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Article

Introducing Intensively Managed Spruce Plantations in Swedish Forest Landscapes will Impair Biodiversity Decline

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Abstract: Due to pressure to raise forest productivity in Sweden, there are proposals to apply more intensive forestry methods, but they could have potentially large effects on biodiversity. Here we report a compilation and evaluation of the extent and significance of such effects. We evaluated potential effects on biodiversity by introducing intensively fertilized Norway spruce plantations as a management option in Swedish forests with low conservation values on insects, vascular plants, lichens, bryophytes, and red-listed species. Due to a lack of specific studies addressing this question, we based the evaluation on a combination of available and appropriate empiric and anecdotic knowledge; literature data, and expert judgments largely available in species data bases. Our evaluations suggest that such forests will only harbor species that are common and widespread in conventionally managed stands and that species of conservation interest will be lacking, due to the low heterogeneity and light intensity of even-aged monocultures with dense canopies, short rotation times and low availability of coarse woody debris. Effects at the landscape scale are more difficult to evaluate, but will be dependent on the area utilized and the conservation value of sites used. We conclude that negative effects on biodiversity can be reduced if: (1) only land with the lowest conservational value is utilized; (2) plantations are spatially arranged to minimize fragmentation of the landscape; (3) the quality and quantity of key structural elements (e.g., coarse woody debris, old living trees and snags) are maintained at the landscape level; and (4) management intensity is relaxed on other land. For effective implementation of these measures, legislative frameworks and policy instruments need to be adjusted and new models for planning and monitoring need to be developed.

Keywords: boreal forests; fertilization; land-use change; plantation forests

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1. Introduction

The growth of human populations, climate change concerns and increasing interest in replacing fossil fuels with biofuels are raising pressure to increase the productivity of agricultural and forest land in many parts of the world [1-6]. This has raised concern about potential conflicts between global food and timber production and preservation of biodiversity [3,4]. Even without the increased demands associated with, for example, biofuel harvesting, intense use and overexploitation of forest resources pose major threats to biodiversity, both globally and regionally [7]. Increases in biomass demands will likely exacerbate the situation, by increasing the pressure to exploit pristine forests and intensify the management of previously extensively managed forests. Identifying ways to maintain, or even increase, production capacity without further jeopardizing biodiversity presents a major challenge. A potential solution may be to utilize designated parts of the land for plantation forestry [8], *i.e.*, establishment of forests or other wooded land of introduced species (characterized by few tree species) and in some cases native species, through planting or seeding, mainly for production of wood or non-wood goods [9].

Although the economic advantages of plantation forestry have been clearly described [10], its effects on biodiversity are less well characterized or, at least appear to be strongly context-dependent, particularly in comparison to other types of land-use [11]. For example, replacement of natural forest with plantation forestry will always have a negative effect, whereas establishment of plantations on degraded land (such as previously deforested or old agricultural land) may increase biodiversity because the plantations may support a greater diversity of species than the previous land use [11-14]. Most previous studies of effects on biodiversity have analyzed landscapes with either relatively large proportions of intact and unmanaged forests or very high proportions of degraded land, supporting little or no intact forests [11]. Few, if any, studies have addressed effects on biodiversity of introducing plantation forests to landscapes supporting natural but since long managed forests, which are typical in large parts of Sweden, where almost all productive forestland is managed for forestry purposes.

Sweden has 23 million ha of productive forestland, on which more than 80% of the growing stock consisting of Norway spruce and Scots pine (*Pinus sylvestris* L.) [15]. Forestry commenced through selective felling centuries ago, but since the 1950s this practice has been replaced by clear-cutting, which is currently applied to almost all non-protected productive forestland. About 200,000 ha is annually clear-cut [15]. Nitrogen fertilization has been used to increase yields for several decades, and is currently applied to about 60,000 ha each year [15]. Nitrogen application is currently only permitted in stands that are at least mature enough to be thinned, implying that trees within the stand should be at least 30 years old. The maximum allowed dose is equivalent to 200 kg N ha^{-1} per application, with a minimum of eight years between applications, and the total N dose per rotation is limited to 150–450 kg ha^{-1}, depending on the region [16].

Although the dominant plant and animal species are generally retained following the initiation of commercial forestry in Sweden, long-term industrial use of the forests has led to some detrimental effects. Notably, there have been dramatic declines in key structural characteristics and ecological processes associated with old-growth forests, accompanied by adverse effects on biodiversity [17]. A number of conservation measures are currently applied to counteract such effects. These biodiversity conservation measures include actions ranging in scale from individual trees to national parks [18]. About 3% of the productive forestland is formally protected, whilst areas that have been voluntarily set aside by forest owners, to meet certification commitments, cover approximately 5% [16].

Further intensification of management in forest landscapes would, intuitively, be likely to have very negative effects on species biodiversity, and if habitats of high conservation status were used for plantations, significant declines in the populations of certain species could occur. However, by predominantly utilizing land of low conservational value, as in many global cases where plantations are being established on deforested land or replacing degraded forests [10-14], the detrimental effects on biodiversity could be substantially smaller or even an improvement.

