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Maintaining biological diversity in Finnish forests



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Suomen metsien biodiversiteetin säilyttäminen

Tässä julkaisussa tarkastellaan metsiemme biodiversiteettiä ja siihen vaikuttavia prosesseja. Työssä tutkitaan sekä luonnon dynamiikan että ihmistoiminnan vaikutuksia metsiemme monimuotoisuuteen sekä tuodaan esille toimenpiteet, joiden avulla monimuotoisuus voidaan tulevaisuudessa säilyttää. Tämän työn keskeisiä osia on tuotu esille Biodiversiteettisopimuksen (Convention of Biological Diversity) 3. osapuolikokouksessa Buenos Airesissa marraskuussa 1996 esitetyssä Suomen kannanotossa 'Maintaining, Conserving and Enhancing Biological Diversity of Forests in Finland' (UNEP/CBD/COP/Third Meeting/Inf. 35, Buenos Aires 1996).

Tämä julkaisu pyrkii edellistä asiakirjaa huomattavasti laajemmin tuomaan esille metsien biodiversiteettiin liittyviä ekologisia lainalaisuuksia. Työssä tarkastellaan mm. metsiemme ja lajistomme erityispiirteitä, ekologisia malleja ja niiden tarjomia mahdollisuuksia arvioitaessa lajistomme säilymistä sekä ekologisesti relevantteja toimenpiteitä ylläpitää biologinen monimuotoisuus.

Boreaaliseen metsäluontoon on aiemmin vaikuttanut ns. luontainen häiriödynamiikka, kuten metsäpalot, tuulenkaadot sekä hyönteisten ja muiden eliölajien (esim. majavan) aiheuttamat bioottiset häiriöt. Boreaalisten metsien lajit ovat sopeutuneet metsäluonnon häiriöiden olemassaoloon ja metsäluonnon dynamiikkaan. Nykyisin kuitenkin lähes kaikki metsät suojelualueiden ulkopuolella pyritään hoitamaan puuntuotannon tavoitteiden mukaisesti. Intensiivinen metsätalous muuttaa metsien rakennetta ja metsätyyppien alueellista koostumusta tavalla, mihin osa lajeista ei ole sopeutunut. Erityisesti vanhoja metsiä suosivat lajit, lehtojen lajit, ravinteisten korpien ja lettojen lajit ja lahoavaa puuainesta vaativat lajit ovat vähentyneet metsätalouden toiminnan seurauksena.

Koska luonnonmetsämaisemaa ja luonnonmetsien rakennetta ei voi säilyttää intensiivisesti puuntuotantoa varten hoidetuissa metsissä, suojelualueiden perustaminen on välttämätöntä. Nykyistä suojelualueverkkoa olisi laajennettava ja tavoitteena tulisi olla, että vähintään 10 % metsämaasta olisi suojeltu kussakin metsäkasvillisuusvyöhykkeessä. Etelä-Suomessa metsien suojeluun liittyy aiemmin talouskäytössä olleiden alueiden ennallistaminen ja suojelutavoitteen toteutuminen on jouduttava mitoittamaan pitkälle aikavälille. Arvio suojeltavan metsän osuudesta perustuu viimeaikaiseen tietoon yhtenäisten metsäalueiden pirstoutumisen kriittisistä kynnysarvoista, suojelualueverkon kattavuudesta käsittää tiettyjen eliöryhmien koko lajisto (linnut, putkilokasvit), vanhojen luonnonmetsien osuudesta metsämaisemassa sekä ekologisten mallien ennusteisiin (eliömaantieteellinen saariteoria, lähde-nielu -malli, metapopulaatiodynamiikka).

Metsänhoidon tulisi ottaa huomioon biodiversiteetin ylläpito talousmetsissä, kuten ns. avainbiotooppien ja muiden arvokkaiden luontokohteiden säilyttäminen hakkuiden yhteydessä. Metsätalouden pitäisi pyrkiä jäljittelemään metsien luontaista dynamiikkaa niin hyvin kuin se on mahdollista. Metsä- ja luonnonsuojelulain uudistus sekä Metsähallituksen toteuttama alue-ekologinen suunnittelu luovat aiempaa paremman mahdollisuuden monimuotoisuuden ylläpitämiseksi talousmetsissä. Näiden toimenpiteiden konkreettinen vaikutus ja riittävyys voidaan arvioida tarkemmin vasta tutkimustiedon karttuessa. Metsätalouden vaikutus lajistoon sekä suojelualueverkon riittävyys monimuotoisuuden säilyttämisessä ovat keskeisiä tulevaisuuden tutkimustarpeita.

Abstract

This paper deals with patterns of biological diversity in Finnish forests and processes, both natural and human-caused, affecting this diversity. Ecologically relevant issues in relation to maintenance of biological diversity, such as problems in measuring biodiversity, implications of ecological models, habitat fragmentation and systematic reserve selection are introduced. The work presents also an overview of means of maintaining biological diversity in Finnish forests.

Forests in boreal zone were originally modified by natural disturbances, such as forest fires and storm fells. The native species of boreal forests have largely adapted to natural disturbances and successive natural dynamics. At present, almost all forest land outside protected areas is subject to systematic silvicultural practices. Intensive forest management changes the structure of forests and regional distribution and proportion of forest types in a way to which all species are not adapted. Particularly, species of old-growth coniferous forests, species of various herb-rich forests, mature deciduous forests, nutrient-rich peatlands, and species requiring decaying wood have decreased.

Because it is impossible to maintain all the characteristics of natural forest landscape and forest structure in intensively managed forests, the foundation of nature reserves is of utmost importance. The present reserve network should be enlarged, and the minimum level should be at least 10% of forest land protected in each biogeographic forest zone and section. The level of the forest land to be protected is based on the critical thresholds of habitat fragmentation, on the systematic selection of areas to consist of all species in particular groups (land birds, vascular plants), on the minimum proportion of old-growth forests in the forest landscape and on the predictions of ecological models. Forest management practices should take into account the demands of sustaining biodiversity, such as preserving small scale 'key biotopes'. In general, forestry should simulate natural dynamics of forests as much as possible.

Introduction

Biological diversity or biodiversity refers to the variety in the living world. Biodiversity is defined hierarchically in terms of genes, species, communities and ecosystems. However, biodiversity is not a strictly defined concept but a term for defining several aspects of variation and heterogeneity in living nature (Haila and Kouki 1994). This means that several alternative criteria can be used to operationalize this term. In addition to biological hierarchy levels, scale is important in considering biodiversity. We may consider point diversity, e. g., at an individual tree level, diversity of a forest patch or stand and diversity of several forest patches in a landscape.

