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Different management regimes in a boreal forest landscape: ecological and economic effects

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Abstract

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Five management regimes were theoretically applied and evaluated in a 10 000 ha boreal forest landscape. Four regimes were designed to enhance conditions for biodiversity conservation, by establishing reserves and by modifying stand management. One regime was purely for timber production. Effects on biodiversity were assessed in terms of changes in population sizes within species or as number of species within ecological groups of the Red-listed species in the landscape. Assessments were based on the effects of management regimes on natural features of significance to animal and plant diversity. Effects on growing stock, harvest level, and economic return were assessed by means of the Forest Management Planning Package. Results indicate that biodiversity can be preserved only if the landscape is managed to satisfy the demands of species that require continuity in habitat conditions, and if management recognises fire-generated successions in boreal forest. Such management encompasses a system of patches managed so that important successional stages are always present in the landscape. The regime based on traditional silviculture did not encompass such features and, consequently, did not maintain biodiversity in the landscape. In the traditional silviculture regime, the future amount of deciduous trees was constant while the amount of old forest strongly decreased. As expected, this regime also generated the highest economic output. The decrease in harvested volumes and net incomes in the other regimes was approximately proportional to the reduction in non-protected, productive forest land.

Key words: conservation, ecological landscape planning, forest management planning, managed forests, natural forest dynamics, Sweden, trade-off analyses.

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Introduction

By comparison with natural forests, features important to plant and animal diversity (composition, structures and processes) are lacking or have been altered in today's Swedish boreal forests (Linder & Östlund, 1992; Esseen, Ehnström, Ericson & Sjöberg, 1997). The number and quality of undisturbed forests, and the amounts of coarse woody debris and deciduous trees, have been heavily reduced. Fires are nowadays rare. In consequence, there is a general shortage of suitable habitats for specialised species and there are at present *ca.* 1100 endangered, vulnerable, rare, or care-demanding forest-dwelling animal and plant species on the Swedish Red Data list (Ehnström, Gärdenfors & Lindelöw, 1993; Ahlén & Tjernberg, 1996; Larsson, 1997; Hallingbäck, 1998; Aronsson, 1999; Thor & Arvidsson, 1999). Growing concern about ecological degradation, such as loss of productivity, extinction of species, *etc.*, has led to a search for management practices which can maintain biodiversity and ecosystem viability.

For stand level, modified silvicultural methods are now under development (*e.g.* Bradshaw, Gemmel & Björkman, 1994; Fries, Johansson, Pettersson & Simonsson, 1997). However, when the aim of forest management includes not only timber production but also maintenance of biodiversity, a larger scale must be considered. For this reason, the 'forest landscape' has been suggested as a suitable unit for forest management planning (Franklin, 1992, 1993; Liljelund, Pettersson & Zackrisson, 1992). A forest landscape may be *e.g.*, 5 000–25 000 ha in extent. One reason for choosing this larger scale is that the spatial arrangement of stands of different qualities determines what species may be present (*e.g.* Forman & Godron, 1986). The concept of using the landscape level in forestry emerged in the Pacific Northwest of the U.S.A. (*e.g.* Harris, 1984; Hansen, Spies, Swanson & Ohman, 1991; Hopwood, 1991; Franklin, 1992). This view soon reached Sweden; in the early 1990s, Swedish forestry companies began to develop 'ecological landscape plans' in certain project areas (Rülcker, Angelstam & Rosenberg, 1994; Törnquist, 1996; Angelstam & Pettersson, 1997; Fries, Carlsson, Dahlin, Lämås & Sallnäs, 1998). The primary aim of these plans was to improve conditions for conserving biodiversity, by means of networks of protected areas and modified management of the matrices. These plans concentrated on development of working methods which could be used in practice by the companies, rather than on analysis of different principles of managing a forest landscape and the outcomes of such management regimes.

A problem forest managers must consider, when planning the management of forest landscapes to conserve biodiversity, is finding a balance between modification of silvicultural methods, and establishment of permanent or temporary reserves. Another problem lies in forecasting the outcome of different management regimes. In the present study, we investigate these problems by theoretically applying five management regimes to a typical Swedish boreal forest landscape. In four of the regimes, timber production was restricted in various ways, to improve conditions for conserving biodiversity, *e.g.* by establishing reserves, by reducing harvest levels in certain areas or by general modification of stand management. The fifth regime was concerned exclusively with timber production.

The aim of the study was to estimate the effects of the different regimes on biodiversity, growing stock, harvest level, and economic return. Results from the study may be of help in choosing a strategy for combining timber production and maintenance of biodiversity in a forest of this type.

In the study, the Red-listed species found by an inventory of conservation values in the landscape, were used as a measure of biodiversity. Problems related to land ownership, *e.g.* how to implement the management regimes in the partly non-industrial, privately-owned area, were not addressed.