The introduction of plantation-style management practices in Sweden has been suggested as a possible contribution to meet the increasing demand for forest biomass. Furthermore, a recent government commission has evaluated the potential for such introductions and the possible consequences of intensive forestry methods (summarized in [19]). A number of methods were considered by the commission, including some not covered by current legislation, such as extending exotic tree plantations, using more propagated material in plantations, and increased use of fertilizers, all of which are typical features of plantation forestry [9]. The objectives of the commission were to evaluate the production potential, identify obstacles for implementation, and consequences for biodiversity, cultural heritage, recreation, and landscape aesthetics of such methods. Here we report work carried out for the commission to identify potential effects on biodiversity (including species richness, species composition, and population viability) resulting from the introduction of intensively fertilized Norway spruce (*Picea abies* [L.] H. Karst.) plantations to the Swedish forest landscape. The objectives of this part of the evaluation were to: (1) predict the potential effects on insects, vascular plants, lichens, bryophytes and red-listed species (including groups that were not independently evaluated) of introducing intensively fertilized Norway spruce plantations at the stand and landscape scales; and (2) discuss potential ways to mitigate negative impacts.

2. Methods

2.1. Assumptions

The evaluations for the government commission [19] that our study contributed to were based on several assumptions regarding practical performance and implementation of intensified forestry. First, it was assumed that no more than 15% of the productive forest land would be utilized at the national level, although this proportion could be substantially higher in specific landscapes. Secondly, that establishment would only be allowed on land with "low conservation value", defined by low amounts of features associated with intact forests, such as dead wood and old trees. The time frame for the evaluations was 50 years, *i.e.*, approximately one forest generation if intensified management is applied. In all analyses, a prerequisite was that no conservation measures, such as retention of living and dead trees, had to be applied within plantation stands. The effects of the intensified management were to be estimated at both stand and landscape levels.

2.2. Forest Management of Today

Forest management of conifers in Sweden is practiced by area regeneration and clear-cutting to almost all non-protected productive forest land. Rotation periods range between 60 and 150 years, depending on site productivity and geographical location. Stands are generally regenerated by planting, with some natural seeding, of *P. sylvestris*. Typical management techniques include soil scarification, pre-commercial thinning, and thinning. To fulfill conservation commitments of the forestry law and to meet certification standards of FSC and PEFC, cutting operations retain some trees individually, in small tree groups, and in zones bordering lakes, watercourses and mires, with on an average 2.8% of the stand area being set aside [16,20].

2.3. Intensive Fertilization Management

The intensive fertilization of young spruce plantations has been developed from a series of fertilization/nutrient optimization experiments, which have demonstrated that it may be possible to increase current production by 100% in southern Sweden and by 300% in the north [21,22]. Such increases in growth rate imply that rotation periods could be shortened, by as much as 40 to 60 years in the north and by 20 to 30 years in the south [23]. To maximize biomass productivity and minimize nutrient losses, the quantity of N and other nutrients in the fertilizer mix are determined according to the nutritional status of the trees [24]. Hence, the dose and composition of the fertilizer applied at each fertilization event vary. Fertilization commences when the trees are about 2–3 m high and is repeated every second year until the stand has a more or less closed canopy (normally after 10 to 12 years) [23]. Before final harvest, two or three additionally applications of fertilizer may be needed to maintain high growth rates, suggesting a total N load of 800 to 1500 kg N ha^{-1} per forest generation [23]. An intensively fertilized stand will be considerably more closed and have lower cover of ground vegetation compared to an unfertilized stand (for a visual comparison, see Figure 1). After seven years of fertilization of 22-year-old spruce stands in southern Sweden (57°08'N, 14°45'E) the average basal areas were 59% higher (27 *vs.* 17 m^2 ha^{-1}), and average volume 62% higher (131 *vs.* 81 m^3 ha^{-1}) than the unfertilized controls [22]. The contrast between fertilized and unfertilized stands was more pronounced in north Sweden (64°07'N, 19°24'E), where 35-year-old spruce stands, which had been fertilized for the same period of time, on average had a 130% higher basal area (23 *vs.* 10 m^2 ha^{-1}) and 174% higher volume (96 *vs.* 35 m^3 ha^{-1}) compared to unfertilized control stands [22].

Figure 1. Contrasts in stand characteristics between unfertilized control plots (**left**) and stands that have been intensively fertilized for 20 years (**right**). Photos in the top row are from the Flakaliden experimental site (64°07'N, 19°24'E) located in northern Sweden and in the bottom row are from the Asa experimental site (57°08'N, 14°45'E) in southern Sweden [22,24], Photo Joachim Strengbom.

2.4. Effects on Biodiversity

The likely effects of intensively fertilized spruce plantations on the occurrence and abundance of insects, vascular plants, lichens, bryophytes, and red-listed species were assessed at stand and landscape levels (the latter defined as areas of approximately 25,000 ha). Analyses were based on probable effects of this form of intensive forest management on species currently found in forests that are considered to be suitable for conversion to plantations. As a foundation for the assessments, we compared the stand characteristics of a normally managed stand and an intensively fertilized stand. Estimates of occurrence and abundance were based on three sources of data. First, we reviewed the available literature, including peer-reviewed papers, theses, and numerous reports such as governmental reports and environmental impact assessments (full list in Appendix 1). Few studies have directly addressed the effects of this type of fertilization, so literature describing general responses to fertilization was included. Second, we estimated effects by comparing the known occurrence of species (by using data from existing databases) on land that might be suitable for intensive forestry to their potential occurrence in intensively fertilized stands (*i.e.*, how the changed stand conditions might influence the occurrence). Third, we complemented the compiled data of individual red-listed species ecology in the database "Artfakta" at the Swedish Species Information Centre (SSIC) with expert opinions of the occurrence of species in the two contrasting stand types, where data were lacking or of poor quality.

