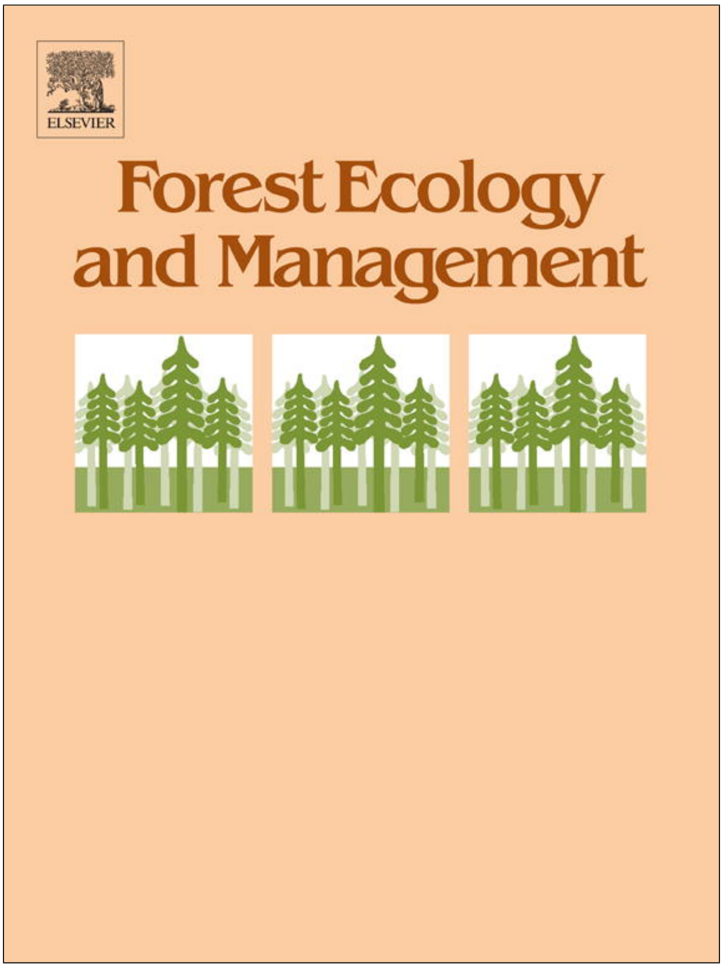
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Review

Environmental considerations from legislation and certification in managed forest stands: A review of their importance for biodiversity

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A B S T R A C T

Negative impacts of forestry on biodiversity have been addressed through environmental considerations held within legislation and various forest certification protocols. We used Sweden as a case study where a long history of forestry aiming at sustained yield of wood fiber has resulted in landscapes with low quantities of old growth structures e.g. dead wood and old forest, but where environmental considerations have been implemented during the last two decades. We reviewed the scientific literature for studies evaluating the environmental considerations included in the Swedish Forestry Act and FSC, compared individual metrics and benchmarks, identified thresholds as well as identified specific gaps missing from current regulations (missing factors/areas of improvement). All environmental considerations listed in the Swedish Forestry Act were found to be relevant for conservation. The strongest scientific support for their importance in maintaining biodiversity in managed landscapes was found for dead wood, tree retention and habitats for sensitive species, including edge zones and woodland key habitats. However, suggested levels fall below identified thresholds. Retention of small habitat patches can provide a lifeboat function for some red-listed species, but the long term survival of these populations is uncertain. Tree species composition was also found be important, and in the boreal region the proportion of deciduous trees is a key factor. For some environmental considerations, there is too limited information from the scientific literature to evaluate their importance in relation to the current levels, e.g. consequences of clear-cut size and shape, and forest roads. Similarly, damage to soil and water affect biodiversity through drainage, leakage and sedimentation, but the effects vary considerably and are often diffuse. There is a need to better adjust the levels of environmental considerations above thresholds from empirical studies. However, it will be impossible within current regulatory framework to maintain all species in all landscapes. Therefore, the allocation of environmental consideration among stands, landscapes and regions need to be considered. Evenly dispersed retention might always stay below suggested thresholds with limited contribution to ecologically sustainable forest ecosystems. More flexibility, where the sum of conservation measures in the landscape as opposed to measures in individual stands are considered, would result in better conservation strategies. This would mean that particular landscapes could be more intensively managed and in other more focus on biodiversity conservation could be taken.

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1. Introduction

Anthropogenic land-use has altered ecosystems around the world. For many ecosystems, land-use has resulted in habitat degradation, severe impacts on biodiversity, altered ecosystem processes and reduced resource levels. As a consequence, many species with reduced abundance now having limited distributions (Harrison and Bruna, 1999; Zanette et al., 2000; Grove, 2002; Akasaka et al., 2010; Krzyzanowski and Almuedo, 2010). With only 11.5% of land protected world-wide in national parks or nature reserves (Chape et al., 2003), the vast majority of productive landscapes undergo persistent anthropogenic disturbance through agriculture, urbanization and forestry. In the boreal forest, intensive management for timber production has caused a loss in biodiversity and decreased habitat quality (Berg et al., 1994b; Siitonen, 2001a; Grove, 2002; Niemelä et al., 2007). The negative impact on biodiversity by forestry has been identified within the Convention of Biodiversity (CBD) and suggests that the 11% of the world's forest area protected in reserves (Anonymous, 2010, 2011) is not sufficient for maintaining viable populations of species demanding old-growth qualities, or adapted to natural disturbances (Lande, 1988; Angelstam et al., 2004; Hanski, 2011).

To better integrate wood production and biodiversity conservation, the forest management model "retention forestry" was introduced in northwestern North America 25 years ago (Franklin, 1989). The concept of retention forestry spread rapidly and was adapted to various forest ecosystems (Nyland, 2002; Mitchell et al., 2006; Sheil et al., 2010). The levels of retention on clear cuts vary between 1% and 30%. Generally, countries with a long history of forest management for sustained yield, e.g., Sweden and Finland, adapted lower retention levels while regions with substantial areas of natural forest, e.g., Canada and Tasmania, have much higher retention levels (Gustafsson et al., 2012). In a similar pattern, increased interest in maintaining multiple functions in forests has worked as an incentive for the development of certification schemes, e.g. FSC, that aim to incorporate social, ecological and economic rights and needs into forest management (Gulbrandsen, 2005; Auld et al., 2008). As with retention guidelines, exact regulations vary among countries depending on local conditions (Keskitalo et al., 2009).

The natural forest ecosystem in temperate and boreal forests is characterised by landscapes composed of a mosaic of different landscape elements such as forests, mires, wooded wetlands, rivers and lakes. Variation in forest structure, i.e. stands of different age and tree species composition, creates a diversity of biotopes (Esseen et al., 1992; Engelmark and Hytteborn, 1999). Biodiversity is maintained by a dynamic of small scale disturbance such as single tree death caused by wind or parasites and large scale disturbances such as fire, insect outbreaks and storms (Pontailler et al., 1997; Niklasson and Drakenberg, 2001). Today forest management has replaced much of this natural disturbance. In Sweden uneven aged old growth stands regenerated after natural disturbances has been replaced by even aged monocultures regenerated after clear felling. Structures such as old trees, dead wood, and decidouos trees and disturbances like fire has decreased in abundance. As a result, remaining habitats are lost and fragmented (Linder and Östlund, 1998; Axelsson and Östlund, 2001). The concept of "retention forestry" is based in part on the idea that the managed landscape must contain the same type of habitats and substrates which in the natural landscape is a result of natural disturbances (Angelstam and Pettersson, 1997; Lindenmayer et al., 2006).