At present the loss of biodiversity is continuously observed all over the Earth. The fundamental and irreversible losses include the extinction of species. The present extinction rates of species are roughly 1000 – 10 000 -fold compared to natural background extinction rates (Wilson 1992, Heywood and Watson 1995, p. 235). Species disappear particularly in tropical areas as a consequence of deforestation. It has been estimated that the area of tropical forests decreases about 1% every year (Groombridge 1992). The published range of tropical forest loss suggests that roughly 1 – 10% of all the world's species will become extinct over the next quarter century (Heywood and Watson 1995).

Finland is situated in the boreal coniferous zone between the temperate deciduous (nemoral) and the arctic zone. Finland is part of Fennoscandian (Baltic) shield (Simonen 1980) which consists mostly of an ancient bedrock area. The land area in Finland is largely covered by moraines and glacifluvial eskers and other landscape formations created by the eroding and retreating glacier.

Finland presented a contribution on forests and biodiversity to the 3rd Conference of the Parties (COP) to the Convention of Biological Diversity (CBD) in Buenos Aires in November 1996. This paper 'Maintaining, Conserving and Enhancing Biological Diversity of Forests in Finland' was prepared mostly in the Finnish Environment Institute and it presented the main characteristics of forest landscape and biodiversity and highlighted the steering mechanisms for maintaining biodiversity in Finnish forests (UNEP 1996a).

The present paper deals with the same topics in more detail and it is more ecologically oriented. Its focus is in patterns and processes of biological diversity in forests with special reference to human-caused changes affecting biodiversity. It presents an overview of the natural history of forests in Finland, and natural dynamics and structure of boreal forests in Fennoscandia. Ecologically relevant issues in relation to maintenance of biological diversity, such as problems in measuring biodiversity, implications of ecological models, habitat fragmentation and systematic reserve selection are introduced. The means of maintaining biological diversity in Finnish forests are discussed.

2 Biogeographic zonality and general patterns of forests in Finland

Based mostly on forest vegetation the boreal zone is divided into southboreal, midboreal and northboreal (sub)zones. The phytogeographic zonation of northwestern Europe has been described in detail by Ahti et al. (1968), and the circumpolar pattern of this zonation has been represented by Hämet-Ahti (1981). Besides latitudinal gradient (from south to north) of (sub)zones there is also a clear oceanity-continentality gradient in west-east direction (see Ministry of the Environment 1994). In this gradient Finnish forests represent suboceanic to slightly continental forests.

The southwestern coast of Finland belongs to the hemiboreal (called also boreonemoral) zone between the boreal and nemoral deciduous zones (Fig. 1). This zone is narrow, but floristically rich (Kalliola 1973) consisting a larger proportion of herb-rich forests than other areas in the country. The very northernmost Finland is part of hemiarctic (subarctic) zone, being dominated by alpine heaths, shrublands and rocky areas.

Finnish forests are largely dominated by conifers, Scots pine *Pinus sylvestris* on dry and submesic sites, and Norway spruce *Picea abies* on mesic sites (subsp. *abies* in the south, and subsp. *obovata* in the north). Conifers grow often mixed with some broad-leaved deciduous trees, the most common being birches, *Betula pendula* on mineral and *B. pubescens* on peaty soils. Alders *Alnus incana* and *A. glutinosa*, aspen *Populus tremula* and rowan *Sorbus aucuparia* are less common. Deciduous trees occur more frequently in younger forests. In northernmost Finland the mountain birch *Betula pubescens* subsp. *czerepanovii* (*'B. tortuosa'*) is the dominating tree species.

Southern broad-leaved deciduous tree species are rare and grow only in edaphically or climatologically favourable sites. These species, oak *Quercus robur*, linden *Tilia cordata*, elms *Ulmus glabra, U. laevis*, ash *Fraxinus excelsior*, maple *Acer platanoides* and hazel *Corylus avellana* occur mostly in hemiboreal areas, and only occassionally in more northern regions. Black alder *Alnus glutinosa*, occurring on moist nutrient-rich habitats, reaches the midboreal subzone. About 75% (234 000 km^2) of the land area in Finland (total land area 305 000 km^2) is covered by forests and other wooded land. About 65% of forests is dominated by pine, 25% by spruce, 8% by deciduous trees, mainly birches, and the rest being treeless areas (Sevola 1997). Originally over 30% of the land area was covered by mires, both open fens and various wooded mires. Owing to drainage the proportion of natural peatlands has considerably been reduced and covers nowadays only 14% of the total land area (see chapter 8).