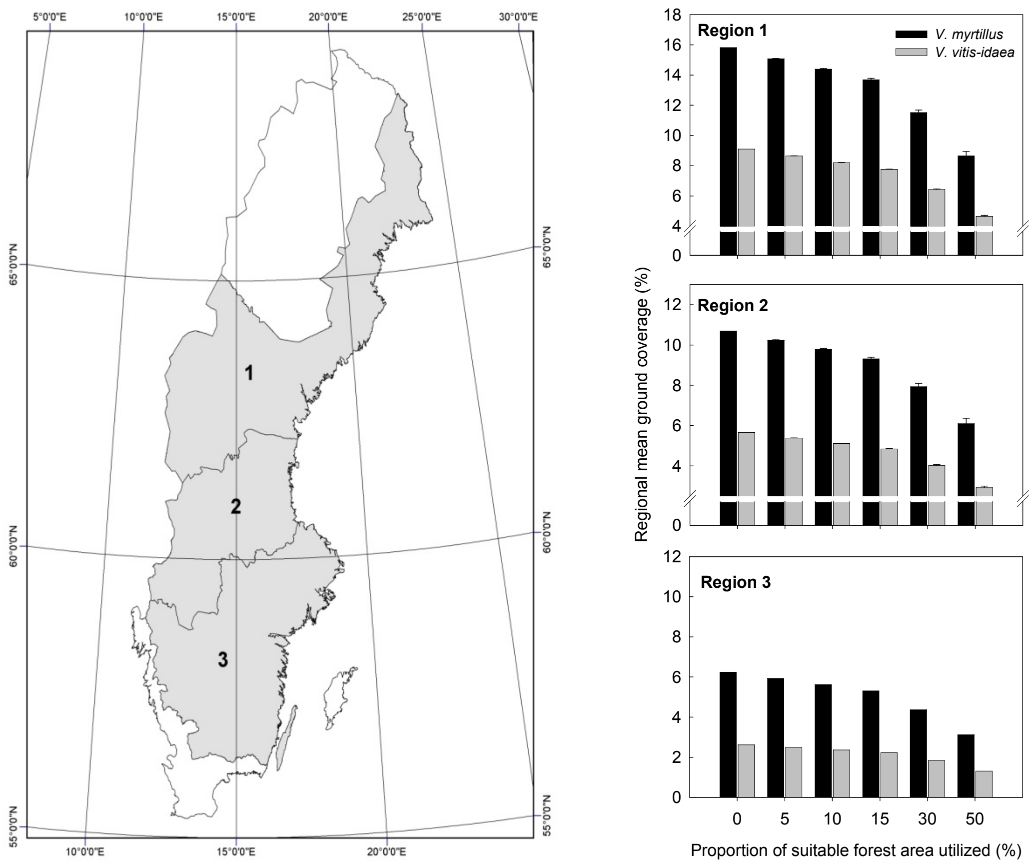
2.5. Insects

We compiled a list of insect species that primarily utilize Norway spruce as a host plant, based on a review of available literature and expert opinions. Insects that depend on wood-decaying fungi associated with different stages of tree decomposition were also listed. Predatory and parasitic insects that prey on other insect species found in spruce forests were included, when information was available. Estimates were then made, based on the literature review and expert opinions, of which species are most likely to be present and survive in intensively fertilized plantations.

2.6. Vascular Plants, Lichens, and Bryophytes

The effects of forest fertilization on vascular plants, lichens and bryophytes have been comparatively well studied, so the available literature was analyzed and summarized. However, no information was available regarding its effects on epiphytes (lichens and bryophytes), so estimates of these effects had to be based on expert judgments. There were also no data available for estimating effects at the landscape levels, so assessments at this level had to be done by scaling of effects from the stand level. We quantitatively analyzed the potential effects of intensive fertilization on the occurrence of two common and functionally important ground-living plant species—the dwarf-shrubs *Vaccinium myrtillus* L. and *Vaccinium vitis-idaea* L—in three regions: south Sweden, south-central Sweden and northern Sweden (Figure 2). We produced scenarios on how the regional mean ground coverage of these two species would be influenced, assuming that 5, 10, 15, 30, and 50% of forest land that regionally had been identified as suitable for intensive management was utilized. From the Swedish national Forest Inventory we got data on the overall current mean ground coverage of the two species in each of the three regions, and data on the mean ground coverage of the two species on forest land identified as suitable for intensive management. The effects on regional mean coverage were then estimated by linear extrapolation of stand-level cover values from intensively fertilized forest stands [25]. Empirical studies [25,26] suggest that *V. myrtillus* and *V. vitis-idaea* would be virtually absent from intensively fertilized stands in south Sweden (region 3 in Figure 2), so their cover at the stand level was set to 0% in our estimations. Based on data reported in [25], the cover of *V. myrtillus* and *V. vitis-idaea* in intensively fertilized stands in south-central (region 2) and northern Sweden (region 1) was set to 0.933% and 0.178%, respectively. In our analyses, these values replaced the current coverage values on 5, 10, 15, 30, and 50% of the forest land identified suitable for intensive forestry, and then the new overall regional mean coverage values were recalculated.

Figure 2. Changes in regional ground coverage for *V. myrtillus* and *V. vitis-idaea* in relation to the proportion of land converted into plantations. Zero percent utilization represents the current regional mean values. Changes in ground cover are presented for three regions of Sweden: (**1**) North Sweden, (**2**) South-central Sweden, and (**3**) South Sweden. Changes are based on current differences in regional cover and the predicted cover if the given proportion of land is utilized for intensive fertilization. Error bars represent 95% confidence limits.



