Modeling studies indicate that in forest landscapes with a long period of ongoing fragmentation, like in Sweden, protection of small stands is an efficient conservation measure (Ranius and Kindvall 2006), and if the protected stands are well spread in the landscape, the possibility to capture a large part of the species pool increases. Perhaps most ecologically fundamental is to mimic the spatial configuration following fire disturbance, which at the stand scale creates large heterogeneity including many small pockets of surviving trees, and which at the landscape scale results in large variation in forest age and composition (Kuuluvainen 2002).

Apart from ecological arguments there are also social and economic aspects worthy to be considered. By distributing the responsibility for conservation measures among all forest owners, the state saves a lot of money. In addition, interest in, and awareness of, biodiversity issues among private forest owners may be raised, contrary to if the responsibility rested solely on the authorities and large companies. If tree retention is made at every felling, forest owners must decide on how to do this and will also demand justification and support for measures they take.

Doubtless, there are also weaknesses associated with small conservation areas. Edge effects act strongly on small areas, disfavoring forest interior species (Jönsson et al. 2007), although on the other hand, disturbance that yields high amounts of deadwood can be an advantage to the early successional saproxylic species of natural forest landscapes. Small fragments of formerly more coherent landscapes might also be subjected to inevitable extinction processes (Berglund and Jonsson 2004). An additional drawback is that there is no long-term guarantee that the voluntary set-aside commitments will continue, and some forest owners are reluctant to inform on the location of their set-asides, which also makes it hard to evaluate their conservation quality. But, as a whole, taking into account positive as well as negative factors and considering ecological as well as social aspects, the multi-scaled model has much in its favor.

WAYS FORWARD

More Efficient Planning

Larger Planning Areas and Co-ordinated Planning

Using a large planning area when selecting reserves or other protected areas improves the possibility to select the areas with highest biodiversity qualities, and also to select areas that complement each other in terms of what habitat types and species they contain (Strange et al. 2006; Wikberg et al. 2009). The Swedish state-administered large- and medium-scale reserves are selected within each county, i.e., a fairly large planning area. However, the selection system resembles mostly a scoring system in which aspects of complementarity among areas are not explicitly included. As such, the reserve strategy does not currently take full advantage of the large planning areas. The key habitat inventory provides a source of information about forests with high conservation values in Sweden, and could be used as a basis for selecting reserves with a stronger emphasis on complementarity. The information includes a description of forest type and a list of structural habitat characteristics and, in many cases, occurrences of species of conservation concern. Based on this and other readily available information, it would be possible not just to focus on conserving, e.g., "old spruce-dominated forests" but to make sure that selected spruce-dominated reserves comprise a spectrum of different types of spruce forests in terms of, e.g., topography, tree age structure, proportion of deciduous trees, ground moisture regime, and amounts and types of deadwood.

For the voluntary medium-scale set-asides, no co-ordination on a level higher than individual forest holdings exists today. A step forward could be the design and implementation of a system for joint planning for several forest owners, perhaps associated with economic rewards for good performance. In a web-based system, conservation officials could guide and co-ordinate the voluntary conservation efforts by providing a dynamic wish list for each region in terms of what forest types, age classes, and specific structures would be needed to benefit a wide range of species in the region. Forest owners would report the characteristics of their current set-asides and in doing so successively fill up specific quotas for the different elements on the list. Although not spatially explicit, such a system could greatly enhance the efficiency of the voluntary set-asides and also provide valuable knowledge on how the state reserves would best complement the voluntary set aside areas.

Acknowledging Land Costs when Selecting Reserves

Although there is a stated objective that conservation measures should be carried out in a cost-effective way, Swedish reserves are currently selected with a very strong emphasis on biological values alone. In theory, whichever of biological values or land costs of potential areas have the largest variability will have the largest influence on the overall cost-effectiveness (Babcock et al. 1997; Ferraro 2003). The evidence available suggests that the variability in costs of areas is often at least as high as that of biological values (Naidoo et al. 2006), and therefore, costs should generally be acknowledged systematically to reach a high cost-effectiveness. Acquiring information about land costs and biological values also carries costs, but these may often be low compared to the land costs of potential areas (Wikberg et al. 2009). Even more expensive surveys, such as species surveys, are likely to pay off when species are unevenly distributed among areas, when rare species are in focus, and when biological values and land costs are positively correlated (i.e., the most species-rich areas are the most expensive). A pilot survey of a small number of areas could be made to estimate variability and correlation before large-scale data collection begins.