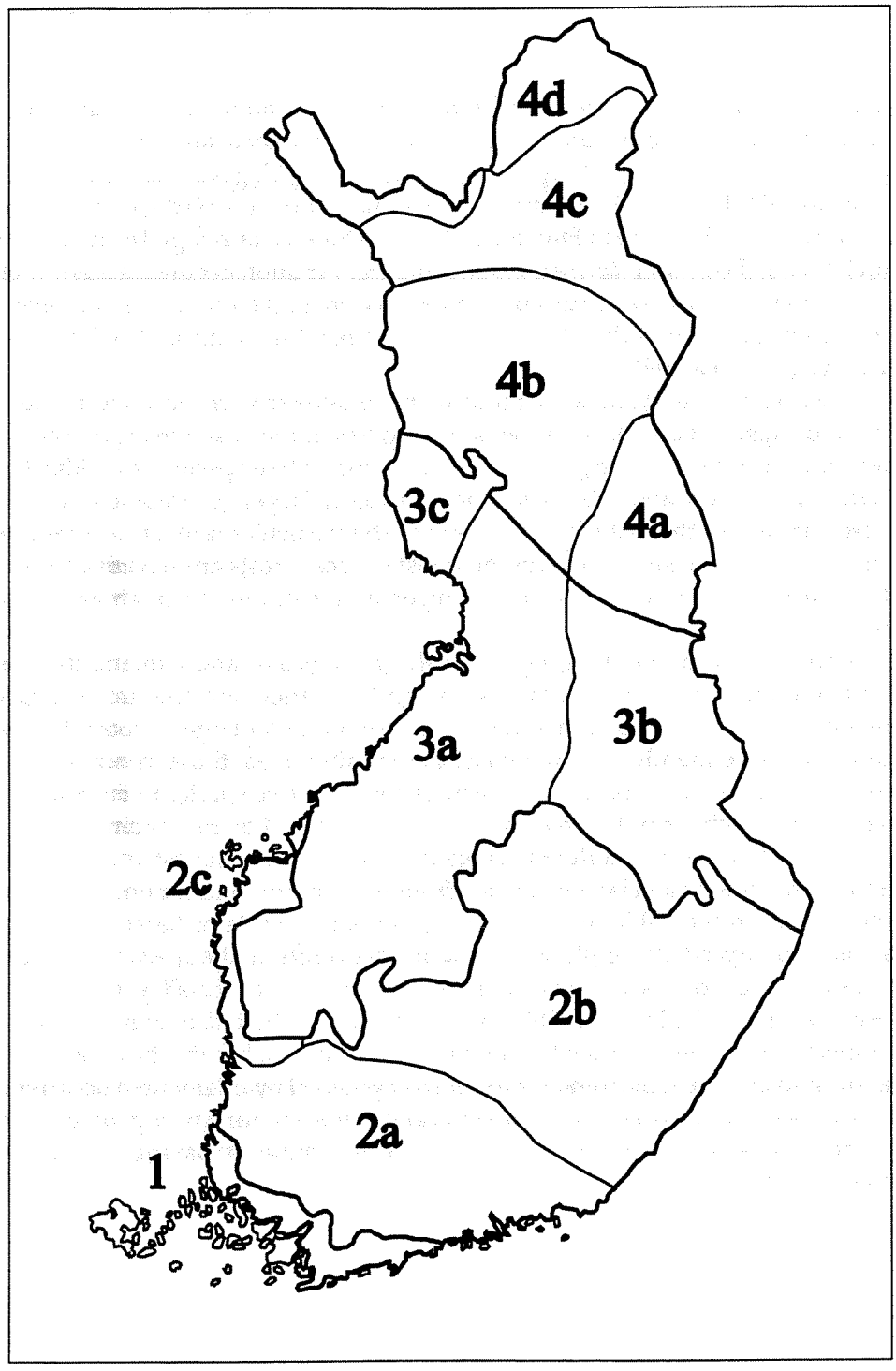

Fig. 1. Forest vegetation (sub)zones in Finland based on Kalela (1961) and Ministry of the Environment (1994). 1 = hemiboreal, 2 = southboreal, 3 = midboreal, 4 = northboreal; a-d refer to the different sections of the (sub)zones.

3 Species' distribution in boreal areas

Species have large ranges in the boreal zone compared to more southern areas, e.g., in the tropics. Also species numbers, both local and regional, are considerably lower in the boreal zone. Spatial variation in species assemblages in boreal areas is, in general, low (Virkkala 1995). For instance, over half of the the bird species in coniferous forests are the same in Finland and central Siberia, although the distance is about 3000 km (Haila and Järvinen 1990). Temporal variation in boreal areas is high, such as species' year-to-year variation in density on a given site. This is probably owing to environmental climatic factors such as harshness, unpredictability and variability (Virkkala 1991a).

However, flora and fauna are much more variable than the low species number would suggest. Populations in separate regions in the vast boreal zone can be genetically fairly different (e.g. proveniences of many tree species), hybridization is relatively common, and vicariance is not unusual in larger geographic scale. Species are adapted to the disturbance regime of the particular forest type that they occupy. For instance, species inhabiting moist spruce forests are sensitive to large scale disturbances because these forests regenerate naturally through gap dynamics.

Fennoscandia differs biogeographically, geologically and climatically from the surrounding areas. The bedrock is different and there are specific geological formations caused by glaciation: eskers, end moraines and large oligotrophic watercourses. Consequently, vegetation and forests differ from those in surrounding areas. For instance, the Scots pine is the most common tree species in Finland, and the mountain birch forms the tree limit in the Fennoscandian mountains.

Ice Age history and different biogeographic factors suggest that selection pressures in Nordic biota largely deviate from those in more continental northern Russian areas. In the Baltic shores and the Scandian mountains habitats are most unstable and unpredictable allowing rapid racial evolution: the speciation process has already reached a variety level in many taxa in less than 10 000 years after the Ice Age (Borgen 1987, Jonsell 1988). These facts suggest that also many forest and mire species can show quite a lot of intraspecific variation, but this has been insufficiently studied. The same trend is further strengthened by fragmented occurrence of many species of nutrient-rich peatlands and herb-rich forests. E.g. natural oak populations in southwestern Finland are genetically different having a number of rare alleles (Mattila et al. 1994).

Characteristics of climate, landscape and natural history in Finland

4

In boreal areas there is a clear climatic seasonality with snow cover in winter. Weather extremes are typical: very cold winters or springs occur irregularly (e.g., once or twice a decade). Weather extremes have considerable effects on the numbers of boreal animals and plants.

Most of Finland's landscape (over 90 %) is less than 300 m above sea level. Although the overall elevation range is small, the local relief (terrain) is rough, height differences between nearby sites can be large, several tens of metres or even over 100 m. In general the Finnish landscape is heterogeneous at the small scale both topographically and edaphically. Geologically the landscape consists largely of a peneplain, a relatively flat land surface produced by a long period of erosion. The bedrock consists mostly of Pre-Cambrian gneissose granites and granites. In scattered areas with basic bedrock (mostly schists) the vegetation is often lush including forest types with grass-herb vegetation, and eutrophic fens. The age of the bedrock area is about two milliard years (1.5 – 2.8 milliard years, Simonen 1980).

Finland and Fennoscandia were covered by Ice masses during the Pleistocene period (2 million – 10 000 years before present, BP). The latest glaciation ended about 10 000 years BP (Donner 1965, Taipale and Saarnisto 1991). Probably as a consequence of glaciation there are only a relatively few tree species, especially conifers, in Fennoscandia.

Tree species composition has varied in Fennoscandia after glaciation ended. Pine and birch colonised Finland quite soon in early postglacial era, but spruce reached Finland probably between 5000 – 4000 years BP (see, however, Kullman 1996). During the so-called Atlantic warm period, 7500 – 4500 BP, southern broad-leaved deciduous trees, such as oak, linden, hazel and elms were more common than at present (Kalliola 1973, Taipale and Saarnisto 1991).

After the glaciation ended, land has risen from the sea at the rate of 0.5 – 1.0 m/century (measured at a vertical axis). The land rising is a consequence of the glacier, the mass of which (thickness about 3 km) pressed the ground (Taipale and Saarnisto 1991). Primary succession occurs on a land risen from the sea. Landscape arisen from the sea in western and southwestern Finland is rather flat, and it was originally widely paludified. In western Finland, in Ostrobothnia even 60% of the land was originally covered by mires.

