Per Angelstam
& Leif Andersson

Estimating the amount of forest reserves needed to preserve biodiversity

During the 1990's there was a strong international trend in forest management towards having to satisfy several objectives other than just wood production. The current Swedish forest policy, like that in many other countries, explicitly defines the objective for biodiversity maintenance as that "all naturally occurring species should maintain viable populations" (SOU 1992).

Traditionally this has been accomplished by protecting forests as nature reserves, national parks and other protected areas. New ideas of management and environmental considerations have changed the contents of the biodiversity conservation toolbox (e.g. Angelstam & Pettersson 1997, Fries *et al.* 1997). Contributions to the preservation of biodiversity will also be made in the managed forests. But still the traditional protection of forests will be an important cornerstone in the long term conservation of biodiversity. Ideally the resulting networks of conservation areas should secure viable populations of even the most demanding species in each type of forest habitat. If the amount of unprotected forest is insufficient, restoration and re-creation of forest habitats may be needed to satisfy the long-term goals of biodiversity conservation. The immediate task, within this background of rapidly disappearing old growth forests and those with high and threatened biodiversity, is to estimate the conservation area needed for different forest ecosystems and to estimate the gaps in the network of protected forest with high conservation value needed to maintain viable populations of forest species. Hence, the term gap-analyses (Scott *et al.* 1987, 1988, 1989, 1993, Iacobelli *et al.* 1995, Jennings 2000).

The area of forest, which has been set aside in regional reserves and national parks in Sweden is not representative of the different Swedish forest types (Nilsson & Götmark 1992). Although 43% of subalpine coniferous forests are protected, less than 2% of the boreal forests, and about 0.5% of the southernmost forests, have been set aside for biodiversity maintenance purposes (Naturvårdsverket 1997). After a debate in the Swedish parliament in 1996 an investigation was carried out to assess the need for additional forest reserves (SOU 1997). As a part of this investigation we were asked to perform an analysis of how much forest should be protected in state reserves to maintain viable populations of species found in different Swedish forest types (Angelstam & Andersson 1997, 2001). The purpose of this article is to present a tentative procedure for quantifying forest protection goals, and to identify the most important gaps in forest protection at the scale of biogeographic regions in Sweden.

MATERIALS AND METHODS

The explicit definition of the biodiversity objective in the Swedish forest policy - that viable populations of all naturally occurring species should be maintained - makes it possible to use the knowledge from conservation biology and landscape ecology to develop a logic by which the forest reserve needs can be estimated. According to Angelstam & Andersson (1997:23ff.) an ideal model should include the following components:

1. Definition of appropriate biogeographical regions for forest ecosystems.

2. Definition of different forest types depending on edaphic and historical factors and their distribution in the biogeographical regions.

3. Knowledge of how each forest type varies dynamically in tree composition, structure, age class and its associated biodiversity, thus forming different forest habitats.

4. a. An estimate of the potential/historic distribution of each forest habitat. Provided that the occurrence of different tree species on different site types is sufficiently well known, this can be estimated by using information about the site type distribution within the landscape (e.g. Arnborg 1945, 1990, Ellenberg 1996).

4. b. In addition the past losses of different forest habitats to non forest habitats should be known.

5. Knowledge of how much of each forest habitat remains in the landscape.

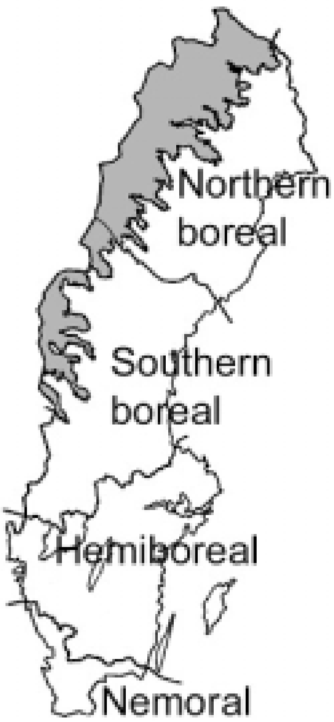
6. Definition of a baseline for the biodiversity.