Material and Methods

The studied landscape

The landscape studied is situated in the middle boreal zone of northern Sweden (Ahti, Hämet-Ahti & Jalas, 1968), 60 km north-west of Umeå

(63°35′ N, 20°15′ E; Fig. 1). It has an area of *ca.* 10 000 ha. The eastern boundary is formed by the river Vindelälven (here 150–170 m a.s.l.). To the west of the river, the terrain consists of coarse, glacifluvial sediments, succeeded by undulating, hilly terrain, mainly covered by deep deposits of glacial till, with several peatlands in the valley bottoms (National Atlas of Sweden, 1994). The highest summit is 402 m a.s.l. Eighty-nine per cent of the landscape is productive forest land, 8% is peatland, while the remainder consists of lakes and agricultural land. Eight per cent of the productive forest land was classified as dry from an analysis of colour infrared aerial photographs, 63% as mesic, and 29% as moist or wet (Fig. 2*a*).

Large-scale logging began in the region about 1850, when large Scots pines (*Pinus sylvestris* L.) were felled to produce lumber for export (Östlund, 1993). As the pulp and paper industry developed at the end of the 19th century, even smaller pines and Norway spruce (*Picea abies* (L.) Karst.) became valuable. The clearfelling system was introduced into the landscape studied in the 1930s. Since about 1950, this has been the only silvicultural system of importance. The clearfelling system normally includes soil scarification, planting of pine, cleaning, and one or more thinnings before the rotation is concluded by clearfelling at a stand age of 100–120 years.

Today, pine, spruce and deciduous trees make up about 46%, 43% and 11%, respectively, of the standing volume in the landscape studied. About 46% of the productive forest land contains stands $\leq$50 years old, and 31% contains stands $>$100 years old (Fig. 2*b*). The youngest portion has, in most cases, been established by natural regeneration or planting after the first clearfelling. The mean standing volume in the landscape studied is *ca.* 104 m^3 ha^{-1}, and mean site productivity is 3.9 m^3 $ha^{-1}yr^{-1}$, which is close to the level in the coastal area of the county of Västerbotten (Anon., 1997). The volume of coarse woody debris has been reduced from a probable natural level of 40–80 m^3 ha^{-1}, to an average of 1.7 m^3 ha^{-1} (Lämås & Fries, 1995*a*). Forestry companies own 72% of the productive forest land; the remaining 28% consists of *ca.* 100 non-industrial private forest holdings. We consider the studied landscape to be representative of a large area of northern Sweden. Historic land use is, for example, similar to land use in a large proportion of the North-Swedish boreal forests (Östlund, 1993). The present age-class and tree-species distributions are similar to those in the two northernmost counties of Sweden (Anon., 1997).

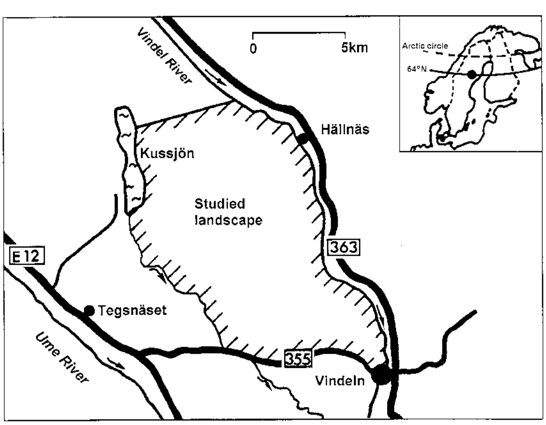

Fig. 1. Location of the studied landscape.

There are differences between the structure of the natural and the man-made landscape, as indicated by the soil moisture map (Fig. 2*a*) and the forest map (Fig. 2*b*), respectively. The shape of the patches formed by differences in soil moisture is more complex than the pattern formed by the stands on the forest map. Another characteristic is that many moist or wet areas have elongated and pointed shapes, indicating the presence of depressions or small streams, which are not found on the forest map. The relatively old forest is fragmented, and no large, continuous areas with stands $>$100 years old now remain. Consequently, about half a century of forestry according to the clearfelling system, has resulted in a considerable change in what may be assumed to have been the natural structure of the landscape studied.

Areas containing Red-listed species or with a high frequency of natural structures (multi-storey tree canopies, patchy distribution of tree species and tree stems, occurrence of large, old and dead trees, especially Scots pines and deciduous trees, *etc.*) – indicating that they have the potential to support Red-listed species – were located by interpretation of colour infrared aerial photographs, followed by a field inventory (Fig. 3) (Sporrong, unpubl. data). Their total area is 670 ha (7.8% of the productive forest land). The six areas with the highest conservation value (*i.e.* those which contain the most