5 Finnish forest type classification

Finnish forests are classified on the basis of field and ground layer vegetation (see, e.g., Cajander 1926, Kalela 1961, Kujala 1979, Lahti 1995 and literature therein). The poorest soils are dominated by lichen-rich pine forests (*Cladina* forest site type), mixed with some mosses and dwarf shrubs (*Calluna vulgaris, Empetrum nigrum* coll.). In dry (*Calluna* forest site types) and submesic (*Vaccinium* forest site type) heath forests dwarf shrubs, *Calluna vulgaris* and *Vaccinium vitis-idaea*, respectively, and mosses (*Dicranum* spp., *Pleurozium schreberi*) dominate. In mature mesic forests (*Myrtillus* forest site type), dominated usually by spruce, bilberry (*Vaccinium myrtillus*) and mosses (*Hylocomium splendens, Dicranum* spp. and *Pleurozium schreberi*) are prevailing, but also some low herbs and grasses occur. Herbs and grasses are more abundant in low-herb heath forests (*Oxalis-Myrtillus* forest site type). The species composition of this southboreal series of forest site types changes in south-north gradient and proportion of, e.g., *Empetrum nigrum* coll., *Vaccinium uliginosum* and *Ledum palustre* in the forest understorey increase to the north. According to these changes parallel types of the southboreal forest types have been differentiated for various boreal subzones (see Fig. 1).

In addition to this large-scale variation in heath forests there are also some more specific forest habitats. Proportions of herbs, ferns and grasses increase along the moisture and edaphic gradient, and many types of dry (e.g. *Melica-Lathyrus* type), mesic (*Maianthemum-Oxalis* and *Hepatica-Oxalis* types), and moist (*Athyrium-Oxalis* and *Matteuccia* types) herb-rich forests have been described (see Ministry of the Environment 1994). Herb-rich forests are clearly restricted to certain edaphically favourable regions. In spite of their small area at present (<1% of all forest land) herb-rich forests contribute a large proportion of species diversity in Finnish forests (see threatened species in chapter 12).

Sunny exposed slopes of great eskers and other glacifluvial formations, like Salpausselkä end moraines in southern Finland, consist of specific esker variants of forests, differing clearly from ordinary lowland forests (Jalas 1950, Heikkinen 1991). These forests are not as dense as ordinary heath forests, and are often mixed with some broad-leaved deciduous trees and include more bushes, herbs and grasses, e.g. several legumes. Some of these esker forests consist of site-specific floristic elements, e.g. *Pulsatilla patens, P. vernalis, Astragalus alpinus, Oxytropis campestris, Anthyllis vulneraria* subsp. *fennica*. The Baltic land upheavel coast has primary forests with their own floristic features, but these have been insufficiently studied.

Paludification is a very common phenomenon in the Finnish landscape, and various peatland forests, like pine bogs and wooded spruce and birch mires are common. Many Finnish mire site types, such as herb- and grass-rich spruce and birch mires, *Alnus glutinosa* -swamps, eutrophic pine bogs and wooded fens (see, e.g., Ruuhijärvi 1983, Eurola et al. 1984) are rare habitats in Europe. Spatially varying coexistence of heath forests, wooded and open mires, and various water bodies with many ecotones cause a great richness in the habitat diversity.

The Cajaderian site type approach has been dominating in the Finnish forest classification. Site types have been characterized by species assemblages in mature tree stands, and circumscription of various floristic successions of forests have been studied insufficiently. For example, only a few studies have been done on the relations between tree species and understorey vegetation or on species richness along the succession (see Tonteri 1994, Oksanen and Tonteri 1995).

6 Natural dynamics of forests

A virgin forest landscape in boreal zone is modified by natural disturbances, such as forest fires, storm fells, insect outbreaks causing defoliation of needles or leaves and other biotic disturbances (Bonan and Shugart 1989, Angelstam 1996, Esseen et al. 1997). Flooding of lakes and rivers affects forests along shores. Paludification is an important landscape factor, particularly on a flat terrain. Disturbances have caused natural structural variation in boreal forest landscape. Disturbances occur both at a small scale (within a forest patch) and at a large scale (forest landscape). Small-scale variation is, for instance, gap dynamics within a forest patch as a consequence of windthrow of individual tree(s) (e.g. Kuuluvainen 1994). Large-scale disturbances consist of large fires or storms felling trees over large areas. Effects of forest fires vary considerably depending on physical factors, such as summer rainfall, summer temperature, prevailing winds, and landscape topography.

Susceptability of tree species to forest fires differs. Norway spruce does not tolerate high temperatures created by fires as well as Scots pine due to its thin bark (Zackrisson 1977, Schimmel 1993). Therefore, most of the spruces burn easily and die out during fire. Consequently, spruce forests occur in moist or mesic sites which burn less frequently than dry sites, where pine forests are dominating. In general, only a part of the trees is burned and dies out in forest fires, particularly in pine-dominated forests (Zackrisson 1977). Pines may reach the age of 600 – 700 years in Fennoscandia but spruces the age of 300 – 400 years. For instance, in virgin coniferous forests in northern Sweden (Muddus national park) the oldest living pines were over 700 years (born in the 1270s), although the forest had burned four times (Engelmark 1987).

Normal fire frequency on a given site is usually 40 – 200 years (e.g. Zackrisson 1977, Haapanen and Siitonen 1978, Lehtonen et al. 1996). In Sweden it has been estimated that about 1% of the forest land burned yearly before systematic fire suppression started in the late 19th century (Zackrisson 1977). Fire refugias are forests that have never burned or burn very rarely, when the fire frequency may be several hundreds of years. These forests are mainly spruce-dominated wet and moist forests (Ohlson et al. 1997).

The amount and proportion of dead and dying trees increase in forest succession. However, after a major disturbance, fire, flood or storm-fell, the amount of dead wood can be very high. Individual trees die out in natural forests also owing to competition between different tree individuals. The volume of dead trees in natural old-growth forests can be about one fourth or one third of the total tree volume. In old-growth coniferous forests the amount of dead wood is approximately 50 – 100 m^3/ha or even more, 100 – 200 m^3/ha (e.g., Andersson and Hytteborn 1991, Parviainen and Seppänen 1994, Kuuluvainen et al. 1998, Siitonen 1998). Over half of the volume of dead wood consists of fallen trees on the ground.