7. Knowledge of thresholds for the amount of the different forest habitats that are needed to maintain viable populations. This should be based on detailed knowledge of the quantitative requirements of the most area-demanding specialists for each forest habitats (i.e. umbrella species; *sensu* Simberloff 1998, Caro & O'Doherty 1999).

8. Knowledge of how much of each habitat type is already protected.

9. There is a need to know to what extent different management regimes can emulate the conditions

FIG. 1



Map of Sweden showing the four biogeographic regions for which reserve needs were estimated. The grey area represents the subalpine forest region.

characteristic of different forest habitats. Conditions continuously produced by normal forest management, including the new forestry practise of considering conservation, should not be a target for protection efforts.

10. The area of different forest habitats needed for long term conservation of biodiversity (point 7) subtracted by the area already protected of each forest habitat (point 8) and the area of habitat produced in managed forests (point 9) gives the amount of forest that has to be protected long-term.

11. An estimate of the amount of each forest habitat that needs to be restored and/or re-created. This is necessary if a sufficient amount of forest is needed for protection of a particular forest habitat and it is not available in the region.

This technique is closely related to the concept of gap analysis (e.g. Scott *et al.* 1987, Jennings 2000), but also includes the aspect of securing viable populations of the most demanding species in each forest habitat. If necessary, restoration and re-creation of forest habitats may be needed to fill the gap between the long-term goal for biodiversity conservation and the present area of forest with conservation values.

Biogeographical forest regions

Latitude and altitude are two basic factors affecting biodiversity (*sensu* Harper & Hawksworth 1995). Extending latitudinally between the 55th and 69th parallels, Sweden has a growing period that varies more than two-fold from the north (‹ 100 days) to the south (› 200 days). Further, prevailing south-west winds and higher altitudes in the north-west than in the east produce distinct gradients in climate and potential natural disturbance regimes (e.g. Ångström 1974, Granström 1993, Angelstam 1998a). Through effects on soils, nutrient accessibility and climate, both altitude and latitude have profoundly influenced the suitability of the land for agricultural development, and therefore the extent of historical forest loss (Selander 1957, Anonymous 1965).

To stratify Sweden into different regions in a way that is compatible with the main types of potential natural vegetation (Sjörs 1956, 1971, Jahn 1991, Påhlsson 1998, Engelmark & Hytteborn 1999) and administrative regions, the following division was made from south to north (see Figure 1):

• Nemoral forest: broad-leaved deciduous forest with *Fagus sylvatica, Quercus robur, Tilia cordata, Acer platanoides, Ulmus* spp. and *Fraxinus excelsior*.

• Hemiboreal forest: transition zone with mixed deciduous and coniferous forest.

• Southern and northern boreal forest: in this study the wide belt of boreal forest with *Pinus sylvestris, Picea abies, Betula* spp., and *Populus tremula* was divided into a southern and a northern part.

• Subalpine forest: boreal forest with low growth rates and under special management regulations, as geographically defined in SKSFS (1997).

This study only considers the issue of biodiversity in productive forests, i.e. excluding the largely unproductive subalpine forests, of which 43 % were protected in 1997. As protected areas can be created and maintained for a number of other reasons such as recreation or cultural values, we do not express any opinion about whether 43% is too much or too little.

Forest types

The diversity of forest types in a landscape is determined by the variation in abiotic, biotic and disturbance factors. Our aims were to be able to rely as much as possible on the national forest survey data on site types to predict the amount of each type of forest vegetation, to use as few types of forest habitats as possible, to use forest types that are used in the Swedish plant ecological literature and that are familiar to managers. Additionally, we used the National Board of Forestry's database on private land holdings.

We reviewed forest disturbance regimes in Sweden and topographical and land use data and then defined 14 different forest types (Table 1).

Disturbance regimes

Different combinations of landscape trait layers create characteristic natural disturbance regimes (*sensu* Pyne 1984, Pickett & White 1985). Disturbance regimes vary along a continuum from large-scale disturbances, such as fire, wind, flooding and insect outbreaks to small-scale or localised disturbances such as gap formation caused by fungi and insects. Disturbance regimes may also differ in the intensity and frequency of the disturbance. In our analysis we used the following simplified set of disturbance regimes, all of which are found in Sweden:

A. Successional development after large-scale disturbance. Large-scale disturbances such as fire or wind initiate succession and allow forests to regen-

TABLE I.