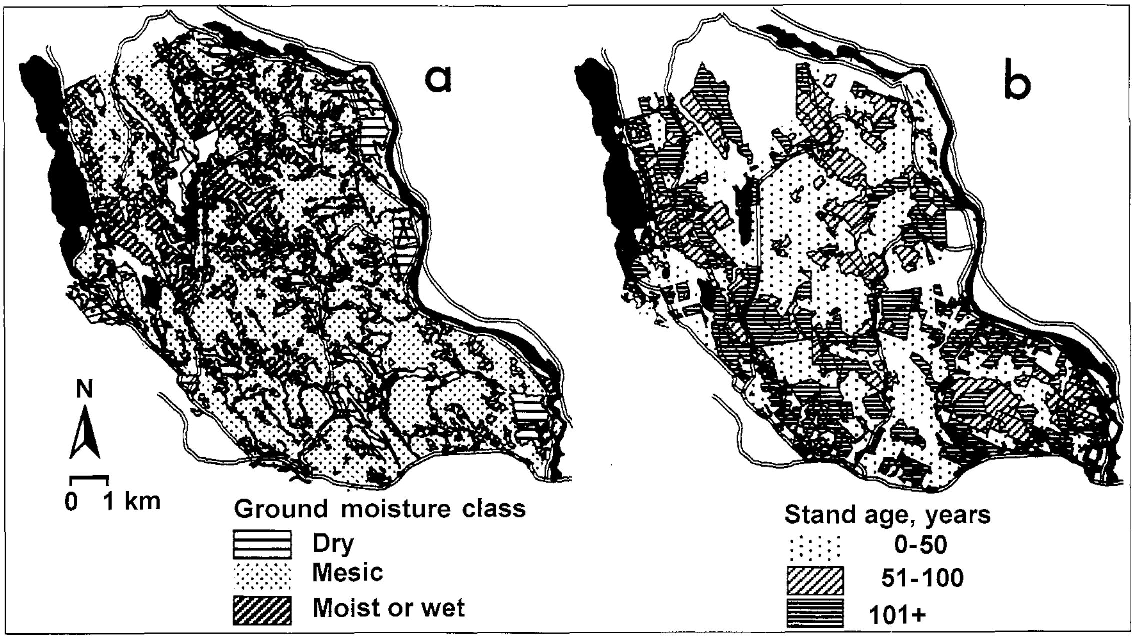

Fig. 2a–b. Soil moisture (a) and mean stand ages (grouped into three ageclasses), (b) in the studied landscape. Soil moisture is classified by interpretation of colour infrared aerial photographs (scale 1:20000) into dry, mesic, or moist or wet. ■ Lakes and rivers, ⫫main roads.

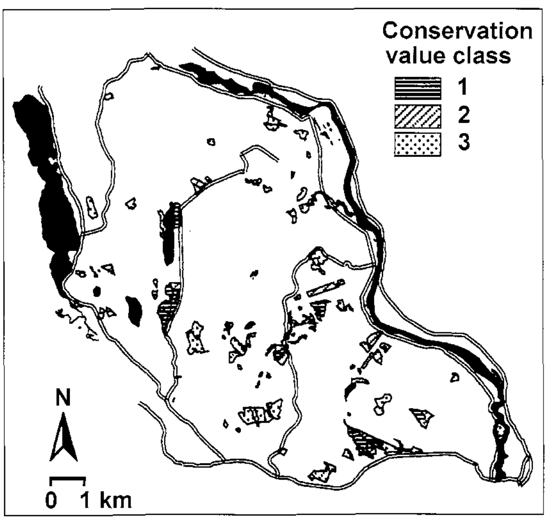

Fig. 3. Areas with high nature conservation values (class 1; highest value–127 ha; 1.5% of the productive forest land in the studied landscape), class 2 (194 ha; 2.2%), and class 3 (353 ha; 4.1%)). ■ Lakes and rivers, ⫫main roads.

'natural' stand structures and the majority of the Red-listed species in the landscape studied), consist of late-successional forests that appeared after fires about 150 years ago. Two of them also contain moist or wet sites dominated by Norway spruce forests regenerated by gap dynamics. The areas of highest value have in common the fact that no thinnings, or only light thinnings, have been carried out during the past 50 years.

Most of the 42 Red-listed species found in the studied landscape, are fungi which use dead wood as a substrate (mainly spruce logs) or lichens confined to old or dead conifers or deciduous trees (Table 1). Some of the species may survive cutting, others do not. Twelve Red-listed species, according to categories defined by IUCN (Groombridge, 1993), are considered to be endangered (3), vulnerable (6), or rare (3). Thirty species, according to categories defined by the Swedish Environmental Protection Agency, are considered care-demanding (Ehnström *et al.*, 1993; Ahlén & Tjernberg, 1996; Larsson, 1997; Hallingbäck, 1998; Aronsson, 1999; Thor & Arvidsson, 1999). Because bryophytes and invertebrates were not systematically examined by specialists, there are probably more Red-listed species in these groups in the studied landscape than are shown in Table 1. Also among vertebrates, there are Red-listed species that probably occasionally occur in the landscape, but which are not shown in the table.