As a consequence of natural disturbances the forest landscape is spatially heterogeneous both at the small and large scale. This heterogeneity, however, differs considerably from human-caused changes, such as forestry (see chapter 8). Disturbances, forest fires and wind-falls, often affect only part of the living trees in forests, and therefore, in spite of frequent disturbances large continuous forest areas

are typical in a landscape of natural forests. Severe storms and high-intensity fires cause a forest succession to begin with a high amount of dead wood from the pre-disturbance tree generations (see Siitonen 1998).

Age structure within a natural forest is highly variable: the forest consist of trees of several age classes, tree generations and tree species. This is partly a consequence of natural disturbances, because only part of the living trees may die out in fires, and fires enable a new tree generation to grow within a forest of old-growth trees remaining.

Originally the proportion of old-growth forests in Fennoscandia has been relatively high. For instance, in the sparsely populated northernmost Finland (northern Lapland), where the influence of man on forests has been the lowest in Finland, 35% of forests were over 200 years and 78% over 120 years old in 1921 – 24 (1st National Forest Inventory, Ilvessalo 1927).

7 History of forest use in Finland

Finland has been continuously populated after the glaciation ended. The south-western part of the country was inhabited permanently during the Middle Age. A greater increase in human population size started in the New Age from the 16th century onwards, when Finns started to colonize eastern and northern parts of the country (Jutikkala and Pirinen 1981). The original people in Finland were fishermen and hunters of game animals (for post-glacial fauna found in cultural sites, see Ukkonen 1993). Finns started to cultivate land: in western Finland permanent fields were cleared from the forest, whereas in eastern Finland slash- and burn-cultivation of forest land was more common. Slash- and burn-cultivation ended in eastern Finland not until the turn of the 19th and 20th century. In eastern Finland even over half of the forest land was subject to slash- and burn-cultivation in the 18th century and early 19th century, when it was most common (Heikinheimo 1915).

Cattle was grazed in Finnish forests to reduce the use of fields and meadows as pastures for cattle in summer. This cattle grazing in forests ended only some decades ago, it was quite common even in the 1950s. Intensive cattle grazing affected the structure of forests considerably, such as the bush layer, as well as the regeneration of trees.

There was also a large scale use of pines for tar production, particularly in western and central Finland. Tar was an important export product of Finland in the 18th and 19th century. In addition, forests have been used for firewood (as a fuel) and buildings for centuries.

Large-scale industrial use of forests started in the 19th century. Sawtimber production started first at the mid 19th century and pulp industry at the turn of 19th and 20th century. At present forest industry is highly important in the economy of Finland, the value of the export of the forest industry was 30% (55,6 milliard Finnish marks) of the total export of Finland (186,3 milliard FIM) in 1996 (Sevola 1997). About 90% of the trees cut in Finnish forests (53 million cubic meters in 1996) are used by forest industry: mainly for pulp, timber and plywood.

Consequences of silvicultural practices on forest structure

8

The exploitation of forests in Finland is both extensive and intensive. Almost all forest land outside protected areas is subject to systematic silvicultural practices. The intensity of management can be analyzed by National Forest Inventories which have been carried out in Finland since 1921 – 24. The occurrence of cuttings prior to the 8th National Forest Inventory in 1986 – 88 was studied (Salminen 1993) in the nine southernmost forestry board districts in Finland covering 27% of all forest land in Finland. 41% of all forest land in these forestry board districts was subject to at least some cutting procedure during the ten-year-period and 89% of all forest land during the 29-year period preceding the inventory.

Managed forests are thinned twice or three times before they are regenerated at the age of 60 – 140 years. The purpose of thinning is to produce high-quality timber and to increase tree volume and tree growth. However, thinnings prevent the formation of decaying trees in managed forests, because in natural forests trees die out as a consequence of competition between different tree individuals. In addition, fallen trees are usually removed from the managed forests.

Oldest living pines (600 – 700 years) have survived several forest fires, which occurred usually once a century on a given site. Owing to regeneration of forest at the age of 60 – 140 years, no old tree generations remain in a landscape of managed forests. Unmanaged old-growth forests consist of tree individuals of several tree generations, whereas managed forests are usually relatively even-aged.

As a consequence of forest management both the amount and proportion of decaying trees are very low at present. In the 8th National Forest Inventory in 1986 – 88 it was calculated that the amount of dead trees (potentially economically usable) in southern half of Finland was only 0.9 m^3/ha, which was 0.8% of the total tree volume (Parviainen and Seppänen 1994). The amount and quality of dead wood is going to be measured in detail in the ongoing 9th National Forest Inventory (Tomppo 1997). In unmanaged, old-growth forests the volume of decaying trees is about 50 – 100 m^3/ha or more (see chapter 6). The decaying tree volume has decreased in this century. For instance, in two areas in northern Sweden the quantity of dead standing trees was 12 – 13 m^3/ha in 1890 – 1900, but less than one m^3/ha in 1960 – 70 (Linder and Östlund 1992, 1998).

In the early 20th century (and late 19th century) cutting of forests was mainly selective, i.e. valuable individual trees were removed from forest. At the turn of 1940s and 50s silvicultural practices changed. Clear-cutting of a stand and replanting or natural regeneration from seed trees was adopted. This change in silvicultural practice had considerable effects on forest landscape, and the earlier contiguous forest areas have been fragmented (see chapter 11). Also the structure of forest patches has become much more homogeneous, 'cultivated' managed forests comprise largely of stands of only one age class.

Contiguous forest areas are also fragmented owing to forest roads built during the past 40 years: there were 5500 kms of permanent forest roads in Finland in 1960, 23 500 km in 1970, 59 000 km in 1980 and 118 500 in 1996 (Sevola 1997). During the past twenty years about 3000 – 4000 km of new forest roads have been constructed annually with a decline in the mid 1990s, in 1994 – 96 about 2500 km of forest roads were built annually (Sevola 1997).

Forest fires have been systematically suppressed in Finland during the past 100 years. In 1952 – 92 only about 20 km^2 of forests were burned annually (Aarne 1993). If about 1% of forests burned yearly in virgin forest landscape (see Zackrisson 1977), about 2000 km^2 of forests would be burning in natural conditions in Finland every year. This is, however, probably an overestimate as the area of wildfires was much lower in the late 19th century before the active fire suppression started (see Parviainen 1996).