DESCRIPTION OF 14 TYPES OF FOREST IN SWEDEN as defined for the analysis (see Angelstam 1998a,b, Dahl 1998, Påhlsson 1998, Selander 1957, Sjörs 1956, 1971); see Figure 1 for reference to the approximate geographic distribution of the different forest types.

Forest type	Description
Boreal succession (found in the whole boreal zone as well as in the hemiboreal zone)	The succession can be initiated by fire, water or wind as well as by abandonment of cleared land. Typical stages in the subsequent development are recent burns, a deciduous phase where spruce gradually takes over and old-growth (Arnborg 1945, 1990, Fries *et al.* 1997, Angelstam 1997, 1998a,b)
Boreal wet forest with gap dynamics (found in the whole boreal zone as well as in the hemiboreal zone)	Flooding or high ground-water tables are characteristic. The tree layer is dominated by shade-tolerant species (Norway spruce), but may also have a considerable amount of deciduous trees in gaps and at edges (e.g. Kuuluvainen 1994)
Boreal pine forest (found in all biogeographic zones)	Stands with several age cohorts of live and dead trees. Under naturally dynamic conditions frequent low-intensity fires on dry sites (e.g Sannikov and Goldammer 1996) maintain this type.
Nemoral succession (found in the hemiboreal and nemoral zones)	The nemoral succession starts after windfall as well as local and/or regional abandonment of cultivation and/or grazing and in competition with remnants of well established vegetation such as woodland pastures and grassland (e.g. Ellenberg 1996)
Nemoral wet forest with gap dynamics (found in the hemiboreal and nemoral zones)	Regeneration takes place in gaps created when large trees or groups of trees fall down. Occasionally wind or high groundwater tables may start succession over large areas (e.g. Jahn 1991).
Beech forest (found in the hemiboreal and nemoral zones)	Oaks can be pioneers in the succession after natural and man-made disturbances as well as regenerating in more or less closed stands (e.g. Jahn 1991).
Oak forest (found in the hemiboreal and nemoral zones)	Pure natural beech forests show gap-phase dynamics but may also have a successional development after large-scale disturbances such as wind breaks (e.g. Jahn 1991, Ellenberg 1996).
Ash/elm forest and other mixed deciduous forest (found in the hemiboreal and nemoral zones)	Mainly with gap-phase dynamics but may also have a successional development after large-scale disturbances such as wind and/or land abandonment (e.g. Jahn 1991, Ellenberg 1996).
Grey alder forest (found in all zones except the nemoral zone)	Primary succession on sites created by abandonment of agricultural land, post-glacial land upheaval along the coast, in deltas, and along meandering rivers.
Forest determined by topographic features (found in all biogeographic zones)	Occurrence of wells, waterfalls and steep cliffs often provide unique and stable microclimatic conditions.
Lime-rich coniferous forest (local)	Occurrence of lime-rich soils and/or bedrock provides unique and stable microclimatic conditions.
Sandy coniferous forest (local)	Occurrence of deep sandy soils (e.g. dunes) provides unique and stable microclimatic conditions.
Open woodland (found in most biogeographic zones)	The types range from wood-pastures and wood-meadows with birches, aspen, sallow and rowan. Key factors maintaining forest biodiversity are the presence of large old trees with holes, and considerable amounts of dead branches in the canopy. For details see Ellenberg 1996, Peterken 1996, Rackham 1976, Angelstam & Mikusinski 1999, Sarlöv-Herlin 1999.
Non-wooded forest land (found in all biogeographic zones)	Occurs after intensive grazing (e.g. heather moors).

erate over large areas simultaneously. Examples of different successional stages are recent burns, young stands of mixed coniferous and/or deciduous trees, and old and old-growth forest stands (e.g. Angelstam 1998a, b). Due to spatial and temporal heterogeneity of disturbances the structural complexity of age classes within a landscape increases with age (Johnson 1992). Viewed over longer time spans, successional stages are usually ephemeral at a particular site. To persist in the landscape, species must be able to disperse from areas with suitable but degrading habitat in order to colonise new sites where the habitat conditions are good or improving. In our analysis we assume that clear-cutting with retention can emulate the ecological conditions that are found in the younger successional stages, but that the older successional stages are largely incompatible with forest management. Naturally regenerated stands in successional stages after disturbance are normally rich in deciduous trees on these site types. Such habitats have decreased severely in managed forests.