In Sweden retention forestry is included in overarching political environmental objectives, e.g. the objective "a rich diversity of plant and animal life" that states "Species habitats and ecosystems and their functions and processes must be safeguarded. Species must be able to survive in long-term viable populations with sufficient genetic variation" (Anonymous, 2012), and implemented through more detailed guidelines as environmental considerations in the Forestry Act (Anonymous, 1994) and certification schemes (Anonymous, 2000) (Table 1). The political environmental objectives have been evaluated several times by the authorities (Anonymous, 2012). The evaluations shows that Sweden is far from reaching most of the goals, and that there are urgent needs for actions in order to halt the biodiversity loss. Three types of action relate directly to the forest sector: 1. Protection and set asides: where the most important sites for biodiversity in the forest landscape are protected as nature reserves, biotope reserves (with economic compensation), or voluntarily protected by forest owners (without economic compensation). 2. Lower management intensity: where sites with some conservation values, or with potential values, are managed by combining forest production and conservation, including restoration and small set asides. 3. Environmental considerations: sites with lower conservation values are managed with environmental consideration, e.g. retention of single trees and small habitats, etc. (de Jong et al., 1999; Gustafsson and Perhans, 2010). In this review, we use Sweden as a case study of a system with a long history of forestry aiming at sustained yield. This has resulted in landscapes with low quantities of old growth structures e.g. dead wood and old forest, but environmental considerations have been implemented during the last two decades. These environmental considerations include measures used in other regions which have implemented retention forestry and thus may be applicable for many regions.

The environmental considerations (i.e. the considerations taken in all stands in all forestry operations, e.g. tree retention, avoidance of damage to soil and water) currently used in Sweden to mitigate the effects of forest management have been stated to be developed based on "intelligent guesses" rather than scientific evidence (Larson and Danell, 2001) and many have yet to be evaluated empirically (Davies et al., 2008). However, increasing numbers of studies

Table 1
Forestry measures to promote biodiversity in Swedish managed forest according to the Swedish Forestry Act and the Swedish FSC Standard for Forest Certification (Anonymous, 2010).

Environmental consideration	Regulations from the Swedish Forestry Act	Law interpretation of the Forestry Act from the Swedish Forestry Board	Recommended level from the Swedish Forestry Board	Swedish FSC standard for forest management	Scientific information on thresholds and suitability of measures
Non-productive forest land	No logging operations in areas larger than 0.1 ha. Single trees may be cut	No logging operations in areas larger than 0.1 ha. Single trees may be cut	No logging operations	No forestry measures at all	2% and 5% of red-listed species in Sweden has NPF land as main or potentially important habitats, respectively (Cederberg et al., 1997). Non-productive forest land (NPF) seems to be moderately important for biodiversity
Tree species composition	Retain some deciduous trees in coniferous forests for the entire rotation period	Site adaptation	Site adaptation	At the time of regeneration felling broadleaved trees shall constitute >10% of stand volume (>5% in N Sweden) wherever natural conditions permit. Management shall aim at having stands dominated by broadleaves on more than 5% of the total area of mesic and moist forest land during the major part of the rotation period	See Table 2
Woodland key habitats (Forestry Act habitats)[a]	Damage from forestry measures shall be avoided or minimized	Between 2% and 10% of the total timber value shall be left after harvesting, prioritized after conservation value	Damage from forestry measures shall be avoided or minimized. No forest measures at all in uneven aged stratified forests with old trees and high abundance of dead wood or in woodland key habitats	No commercial forest measures at all in uneven aged stratified natural forests with old trees and high abundance of dead wood or in woodland key habitats	10–50% of natural habitat is needed for efficient conservation (Lande, 1988; Andrén, 1994; Angelstam et al., 2004; Hanski, 2011). Larger reserves play an important role for maintaining biodiversity (e.g. Siitonen, 2001b; Lindenmayer et al., 2006; Hjältén et al., 2012). Small-sized key habitats capability to maintain assemblages over time is unclear (Franc et al., 2007; Berglund and Jonsson, 2008; Ranius et al., 2008; Timonen et al., 2011)
Plant and animal species	Damage on red-listed species and species regionally rare shall be avoided or minimized	Between 2% and 10% of the total timber value shall be left after harvesting, prioritized after conservation value	Damage on red-listed species and species regionally rare shall be avoided or minimized	Occurrences of red listed species outside woodland key habitats shall be documented and measures to protect these shall be taken	For many red-listed species it is not enough to conserve small single objects (trees or small habitat patches) (Lõhmus et al., 2006; Junninen and Komonen, 2011). Single objects could serve as lifeboats for some species (Gustafsson et al., 1999; Hylander et al., 2004; Lindhe et al., 2004; Lõhmus et al., 2006; Perhans et al., 2007; Djupström et al., 2008; Drapeau et al., 2009). Measures to protect individual species might be important as a complement to the reserve network
Buffer zones	Buffer zones of bushes and trees shall be retained adjacent to non-productive forestland, the sea, lakes and water courses, open agricultural land, and settlements, to an extent needed for consideration of plant and animal life, cultural environments and landscape	Between 2% and 10% of the total timber value shall be left after harvesting, prioritized after conservation value	Buffer zones of bushes and trees shall be retained adjacent to non-productive forestland, the sea, lakes and water courses, open agricultural land, and settlements, to an extent needed for consideration of plant and animal life, cultural environments and landscape	Promote continuously forested transition zones conditioned by topographical, hydrological and ecological features along watercourses, open water, wetlands, non-productive forest land and other with specific biodiversity values. Maintain or create open forest edge zones, in order to keep biodiversity related traditional management	Strong scientific support for buffer zones to protect water habitats (Gundersen et al., 2010).45 m buffers are needed to fully protect riparian functions (LeDoux and Wilkerson, 2008). On a landscape scale 54–80% forest cover in a catchment is needed to maintain taxa richness (Törnblom et al., 2011; Black et al., 2004)

Table 1 (*continued*)