Virgin mires have been drained, earlier for agricultural purposes, but from the late 1950s onwards for forestry. About 7000 km^2 of mires have been cleared as fields and over 50 000 km^2 drained to increase tree growth. Peak of drainage of mires was in the 1960s and early 1970s, but the drainage has continued until the early 1990s. 75% of all mires in southern half of Finland has been drained for tree production, 60% in southern part of northern Finland and 23% in northern part (Lapland) of northern Finland (Sevola 1997). About 60% of the remaining virgin, unditched mires are in Lapland, in areas which are not suitable for tree production. The loss of virgin mires has been proportionally the greatest in the most productive mire types, such as in various eutrophic fens and in grass- and herb-rich spruce mires. In southern and central Finland the majority of unditched mires are in the middle of drained areas, and thus the drainage of the surrounding mires affects the water level of unditched mires.

In southern Finland no large areas of old-growth forests were left in the early 20th century due to cuttings and slash- and burn-cultivation. In contrast, in northern Finland large areas of old-growth forests remained still in the mid 20th century. In northern Finland large-scale forestry started particularly after the second world war in the late 1940s and early 1950s, when clear-cutting was also adopted as a silvicultural practice. Consequently, the proportion of old-growth forests has continuously decreased. The proportion of forests over 120 years old was 55% of the whole forest land in northern half of Finland in 1921 – 24 (1st National Forest Inventory, Ilvessalo 1927), 44% in 1951 – 53 (3rd Inventory, Ilvessalo 1957) and 25% in 1992 – 94 (8th Inventory, Aarne 1995).

Mature broad-leaved deciduous forests have decreased in southern Finland during the past 50 years as a consequence of forest management. Deciduous forests covered 17.5% of the total forest land in southern Finland in 1951 – 53, but 8.4% in 1986 – 92 (Ilvessalo 1957, Aarne 1995). During the past 20 years the proportion of deciduous forests has no longer decreased due to establishment of young stands of birch *Betula pubescens* in drained mires. Deciduous trees did not have any greater economic value for the forest industry in the 1950 – 1960s, and forests dominated by birch and other deciduous (hardwood) trees were largely cut and replanted by conifers in the 1950s and 60s. Nowadays pulp industry needs more deciduous (hardwood) trees due to their recently discovered high-value in producing high-quality paper. At present there are too few birch forests for the needs of forest industry and, thus, about 5 million cubic meters of hardwood (mainly birch) has been imported yearly in the 1990s, mainly from Russia (Sevola 1997). About one third of the hardwood used by the forest industry is imported.

9 Measuring biological diversity

It is important to notice the hierarchy of diversity in relation to scale. This hierarchy can be divided spatially, e.g., as follows: (Whittaker 1977, communities or species richness):

(1) Alpha (α) diversity: species richness of standard site samples (e.g., single forests)
(2) Beta (β) diversity: differentiation between communities along habitat gradients (e.g., patches of different-aged forests)
(3) Gamma (γ) diversity: larger geographic region (landscape level)

For instance, if a large old-growth forest area is fragmented (see chapter 11) due to clear-cuttings, species numbers may increase locally (alpha or beta-diversity), although species preferring old-growth forests decline in or disappear from this particular area. There might be an increase of species preferring edges, bushes, open areas and increase of habitat generalists. However, if all or most continuous old-growth forests in a larger geographical region (e.g., Finland) are fragmented, species numbers (gamma-diversity) decrease as a consequence of disappearence of species of old-growth forests. Therefore, measuring species numbers, and biodiversity in general, is scale-dependent.

Species diversity of communities has been measured by diversity-indices or distinctive species groups. Diversity indices (such as Shannon-Wiener index, $H' = -\Sigma p_i \ln p_i$, where p_i is the proportion of species i in the community) reflect distribution patterns of species in different communities. Diversity indices do not take any qualitative aspects of different species into account. A community consisting of relatively common species could receive a higher value of diversity index than a community consisting of rare and endangered species. Therefore, these indices are poor indicators of biodiversity, as no species' quality is measured.

Distinctive species groups may better measure biological diversity. By using so-called taxonomic diversity (Vane-Wright et al. 1991, Krajewski 1994) distinctive species groups can be weighed according to their taxonomic distinctness and priority areas for conservation can be identified. This method is important for between-area or between-region comparison of biodiversity. Taxonomic diversity indices identify species or species groups that contribute the most and the least to the biological diversity. In measuring biological diversity, conservation priority should be emphasized that is number of decreased and endangered species, rare communities and ecosystems.

10 The significance of ecological models

The distribution of species in natural and fragmented landscape can be analyzed by specific ecological models, such as island biogeographic model, source-sink model and metapopulation dynamics.

Island biogeographic theory predicts the relation between the size of an island and species number (MacArthur and Wilson 1967). In addition to the size, also isolation of an island affects species numbers. In general, the number of species increases by the area-species equation $S = cA^z$, where A is the area and S is the species number. C and z are constants which depend on, e.g., the group of organisms considered. In general, a tenfold increase in area doubles the fauna and flora, or in other way: a tenfold decrease in area causes the number of species to decline into half. Island biogeographic model has been adjusted to oceanic islands or other islands surrounded by water. However, island biogeographic model has implications also to terrestrial ecosystems, particularly in connection with fragmentation of earlier contiguous habitats (Wilson 1992). Island biogeographic model has been utilized, e.g., in the tropics when estimating the amount of species disappearing as a consequence of deforestation (e.g. Groombridge 1992).

In boreal forest zone, old-growth forests are islands in a 'sea of managed forests.' However, for species preferring old-growth forests the surrounding managed forest habitats are not as hostile as sea for the island organisms. For species preferring old-growth forests the size of the forest area is important. For instance, in nature reserves in southern Finland the density of cavity (hole-) nesting bird species preferring old-growth forests increased as the size of the old-growth forest area (>100 years) increased, suggesting that cavity nesting species of old-growth forests prefer large forest areas (>5 km^2, Virkkala et al. 1994).

Quality of habitats is different in various habitat patches of a forest landscape. According to source-sink model, sources are subpopulations being demographically viable (population growth rate, $r > 0$) whereas sinks are subpopulations of demographical inviability ($r < 0$) for a particular species (Pulliam 1988). Sinks will ultimately become extinct unless they receive immigrants from the source. Preserving source populations in boreal forests is of utmost importance. Several species and species groups prefer large, old-growth forest areas (e.g., in size over 10 km^2), although the species may occur also in small patches of old-growth forests or in moderately managed forests (Virkkala 1990, 1996 and references therein). For these species small patches of old-growth forests and managed forests most probably are sink habitats, and thus these populations are dependent on source populations in large, old-growth forest areas.