B. Cohort dynamics. In the boreal zone, natural Scots pine forests are characterised by frequent low-intensity fires that produce stands with several age-classes of trees, and with a continuous supply of dead wood in different stages of decay (e.g. Sannikov & Goldammer 1996). Such a forest has a park-like appearance. Burned and/or grazed oak forests of the old cultural landscape with a more or less dense canopy show similar dynamics (e.g. Ellenberg 1996). When grazing animals are at low densities, the regeneration of trees is possible and a new cohort of trees is formed. This kind of dynamics can, to a large extent, be emulated in forest management with repeated retention of trees and dead wood, and the use of fire as a biodiversity management tool.

C. Gap-phase dynamics. In the absence of large-scale disturbances such as fire, wind, or insect outbreaks, young shade-tolerant trees regenerate in small openings, and gaps are formed as single large trees or small groups of trees fall down (Jahn 1991, Kuuluvainen 1994). In naturally dynamic landscapes, stands with these types of dynamics usually occur as corridors, networks or clusters in the moist and wet sites of the landscape. Such forests have a relatively moist and stable microclimate and a continuous supply of dead wood in different stages of decay. This type of forest dynamic is more difficult to emulate in management than succession and cohort dynamics. Therefore we argue that a higher proportion of gap-phase dynamics need forest reserve status.

D. Forest types determined by local abiotic factors. Occurrence of lime-rich soils, high ground water, ravines and steep cliffs often provide unique and stable microclimatic conditions.

E. Cultural disturbances. Human activity has caused a dramatic reduction and fragmentation of the once primeval forests (Mayer 1984, Mantel 1990, Hannah *et al.* 1995). However, to maintain summer and winter food for cows, sheep and other domestic animals, land has been managed using fire, mowing, clearing, pollarding and flooding (e.g. Kirby & Watkins 1998). During periods of unsuitable land use, political instability or war, land has either been severely disturbed or left idle. However, as farming and forestry was intensified, biodiversity in woodland pastures and wooded meadows has reduced through loss of structural diversity (e.g. Tucker & Evans 1997). A combination of the need to set aside such areas as reserves and to manage them in specific ways makes this type of dynamic particularly difficult to maintain.

Different forest habitats were defined for the 14 forest types divided up into different age classes and in some cases also variations in the deciduous tree content.

Forest types and their past occurrence

Using knowledge about the topography, soils, bedrock, hydrology and climate (e.g. Ellenberg 1996, Hägglund & Lundmark 1977) the site type distribution can be estimated. This in turn can be used to estimate the past distribution of different combinations of tree species and disturbance regimes (e.g. Arnborg 1945, 1990, Angelstam 1998a, b). To estimate the relative amount of different boreal successional stages we used the information presented by Johnson (1992) and Sannikov & Goldammer (1996), later confirmed for Sweden by Niklasson (1999).

Using site type data from National Forestry Survey and the National Board of Foresty's database on private holdings the potential occurence of different forest types in the remaining forest land was calculated.

Loss of forest land - how much remains

Assuming that thresholds for long-term persistence of metapopulations are generally applicable, it is important to assess to what extent habitat loss has already occurred. Should extensive past habitat loss be the case, the urgency of protecting remnants of forest habitats with high conservation value is reinforced (cf. Pressey *et al.* 1996). For this purpose we considered the past loss of forest land when estimating the historic loss of different forest habitats. Finally, we also attempted to take into account historical changes in the tree species composition (cf. Larsson 1983, Björse & Bradshaw 1998, Björse 2000). For example, we considered farmland planted with Norway spruce outside its southern natural boundary as a loss of the authentic forest area. Similarly we estimated, based on historical records of tree species composition, the decline of oak forest in the hemiboreal and nemoral regions.