Fig. 5 A recently burnt area in a nature reserve in boreal Sweden. Photo: Lena Gustafsson

Although acknowledging costs along with biological values increases the overall cost-effectiveness, in some cases high-cost areas need to be protected because of their unique biological values. We, therefore, argue that only areas that are ultimately replaceable should be subject to prioritization. In practice, taking land costs into account in reserve selection will lead to more areas being selected, but at a lower average cost, than selection based solely on biological criteria. This may be perceived by the forestry industry as a drawback because of the need to exclude larger areas from production. On the contrary, from an ecological perspective and especially in the long term, conserving larger areas could imply important advantages.

Opportunism Versus Systematic Selection

A systematic approach to selecting conservation areas gives a list of areas that most efficiently would meet the conservation goals, and preferably also a ranking within the list based on relative qualities of the areas. In practice, however, such a ranking is often difficult and even sub-optimal to follow strictly as practical factors influence on the process and determine the success of the outcome (Knight and Cowling 2007). Recognizing different opportunities as they arise and changing temporal priorities accordingly can therefore often be advantageous (Noss et al. 2002). Systematic selection is also hampered by the fact that areas very rarely can be simultaneously selected and protected; instead both processes are usually successive and slow.

To facilitate practical use, we suggest that such opportunism within conservation planning should be divided into three types: "crisis opportunism," "economic opportunism," and "social opportunism." By crisis opportunism we mean changed priorities due to a threat of land conversion or logging of an area, a process that sometimes prevails when state reserves are selected in Sweden today. By economic opportunism we mean that an area not originally intended for inclusion in a reserve network is prioritized for its low cost. Prices of forest land may be temporarily lowered due to storms, flooding or fire, or decreased market demand for timber, while the ecological values are maintained or in some cases increased. By social opportunism, finally, we mean prioritization of areas which the land owner has an interest and a will to conserve. Apart from a facilitated reserve establishment process, applying this form of opportunism may also encourage land owners to take an active part in conservation. Both economic and social opportunism are used to a low degree in Sweden today but has a great potential to be further developed and integrated into existing routines for selecting reserves.

More Progressive Approaches

The Future Forest Landscape

There are clear indications that the Swedish forest landscape will undergo further rapid change in the coming decades (Statens Offentliga Utredningar 2006) (Fig. 6). Forest residues (twigs and tops) are already being used as bioenergy, and stump harvest has recently been introduced for the same purpose. Use of nitrogen fertilizers has increased steadily during the last 5 years (Swedish Forest Agency 2008), as well as regeneration with genetically improved material. It is likely that plantation forestry with exotic tree species will increase in the near future (Swedish Forest Agency 2009; Larsson et al. 2009), although concerns have been raised about environmental impacts (Gustafsson et al. 2010). Coupled with climate change this implies that the tree growth will increase, and, as a consequence, rotation times will probably shorten (Bergh et al. 2005), and stands will become darker and more homogenous. One scenario is that the future forest landscape will be separated into younger and younger production forests and older and older reserves (Swedish Forest Agency and SLU 2008). If this becomes reality, the efforts on different scales in the multi-scale model need to be increased, to compensate for negative biodiversity effects, and new thinking will be necessary. There is also a need to further investigate the efficiency of tree retention in stands and landscapes managed with different degrees of intensification. It is likely that the value of retention measures to biodiversity is considerably smaller in plantation forests compared to less intense management regimes. Should this be the case, it will be motivated to adjust retention levels according to context.