A third important ecological model is metapopulation dynamics. Metapopulation is an assemblage of a species' local populations which interact via individuals moving among populations (Hanski and Gilpin 1991, 1997, Hanski 1998). Fragmentation of habitats may cause a metapopulation structure that is a set of local populations in isolated habitat patches of an earlier contiguous landscape. In a metapopulation continuous local population extinctions and recolonizations of patches take place. The number of available habitat patches should, however, be much greater than the number of inhabited patches in any particular time. The metapopulation persists, if colonization rate of patches exceeds extinction rate. If

the number of habitat patches declines under a certain critical level, the whole metapopulation will go extinct although there may still be suitable habitat patches left in the landscape.

In general, ecological models predict that there are critical thresholds for the preferred habitat of a given species. Only part of the habitat patches preferred by a species are occupied at a given moment (metapopulation dynamics). This means that the number of available habitat patches or areas must be considerably greater than the number of actually inhabited patches or areas in a given moment. Quality of inhabited patches is important. If all inhabited patches of a species are sink populations, the population may not survive without recruits from a source population (source-sink model). A decrease in habitat area causes a decrease in the numbers of species preferring this habitat (island biogeographic model). The survival of a species is largely dependent on the dispersal ability of a species, that is the capacity of individuals in moving into the habitat where survival is high and offspring production is possible. For instance, several species of old-growth boreal forests probably have a weak dispersal ability.

II Habitat fragmentation

Habitat fragmentation is the process of subdividing a continuous habitat into smaller pieces. In general, habitat fragmentation consists of three componens: (1) the loss of original habitat, (2) reduction in habitat patch size and (3) increasing isolation between habitat patches. All these components decrease the biological diversity of the original habitat.

By using simulations and reviewing the available data of the effects of fragmentation Andrén (1994) analyzed the critical values of habitat fragmentation. He observed that there most probably is a threshold in proportion of suitable habitat in the landscape, above which habitat fragmentation is merely habitat loss, the decrease of species is linearly correlated with the decrease of available habitat. Andrén observed that the threshold might be between 10 and 30% of the suitable habitat remaining in the landscape. Thus, when the proportion of the suitable habitat is less than 10% of the original value, species preferring this habitat clearly decrease more than the amount of available habitat predicts. So if we have 30 or 50% of the available habitat left on the landscape the population size of a species preferring this habitat is predicted to be 30 or 50% of the original population size, respectively. But if we have 10% of the habitat left, then the population size of a species is clearly less than 10% of the original population.

The response of a species to landscape changes depends on specialization to different landscape elements (Andrén et al. 1997). Species preferring a decreasing habitat type in a landscape are affected by fragmentation whereas generalist species occurring in several habitat types are not. Specialized species preferring a decreasing habitat type may vary also in sensitivity to changes in fragment size and degree of isolation.

12 Effects of forest management on biota

Forest management and other human use of forest resources change the structure of forests and regional composition of different-aged and types of forests in a way to which all species are not adapted. Although a large proportion of species in boreal forests are habitat generalists, many species having specific habitat requirements cannot survive in an intensively managed forest landscape.

Particularly species of old-growth coniferous forests, species of various herb-rich forests, species of mature deciduous forests, species of nutrient-rich peatlands, and species requiring decaying wood have decreased. 41% (692 out of 1692 endangered species in Finland, Rassi et al. 1992) of all endangered animals, plants and fungi in Finland are threatened predominantly by forest management (Table 1 and 2). Species benefitting from silvicultural practices, such as increased fragmentation, are largely habitat generalists that is species occurring in several habitat types. Particularly numerically dominant species tend to be generalists, distributed broadly across different forest types and across successional gradient (Haila et al. 1994). For instance, in forest birds and carabid beetles the proportion of species specializing in old-growth forests is about 10% (Haila 1994), but the proportion is much higher in saproxylic (species depending on decaying wood) beetles and wood-decomposing fungi. The declined species (like many birds, beetles, liverworths and mosses, lichens and polyporous fungi) are mainly habitat specialists, they are dependent on particular habitat components decreased in managed forests.

Decaying trees comprise an important feature of natural forests. In natural stands there is a continuity of trees of different decaying stages. It has been estimated that of the roughly 20 000 forest species in Finland about 4000 – 5000 species are dependent on dead wood that is about one fifth or one fourth of all forest species (Ministry of the Environment 1994, Siitonen 1998). The species groups particularly dependent on decaying trees are beetles and decomposing fungi. In Sweden, 20% of all beetle species (880 out of 4350 species) are dependent on decaying trees (Ehnström and Waldén 1986). In Finland, about 25 % of all beetle species are saproxylic (900 out of 3600, P. Rassi, pers. comm., Siitonen 1994). In certain groups of decomposing fungi, polyporous fungi and Corticiaceae (altogether about 500 species in Finland), the great majority (over 90%) of species require decaying wood. About 20% (104 species) of these species are regarded as threatened due to forest management (Rassi et al. 1992). It has been estimated that about 80% of these fungi in Finland suffer from the effects of forestry (Renvall 1995), which includes the removal of decaying trees. These decomposing fungi are often confined to specific decaying stages of a dead tree. They operate in the decaying succession of trees: the occurrence of one decomposing fungus species is dependent on the decomposition of a tree caused by another species (Renvall and Niemelä 1994). The occurrence of decomposing communities demands a continuity of dead trees of different decaying stages, and also a continuity of living trees on a specific site.

Also several species of lichens and bryophytes (liverworths and mosses) need the continuity of living trees, this means that there has been a permanent forest cover on a site for several centuries. The importance of continuity of trees and old-growth forests was clearly shown in northern Sweden by Pettersson et al. (1995). They observed that the numbers of invertebrates (insects, spiders) on the branches

Table 1. The number of threatened species according to their preferred habitat (Rassi et al. 1992). I = vertebrates, II = invertebrates, III = vascular plants, IV = bryophytes, lichens and fungi.