To estimate the amount of forest land that has been transformed to non-forest land cover classes we used the 1996 data from the National Forest Survey. Forest was defined as forest land, subalpine coniferous forest, rocky outcrops and other impediments. Cleared forest included both grasslands (grazed pastures and electric powerlines) and commercial land (agricultural land, urban areas and human infrastructure). To illustrate the latitudinal and altitudinal trends in loss of forest land we stratified Sweden according to the biogeographic regions in **Figure 1,** and in altitudinal intervals separated by 100, 200 and 400 m a.s.l..

How much of each forest habitat remains

Using forestry data from National Forestry Survey and to some extent the National Board of Foresty's database on private holdings the potential occurence of different forest habitats in the remaining forest land was calculated. Not only site type data was used but also age, tree-composition and shrub-layer were used to sort Swedish forests into the 14 forest types and their different habitats (for details see Angelstam & Andersson 1997: appendix B:2)

What is the base line for forest biodiversity in Sweden?

Both the nemoral and hemiboreal vegetation zones can be characterised as cultural landscapes with a long history of agriculture including woodland pastures, wooded meadows and grazed forests (Selander 1957, Jokipii 1987, Berglund 1991, Angelstam 1997). This type of landscape largely came to an end during the 19th century and the first half of the 20th century, after a series of land reforms were initiated to encourage more intensive forms of land use. Except for some areas with intensive local forest use (e.g. Wieslander 1936), land use in the boreal forest was intensified only about 150 years ago when large-scale logging gradually extended into the interior of Northern Sweden (e.g. Angelstam 1997, Esseen *et al.* 1997). Given the fact that the climatically determined vegetation zones have been stable during the past millennium (Björse & Bradshaw 1998, Björse 2000), we use the situation in Sweden about 150-200 years ago as the base-line for discussing the historic loss and alteration of habitats hosting forest biodiversity.

Habitat loss thresholds

Functional connectivity is a concept that includes both the spatial configuration of habitats and the life-history traits of species' populations (e.g. Forman 1995). Sufficient spatial and temporal connectivity of stands of a particular forest habitat is a crucial prerequisite for the maintenance of viable populations of species that specialise in that forest habitat (e.g. Tilman & Kareiva 1997, Jansson &

Angelstam 1999). Both theoretical models and empirical data suggest that there are thresholds in a species' response to habitat loss at the landscape scale (e.g. Franklin & Forman 1987, Bascomte & Soulé 1996, Tilman & Kareiva 1997, With *et al.* 1997). Data on the effects of habitat loss on populations at the landscape level (Rolstad & Wegge 1987, 1989, Andrén 1994, Carlson & Stenberg 1994, Jansson & Angelstam 1999) falls in the range of 10-30% of the original habitat coverage. Well aware of the tentative nature of these numbers, we used 20% as the critical threshold value for our calculations.

How much is already protected?

Data about the amount of forests protected were obtained from the Swedish Environmental Protection Agency. Due to poor data on forests in Swedish protected areas the distribution among different forest types and habitats was particularly difficult achieve and had to be recalculated for some types.

Management regimes - forest habitats produced in managed forests

A common view is that management guidelines can be derived by sufficient emulation of the disturbance regimes found in authentic forest landscapes. In Fennoscandia, forest management methods that attempt to mimic the natural dynamics of boreal forests on different site types have been developed (Rülcker et al. 1994, Bradshaw *et al.* 1994, Fries et al. 1997, Angelstam 1997, 1998a, b, Niemelä 1999). Consequently, during the 1990's changes in practical forest management methods have improved the stand qualities on clear-cuts and in young forests in the matrix surrounding reserves. It is therefore important that the potential long-term benefits of these changes to forest biodiversity are considered also in the design and management of forest reserves.

Briefly the new management system for commercial forests is based on differentiation of the managment in four types of objectives (goal classes). All forest stands in the new forestry plans are designed to one of these objectives (goal classes).

The first one is production with general consideration to biodiversity. This management type is by far the most dominant, covering the forests where production is the main objective.

The second management type combines production and biodiversity goals where both interests have to be considered in a more equal level.