Table 1. *Red-listed species found in the studied landscape, by preferred biotope and by important features, etc., on which they depend (Ehnström & Waldén, 1986; Ahlén & Tjernberg, 1996; Larsson, 1997; Hallingbäck, 1998; Aronsson, 1999; Thor & Arvidsson, 1999). Species nomenclature follows the Red-lists cited above*

Species	Organism group[a)]	Threat category	Preferred biotope	Features, etc.[b)]
Pytho abieticola	I, beetle	2	Spruce forest	Spruce logs (with bark)
Amylocystis lapponica	F	2	Spruce forest	Spruce logs
Cystostereum murraii	F	4	Spruce forest	Spruce (stumps or logs); moist microclimate
Fomitopsis rosea	F	4	Spruce forest	Spruce logs
Perenniporia subacida	F	2	Spruce forest	Spruce logs (wood); moist microclimate
Phellinus ferrugineofuscus	F	4	Spruce forest	Spruce logs (bark)
Phellinus nigrolimitatus	F	4	Spruce forest	Spruce logs
Phlebia centrifuga	F	4	Spruce forest	Spruce logs
Pseudographis pinicola	F	4	Spruce forest	Spruces (stem base with rough bark)
Bryoria nadvornikiana	L	4	Spruce forest	Spruce branches
Chaenotheca gracillima	L	4	Spruce forest	Spruce snags (wood); moist and shady conditions
Chaenothecopsis viridialba	L	4	Spruce forest	Spruce trunk (bark); moist site
Microcalicium ahlneri	L	4	Spruce forest	Spruce or pine (snag or trunk); moist site
Ramalina thrausta	L	1	Spruce forest	Old spruce, branches; moist microclimate
Anastrophyllum hellerianum	B	4	Spruce forest	Logs; moist microclimate
Lophozia ascendens	B	4	Spruce forest	Logs; moist microclimate
Epipogium aphyllum	Va	4	Spruce forest	Ground; moist
Ranunculus lapponicus	Va	4	Spruce forest	Ground; moist-wet
Agathidium discoideum	I, beetle	4	Deciduous/spruce forest	Large aspen logs
Melandrya barbata	I, beetle	1	Deciduous/spruce forest	Large aspen logs
Clavicorona pyxidata	F	4	Deciduous/spruce forest	Aspen logs
Haploporus odorus	F	4	Deciduous/spruce forest	Old goat willow (bark)
Calicium adaequatum	L	4	Deciduous/spruce forest	Alder branches; moist microclimate
Chaenotheca laevigata	L	2	Deciduous/spruce forest	Snags (wood)
Collema nigrescens	L	4	Deciduous/spruce forest	In boreal forest: Aspen (bark); moist microclimate
Collema curtisporum	L	1	Deciduous/spruce forest	Medium-aged aspen (bark)
Collema furfuraceum	L	2	Deciduous/spruce forest	Old aspen (bark)
Collema subnigrescens	L	4	Deciduous/spruce forest	Old aspen (bark); shady and moist microclimate
Ramalina sinensis	L	4	Deciduous/spruce forest	Old aspen or willow (bark)
Sclerophora coniophaea	L	4	Deciduous/spruce forest	Spruce, alder or birch (bark on trees or stumps)
Dryocopus martius	Ve, bird	4	Deciduous/spruce forest	Nest-holes in large aspen or pine
Picus canus	Ve, brid	3	Deciduous/spruce forest	Nest-holes in aspen
Cladonia parasitica	L	4	Pine forest	Pine logs (wood)
Ursus arctos	Ve, mammal	4	Forest land	
Picoides tridactylus	Ve, bird	4	Natural boreal forests	Nest-holes in several tree species
Tetrao urogallus	Ve, bird	4	Unfragmented forest	
Carex rhynchophysa	Va	3	Riparian zone	Ground, oxygen and nutrient rich
Margaretifera margaretifera	I, mussel	2	Stream	
Salmo trutta	Ve, fish	4	Stream	
Grus grus	Ve, bird	4	Mire	
Botrychium lanceolatum	Va	3	Meadow	Ground, dry and nutrient poor
Botrychium multifidum	Va	4	Meadow	Ground, dry and nutrient poor

[a)] B = Bryophyte, F = Fungi, I = Invertebrate, L = Lichen, Va = Vascular plant, Ve = Vertebrate.
[b)] Many Red-listed fungi seem to prefer large logs (Kruys, Fries, Jonsson, Lämås & Ståhl, 1999).

Management regimes

Different management regimes, aiming at different levels of timber production and maintenance of biodiversity, were applied to the landscape. Three main approaches were used: No Protected Areas (NPA), Protected Areas (PA), and a Landscape Planning approach (LP) (Table 2). Except for the NPA option, these approaches designate areas for certain silviculture regimes, *e.g.* reserves, prescribed burning, or extended rotations. Furthermore, areas outside such designated areas could be managed either for a Highest net present value of Timber Production approach (HTP), or a Modified Timber Production approach (MTP). The LP option, however, was combined only with the MTP approach. Thus five management regimes were applied to the landscape.