Environmental consideration	Regulations from the Swedish Forestry Act	Law interpretation of the Forestry Act from the Swedish Forestry Board	Recommended level from the Swedish Forestry Board	Swedish FSC standard for forest management	Scientific information on thresholds and suitability of measures
Tree retention and dead wood	Consideration to plant and animal species, cultural landscape, bushes and single trees shall be taken in all forestry measures. Coarse broadleaved trees, rare tree species, very old trees, dead or dying trees, hollow trees, nesting trees and potential nesting trees, and culturally marked are all prioritized for retention	Between 2% and 10% of the total timber value shall be left after harvesting, prioritized after conservation value	Consideration to plant and animal species, cultural landscape, bushes and single trees shall be taken in all forestry measures. Coarse broadleaved trees, rare tree species, very old trees, dead or dying trees, hollow trees, nesting trees and potential nesting trees, and culturally marked are all prioritized for retention	All high biodiversity value trees shall be retained. At least 10 eternity trees (including high biodiversity trees) shall be retained per ha. All snags, windthrows and trees that have been dead for more than one year shall be retained, as well as at least two coarse new windthrows per ha. On average three high stumps or girdled trees shall be created per ha after regeneration felling or thick-stem thinning	Thresholds for dead wood: 20–30 m^3/ha (Müller and Bütler, 2010)Thresholds for tree retention: Ground dwelling beetles; 50 m^3/ha; (Hyvärinen et al., 2005). Plants: 20% of the timber volume; (Rosenvald and Löhmus, 2008). Birds: 100 trees per hectare; (Schieck and Hobson, 2000; Schieck et al., 2000). Current levels of dead wood and tree retention are insufficient
Clear cuts	Size and shape of clear cut shall be adapted to the natural and cultural landscape. Limited clear cut size shall be sought	No restriction on the size of a single clearcut. However, estates larger than 50 ha are restricted to maximum 50% of bare land and young forest area (<20 years)	Size and shape of clear cut shall be adapted to the natural and cultural landscape. Limited clear cut size shall be sought	Care-demanding patches, edge zones, groups of trees and biodiversity value trees shall be retained so as to avoid large treeless areas	Different organism groups react differently to clear-cut size (Pawson et al., 2006). Large clear-cuts have a negative effect on epiphytic chlorolichen (Hilmo et al., 2005). Forest arthropods can utilize small clear-cuts (Shure and Phillips, 1991). The species richness of birds sometimes increases with size of the clear-cut but only up to approximately 20 ha (Rudnicky and Hunter, 1993)
Soil and water damage	Damages on soil and water from nutrient leakage, fertilization, pesticide distribution, ditching, removal of forest residuals, and trail accessibility shall be avoided or limited in any forestry action			Procedures hall be implemented to avoid soil damage caused by vehicles If substantial soil damage affect water courses, areas of specific biodiversity values or of particular interest for outdoor recreation action shall be taken to restore the damage	Soil and water qualities and biodiversity are affected by most forestry measures (e.g. Wiklander et al., 1991; Vuori et al., 1998; Joensuu et al., 2002; Nicholls et al., 2003; Lindberg and Persson, 2004; Battigelli et al., 2004; Davies et al., 2005; Nieminen and Setälä, 2001; Egnell et al., 2007; Jonsell, 2007; Nitterus et al., 2007; de Jong et al., 2012),Measures to reduce soil and water damage are not tested
Forest roads	Plan forest roads so as to minimize damage to the woodland and safeguard the cultural heritage			Avoid damage to natural watercourses. Remove obstacles to migration of aquatic animals in watercourses with special diversity value and in maintenance of culverts	There is consensus that roads affect biodiversity (e.g. Trombulak and Frissell, 2000; Price et al., 1974; Mader, 1984), but the mitigating effects of EC at road construction are not well evaluated
Prescribed burning				Major landholders shall burn the equivalent of 5% of the regeneration area on dry and mesic soil. The burnt area can be adjusted by tree retention, natural regeneration or burning of areas exempt from forestry	Fire is necessary to maintain biodiversity in boreal forests (e.g. Muona and Rutanen, 1994; Penttilä and Kotiranta, 1996; Wikars, 2002; Fisher and Wilkinson, 2005; Toivanen and Kotiaho, 2010). Current levels including FSC standard burns is only ca 3% of the burned yearly compared to before 1900 AD (Zackrisson and Östlund, 1991; Granström, 2001), suggesting that the current levels are insufficient

(*continued on next page*)

Table 1 (*continued*)

Environmental consideration	Regulations from the Swedish Forestry Act	Law interpretation of the Forestry Act from the Swedish Forestry Board	Recommended level from the Swedish Forestry Board	Swedish FSC standard for forest management	Scientific information on thresholds and suitability of measures
Set asides			Exempt 5% according to the Green Forest management plan	Exempt 5% of productive forest land from production forestry. Areas are prioritized in relation to significance for biodiversity and landscape representativeness	Suggested thresholds of 10–30% suitable habitat for species long term survival is not reached by the minimum level in the forestry act or FSC standard (Andrén, 1994; Angelstam et al., 2004; Hanski, 2011). Although 5% is a significant addition to the 3–4% formally protected area in Sweden it might not be sufficient for long- term maintenance of biodiversity

[a] In the forestry act the expression "Forestry Act habitats" is used to define habitats valuable for conservation. However in the practical conservation work as well as in the scientific literature "Woodland Key habitats" is more often used. The definitions of "Forestry Act Habitats" and "Woodland Key Habitats" overlap to a large extent and therefore we have chosen to use the more common and well-known "Woodland Key Habitat" throughout this review.

focused specifically on ecological impacts of forestry (Sverdrup-Thygeson and Lindenmayer, 2003; Hilszczański et al., 2005; Gibb et al., 2006b; Schroeder et al., 2006; Johansson et al., 2007; Gibb et al., 2008) can be used to evaluate the value of the measures included within the environmental considerations of regulatory documents. With advances in empirical studies, current environmental considerations must be revisited and reconsidered in light of the current state of knowledge. Such iteration is the basis for effective adaptive forest management. However, few attempts have been made to compile and synthesize this new knowledge and evaluate its implications for the environmental consideration used in Fennoscandia and elsewhere (but see e.g. (Lindenmayer et al., 2006; Gustafsson and Perhans, 2010)). Here we evaluate the effects of environmental considerations on biodiversity in boreal forest ecosystems, with Sweden as a case study, based on existing scientific literature. More specifically we address the following questions:

1. Is there scientific support for the measures currently included in retention forestry? and How do measures in the Swedish Forestry Act and the Swedish FSC-standard serve as an example for retention forestry in general?
2. Are the current levels of the measures sufficient to fulfill environmental biodiversity goals and supported by scientific literature?
3. How could current measures be improved based on new scientific results?

2. Background and definitions

Environmental considerations (specified in regulatory documents, hereto after referred to simply as environmental considerations, EC) should be implemented in all stands and throughout all forestry operations. These include retention of or special attention afforded to conservation of dead wood, old trees, hollow trees or special habitats (de Jong et al., 1999). The Swedish Forest Agency defines environmental considerations as all actions that pertain to conservation values, ground, water, cultural environments including the biological cultural heritage and social values, made within any forest operation (Skogsstyrelsen, 2008). Two different levels of environmental considerations are used, the minimum level and the recommended level. The minimum level defines that if values important for conservation exist, considerations should be taken in the specific stand/property up to a specified level, which means that the regulations are not allowed to be so extensive that ongoing land use is severely complicated (Skogsstyrelsen, 2008). The level of tolerance is defined in relation to the net income from forestry and the level varies between 2% and 10%, i.e. the landowner must accept to retain 2–10% of the net income. The recommended level is formulated and communicated by the Swedish Forestry Agency. It is the authorities' interpretations of the goals in the forestry policy that state what can be expected from the Swedish forestry sector in order to reach the political goals (Skogsstyrelsen, 2008). The recommendation in a given case is the result of a negotiation between the land holder and a Forestry Agency official, based on local conditions and existing conservation values. The minimum level is required according to the Forestry Act, while the advisory level is voluntary (Skogsstyrelsen, 2008).

When the Forest Stewardship Council (FSC) was introduced in Sweden a third level of environmental considerations was established. The FSC-standard is a forest management standard that regulates environmental considerations in relation to forest management, but also has a social dimension related to indigenous peoples' rights, community relations and workers' rights, and an economic dimension; that the FSC-forestry shall be economically viable. The basic structure is the same for all forest management standards in the world. The indicators in the national forest management standard are formulated through stakeholder negotiations. About 50% of the productive forest land in Sweden is certified under the FSC scheme. Besides retention of high conservation values the FSC-standard also includes other measures such as creation of conservation values (e.g. prescribed burning or creation of artificial high-stumps) or more target oriented conservation measures (e.g. managing stands to reach a certain deciduous component at the time of regeneration cutting) (Anonymous, 2000).