2.7. Red-Listed Species

The Swedish Red List from 2005 reports 1862 red-listed species to occur in Swedish forests [27]. Of these, 101 were identified that may be found in forests considered to be of low conservational status. This value was calculated by excluding groups of species that were unlikely to be found in such habitats, as follows. Exclusions were based on information of individual red-listed species ecology in the database "Artfakta" at SSIC. First, a total of 335 species listed as data-deficient (DD) or regionally extinct (RE) were excluded. Second, another 1016 species were excluded as these were species predominantly occurring in forests that are not appropriate for intensive forestry (including old-growth forests, hardwood forests, recently burnt forest, forest influenced by woodland pasture, forested wetlands, mountain birch forest, forest on nutrient-poor sediment, and saproxylic species confined to hardwood trees. Finally, another 390 species were excluded based upon expert knowledge (for details, see [28]) of species-specialists working at the SSIC. The geographical distributions of species [27] were taken into account by making separate classifications for southern, central, and northern Sweden. The current distributions of species were based on published data [27], updated with more recently reported observations at the Swedish Species Gateway [29]. The potential effects of intensive fertilization on the occurrence of these red-listed species were then evaluated [27] by examining the habitat requirements by combining the information in the database "Artfakta" complemented with field experiences of SSIC experts for each species. Finally, their habitat requirements were compared with the characteristics of an intensively fertilized spruce stand to provide an estimate of the change in occurrence of these species. A full description of the contrast between stands is provided in section 2.2.

To estimate effects at the landscape level, the current distributions of red-listed species were compared to the distribution of land identified as suitable for intensively fertilized forestry, *i.e.*, forest land with low conservation values. The major source of ecological information was SSIC's database on the ecology of red-listed species, complemented with expert judgments from SSIC's species specialists. The ecological database contains data from publications and specialist knowledge from Swedish species experts, and has continually developed since late 1990s. Currently, it includes data on about 1000 ecological parameters (e.g., substrate and habitat type and abiotic conditions) classified into five categories, describing whether a factor (for example habitat type) is (1) harmful; (2) avoided; (3) of no importance; (4) utilized; or (5) important for the occurrence of the total population of a given species in Sweden. Compiled information from the database "Artfakta" is accessible as species fact-sheets on the internet [30] and extracts from this database is available on request from SSIC [30].

3. Results and Discussion

In a recent review, Brockerhoff *et al.* [11] suggested that plantation forests may promote biodiversity by: (1) providing a supplementary feeding habitat for species that are otherwise confined to small pockets of remnant intact forests; (2) increasing landscape connectivity and facilitating dispersal among otherwise isolated pockets of pristine forests; and (3) providing buffer zones, thereby reducing the edge effects of fragments of intact forest zones. These mechanisms all refer to comparisons of plantations with deforested areas or degraded forests, *i.e.*, land with low biodiversity. Our study differs because it examines the effects of establishment of plantations on less intensively managed land, *i.e.*, land with higher biodiversity. Unsurprisingly, therefore, more adverse effects on biodiversity were indicated by this assessment compared with the majority of cases presented by Brockerhoff *et al.* [11].

A common feature of predictions for all species groups evaluated in this study was that there will be major effects on biodiversity at the stand level. Compared to a conventionally managed stand, an intensively fertilized spruce plantation has a dense canopy (and thus low light availability), low heterogeneity (since it is an even-aged monoculture) and is a short-lived habitat (due to the short rotation time and, hence, low forest continuity). Thus, it is likely to be dominated by generalist species and have low diversity. Many late successional species are negatively influenced by forestry, and the short rotation periods in the plantations will further disfavor such species.

Effects at the landscape scale are more difficult to evaluate, but will at least be proportional to the land area utilized (*i.e.*, without considering potential problems associated with reductions in population sizes and increased fragmentation). The difficulty in assessing effects at the landscape level partly arises because they will be strongly dependent on the type of land being converted. Most of the species found on land of low conservational value will be abundant, with a wide distribution within the landscape. This suggests that, although effects in an individual stand may be major, effects at the landscape level may, for this type of species, be relatively minor. However, if the introduction of plantations results in habitat loss, it will, regardless of the strength of the effect, lead to a reduction in population densities. For species with limited distributions, or species that have already been negatively influenced by forest management, the detrimental effects will be much greater. Any additional habitat loss for such species may become critical due to constriction of population sizes to such an extent that random extinction events could affect their long-term survival.

Our assessment only covers a selection of species groups and thus does not address all of the potential effects on biodiversity of introducing intensively fertilized plantation forestry. Irrespective of type, design and intensity of forest management, certain species will always take advantage and be favored by the new conditions, while others will be disfavored. A recent study, for example, shows that stand-level abundance and species richness of common birds may be higher in intensively fertilized spruce forests than in comparable unfertilized reference forests [31]. Such studies are valuable for increasing our knowledge and understanding of the effects of land use changes, but comparison of species numbers is not sufficient. Rather, management for desired biodiversity needs to be critically based on knowledge of how individual species are affected. In order to ensure future sustainability and ecosystem system functions, and thus preserve biodiversity, increasing the number or abundance of common and widespread species cannot compensate for the decline and, ultimately, loss of species not favored by land use change.