Highest Timber Production (HTP)

The HTP approach illustrates a single aim, commercial forestry aiming at the production of valuable timber. Silviculture was based on the clearfelling system, and regeneration measures generally consisted of soil scarification, planting or natural regeneration under seed trees. Cleaning, and one or more thinnings, aimed at improving conifers, were normally carried out during a rotation.

Modified Timber Production (MTP)

The MTP approach is based on important measures in Swedish boreal forests for enhancing biodiversity, *i.e.* increasing the number and quality of undisturbed forests, the amounts of coarse woody debris, the number of large and old deciduous trees, and reintroducing fire as an ecological process (Esseen *et al.*, 1997).

In particular, 5% of the productive forest land, in addition to reserves, was withdrawn from the calculation of potential cut to provide for the retention of small patches of forest, and for buffer or restoration zones. The aim of buffer zones is to reduce negative effects from the matrix on features and species in selected habitats (Baker, 1992; Murcia, 1995; Angelstam, 1997; Fries *et al.*, 1998). Their shape and management should therefore vary, depending on the situation. Restoration zones are established to support habitats valuable for conservation by enhancing processes characteristic of that particular habitat.

In thinning operations, the priority for cutting deciduous trees was lower in the MTP than in the HTP approach. At final harvest, 1% of the standing volume was left to represent retention of single green trees and the creation of snags at final harvest. Prescribed burning, which leads to increased regeneration costs and a natural regeneration mainly of deciduous trees, was implemented on 3% of productive forest land in the first 50-year period (corresponding to 5% of the final harvested area in the NPA approach).

The MTP approach also includes uneven-aged silviculture on a minor proportion of the moist spruce sites. However, in the planning system used (see 'Evaluation of effects on timber production' below), such silviculture was impossible to apply. Instead, the above 5% area set aside was assumed also to represent the possible reductions in timber production caused by uneven-aged silviculture.

Table 2. *The various components which form the management regimes. (PFL denotes productive forest land.)*

Regime	Protected area of PFL[a] %	Prescribed burning	Green tree retention	Priority for cutting deciduous trees at thinning	Small patches of forest left in final harvest	Buffer zones around selected streams	Management for continuity of successional biotopes
NPA + HTP	0	No	No	High	No	No	No
NPA + MTP	0	Yes[b]	Yes	Low	Yes	No	No
PA + HTP	2.5–25	No	No	High	No	No	No
PA + MTP	2.5–25	Yes[b]	Yes	Low	Yes	No	No
LP + MTP	4.1	Yes[c]	Yes	Low	Yes	Yes	Yes

[a] Apart from small patches left in cuttings, if any.
[b] 1% of standing volume left at final cutting prior to prescribed burning.
[c] 25% of standing volume left at final cutting prior to prescribed burning.

It is not possible to depict differences between the HTP and the MTP approaches on a small-scale map. However, one characteristic and fundamental difference between the HTP and the MTP approaches is that every landscape patch will in the long term be more homogeneous and have more distinct borders in the HTP than in the MTP approach (Fig. 4). Modification of the MTP approach, and the proportion of productive forest land withdrawn, are similar to those agreed upon in the Swedish FSC certification process (The Swedish FSC Working Group, 1997).

No Protected Areas (NPA)
In the NPA approach, no areas were established as reserves. The NPA approach was combined either with the HTP approach, forming the NPA + HTP regime, or with the MTP approach, forming the NPA + MTP regime.

Protected Areas (PA)
In the PA approach, areas were established from which no timber was removed. The approach was applied so that 2.5, 5, 15, and 25%, respectively, of the productive forest land in the study area was protected (hereafter referred to as PA2.5, PA5, *etc.*). The proportion 15% was included in our analyses because an expert group judged that this level is needed to maintain biodiversity in Swedish forests (Liljelund *et al.*, 1992; Lämås & Fries, 1995*b*). The line of action suggested by the group, established as official policy in 1993, was instead to reduce the proposed reserved proportion 'by more than half', and to modify management of the remainder of the forest land. This was the basis for our choice of the proportion 5%. The PA options were combined either with the HTP approach, forming the PA + HTP regimes, or with the MTP approach, forming the PA + MTP regimes.

The procedure for establishing reserves was as follows: First, patches with the highest conservation value (conservation value class 1) were selected as reserves. Reserve areas were then chosen among the older portion of stands, especial attention being paid to conservation value class 2, with the ambition to protect most of the site types in the landscape. To reduce negative edge effects on the reserves, we attempted to reduce the perimeter : area ratios and to form relatively large reserve units. When a higher proportion of reserved area was established, connections between areas of high conservation value were made whenever possible. In the combination PA and MTP, small patches can be left adjacent to protected areas, as buffer zones or restoration zones.