3. Methods

For the literature review we have used the data base Web of science. We searched for key-words connected to subjects in the forestry act and in the FSC standard: dead wood, buffer zone and retention trees. In some cases the key-word to use is not so obvious and we selected more general key-words covering conservation and forestry: forest biodiversity, conservation measures and forest, and different combinations of these keywords. We restricted the searching to the boreal area (Northern America, Northern Europe and Northern Asia). In total several hundreds of scientific papers were found of which the most relevant were sorted through further scrutiny of titles and abstract. This was done by relating the content to subjects in the forestry act and in the FSC standard such as importance of clear-cut size and tree-species composition, disturbances causing soil and water damage or consequences of forest roads, the conservation value of non-productive forest land, and the value of prescribed burning. We prioritized recently published papers (after 2000). We also searched through relevant books and reports published by the government, authorities, forestry industry, university departments and other organisations.

4. Literature review

In our literature review we scrutinized the scientific literature for studies testing each of the environmental considerations listed in Table 1. To avoid overlap and increase focus we combined the considerations titled "Forestry Act habitats", "Plant and animal species" and "Set asides" under the sub-chapter "Conservation of species and habitats". We then structured the review into subchapters where we first considered the conservation of species and habitats, then the importance of forest composition and specific structures (e.g. decidouous trees and dead wood). Finally we reviewed the value of consideration to avoid damage at forestry measures e.g. the size and shape of clear-cuts and avoidance of damage to soil and water.

4.1. Conservation of species and habitats

The environmental goal in the Forestry Act and the FSC-standard specifically addresses the obligation to maintain populations and habitats hosting red-listed species. The level of retention is limited by the legal interpretation of the forestry act, i.e., 2–10% of the timber value (Table 1). There are few studies that directly evaluate how environmental considerations aimed at specific species affect their long term survival in the landscape (but see Ranius and Kindvall, 2006) but the area of suitable habitat in the landscape is shown to be important for the occurrence of red-listed species (Paltto et al., 2006; Franc et al., 2007). There are studies showing that retention trees, dead wood and woodland key habitats (WKH, as defined by the Swedish forest agency (Norén et al., 2002)) contain many red-listed species, (Gustafsson et al., 1999; Hylander et al., 2004; Lindhe et al., 2004; Lõhmus et al., 2006; Perhans et al., 2007; Djupström et al., 2008; Drapeau et al., 2009) but for many red-listed species it is not enough to conserve single objects, e.g. trees. For those larger habitat patches are needed (Lõhmus et al., 2006; Junninen and Komonen, 2011). Small-sized key habitats might serve as core areas for red-listed species (Gustafsson, 2002; Vasiliauskas et al., 2004; Jönsson and Jonsson, 2007; Berglund and Jonsson, 2008; Djupström et al., 2008; Timonen et al., 2011), but there are also examples where WKHs contain equal or even fewer red-listed species compared with the surrounding landscape (Gustafsson, 2002; Sverdrup-Thygeson, 2002; Vasiliauskas et al., 2004; Ericsson et al., 2005; Junninen and Kouki, 2006; Pykälä et al., 2006; Jönsson and Jonsson, 2007; Berglund and Jonsson, 2008; Djupström et al., 2008; Hottola and Siitonen, 2008; Timonen et al., 2011). Furthermore the capability of small-sized woodland key habitats to maintain assemblages and/or species over time is unclear (Franc et al., 2007; Berglund and Jonsson, 2008; Ranius et al., 2008; Timonen et al., 2011). In contrast, it is well accepted that larger reserves play a profound role for maintaining biodiversity (Siitonen, 2001b; Lindenmayer et al., 2006; Hjältén et al., 2012). Threshold values of 10–50% of a habitat are suggested for efficient conservation (Lande, 1988; Andrén, 1994; Angelstam et al., 2004; Hanski, 2011). Results from gap analysis have suggested that to reach the goal of biodiversity conservation in Swedish boreal forests, 8–13% of the boreal forest need to be set aside for conservation and an additional 3–5% needs to be restored. These targets assume that environmental considerations according to the Forestry Act and certification standards are implemented within managed stands (Angelstam and Andersson, 2001). In strongly fragmented landscapes, WKHs can be a valuable and efficient addition to the reserve network. However, in the long term most WKHs are too small to permanently sustain viable populations of species disfavoured by forestry. In strongly fragmented landscapes these population will experience metapopulation dynamics (Hanski, 1998; Ranius and Roberge, 2011). Thus, their value varies with species characteristics and WKHs are more valuable for species with good dispersal capacities that can disperse between habitat (Götmark and Thorell, 2003; Aune et al., 2005; Ranius and Kindvall, 2006; Laita et al., 2010). Many saproxylic insects can only utilize a substrate for a few years (Boulanger and Sirois, 2007; Ulyshen and Hanula, 2010) and a constant input of new dead wood is necessary for these species to maintain viable population in isolated habitats. In addition, values and the relative importance of specific WKHs, retention groups and reserves differ among organism groups (Gustafsson et al., 1999; Gustafsson, 2000; Gustafsson et al., 2004; Sippola et al., 2005; Perhans et al., 2007). Some substrates e.g. large-diameter sun-exposed dead wood are underrepresented in WKHs (Jönsson and Jonsson, 2007). For species favored by these substrates other conservation measures are needed. In conclusion, environmental considerations (ECs) targeting specific species or habitats might be important as a complement to the reserve network. Their importance varies depending on landscape context and target species, and their long term importance is unclear. Landscape planning for maintaining metapopulation dynamics is important for conservation but is associated with several problems, such as a lack of predictive tool and difficulties in implementations.

4.2. Nonproductive forest land (NPF) exempt from forestry

Nonproductive forest land (NPF) is defined as forest land that produces less than 1 m^3 wood/ha/year. In such areas, Swedish Forestry Act and FSC-standards recommend that forestry measures including logging, thinning and fertilization should be avoided (Table 1). Due to low growth rates, NPFs have been exempted from forestry and therefore can contain high conservation values. NPFs also cover a substantial area, e.g., wet forests and rock outcrops cover approximately 14% of the area of Sweden (Jasinski and Uliczka, 1998).

Generally, more productive sites have higher species richness and abundances than lower productive sites. This has been demonstrated for vascular plants (Scheiner and Reybenayas, 1994; Gjerde et al., 2005), birds and beetles (Stokland, 1997), bryophytes, lichens and polypore fungi (Gjerde et al., 2005). For many species these patterns may be explained by the higher production and availability of dead wood at high productivity sites (Storaunet et al., 2005), e.g., species richness of wood fungi is strongly connected to the amount and quality of dead wood (Gustafsson et al., 2003; Sippola et al., 2004). For epiphytic lichens and mosses there are clear differences in communities between richer and poorer sites (Boudreault et al., 2008). The species groups most commonly represented on NPFs are mosses, lichens and insects, but few species are dependent on NPFs for their survival in the landscape (Jasinski and Uliczka, 1998). Similar patterns are found for red-listed species; only 2% have NPFs as their main habitat. For these species, NPFs are important for their survival. For another 5% of the red-listed forest species NPFs are of some importance (Cederberg et al., 1997). Several studies show examples of how tree covered NPFs surrounded by managed forest could function as refuges when the surrounding landscape lose species richness through intensive forest management (Sjöberg and Ericson, 1997). Thus, the scientific support for avoiding forestry measures

Table 2
Examples of threshold values for deciduous trees for different taxa.