Finally there are two types of management where preservation of biodiversity is the ultimate goal. One of them applies a management regime where nothing is to be done, the stands are left for free development. The second type applies a management regime where some activities have to be performed, but only to promote biodiversity.

For forest habitats where normal management is sufficient to maintain biodiversity there is no need to create forest reserves (e.g. recent burns and young forests). For forest habitats where a higher degree of consideration is required (some successional stages of Scots pine forests with cohort dynamics), the management type with combined goals should suffice if adequately implemented; hence, there should not be any need for forest reserves. By contrast, for forest habitats requiring a total focus on preservation of biodiversity reserve status is crucial. For successional stages older than the maximum age of final harvesting (e.g. late deciduous successions and old-growth) and those with gap phase dynamics, the type without any management (free development) is often the most appropriate one. The most demanding management objective is when it is necessary to both set aside reserves and where costly management actions are required (e.g. cultural landscape forest habitats such as woodland pastures, as well as nemoral successions after abandonment of historic types of agricultural land management).

How much of each forest habitat needs to be protected

A number steps were then taken to estimate the amount needed of the different forest types that require forest reserve status (for details see Angelstam & Andersson 1997: appendix A and **Table 3**). First, we used the available information on the critical habitat loss threshold values for metapopulation persistence to estimate the proportion of each forest habitat that is required for the long-term survival of viable populations of species found in that specific forest habitat. This threshold value (selected as 20 %) was applied to the area of each forest habitat (step A). In step B the disturbance regime of each forest type was summarised and analysed to understand the extent to which different types of external and internal disturbances affect their characteristic dynamics. If standard forest management was judged to emulate the composition and structure of the forest habitat, like in young successional stages, the need for protection was not considered necessary. The resulting area is the long-term need of forest protection (i.e. A-B). The long-term goal was then broken down into five categories (C to G in **Table 3**). First the long-term goal was reduced by the area of forest already protected (step C). Then the long-term goal was reduced by an estimate of the positive effect on biodiversity of the new seemingly environmentally sound forest management regimes. To determine to what extent modified management may emulate the natural disturbance regime (e.g. Rülcker *et al.* 1994, Fries *et al.* 1997) we compiled expert knowledge from managers and forest ecologists. If emulation appeared possible the need for protection was reduced in proportion (step D).

How much has to be restored/re-created?

The difference between the area already contributing to biodiversity maintenance estimated in steps C and D (in **Table 3**), and the existing unprotected forests with high conservation values according the data in the National Forest Survey (step E), and cultural landscape habitats (step F) yielded an estimate of the need for habitat restoration (step G).

Because of insufficient official data on the different forest habitats, as well as an absence of full knowledge about the qualitative and quantitative requirements for long-term viability of different umbrella species representing different forest habitats, in reality, this ideal approach cannot be fully employed without considerable simplification. In spite of these limitations we made an attempt based on the best available knowledge. Here we stress the logic of making the calculations, rather than the tentative nature of the numerical results. For the full details of all the technicalities of the calculations and necessary simplifications we refer to Angelstam & Andersson (1997).

RESULTS

Loss of forest land

The relative loss of forest land to other forms of land use such as agricultural land, urban areas and human infrastructure in Sweden is clearly related to both altitude and latitude (**Table 2**). The extreme case is at low altitude in the nemoral region where the estimated loss of forest land is 62%. Generally, in southern Sweden below 200 m a.s.l. about 25 % of the original forest cover has been lost to other land cover types.

Forest reserve needs

The estimated long-term need for forest reserves for maintenance of the most demanding forest species ranged from 9% of the forest land in the north boreal to 16 % in the southern nemoral region (**Table 3**). Our estimate of the amount of remaining unprotected forests with characteristics that are not compatible with the current state-of-the art in forest management was 3% or 700 000 ha for the whole country of Sweden. As shown in Table 3 there is a clear north-south gradient from 3.5% in the north boreal forest zone to 1.9% in the nemoral zone. The proposed short-term forest reserve needs are presented in Table 3 and Figure 2. These represent only forest habitats, which were judged to be sustained using the new and more environmentally friendly forest management methods that are employed within the framework of the new Swedish model for biodiversity maintenance. We also estimated the area that does not have to be protected if the new more environmentally friendly forest management methods are fully employed with complete success. On average this amounted to 27% of the short-term goal. In Southern Sweden maintaining the cultural landscape with trees, appears as important as protecting forest habitats.