The establishment of 2.5% (*ca.* 220 ha) of the productive forest land as reserves made it possible to preserve the six areas in conservation value class 1 and the 5.2 ha stand containing the endemic lichen *Cladonia parasitica* (Hoffm.) Hoffm., characteristic of the landscape. By preserving *ca.* 19 ha of dry sediment dominated by pine > 100 years old, an additional major forest type was included among the reserves (Fig. 5*a*). Ninety-four per cent of the reserved productive forest land contained forests > 100 years old, 85% was classified as having a value for conservation (Table 3).

With a protected proportion of 5% (*ca.* 430 ha), the reserves encompassing four of the six most highly valued areas were enlarged, and four of them could be connected in pairs (Fig. 5*b*). In addition to the 19 ha of dry sediment with pine, it was also possible to establish a 24-ha reserve in a relatively rare and sensitive, but species-rich forest type, *i.e.* a spruce-dominated stand on wet ground, with many natural structures unaffected by cutting.

Protection of 15% (*ca.* 1300 ha) of the productive forest land made it possible to establish a 900-ha reserve in the central part of the studied landscape (Fig. 5*c*). Because of the distribution of stands with conservation value, the reserve had a relatively complex shape. It contained two of the areas with conservation value class 1 and a set of biotopes characteristic of the boreal Swedish forest landscape of today, *i.e.* managed young, medium-aged and old stands, large mires, lakes, and a fairly pristine stream. A new, relatively large reserve (170 ha), mainly made up of stands with conservation value class 3, and including several patches with conservation value class 2, was established in the eastern part of the studied landscape.

With the protection of 25% (*ca.* 2180 ha) of the productive forest land, the 900-ha reserve in the 15% case was increased to about 1750 ha (Fig. 5*d*). This resulted in a higher area : perimeter ratio of that reserve, at the expense of the inclusion of large areas with stands ≤ 50 years. A further result was the protection of a large