3.1. Insects

From our literature review and the expert judgments we obtained it is clear that a large set of insects in Sweden are associated with Norway spruce, and most of them (ca 400 species) are associated with dead spruce wood, especially wood of substantial dimensions, *i.e.*, coarse woody debris (CWD). Of these, about 100 prefer Norway spruce over other tree species, and only about 10 are obligate spruce specialists. Further, approximately 100 of the red-listed insects in Sweden, the majority of which are beetles, are associated with woody debris from Norway spruce. There is likely to be much less CWD in intensively fertilized spruce plantations than in comparable conventionally managed forest stands, due to their short rotation periods and intensive management. Consequently, species dependent on this type of habitat are likely to be less common, or completely absent in such plantations. Also, due to the short rotation periods of intensively fertilized stands microhabitats like wood colonized by certain sets of wood-decaying fungi, tree trunks hollowed out by wood-rotting fungi, and the coarse bark of spruce trees in old-growth forests, do not have time to develop and thus, the insects that are reliant on them will be absent or present only in small densities [32]. Consequently, it is unlikely that insect species found in an intensively fertilized spruce plantation will be of conservational importance, with possible exceptions of some bark beetles and long-horn species that utilize dead branches of living trees (for example *Phloetribus spululosus* Rey.) or smaller-sized woody debris (such as *Pityogenes chalcographus* L. and *Molorchus minor* L.), Examples of species associated with Norway spruce that may become promoted include 18 sawfly species (both Hymenoptera and *Symphyta*), 12 species of aphids, and approximately 40 species of butterflies.

3.2. Vascular Plants, Lichens, and Bryophytes

There are likely to be very few ground-living plants, epiphytic lichens or bryophytes in the intensively managed stands, due to the dense canopy and (hence) low light availability [25,26]. Thus, stand-level effects on these groups of organisms will probably be large. Furthermore, conventionally managed, unfertilized stands in southern Sweden have a sparse ground cover of vascular plants, while unfertilized stands in northern Sweden have richer and more developed ground vegetation. This suggests that the contrast between intensively managed stands and conventionally managed stands will be smaller, in absolute terms, in southern Sweden than in northern Sweden [25]. In north Sweden the plantations might even represent a new habitat type, not previously found in the landscape, so the effect may be larger than in the south in this respect. However, the difference in contrast will depend on the type of forest used as a reference. Since southern Sweden has a longer management history (including extensive planting of spruce), seen over a longer time-perspective, the effect of intensified management may be similar in both regions.

Effects on plants at the landscape scale will be smaller than at the stand level. In common with the other species groups evaluated, sparsely occurring plant species that are associated with late stages of forest succession are likely to be most adversely affected. Examples include the bryophyte *Hylocomiastrum umbratum* (Hedw.) Fleisch., lichens such as *Alectoria sarmentosa* (Ach.) Ach., and vascular plants such as *Moneses uniflora* (L.) A. Gray, *Pyrola chloratha* Sw., and the orchid *Goodyera repens* (L.) R. Br. Assuming that intensively managed stands will provide unsuitable habitats, the introduction of plantations on 10 to 15% of the forest land will result in population declines.

Ericaceous dwarf-shrubs are the dominant ground vegetation species in the forest type that will be used for intensive fertilization. Reductions in their abundance in such forests may have important implications. Besides the production of economically important berries [28], a large number of insects and birds are directly or indirectly dependent on these dwarf shrubs [33]. Our analysis suggests that introducing intensively fertilized plantations will result in reductions of the regional mean cover of the dwarf shrubs *V. vitis-idaea* and *V. myrtillus* (Figure 2). The regional changes in mean cover will be proportional to the amount of land used for plantations. If 15% of the forest area identified as suitable is utilized for plantations, our estimates (based on survey data and extrapolation of stand level effects) suggest that the regional mean cover of *V. vitis-idaea* will be reduced from 2.6% to 2.2% in southern

Sweden and from 9.1% to 7.8% in northern Sweden (Figure 2). For *V. myrtillus* the estimated reduction would be less than 1% (6.2 to 5.2%) in the south, and 2% (1.6 to 1.4%) in the north (Figure 2). Although the changes in absolute terms may seem small, the effects in relative terms may be more important. Already at a utilization of 10% of the suitable forest area, the reduction in relative terms corresponds to 9–10% (Figure 2). Although the effects will most likely be of limited importance for the long-term survival of these species, as they are abundant and widespread, a reduction in abundance of functional important species may have important cascading effects on associated species, such as those that rely on their leaves, pollen, or nectar. In southern Sweden, where the regional occurrence of dwarf-shrubs is lower than in the north, such effects may be especially important. For example, if 50% of the suitable area of a forest landscape in southern Sweden is converted into plantations, our estimates suggest that the mean coverage of *V. vitis-idaea* will be reduced from 2.6% to 1.3%, and the mean coverage of *V. myrtillus* from 6.2 to 3.1%, the regional abundances will be reduced to half of the current values. Such high utilization may seem unlikely, but without regulations that limit the exploitation at local and regional scales, this type of effects should not be dismissed.

3.3. Red-Listed Species

Over half of the red-listed species in Sweden occur in forest environments [30,34]. Our analyses show that the Swedish forestland of low conservation value suggested as suitable for intensive forestry could potentially harbor as many as 101 red-listed species (Appendix 2). The set of 101 red-listed species that may potentially occur on forestland suitable for intensive forestry (Appendix 2, Table 1) consist primarily of macro-fungi (42%), birds (16%), beetles (16%), and vascular plants (7%). Almost 30% of these species are dependent on CWD, which will be in short supply in plantations. The species that could, potentially, occur in the plantations are species that are dependent or thrive on structures that will also be common in such stands, for example dead and living braches on trees, and fine woody debris on the ground. The red-listed species that could, potentially occur in spruce-dominated forest include two lichen species (*Bryoria nadvornikiana* (Gyeln.) Brodo and D. Hawksw. and *Lobaria scrobiculata* (Scop.) DC) and two species of beetles (*Callidium aeneum* De Geer and *Obrium brunneum* Fabricius) that are associated with tree branches, living spruce shoots, or fine woody debris (fallen twigs and branches). Although the substrates that these species depend on may be readily available in the plantations, other factors such as low light availability and short rotation time could reduce their occurrences. Our evaluation implies that habitat, substrate and abiotic requirements will not be met for of any presently red-listed species in intensively fertilized stands (Table 1). We conclude that it is unlikely that such stands will be inhabited by any red-listed species.