Fig. 6 A typical Swedish boreal forest landscape, used for industrial forestry with a clear-cutting regime. Photo: Lena Gustafsson

Temporary and Permanent Reserves

Conservation area networks that are fixed in time and space have been challenged as too static and partly non-functional, and proposals have been put forward for more dynamic approaches (Bengtsson et al. 2003), but so far, with few exceptions (Rayfield et al. 2008) only expressed in very general terms. In boreal regions, the overbearing fire dynamics have implied that species are adapted to landscapes in constant change. However, there are species that depend on long continuity in time of interior forest conditions and for such species permanent reserves are necessary, preferably established by the state since this implies a long-term commitment. For other species of conservation concern, more tolerant to disturbance, temporary reserves could be an option. Since the reserves would move in space, they would be especially suitable for species with good dispersal ability. The forest owners' voluntary set-asides would be well suited for this type of protection, since the planning of properties is well controlled by the owners and often can be made with short notice, contrary to the set-aside process of the state, which is more time-consuming. Temporary reserves, which can also be seen as a prolongation of rotation times, would also result in a more steady flow of pulp and timber, which is essential for the forest sector since less areas mature to be harvested are permanently withdrawn from production.

Before temporary reserves are introduced in practice, the knowledge on minimum forest ages for late-successional but easily dispersed species needs be improved to determine the necessary prolongation of rotation times. Also, there is a need to further examine whether certain species, like large mammals, will experience dispersal barriers if reserves move in space and time. For instance, there are indications that the distribution of predators like wolverine and wolf is negatively affected by infrastructural development (Karlsson et al. 2007; May et al. 2006).

Protection of Young Forests

Reconsideration is also warranted of the almost total dominance of old forests in all types of protected areas. In boreal natural forest landscapes, a large proportion is constituted by young age classes succeeding fire, with residual trees and large deadwood quantities. The flora and fauna of such early successional stages are understudied, and there certainly are species and ecosystem processes worth acknowledging in a conservation context. One interesting, and presumably cost-effective, approach would be to protect forest in different age classes, since young forestland is considerably cheaper than old. Another approach would be to extract a certain proportion of the trees in old forest before setting aside a conservation area, perhaps also followed by burning of the logged-over stand to favor fire-dependent and deadwood-associated species. Such an action most likely would yield considerable biodiversity benefits since many natural forest species are tolerant to, and even promoted by, semi-open conditions, and it would also result in an economic compensation to the forest owner.

Adapting to Climate Change

An important challenge is to design conservation measures not only to meet current needs but also to strategically buffer and adapt to the likely changes in species distributions due to climate change. In this perspective, the retention schemes, i.e., actions on the lowest scale level, might become even more important in the future. Already today, retention patches outnumber the conservation areas on the higher scale levels, and this will become even more pronounced as successively more stands are logged during the coming decades. With patches of old live, and dead trees being spread rather evenly throughout the forest landscape, the possibilities for species to disperse to new sites under a climate change scenario will increase, and consequently the lowest level will be an assurance in a future filled with uncertainties.

Furthermore, most likely there will be a large immigration of species to countries in the northern boreal region due to climate change, since plants and animals will follow the raise in temperature toward northern latitudes (Thuiller et al. 2005). Many of these species will increase their total population sizes, since they will persist also in their original distribution areas. There will, however, be examples of species that are sensitive to changes in climate and habitat at their present sites, and as such run the risk of becoming extinct. For these, a proactive conservation action could be to create “receiver habitats” further north, e.g., in Sweden. One example would be to plant tree and shrub species found in middle Europe but so far not in Sweden and, thus, create new forest types to which rare species are associated, although this would challenge the present forest policy with prohibition to regenerate with exotic tree species.

CONCLUSIONS

The 30-year multi-scaled forest conservation model works well but is in need of development to meet a future with increased pressure on the forests and their associated biodiversity. The new component of the lowest scale-level (tree retention) has added a valuable element to the production forest landscape, although doubts can be raised about the currently small amount of conservation trees retained. Conservation efforts on this level offer great potential to increase forest owners’ awareness and motivation for conservation. Further evaluation of the model and its efficiency is important, to assess the contribution of the different scale levels to species, structures and processes. Overall, we are convinced that new innovative approaches are essential to adapt to future changes in the forest landscapes, and also that values and goals that are fundamental to many conservation policies today, like restriction of conservation actions to “natural species and habitats,” will be challenged.

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