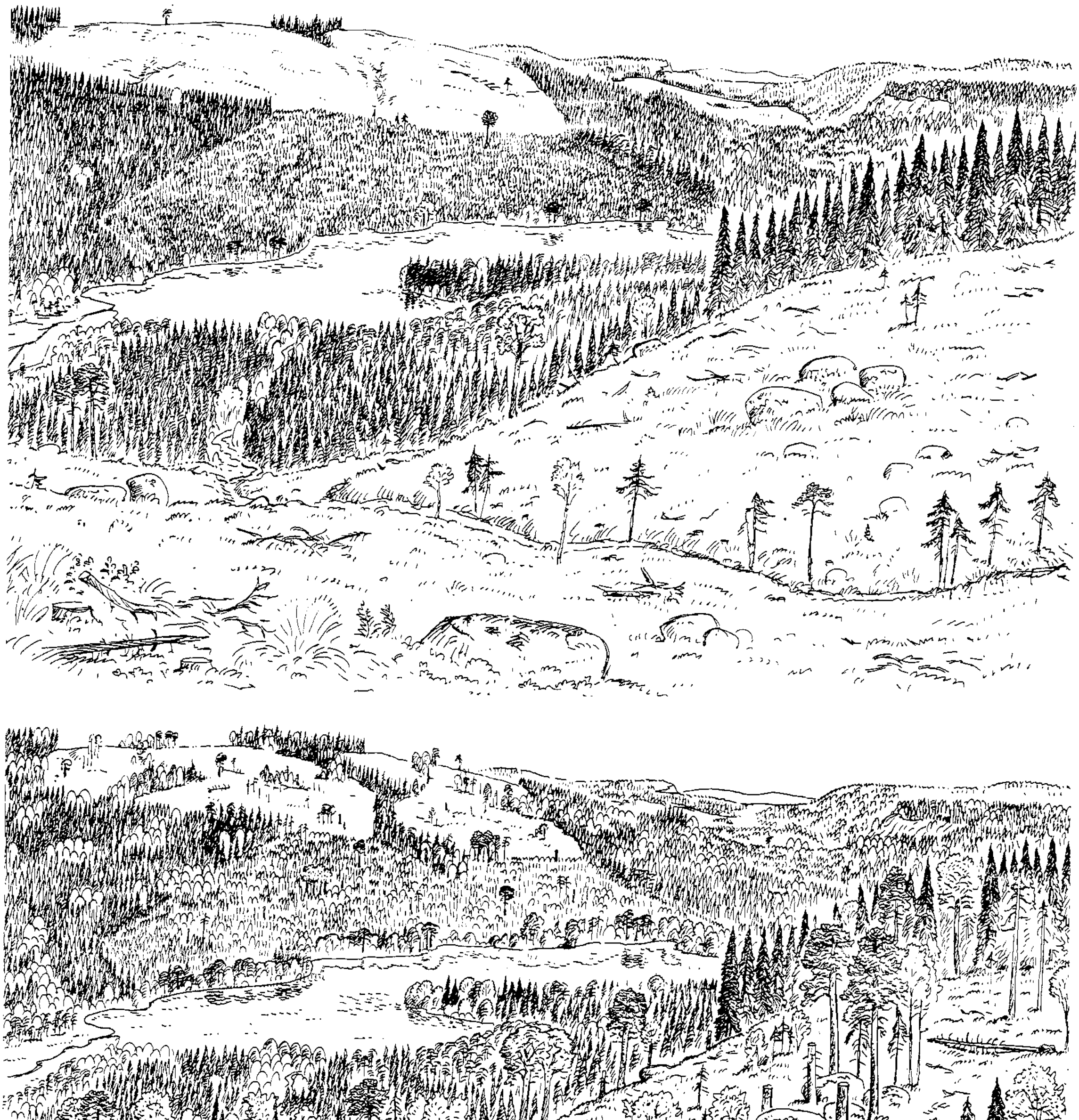

Fig. 4. In the HTP option (top), landscape patches will in the long term be more homogeneous and have more distinct boundaries than in the MTP option (bottom).

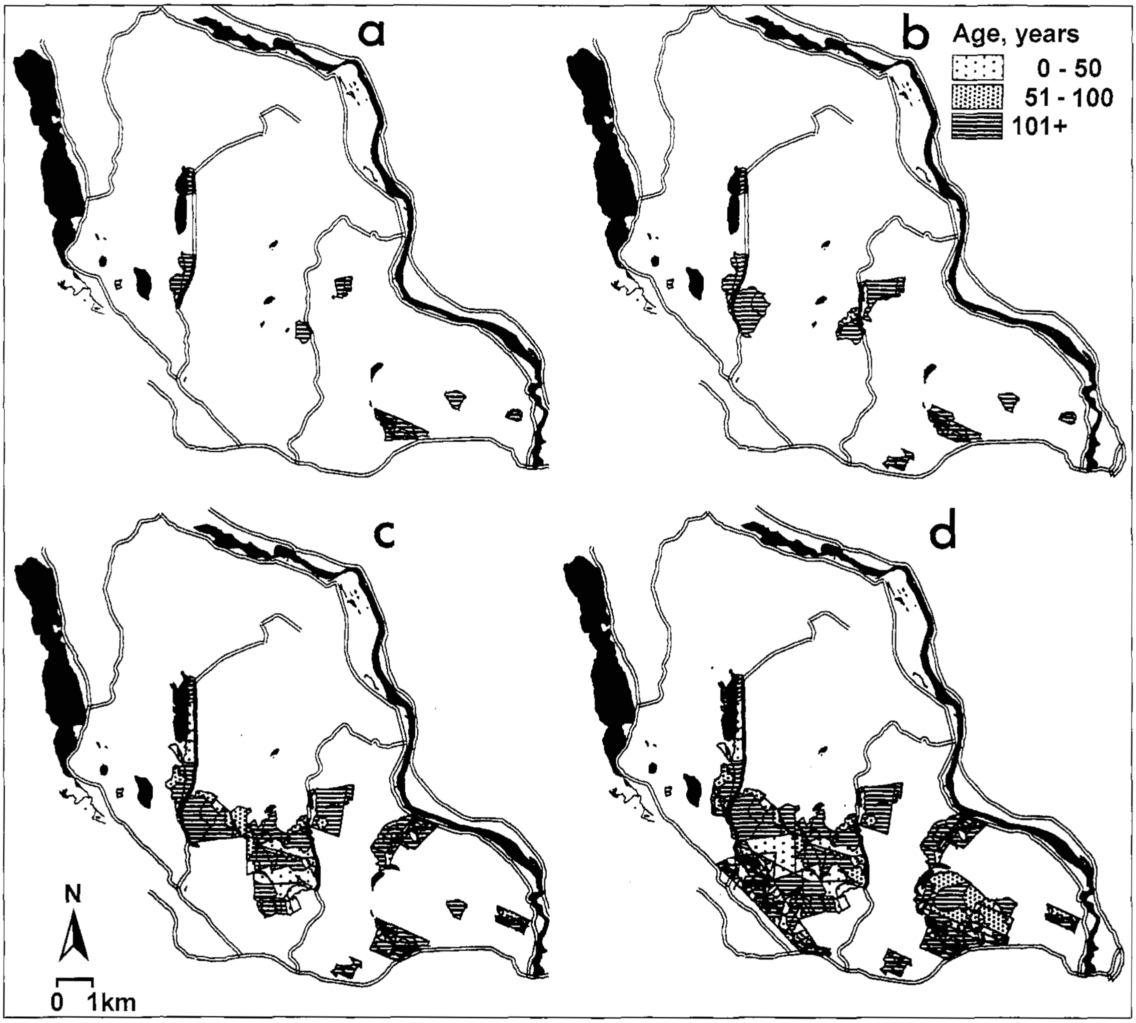

Fig. 5a–d. Protected areas in the PA approach, when 2.5 (a), 5 (b), 15 (c), and 25 (d) per cent of the productive forest land was reserved. ■ Lakes and rivers, main roads.