Estimating potential effects at the landscape scale is more complicated. None of the red-listed species that could occur on the forest land that has been identified as suitable for intensive forestry (Table 1) are likely to have their source population on such lands. However, due to the conditions (as described above) prevailing in these stands, they are likely to be lost from the plantation forests, thus reducing their overall population densities. Estimating effects of this type of habitat loss is difficult, requiring empirical data and detailed analyses at the individual species level (which are beyond the scope of this paper). However, additional habitat losses, caused by increasing management intensity, are likely to increase the vulnerability of species that are already threatened or have declined as a result of forest management.

Table 1. Number of Swedish red-listed species potentially inhabiting three types of managed coniferous forests, assessed on the basis if habitat, substrate and abiotic conditions may be appropriate for their presence. The species are divided into organism groups. The total number of red-listed species occurring in Swedish forests is 1862 [34].

	Number of red-listed species potentially occurring in:		
Organism group	Managed coniferous forests with ordinary conservation values	Managed coniferous forests with low conservation values	Intensively managed spruce plantations
Beetles	185	16	0
Birds	30	16	0
Bugs	9	2	0
Butterflies	71	3	0
Flies	46	0	0
Lichens	106	5	0
Macrofungi	280	42	0
Mammals	11	6	0
Bryophytes	49	0	0
Vascular plants	66	7	0
Wasps	39	4	0
Others	28	0	0
Sum	**920**	**101**	**0**

3.4. Mitigation of Effects

The analyses presented here indicate that introduction of intensively fertilized forest plantations will have predominantly negative effects on biodiversity. However, we have identified a number of measures that could mitigate such effects, most importantly: (1) choice of land type and locations of plantations; (2) preservation of key structural elements; and (3) reduction of management intensity on other land. The potential significance of these measures is discussed below.

3.4.1. Choice of Land Utilized

One of the assumptions in this assessment was that the land used for plantations should be of low conservational value. Negative effects on biodiversity would clearly be reduced if the land used for plantations only support common and widely distributed species. Hence, in order to minimize effects on biodiversity, it will be important to establish procedures to ensure that only stands with low conservation values are subjected for plantations. Surveys of valuable structures for biodiversity and for species may be necessary prior to establishment. Further, land of the lowest conservation value should be selected for establishment of plantations in preference to areas with higher conservation status. Negative effects can also be reduced if a limit is set on the proportion of an individual landscape that can be converted to plantations. As the proportion of plantations in the landscape increases, the availability of areas with low conservational value will decrease, implying that the utilization of land with higher conservational value will gradually increase. Accordingly, limiting the proportion of a landscape that can be converted to plantations would restrict the negative biodiversity effects. Moreover, to prevent more species being threatened and to protect those that are currently red-listed, we recommend that no intensive forest management should be allowed in species-rich regions, for example, pine forests on calcareous bedrock on the island of Gotland, and the species-rich forests of eastern Småland (SE Sweden).

Our assessment is based on the assumption that only land of low conservational value is utilized, and we stress that, to limit negative conservational effects, it is essential to prevent utilization of land of higher conservational value for intensively fertilized forest plantations. At present there is no legal mechanism to protect land from being used in this way, thus it is essential to develop, and implement, such a regulatory instrument in Sweden before more intensified forest management, including intensive fertilization of Norway spruce plantations, is introduced.

3.4.2. Location of Plantations

Appropriate placement of plantations in the landscape will be important for minimizing negative effects on biodiversity, as it will influence the degree of fragmentation. Although it has been difficult to assess the likely severity of the effects of fragmentation, the plantations will probably hinder rather than facilitate dispersal among pockets of natural forest. Consequently, none of the potentially positive effects of the plantations on matrix quality may occur [35]. Thus, to minimize negative effects on biodiversity, the locations of the plantations should be spatially arranged to minimize fragmentation of the existing matrix. Evidence from plantations in Australia suggests that in order to increase landscape heterogeneity, and thus biodiversity, large areas of plantations should be interspersed with small areas or strips of natural vegetation [13,14], such as corridors of retained natural vegetation along rivers. In addition, locations close to nature reserves should be avoided, as plantations may have negative effects on the quality of adjacent forest stands [36].

3.4.3. Preservation of Key Structural Elements

The continuity of key structural elements, such as CWD, old trees, and deciduous trees, is considered to be important for maintaining forest biodiversity [17,36]. Retention of such structures is a fundamental aspect of the type of forestry that focuses on multiple values rather than solely on timber production [37,38]. Currently, this type of retention is important measures applied by the forest industry in Sweden to meet general conservation concerns, enforced by the Swedish Forestry Act, and included in national certification standards. In this evaluation, we assumed that no such conservational measures would be applied in plantation forests, but if they were the effects may be less severe than we have estimated.

During this study, two important questions related to conservational concern emerged. First, is it feasible and rational to impose requirements to retain green trees and CWD within stands used for intensively fertilized plantation management? Second, if feasible, would the retention have the intended effect, *i.e.*, function in the same way as in conventionally managed stands? So far, no studies have directly addressed the functionality of tree retention in intensively managed forests. However, it seems likely that damages to the retained CWD will increase with more frequent use of machines [39].