Taxa	Type of EC	Threshold	References
Dendrocopos leucotos, White backed woodpecker	Deciduous forest	Deciduous forest (90% deciduous trees at the stand level) with large amounts of dead wood. 10% of the landscape has to comprise suitable habitat	Virkkala et al. (1993) and Carlson (2000)
Bonasa bonasia Hazel grouse	Deciduous forest	10 ha has to comprise suitable habitat (high level of deciduous trees and multi-layered)	Saari et al. (1998)
Tawny owl *Strix aluco*,	Deciduous forest	20% cover of deciduous forest within 500 m is needed for 50% probability of occurrence	Sunde et al. (2001)
Dendrocopos minor, Lesser spotted woodpecker	Deciduous forest	Breeding: at least 40 ha of deciduous dominated forest spread out on maximum 400 ha	Wiktander et al. (2001)
Aegithalos caudatus, Northern long tail tit	Deciduous trees	15–20% deciduous trees at the landscape level (1 km^2 squares) is needed to maintain viable populations. Distance between suitable habitat patches <500 m	Jansson and Saari (1999)
Bird species richness	Deciduous trees	Increase if the proportion of deciduous trees is increased from 0% to 5%. If deciduous increased more no further increase.	Jansson and Andrén (2003)
Bats	Deciduous forest	Deciduous forest close to water is an important habitat for bats (de Jong and Ahlén, 1991) and the species richness of bats is positively correlated to the proportion of deciduous forest in the landscape	de Jong (1995)
Molluscs	Deciduous trees	Aspen present in the landscape, occurrence of patches of at least 0.05 ha close to other stands is considered important	Suominen et al. (2003)

in NPFs, as stipulated in the Forestry Act and FSC-standards, is limited.

4.3. Tree species composition

The Forestry Act stipulates that some deciduous trees in coniferous forests should be maintained for the entire rotation period. The FSC standard have more precise guidelines of 5–10% deciduous trees in stands and 5% of the landscape consisting of stands dominated by deciduous trees (Table 1). Several studies evaluate the importance of deciduous trees and mixed forests for different species/organism groups like birds (Berg, 1997; Bosakowski, 1997; Donald et al., 1998; Hobson and Bayne, 2000; Girard et al., 2004; Young et al., 2005), frogs and toads (Constible et al., 2001), mammals (de Jong and Ahlén, 1991), lichens and mosses (Gustafsson et al., 1992a; Gustafsson et al., 1992b; Ask and Nilsson, 2004), vascular plants (Saetre et al., 1997; Berger and Puettmann, 2000; Chipman and Johnson, 2002), fungi (Hattori, 2005), arthropods (Ranius, 2000; Barbaro et al., 2005) and molluscs (Suominen et al., 2003).

There is no generally accepted single threshold value for proportion of deciduous trees required for conserving viable populations of species. The demands differ among species and regions. However, suggestion for thresholds exist for several species including birds (Virkkala et al., 1993; Saari et al., 1998; Jansson and Angelstam, 1999; Jansson and Saari, 1999; Carlson, 2000; Sunde et al., 2001; Jansson and Andrén, 2003) mammals (de Jong, 1995; Reunanen et al., 2000) and molluscs (Suominen et al., 2003) (Table 2). In some cases the scientifically suggested thresholds are higher than is suggested in the Forestry Act (maintained levels) or in the FSC regulations (5–10%). In general, species associated with late successional deciduous trees have been negatively affected by forestry, and increasing the proportion of deciduous trees will in most cases be efficient for species conservation (Berg et al., 1994b; Easton and Martin, 1998).

The proportion of deciduous trees can effect populations in several ways, through direct and indirect effects on populations and species interactions (Bayne et al., 1997; Saetre et al., 1997). Tree species composition affects the available qualities of dead wood which is correlated with the number of insect species (Langor and Spence, 2006). Some species specialized on long-lasting resources, such as dead wood of oak, have limited dispersal ability (Ranius and Hedin, 2001), and require resources of dead wood of good quality nearby. Many saproxylic species are strongly dependent on forest continuity to maintain viable populations (Similä et al., 2003; Hjältén et al., 2012). For many species, the quality (e.g. age, diameter, bark structure) and position in the stand (sun exposed, shaded, or close to water) of the deciduous trees are important factors (Berg, 1997). Existence of aspen at the regional level is important for the survival of several epiphytic mosses and lichens (Hazell et al., 1998; Ojala et al., 2000). In conclusion, deciduous trees are important factors for maintaining biodiversity but the levels in the Forestry Act and FSC-standard are in many cases lower than suggested thresholds.

4.4. Tree retention and dead wood

4.4.1. Dead wood/dead trees

The Forestry Act makes no specific quantitative recommendations on the amount or quality of dead wood produced at clear-felling, which makes evaluation difficult. FSC specifies that "at least two coarse new wind throws and on average three high stumps or girdled trees shall be created per ha after regeneration felling or thick-stem thinning". There is strong evidence that dead wood plays an important role for biodiversity in forest ecosystems, by adding structure and function as habitat for both terrestrial and aquatic species e.g. (Markusson, 1998; Nyberg and Eriksson, 2001; Siitonen, 2001b; Eriksson and Näslund, 2002; Grove, 2002; Stokland et al., 2012). The species composition of saproxylic (wood living) species in dead wood differ depending on tree species (Lindhe et al., 2004), whether the wood is standing or lying (Jonsell and Weslien, 2003; Gibb et al., 2006a; Hjältén et al., 2007; Hjältén et al., 2012), exposure (Lindhe et al., 2005), fire (Wikars, 2002; Hjältén et al., 2007; Johansson et al., 2007), diameter (Schroeder et al., 1999), and species interactions (Jonsell et al., 2005). For example, the succession of wood fungi (Niemelä et al., 1995; Renvall, 1995) and the assemblage composition of fungi living beetles (Jonsell et al., 2005) depend on the fungi flora in the wood. This means that a diversity of substrates is needed to conserve species associated with dead wood in boreal forest (Martikainen et al., 2000; Jonsell and Weslien, 2003; Similä et al., 2003; Hjalten et al., 2007; Johansson et al., 2007; McGeoch et al., 2007). Dead wood volumes in old growth forest is large (30–90 m^3/ha) and new wood is added through natural disturbances (Clark et al., 1998; Fridman and Walheim, 2000; Stenbacka et al., 2010). The volumes in managed forests are significantly lower (ca 7.7 m^3/ha) (Skogsstyrelsen, 2011) and large parts of the dead wood, especially later decay stages, is destroyed at clear felling and mechanical soil scarification (Hautala et al., 2004). This reduction of dead wood volume and decompositional stages has negative effects on biodiversity (Berg et al., 1994a; Berg et al., 1995; Esseen et al., 1997; Siitonen, 2001b; Grove, 2002). Calculations show that clear cuts created in FSC certified forestry contain 50% more dead wood than clear cuts created earlier without any considerations. In addition, FSC measures are calculated to 2–3-fold increases in dead wood volumes in 100 years in certified forest compared with uncertified, the large proportion of the increased dead wood will be created in the 5% voluntary set asides and from the retained living trees (Ranius et al., 2003; Ranius and Kindvall, 2004). This means that it will take approximately one rotation period to reach the threshold of 20–30 m^3/ha suggested in a recent review (Müller and Bütler, 2010). Created high stumps are used by several groups of insects, including red-listed species (Schroeder et al., 1999; Hilszczański et al., 2005; Lindhe et al., 2005; Johansson et al., 2006; Johansson et al., 2007; Hjältén et al., 2012) and fungi (Lindhe et al., 2004), and the species composition differs from that found in low stumps (Hedgren, 2007; Hjältén et al., 2010b). Dead wood created on clear-cuts especially favor species associated with exposed habitats (Kaila et al., 1997; Lindhe et al., 2005) e.g. early successional species adapted to disturbances. To conserve old-growth associated species other measures are needed (Siitonen, 2001a; Gibb et al., 2006b; Johansson et al., 2007; Hjältén et al., 2012). High stumps only comprise a small fraction of the total volume of dead wood and the total bark area in the landscape. For most common species, less than 5% of the total population in the landscape is found on created high stumps. For one species, *Hadreule elongatula*, high stumps on clear cuts were the most important substrate (Schroeder et al., 2006) and that a majority of emergence holes of the red-listed beetle *Peltis grossa* in a landscape were found in 7–10 year old coarse artificial high stumps (Djupström et al., 2010). This indicates that the importance of artificial high stumps may increase with time, and that they may have effects at the population level for single taxa, even if they represent a low proportion of the total amount of dead wood created after a clear cut. Thus, dead wood is undoubtedly a key structure for biodiversity in forest ecosystems but suggested threshold values for species are generally higher than the recommendations in the Forestry Act and FSC-standard. In addition, dead wood are usually only used by a specific species for a limited period of time, e.g. a couple of years (Boulanger and Sirois, 2007; Ulyshen and Hanula, 2010). Thus, new suitable substrates must be found within dispersal distance to maintain metapopulation dynamics and isolated population are unlikely to persist (Hanski, 1998). This should be considered in landscape planning.