Need for restoration and re-creation of forest habitats

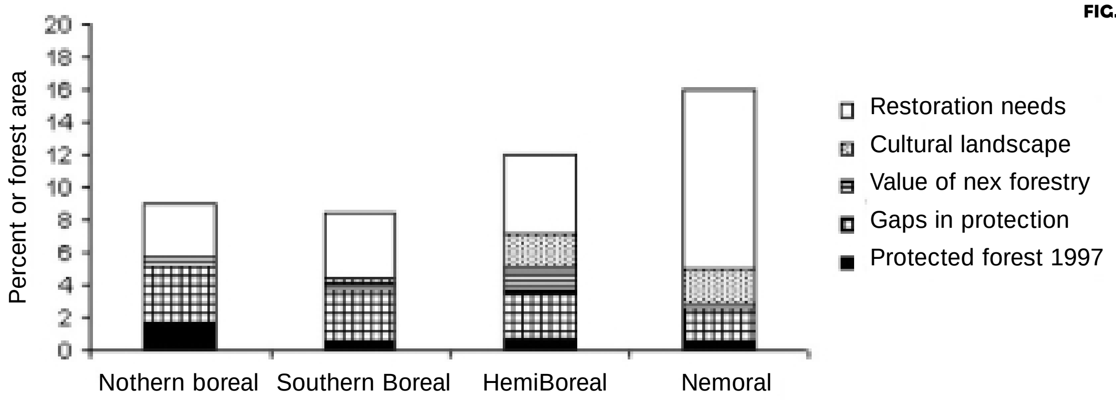
The considerable gap between the long-term goal for forest protection on the one hand, and the contribution of new forest management methods and the available forest habitats to protect on the other hand (**rows D and E in Table 3**) suggests two things. First, that it is urgent that the amount of protected forest is increased to encompass the existing forests with a high conservation value, and second, that protection of forest alone is insufficient to reach the biodiversity maintenance goals. The long history of land use change over the past 150-200 years thus calls for substantial forest ecosystem restoration. Due to regional differences in the extent of past land use changes this need for restoration increased from the north boreal forest (3%) to the nemoral forest (11%).

TABLE 2.
PROPORTION OF THE LAND AREA (AS PERCENTAGE) WITHIN DIFFERENT BIOGEOGRAPHIC REGIONS (FIG. 1) AND AT DIFFERENT ALTITUDES, WHICH HAS BEEN TRANSFORMED TO GRASSLAND, AGRICULTURAL LAND AND URBAN AREAS (unpublished data from the National Forest Survey 1990-1994).

Region	‹100 m	100-200 m	200-400 m	›400 m	Total
Subalpine	-	-	1.0	0	0.5
Nothern boreal	14.6	4.0	2.4	1.8	4.4
Southern boreal	30.2	14.7	4.2	2.0	8.1
Hemiboreal	38.8	19.0	15.7	-	29.2
Nemoral	61.5	21.1	-	-	49.2

Graph describing the different components of the long-term need for forest protection in Sweden (cf. Table 3). The deviations from the 20% threshold level is explained by differences in the mixture of disturbance regimes and the difference in the extent to which regular forestry can emulate them.

FIG. 2



DISCUSSION

The need for improved knowledge

To our knowledge, this study is the first attempt to include in estimates of the need for protected forests both (1) the quantitative habitat requirements at the landscape scale of area-demanding forest specialist species, (2) potential natural and cultural disturbance regimes, and (3) at the same time consider the benefits to biodiversity of managing the matrix around reserves in a more environmentally friendly fashion. The results clearly indicate two trends for the Swedish forest environment that are insensitive to the absolute values of the numerical results presented in **Table 3.** First, in regions with a relatively short land-use history in northern Sweden, there is more left to protect than in areas with a longer land-use history in southern Sweden. Second, in regions where the composition of forest types is dominated by those that are difficult to emulate with today's forest management (e.g. gap-phase dynamics), more forest needs to be protected than in forests that have a dynamic that consists of different successional stages with more or less even-aged stands. Consequently, there is a considerable need for habitat restoration in southern Sweden. This is both because of a long history of habitat loss due to land clearing for agriculture and other non-forest land use, and also because the forests have authentic dynamics that are more difficult to emulate. This is also consistent with the more severe situation for the level of threat to species found in southern Sweden (Gärdenfors 2000).