Moreover, the low light availability and lack of sun exposure of retained trees and CWD within plantations may reduce the substrate quality for epiphytic lichens [40,41], and wood-living insects [42,43]. Hence, it seems likely that both the quality and function of key structural elements will be poorer inside than outside a plantation, implying that this type of conservational effort will be more effective if applied outside the plantations. Thus, if the functionality and quality of key structural elements are to be maintained at the landscape level, more trees may need to be retained outside plantations.

3.4.4. Reduced Management Intensity on Other Land

The high production potential of plantation forests suggests that less land would be required to maintain current levels of production, opening the possibility to set aside more land for conservation, or establish more low-intensive management areas, both of which may be beneficial for biodiversity at the landscape level. One option would be to designate zones with different management intensities, e.g., unmanaged reserves, extensively managed forests, and intensively managed forests; similar to the triad approach [44]. Simulations of boreal forest scenarios in Canada suggest that such an approach can be more successful than current forestry practices for simultaneously meeting demands of the forest industry and reducing negative effects on biodiversity [45]. However, in the cited simulations, the proportions of land allocated to reserves and to low intensive management were much higher than current proportions in Sweden, implying that both the proportions of forests that are managed less intensively than now, and the area protected from logging, would have to be substantially increased before the Canadian results could be validly applied to Swedish conditions. Furthermore, a large proportion of the forestland in Sweden is privately owned, which could hinder the introduction of such management zones.

4. Conclusions

According to our estimates intensively fertilized spruce plantation stands will, compared to conventionally managed stands, only support common and widespread species, and the diversity of insects, vascular plants, lichens, bryophytes, and red-listed species will be much lower in them. This is the effect of to their low heterogeneity (even-aged monocultures), dense canopy cover (hence low light availability within the stand), short rotation time, and low amount of CWD. Effects at the landscape scale are much more uncertain, and will largely depend on how much and the type of land that is converted, the location of plantations in the landscape, and their effect on quantity and quality of key structural elements. We have identified measures that may mitigate the negative effects of intensively managed forest plantations on biodiversity. However, before mitigation can be effectively implemented, both legislative frameworks and other policy instruments need to be adjusted and new models for planning and monitoring need to be established and introduced. Undoubtedly, more careful knowledge of biodiversity effects of intensively managed plantations requires well designed field-surveys and experiments. Such studies require extensive work and time. At conditions when such information partly or largely is missing, as in this study, evaluations of appropriate empirical and anecdotic data will provide important “stat of the art knowledge” needed for decisions.

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Appendix 1.

Key literature used to assess the impact of introducing intensively fertilized spruce plantations.

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Red-Listed Species

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Appendix 2.

Red-listed species that may occur in forests suggested as suitable for intensive forestry, their habitat requirements (tree species and wood quality), their potential occurrence in intensively fertilized spruce forests, and their regional occurrence. For further explanations, see text.

			Tree species [1]						Wood quality [2]					Regional occurences		
Species group	**Scientific name**	**Red-List Category 2005**	***Pinus sylvetsris***	***Picea abies***	***Betula spp***	***Populus tremula***	***Salix caprea***	***Sorbus aucuparia***	**Living**	**Dead**	**Fine wood**	**Coarse wood**	**Potential occurrence in intensive Norway spruce plantations**	**Götaland**	**Svealand**	**Norrland**
Mammals	*Canis lupus*	CR												x	x	x
	Lynx lynx	VU												x	x	x
	Myotis mystacinus	VU							x	x		x		x	x	
	M. nattereri	VU							x	x		x		x	x	x
	Pipistrellus nathusii	NT							x	x		x		x	x	
	Ursus arctos	NT													x	x
Butterflies	*Baptria tibiale*	EN														x
	Endothenia hebesana	NT														x
	Lopinga achine	NT												x		
Birds	*Aquila chrysaetos*	NT	x						x	x	x	x		x	x	x
	Bubo bubo	NT												x	x	x
	Caprimulgus europaeus	VU												x	x	x
	Columba oenas	NT	x			x			x	x		x		x	x	x
	Dendrocopos minor	NT							x	x		x		x	x	x
	Ficedula parva	NT							x	x		x		x	x	x
	Haliaeetus albicilla	NT	x						x	x	x	x		x	x	x
	Jynx torquilla	NT			x	x		x		x		x		x	x	x
	Nucifraga caryocatactes	NT							x	x		x		x	x	x
	Parus cinctus	NT								x		x			x	x
	P. palustris	NT								x		x		x	x	x
	Perisoreus infaustus	NT													x	x
	Pernis apivorus	EN										x		x	x	x
	Phylloscopus borealis	VU														x
	Picoides tridactylus	VU							x	x		x		x	x	x
	Strix nebulosa	NT							x			x			x	x
True bugs	*Aradus bimaculatus*	NT				x			x		x			x	x	x
	Aradus erosus	EN	x	x								x		x	x	