4.4.2. Tree retention

The level of retention is limited by the legal interpretation of the Forestry Act, i.e., 2–10% of the timber value. The FSC-standard stipulates at least ten trees per hectare and that all high biodiversity trees shall be retained (Table 1). There are several ecological reasons for tree retention after clear cutting including: (1) survival over the regeneration phase of species linked to mature forest i.e., “life boating”, (2) increased structural variation in the future stand, (3) enhanced connectivity in the forest landscape, (4) promotion of early successional species linked to dead wood an living trees, and sustaining ecosystem functions (Franklin et al., 1997; Gustafsson et al., 2010). Tree mortality of retention trees is higher than for trees in mature forests (Rosenvald et al., 2008). Thereby the retention trees contribute to the continuity of coarse woody debris, especially favoring species associated with sun exposed dead wood (Gustafsson et al., 2010).

For “life boating” retention trees are suggested to be most effective for ectomycorrhizal fungi, epiphytic lichens and small ground dwelling animals (Outerbridge and Trofymow, 2004; Hedenås et al., 2007; Hedenås and Hedstrom, 2007; Rosenvald and Löhmus, 2008). Most studies involve a much higher retention level than the Swedish level of 5–10 retained trees/ha (Skogsstyrelsen, 2001). However, many forest species with declining populations can benefit from increasing the number of retained trees (10–50 m^3/ha) (Hyvärinen et al., 2005). With retained trees (50 m^3/ha) or retention patches (0.1–2 ha) the ground-dwelling beetle fauna is more similar to the beetle fauna in mature forest than on a clear cut (Lemieux and Lindgren, 2004; Hyvärinen et al., 2005). Other examples show that more than 20% of the timber volume needs to be retained for survival of plants living in older forests (Rosenvald and Löhmus, 2008) and with 10% of retained trees the territories of resident forest passerines were doubled compared to current retention practice (Söderström, 2009). After harvesting the bird community is dominated by birds related to disturbance and open habitats. After 15 years most bird species associated with mature forests had returned to the area with retained trees (100 trees per hectare), but not to the clear cut (Schieck and Hobson, 2000; Schieck et al., 2000).

Many studies support the priorities of old trees, coarse trees, and deciduous trees for tree retention, as is recommended in the Forestry Act (Niemela et al., 1996; Lõhmus et al., 2006; Lie et al., 2009; Gustafsson et al., 2010; Lõhmus and Lõhmus, 2010). However, the long-term effect of retained trees has not been studied since the practice is relatively recent (Gustafsson et al., 2010). To choose trees more likely to resist wind felling, which is the major cause of retention tree mortality, is important for trees to survive and contribute with structural variation in the coming forest generation (Rosenvald et al., 2008). In general retention of deciduous trees gives a higher conservation benefit (Niemela et al., 1996; Lõhmus et al., 2006). The increased mortality of the retained trees (Jönsson et al., 2007; Rosenvald and Löhmus, 2008) also enables a continuity of fresh dead wood. Dying retained trees in groups can contribute to a longer survival of saproxylic species associated with closed forest after harvesting (Koivula, 2002; Martikainen et al., 2006; Matveinen-Huju et al., 2009). But the most important contribution is that the sun-exposed dead wood favors many red-listed species of saproxylic insects adapted to early successions after natural disturbance (Kaila et al., 1997; Lindhe et al., 2005).

The life-boating effect of tree retention is limited, given the low proportion of trees left following FSC or the Forestry Act, and their importance as old growth legacy, adding structural diversity to the young stands remains to be tested. The most distinct effect of retained trees are that the dead wood created when they die enables for saproxylic species adapted to large scale disturbance such as fire or storm felling to survive in the landscape. Retained trees on clear-cuts can thereby work as a complement to forest reserves and voluntary set asides, that favors late successional species (Djupström et al., 2008; Gustafsson et al., 2010).

4.5. Buffer zones

The forestry act and the FSC-standard only stipulates that buffer zones should be created along water, wet lands, etc. No further recommendations are given on the size of the buffers (Table 1). In the scientific literature, there is no general rule about how wide a buffer zone need to be in order to be effective. The scientific support for the value of buffer zones for protecting water habitats is strong (Gundersen et al., 2010). The forest edge close to streams and lakes might be regarded as one ecological unit (Malanson, 1993; Naiman et al., 2005; Zinko, 2005), and buffer zones and sedimentation ponds are useful to reduce negative effects from e.g. forestry (Vuori and Joensuu, 1996; Vuori et al., 1998). An ecologically functional buffer zone regulates light and temperature, filters water from the surroundings on particles and nutrients, and add dead wood to the water (Henrikson, 2007). Buffer zones can reduce water fluctuations and erosion (Bergquist, 1999). Especially along small streams at the top of the watershed buffer zones are important (Bergquist, 1999; Nyberg and Eriksson, 2001). The size of the buffer zone needed for conservation varies depending on a number of factors such as topography. A recent review showed that 45 m buffers are needed to fully protect riparian functions (LeDoux and Wilkerson, 2008). To avoid high water temperatures 70% of forested streams need to be shaded (Rutherford et al., 1997). On a larger scale, thresholds of 54% forest cover in a catchment is needed to maintain taxa richness of the insect order Plecoptera (Törnblom et al., 2011), studies of other taxa suggest 70–80% (Black et al., 2004).

Buffer zones might be important as terrestrial habitats (Komonen, 2009; Marczak et al., 2010). Forest strips along running water are species rich and host distinct species assemblages, possibly due to deciduous trees, and can therefore serve as sources of specific species of wood fungi and other wood living organisms (Komonen et al., 2008). Natural edges and transition zones between habitats can function as ecological filters or dispersal corridors (Baldwin and Bradfield, 2005). Buffer zones can reduce effects of fragmentation by increasing connectivity. However, the buffer zones are usually narrow and their importance as habitat may be reduced by edge effects (Ries et al., 2004; Selonen et al., 2005). Obvious negative edge effects has been shown for mosses up to 45 m into the stand (Baldwin and Bradfield, 2005), similar patterns exist for beetles (Pohl et al., 2007).