There are, however, several critical assumptions in our study that must be evaluated and refined. First, knowledge of the authentic dynamics of different forest types is highly variable. In general, the longer the land-use history, the more difficult it becomes to find appropriate reference areas (e.g. Ellenberg 1996, Peterken 1996). Hannah *et al.* (1995) estimated the remaining proportion of unexploited forests from the Atlantic ocean to the Ural mountains to be about 20% for the boreal, 2% for the hemiboreal and 0.2% for the nemoral forest regions. The difficulty in maintaining forest diversity and the urgency to find these remnants thus clearly increases towards the southern forest types. However, in some areas with a long land-use history, forest biodiversity has to some extent been rescued by the presence of woodland pastures and wooded meadows of the old cultural landscape (Thomasius 1978, Mantel 1990, Tucker & Evans 1997, Peterken 1996, Angelstam 1999,). Finding good reference areas for the south Swedish forest types and cultural landscapes is crucial in order to develop better knowledge of how to manage and restore these forest habitats.

TABLE 3.
RESULTS FROM THE ANALYSIS OF GAPS IN THE PROTECTION OF FOREST BIODIVERSITY CONSERVATION AREAS IN SWEDEN
(from Angelstam and Andersson 1997)

From the chosen theoretical habitat threshold value of 20% (row **A**) the summed amount of the different forest habitats which can be maintained within normal forestry is subtracted (row **B**). This (**A-B**) yields the long-term goal for forest protection, which is composed of the existing area of protected forest (**C**), the positive effect of a complete compliance to the current biodiversity management practices such as stand considerations and ecological landscape planning **(D)**, existing unprotected forest habitats, the dynamics of which are compatible neither with regular forest management nor management with nature considerations (**E**) and existing cultural landscape habitats (**F**). The last row (**G**) represents the need for restoration of forest habitats in order to achieve the long-term goal. As noted in the table below, the apparent accuracy of the figures varies considerably.

Area of region (sq km)	Nothern-boreal 61,000	Southern boreal 85,900	Hemiboreal 62,900	Nemoral 9,100
A Estimated habitat threshold value (%)	≈ 20	≈ 20	≈ 20	≈ 20
B Forest environments without need for reserves (%)	≈ 11	≈ 12	≈ 8	≈ 4
A-B Long-term goal (%)	≈ 9	≈ 8	≈ 12	≈ 16
Breakdown of long-term goal:				
C Protected area in 1997 (%)	1.6	0.4	0.7	0.6
D Reduction of the need to protect forests due the ideal application of nature considerations in forestry (%)	≈ 0.7	≈ 0.5	≈ 2	≈ 0
E Short-term goal for reserve creation (%)	3.5	3.3	2.9	1.9
F Cultural landscape habitats (%)	0	0.3	1.9	2.2
G Need for restoration (%)	≈ 3	≈ 4	≈ 5	≈ 11

Second, to assess the status of biodiversity, the results of the monitoring process must be compared with some kind of benchmark. Only in this way will we know when the long-term maintenance of viable populations and system functioning has been achieved. For most forest habitats detailed knowledge of the amount sufficient to maintain long-term viable populations of the different species groups is poorly known. In particular this applies to naturally fragmented forest types like wet spruce forests as well as cultural landscapes with scattered large trees and dead wood. As soon as better knowledge about the existence and value of habitat loss thresholds for different species in different forest habitats becomes available, it is urgent that our analysis is revised.

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P. Angelstam
Swedish University of Agricultural Sciences (SLU)
Department of Conservation Biology
Grimsö Wildlife Research Station
SE-730 91 Riddarhyttan, Sweden
E-mail: angelstam@nvb.slu.se

Leif Andersson
Pro Natura Halnagården
SE-545 93 Töreboda, Sweden
E-mail: leif.andersson@pro-natura.net