Appendix 2. *Cont.*

Species group	Scientific name	Red-List Category 2005	Tree species [1] *Pinus sylvetsris*	*Picea abies*	*Betula spp*	*Populus tremula*	*Salix caprea*	*Sorbus aucuparia*	Wood quality [2] Living	Dead	Fine wood	Coarse wood	Potential occurrence in intensive Norway spruce plantations	Regional occurences Götaland	Svealand	Norrland
Plants	*Actaea erythrocarpa*	VU														x
	Botrychium virginianum	VU												x	x	x
	Calypso bulbosa	NT														x
	Chimaphila umbellata	VU												x	x	x
	Epipogium aphyllum	NT												x	x	x
	Galium triflorum	VU												x	x	x
	Taxus baccata	NT												x	x	x
Lichens	*Bryoria nadvornikiana*	NT		x	x		x	x	x	x	x		x[3]	x	x	x
	Chaenotheca gracilenta	VU		x	x		x		x	x		x		x	x	x
	Eopyrenula leucoplaca	NT				x			x	x	x	x		x	x	x
	Lobaria pulmonaria	NT							x	x		x		x	x	x
	L. scrobiculata	NT		x	x	x	x	x	x	x	x	x	x[3]	x	x	x
Beetles	*Agrilus guerini*	NT					x		x					x		
	Ampedus cinnabarinus	NT			x	x				x		x		x	x	x
	Aplocnemus impressus	NT	x							x				x	x	
	Callidium aeneum	NT	x	x					x	x	x		x[3]	x	x	x
	Corticeus suturalis	NT		x						x				x	x	x
	Cyphea curtula	NT				x			x	x		x		x	x	x
	Epuraea deubeli	NT	x	x						x				x	x	x
	Ernobius longicornis	NT	x						x	x	x			x	x	x
	Gnathoncus nidorum	NT	x	x	x	x				x		x		x	x	
	Hylis procerulus	VU		x						x				x	x	
	Leiopus punctulatus	VU				x				x					x	
	Obrium brunneum	NT	x	x						x	x		x[3]	x		
	Pentanota meuseli	NT	x	x						x				x	x	x
	Phyllodrepa clavigera	NT	x	x	x					x		x			x	x
	Pseudeuglenes pentatomus	VU				x				x		x		x	x	x
	Silvanus bidentatus	NT	x	x		x			x	x		x		x	x	x
Wasps	*Chrysis brevitarsis*	VU			x											x
	Orussus abietinus	VU		x						x					x	
	Tremex fuscicornis	NT			x									x	x	x
	Xeris spectrum	NT		x										x	x	x
Fungi	*Byssoporia terrestris*	NT		x						x				x	x	x
	Ceriporiopsis subvermispora	NT		x	x	x				x		x		x	x	x
	Clitocybe alexandri	NT		x										x	x	x
	C.vermicularis ^{s}	NT												x	x	x
	Conferticium ravum ^{W}	NT				x				x		x			x	x
	Cortinarius agathosmus ^{m}	NT		x										x	x	x
	C. atrovirens ^{m}	VU	x											x		

Appendix 2. *Cont.*

Species group	Scientific name	Red-List Category 2005	Tree species [1] *Pinus sylvetsris*	*Picea abies*	*Betula spp*	*Populus tremula*	*Salix caprea*	*Sorbus aucuparia*	Wood quality [2] Living	Dead	Fine wood	Coarse wood	Potential occurrence in intensive Norway spruce plantations	Regional occurences Götaland	Svealand	Norrland
	C. aureofulvus [m]	VU	x	x										x	x	x
	C. badiovinaceus [m]	NT		x										x	x	x
	C. caesiostramineus [m]	NT	x	x		x								x	x	x
	C. corrosus [m]	VU	x	x										x	x	x
	C. cumatilis [m]	VU		x										x	x	x
	C. cupreorufus [m]	NT	x	x										x	x	x
	C. dionysae [m]	NT		x										x	x	
	C. elegantior [m]	NT	x	x										x	x	x
	C. fraudulosus [m]	NT		x										x	x	x
	C. ionophyllus [m]	NT		x										x	x	x
	C. meinhardii [m]	NT		x										x	x	x
	C. mussivus [m]	NT	x	x										x	x	
	C. phrygianus [m]	VU	x											x	x	x
	C. pseudoglaucopus [m]	VU	x	x										x	x	
	C.russus [m]	NT		x										x	x	x
	C. sulfurinus [m]	NT	x	x										x	x	x
	C. venetus[m]	NT	x	x										x	x	x
	Crustoderma dryinum [w]	VU	x	x						x		x		x		x
	Gomphus clavatus [m]	VU		x										x	x	x
	Hydnellum auratile [m]	VU	x	x										x	x	x
	H.geogenium [m]	NT		x										x	x	x
	H. suaveolens [m]	NT		x										x	x	x
	Hygrophorus gliocyclus [m]	VU	x											x	x	x
	H. inocybiformis [m]	VU		x											x	x
	Kavinia alboviridis [w]	NT		x	x	x						x		x	x	x
	Lactarius musteus [m]	NT	x											x	x	x
	Lepista densifolia [s]	NT												x	x	x
	Leucopaxillus cerealis [s]	NT												x	x	
	Lyophyllum semitale [s]	NT												x	x	x
	Metulodontia nivea [w]	NT	x	x						x				x	x	x
	Phellodon niger [m]	NT		x										x	x	x
	Radulodon eriks sonii [w]	VU				x				x		x		x	x	x
	Sarcodon glaucopus [m]	VU	x	x										x	x	x
	Stropharia albocrenulata [w]	NT		x		x			x	x		x		x	x	
	Tricholoma matsutake [m]	NT	x											x	x	x

[1] Species generally associated to forest, not to specific trees; [2] Classification for saproxylic species only; [3] This potential habitat was not assessed as important due to the prevailing stand characteristics of intensively fertilized plantations; [m, s, and w] Fungal lifeform saprotophic soil-dwelling, wood-inhabiting, and mycorrhizal.