Buffer zones along water bodies and corridors between clear cuts are used by several squirrels as foraging habitat (Potvin and Bertrand, 2004), bats as hunting area (de Jong, 1995) and goshawk for breeding (Penteriani, 2002). The value of the buffer zones varies depends on slope, aspect, humidity and substrate availability. Slope and aspect affect the size of the edge effect because sun exposure is higher for a south facing edge (Hylander, 2005; Selonen et al., 2005). The value of a buffer zone for diversity conservation varies with humidity/moisture. Buffer zones of 10 m on each side of a stream can prevent extinction of mosses and snails sensitive to disturbance at clear cutting, at least in the short term (Hylander et al., 2004; Dynesius and Hylander, 2007). However, red-listed species associated with logs, bases of trees and moist ground are negatively affected by clear cutting even when narrow buffer zones are created and broader buffer zones are needed to protect these species from edge effects (Hylander et al., 2005).

In a meta-analysis Marczak et al. (2010) demonstrated that the importance of buffer zones as a terrestrial habitat varies. In general, forest-edge specialists increase, while forest-interior species decrease. Buffer zones along water are positive for species negatively affected by forestry, at least in the short term. Extra caution is required along sites with high conservation values or with high erosion risk.

In conclusion, buffer zones have positive effects for both terrestrial and aquatic biodiversity. The size of buffers required varies among organism groups and according to landscape variables but the restriction to 2–10% of the timber value is generally too low to serve as functional buffer zones.

4.6. Size and shape of clear-cuts

According to the Swedish Forestry Act, the size and shape of clear cut shall be adapted to the natural and cultural landscape. The size of clear cuts should be limited. The FSC-standared states that large treeless areas should be avoided (Table 1). There are no consistent pattern regarding the effect of clear-cut sizes on biodiversity and different organism groups react differently (Pawson et al., 2006). However, large clear-cuts have a negative effect on the abundance of the epiphytic chlorolichen (Hilmo et al., 2005). Arthropods from the surrounding forest can utilize small clear-cuts (Shure and Phillips, 1991) but in larger clear-cuts the forest associated species usually disappears after a few years, sometimes leading to reduced species richness (Buddle et al., 2006b; Hjältén et al., 2010a). The species richness of birds sometimes increases with size of the clear-cut but only up to approximately 20 ha (Rudnicky and Hunter, 1993).

Clear-cuts close to water affect the fish fauna. If the clear-cut is closer than 5 m from the water all fish species except pike is affected. Clear-cuts located further from water bodies result in a richer fish fauna, probably as a result of increased nutrient leakage (Markusson, 1998). This suggests that the shape of clear-cuts should be adapted so that landscape features such as streams and water are left unaffected. In summary, thresholds regarding how clear-cut size affects biodiversity are not available.

4.7. Prescribed burning

The FSC-standard stipulates that major landholders shall burn the equivalent of 5% of the regeneration area on dry and mesic soil annually. The Forestry Act does not demand burning (Table 1). Fire used to be the most important disturbance in Scandinavian boreal forests (Zackrisson, 1977; Niklasson and Granström, 2000; Reich et al., 2001) and thus many boreal species are adapted to fire (Granström and Schimmel, 1993; Wikars, 1997; Wikars, 2002). Even if the effective fire suppression almost has eradicated fire as a natural process, generalist species associated with fire in the natural landscape have been able survive on clear cuts (Granström, 2001; Hyvärinen et al., 2009). However, some species breed almost exclusively in burned forest (Wikars, 1997; Buddle et al., 2006a) and several specialized species associated with fire have declined some of which are red-listed (Gärdenfors, 2010). Today, less than 0.02% of the forest burn each year compared with approximately 1% before 1900 AD (Zackrisson and Östlund, 1991; Granström, 2001). The approximately 4000 ha that according to the FSC-standard shall be burnt every year add another 0.01 %. Prescribed burning normally leads to negligible effects on the organic soil layer compared to natural fires (Granström, 2001). Lightning ignitions result in forest fires only when the soil is excessively dry (Nash and Johnson, 1996), but prescribed burning can be implemented as soon as it is possible to burn (Granström, 2001). However, prescribed burning on clear cuts favor a different set of pioneer fungi and insects compared with clear cut without fire (Hjältén et al., 2010a; Berglund et al., 2011). Prescribed burning increase biodiversity and results in higher number of individuals of several insect groups, especially saproxylic insects (Hyvärinen et al., 2009). Several fire dependent beetles have increased since prescribed burnings were introduced in the 1990s (Wikars, 2004). Fire killed trees provide suitable habitat and constitute important food sources for many species (Muona and Rutanen, 1994; Penttilä and Kotiranta, 1996; Wikars, 2002; Fisher and Wilkinson, 2005; Toivanen and Kotiaho, 2010), so to be efficient and aid the long term survival of saproxylic species, tree retention in the burned sites is required (Toivanen and Kotiaho, 2007; Hyvärinen et al., 2009; Toivanen and Kotiaho, 2010). Although most fire associated insects have good dispersal capacities many species have limited distributions today (Wikars, 1997). The local species pool and the occurrence of fires in the surrounding landscape has been proven important for which species that colonize a burned area (Johansson et al., 2011). For sessile organisms such as vascular plants in the seed bank that require heating for germination, the choice of site and season for prescribed burning are even more important (Granström, 2001; Risberg and Granström, 2009). Although fire associated species generally are considered as good dispersers, they are still dependent on re-occurring fires in the landscape to maintain metapopulation dynamics (Hanski, 1998; Kouki et al., 2012). Thus, for landscape planning clumped distribution of prescribed fires should be prioritized over a random distribution. In conclusion, prescribed burning is an efficient way of creating habitat for fire dependent species. However, current levels including FSC standard burns constitute approximately 3% of the annually burned area compared with before 1900 AD, suggesting that the current levels are insufficient.

4.8. Avoidance of damage to soil and water

The Forestry Act states that damages on soil and water from nutrient leakage, fertilization, pesticide distribution, ditching, removal of forest residuals, and trail accessibility shall be avoided or limited in any forestry action. The FSC-standard also demands restoration if sensitive areas are damaged (Table 1). No studies directly evaluate how environmental considerations in forestry to prevent damage to ground and water affect biodiversity (Table 1). It is however well-established that soil and water qualities as well as biodiversity are affected by forestry measures such as clear felling (Davies et al., 2005), mechanical soil scarification (Wiklander et al., 1991; Battigelli et al., 2004), ditching (Wiklander et al., 1991; Battigelli et al., 2004), fertilization (Vuori et al., 1998; Nieminen and Setälä, 2001; Joensuu et al., 2002; Nicholls et al., 2003; Lindberg and Persson, 2004) and biofuel harvest (Egnell et al., 2007; Jonsell, 2007; Nitterus et al., 2007; de Jong et al., 2012). These changes result from the direct effects of habitat shift and indirect effects related to increased leakage and sedimentation. Even if both sedimentation pools and buffer zones are created at ditching, increased sedimentation reduces diversity and affects assemblage composition (Vuori et al., 1998), decreases the distribution of *Fontinalis* moss and invertebrates (Vuori and Joensuu, 1996), leads to failed regeneration of the freshwater pearl mussel, *Margaritifera margaritifera* (Österling, 2006), and reduces the development of brown trout (*Salmo trutta*) (Nyberg and Eriksson, 2001). Thus, it is well established that forestry activities damage soil and water but to what extent limitations of the damage also limit negative impact on biodiversity is not tested.