Table 3. *Percentage of reserved area by land class (productive forest land (PFL), mires or lakes), ageclass (on PFL), and conservation value class (CVC) in per cent, when 2.5%, 5%, 15% and 25%, respectively, of the landscape's PFL was reserved in the PA options*

Proportion protected PFL	Land class			Age class			Conservation value class			
	PFL	Mire	Lake	−50	51–100	101–	CVC1	CVC2	CVC3	No CVC
2.5	99	1	0	3	3	94	49	23	13	15
5	95	5	0	1	6	93	24	16	44	16
15	85	11	4	24	13	63	9	9	41	41
25	89	9	2	27	20	53	5	6	31	58

proportion of the stream system, the habitat of the vulnerable mussel *Margaritifera margaritifera* L. In the 15% case, three reserves in the eastern part of the studied landscape were connected to form a 650-ha reserve.

Landscape Planning (LP)

The LP approach used is a development of the 'key habitat–corridor model' which is based on principles of island biogeography and landscape ecology (Fries *et al.*, 1998). It is a spatially explicit model, based on existing areas with conservation values or other areas of conservation interest. In essence, these patches constitute sources for the dispersal of rare and threatened species and, whenever this is justified, can be linked together by corridors. A conservationally valuable area can be supported by zones, functioning as buffers or restoration zones.

In the LP approach, areas were protected as a static element (*i.e.* reserves) to provide, among other things, habitats for species dependent on the stable conditions present in undisturbed spruce forests. Furthermore, to secure the continuity of successional biotopes, a dynamic element (in the sense that forest types move through time within the landscape) was formed by means of prescribed burning and management of areas rich in deciduous trees.

As a component in the static element, a 357-ha reserve was formed, which included upland sites, mires, a lake, and parts of the stream which drains it (Fig. 6*a*). The reserve also included two of the six areas in the landscape with the highest conservation values, and the only mire in the landscape with documented high floristic values. On the third of the reserve's productive forest land that is moist or wet, spruce forests regenerated by gap dynamics are already present or assumed to be developing.

Another static part is based on five streams which are either relatively pristine, have suitable edaphic conditions or are situated so they can play a key part in a landscape plan aimed at nature conservation (Fig. 6*a*). Buffer zones were established, averaging 25 m on both sides of the streams. This resulted in the preservation of 64 ha of productive forest land and 24 ha of mire, and therefore added 88 ha to the permanently reserved area. Together with protected forest land, mires, lakes and relatively narrow restoration or buffer zones within the MTP approach, these streams will contribute to a stable network of undisturbed forest in the landscape. On 28% of the productive forest land in the stream buffer zones, stand age was ≤ 50 years, on 38% it was 51–100 years, and on 34%, >100 years. Consequently, it will take a long time before these buffer zones will contain forests with relatively high frequencies of natural features.

The last static part of the LP approach was the preservation of the four areas with conservation value class 1, which were not included in the 357-ha reserve and the 5.2 ha *Cladonia parasitica* habitat (Fig. 6*a*). These five areas include both fire-influenced sites and 'fire refugia' (Segerström, Bradshaw, Hörnberg & Bohlin, 1994). They were somewhat enlarged to reduce their perimeter : area ratio. The five areas added 140 ha of productive forest land to the permanently reserved area, which in the LP regime therefore encompasses 569 ha, of which 352 ha is productive forest land.

The dynamic part of the LP regime regulates the flow of successional biotopes dominated by deciduous trees or spruce. This was done by prescribed burning and by extending rotation length in some stands rich in deciduous trees.

During the first 50-year period, 20 selected stands, with a mean size of 12 ha, were burned (*i.e. ca.* 5% of the final harvested area; Fig. 6*b*). On the sites included in this fire plan, 25% of the standing volume was retained. To achieve variation in the results after burning, fire was used on sites with varied distribution of tree species (range 0–20% of deciduous trees), site index (range 17–23 m in dominant height at a total age of 100 years), soil moisture (32% dry, 55% mesic and 13% moist or wet productive forest land) and topography (nine stands on flat ground, nine in slopes, and two on ridges). An important consideration, which restricts the choice of sites to burn, is the desire to keep edges with a high fire hazard as short as possible. Roads, mires, lakes and stands ≤ 25 years old were considered safe (Schimmel & Granström, 1996), while stands >25 years old, bordering prescribed burning areas, were assumed to need protection. For all planned fires, a total of *ca.* 22% of the edge length (range 0–63%) will need extra measures, such as watering or removal of fuel, to prevent the spread of fire. This is the main reason why regeneration costs for prescribed burning were increased, compared with the cost of mechanical scarification and planting.

To bridge the age gap between existing late fire successions and those which will be initiated by prescribed burning, the development of deciduous trees and other natural structures typical of fire successions was enhanced in 20 stands with a relatively large proportion of deciduous trees (Fig. 6*b*). The older (total age range *ca.* 70–160 years) of the 20 stands have conservation