4.9. Adjusted routines for forest road constructions

The Swedish Forestry Act stipulates that forest roads should be planned so as to minimize damage to the woodland and safeguard the cultural heritage. The FSC-standard demands avoidance of damage to natural watercourses, removal of obstacles to migration of aquatic animals in watercourses with special diversity value and in maintenance of culverts (Table 1). Forestry has highly expanded the network of roads in forest ecosystems (Trombulak and Frissell, 2000). In the Swedish forest, 75% of the forest landscape is within 500 m of a road. Approximately 560 000 km roads are built in Sweden and more than 200 000 km of these are roads are built for the benefit of forestry (Bernes, 2011). Road construction increase fragmentation in both terrestrial and water habitats (Forman and Alexander, 1998; Park et al., 2008) and affect species distributions and community compositions (Bowman et al., 2010; Salek et al., 2010). One review identifies seven main effects of roads on ecosystems; mortality from road construction, road kills from vehicles, altered animal behavior, changes in the physical environment, changes in the chemical environment, spread of exotic species and increased human disturbance (Trombulak and Frissell, 2000). Examples of altered behavior include altered den selection and movement patterns of wolves (Kaartinen et al., 2010; Gurarie et al., 2011). Roads can also impact the spread of invasive species (Cameron and Bayne, 2009), and lightning fire frequency (Arienti et al., 2009). For some species, the impact of forest roads on their range selection is small, but the cumulative effect of different human activities is shown to be important for home range selection (Anttonen et al., 2011). For aquatic organisms, the effects of roads are similar to the effects of ditching. Additionally, the road bed can act as a dam, restricting the water flow to downstream areas (Noss, 1995). Roads can act as barriers for migrating fish as a consequence of wrongly adapted culverts (hanging culverts) and increase stream fragmentation (Park et al., 2008). Although there is no doubt that forest roads affect forest ecosystems, studies evaluating considerations taken at road construction and expansion of the forest network are largely missing. Suggested measures to reduce the negative impact of roads include various mitigation options to minimize road impact, road closure and obliteration (Noss, 1995). Studies on the effects of roads on ecosystems are strongly biased towards studies on mammals. Few studies consider other taxonomical groups but see (Price et al., 1974; Mader, 1984) and large parts of biodiversity are almost unstudied. Thus, there is consensus that roads affect biodiversity but the effects of EC at road construction are not evaluated.

5. Discussion

5.1. Support for environmental considerations?

Our review shows that there is a strong scientific support for the measures included as environmental considerations such as setting aside specific habitats, retaining trees, keeping dead wood and saving edge zones for conservation purposes at forest operations. Protection of red-listed species in WKHs, retention patches and structures is a cornerstone in Swedish conservation policy in the managed forest landscape. There is evidence that these small habitats can provide a life-boat function for some red-listed species, but the long term survival of these populations is uncertain (Berglund and Jonsson, 2008; Ranius et al., 2008; Timonen et al., 2011). This stresses the need for landscape planning based on metapopulation theory (Hanski, 1998), considering e.g. the dispersal ability of different species (Ranius and Roberge, 2011). Tree species composition is also important, and in the boreal region the proportion of deciduous trees is a key factor. Concerning red-listed species, non-productive forest land (NPF) seems to be moderately important. Most of the non-productive forest land does not contain important structures for red-listed species. In some cases NPF contain dead wood, old trees, and they might have importance for dispersal in the landscape. For other EC measures there is too limited information from the scientific literature to evaluate their importance in relation to the current levels, e.g. consequences of clear-cut size and shape, as well as forest roads, is difficult to evaluate from the scientific literature. Similarly, damage to soil and water affect biodiversity through drainage, leakage and sedimentation, but the effects vary extensively and are often diffuse. Our conclusion is that all environmental considerations listed in the Swedish Forestry Act are relevant for conservation, but their importance varies. In some cases there is not enough support from scientific studies to develop more specific guidelines.

5.2. Correct levels of measures?

Few studies evaluate the relative importance of different environmental considerations or the levels suggested in the Forestry Act or in FSC. Generally, the minimum levels in the Forestry Act are low compared with suggested thresholds (Jansson and Angelstam, 1999; Carlson, 2000; Angelstam and Andersson, 2001; deJong et al., 2004; Penttilä et al., 2004; Junninen and Komonen, 2011). This is especially obvious for the volume of dead wood (Siitonen, 2001a; Müller and Bütler, 2010; Junninen and Komonen, 2011; Skogsstyrelsen, 2011). Suggested thresholds of 10–30% suitable habitat for species long term survival is not reached by the minimum level in the Forestry Act or FSC standard (Andrén, 1994; Angelstam et al., 2004; Hanski, 2011). Thus, it is unlikely that the minimum level of environmental considerations in the Forestry Act is sufficient to maintain biodiversity in the long term. The same is true for the advice level that stipulates existing structures and habitats to be conserved. Although this is much higher conservation ambitions than the minimum level (i.e., the 2–10% that can be demanded according to legislation), in landscapes with long history of forestry important structures and habitats are lacking. In these landscapes little EC will be taken. Compared with the Forestry Act that only requires conservation of biodiversity values that are already present, the Swedish FSC-standard stipulates creation of new values, e.g. by creating snags, leaving retention trees and prescribed burning. These restoration measures are important since many forest stands lack or have few structures important for conservation.

Independent of which level of EC that will be chosen, protection of forest areas will be important also in the future. No examples show that the present level of the Forestry Act or FSC is enough for persistence of species associated with closed stands or shaded habitats.

5.3. Suggested improvements – ways forward

Our review suggests that to mitigate the effects of forest management on biodiversity and improve the situation to threatened forest species, the levels in the Forestry Act and FSC need to be adapted to the current knowledge on habitat demands and thresholds for demanding species. It is evident that landscape qualities, including the local species pool is important for the efficiency of conservation and restoration measures (Mykrä et al., 2000; Johansson et al., 2011). In managed landscapes, the range of patch sizes is much smaller than in naturally dynamic landscapes (Mykrä et al., 2000). As a consequence increased fragmentation and decreased connectivity decrease the quality of habitat patches. In such landscapes, many species may persist under their habitat threshold facing an extinction debt (Tilman et al., 1994; Hanski, 2000). However, it is probably not possible to maintain all species in all landscapes. Evenly dispersed measures might always stay below suggested thresholds with limited contribution to ecologically sustainable forest ecosystems. Therefore, the allocation of environmental consideration among stands, landscapes and regions needs to be considered to maintain metapopulation dynamics (Hanski, 1998; Ranius and Roberge, 2011). More flexibility, where the sum of conservation measures in the landscape as opposed to measures in individual stands are considered, should probably result in better conservation strategies. This would mean that some landscapes could be more intensively managed and in other more focus on biodiversity conservation could be taken. This is particularly important when intensified management methods, such as intensive fertilization and stump harvesting, are introduced. Zoning approaches, where conservation efforts are spatially aggregated in some landscapes has been suggested as alternatives to evenly distributed environmental considerations e.g. "third-of-a-third" suggested by Hanski (2011), i.e. in one third of the landscapes one third of the area should be devoted to conservation. This would mean that the conservation efforts would be more aggregated reducing negative impacts of fragmentation and connectivity loss. However, empirical studies evaluating such approaches are missing. Implementing a differentiated spatial distribution of environmental consideration will require landscape strategies to a larger extent than is currently occurring in Sweden.

To reach ecological threshold values for important structures, restoration is urgently needed. Restorations should be aimed at increasing the amount of dead wood, create forest stands dominated by deciduous trees and recreating natural water disturbance and fire disturbance regimes by prescribed burnings. To have conservation related targets integrated into the management practice during the whole rotation period, and not only taking environmental consideration during final felling, would lead to a restoration of conservation values on a landscape level. Dead wood, for example, must be actively produced not only at regeneration felling but also at thinning operations, and in protected areas such as voluntary set-asides and in suitable reserves. This would greatly improve, not only the potential to maintain viable population of species dependent on continuous input of dead wood at stand level, but also metapopulation dynamics in the landscape.

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