	I	II	III	IV	Total	%
Forests	15	318	38	356	727	43.0
Heath forests	2	111	3	135	251	
Old-growth	2	105	1	107	215	
Herb-rich forests	6	158	25	205	394	
Old-growth	1	72	1	45	119	
Esker forests	1	15	7	-	23	
Burned areas	-	14	-	-	14	
Mires	1	29	21	32	83	4.9
Eutrophic fens	-	8	15	15	38	
Other fens	1	5	-	4	10	
Pine bogs	-	12	1	2	15	
Spruce mires	-	3	5	9	17	
Aquatic habitats	26	68	18	41	153	9.0
Baltic sea	5	1	2	14	22	
Oligotrophic lakes	7	14	2	3	26	
Eutrophic lakes	3	21	5	5	34	
Rivers	10	23	-	1	34	
Brooks	1	2	1	9	13	
Springs	-	1	8	9	18	
Shores	4	57	46	32	139	8.2
Baltic sea shores	2	31	21	17	71	
Lake and river shores	2	24	25	15	66	
Rocky areas	1	16	23	117	157	8.2
Alpine habitats	6	22	20	22	70	9.3
Semi-natural and man-made habitats	8	223	61	71	363	21.4
Wet meadows	1	18	8	6	33	
Coppiced meadows	-	34	13	22	69	
Dry meadows	1	122	27	23	173	
Cultivated land	4	7	3	-	14	
Parks	1	12	4	13	30	
Waste land	-	20	6	2	28	
Buildings	1	8	-	5	14	

of spruce were fivefold in natural forests where spruces were 200 years old if compared to spruces of managed forest of 100 years old. The higher number of invertebrates in the older trees of natural forests was due to the abundance of slow-growing lichens in these trees. Bird species of so-called foliage-gleaning guild forage on invertebrates on the branches, such as, e.g., tits *Parus* spp. Several, resident species of foliage-gleaning guild (Siberian tit *Parus cinctus*, crested tit *P. cristatus*, willow tit *P. montanus*, Siberian jay *Perisoreus infaustus*) have considerably decreased in Finland during the past 50 years (Väisänen et al. 1986). These species suffer, e.g., from the effects of forest fragmentation caused by forestry (Helle and Järvinen 1986, Virkkala 1990), but probably also because there are less food resources avai-

Table 2. The number of species threatened primarily by forest managament practices (Rassi et al. 1992). I = vertebrates, II = invertebrates, III = vascular plants, IV = bryophytes, lichens and fungi.

	I	II	III	IV	Total
Forest management, in general	7	274	35	376	692
Undefined forest management	-	14	21	123	158
Changes in tree species composition	3	74	12	129	218
Changes in age structure of forests	2	32	2	63	99
Decrease of decaying trees	2	154	-	61	217

lable in managed forests. This example shows that there are complex interactions in an old-growth forest: high age and slow growth of trees increase the amount of lichens, and the more lichens the more invertebrates on branches, and the more invertebrates the more foliage-gleaning birds.

Broad-leaved deciduous trees were earlier largely removed from a forest. However, large, decaying aspens are of extremely high value for biota, such as for saproxylic beetles, mosses, lichens and polyporous fungi (e.g., for beetles, see Siitonen and Martikainen 1994, for lichens, see Kuusinen 1994, 1996). Large aspens also provide cavities for cavity nesting birds and mammals, like the flying squirrel *Pteromys volans*. Aspen has been regarded as a 'key species' in boreal forests, that is a species on which a particularly high number of species is dependent. The earlier, systematic removal of large aspens from forests for silvicultural reasons has had detrimental effects on biota.

There are several epiphytic lichen species which cannot survive in managed forests of short continuity of aspens even though some old aspen trees would occasionally be available (Kuusinen 1994). There was a clear negative relation between the occurrence of epiphytic lichens on aspen and forest management indicating the importance of the length of forest continuity (Kuusinen 1994). Such lichen species clearly preferring unmanaged, old-growth forests include, e.g., *Lobaria pulmonaria, Nephroma bellum, N. parile, N. resupinatum, Pannaria pezizoides* and *Parmeliella triptophylla* (Kuusinen 1996). Only a continuous supply of old aspens in moist shaded areas will guarantee the survival of epiphytic lichen species.

Siitonen and Martikainen (1994) compared beetles and flat bugs living on the decaying wood of aspen between Finnish and Russian Karelia. In Russian Karelia they observed 14 species (185 individuals) considered threatened in Finland but only one threatened species (one individual!) in Finnish Karelia. Siitonen and Martikainen (1994) suggested that the high numbers of rare and threatened species at the sites studied in Russian Karelia were attributable to the different management history of the forests, particularly to the abundance and continuity of large, dead aspens.

The decrease of mature, deciduous forests has caused a decline of several species preferring these forests. For instance, the white-backed woodpecker *Dendrocopos leucotos* feeds on wood-boring and bark-living insect larvae occurring mainly in dying and dead deciduous trees (Aulén 1988). The white-backed woodpecker has decreased and become an endangered species both in Finland (Virkkala et al. 1993) and in Sweden (Aulén 1988) owing to cutting and managing of mature deciduous forests, such as removal of dying trees.

Virkkala (1990) studied the effects of silvicultural practices on birds in northern Finland. The total bird density or species numbers did not differ between managed and virgin, old-growth coniferous forests. The composition of bird assemblages was, however, different. Species more common in managed habitats were abundant habitat generalists, such as the willow warbler *Phylloscopus trochilus* and the redwing *Turdus iliacus*. These species have increased in Finland due to forest management during the past decades.

Forest management had a negative impact on the densities of species preferring old-growth forests (Virkkala 1990), such as the redstart *Phoenicurus phoenicurus* and the so-called northern taiga species (capercaillie *Tetrao urogallus*, three-toed woodpecker *Picoides tridactylus*, Siberian tit, Siberian jay, pine grosbeak *Pinicola enucleator*). Northern taiga species are mainly resident, and these species have considerably declined in Finland. The decline of these species can be connected with the negative effects of fragmentation and the exclusion of large coniferous and dead trees from managed forests. The capercaillie, the Siberian tit and the Siberian jay have relatively large home ranges and they prefer large forest areas. The breeding success of the Siberian tit is poor in intensively managed forests. Redstart, Siberian tit and three-toed woodpecker are cavity nesting species suffering from the lack of suitable nest-sites. The three-toed woodpecker also feeds on wood-boring insects abundant in decaying trees.

Although bird species preferring old-growth forests have declined in managed forests and in small patches of old-growth forests, their population densities remained the same between the 1940 – 50s and the 1980s in a large area of old-growth forests covering about 1000 km^2 (Sompio Strict Nature Reserve – Urho Kekkonen National Park, Virkkala 1990, 1991b). Large areas of old-growth forests may maintain their original species composition and species' population size and may also act as population sources for species preferring old-growth forests.

Clear-cuts affect biota in mature or old-growth forests in a fragmented forest landscape also indirectly. For instance, several vole species prefer and are abundant particularly in clear-cuts (Hansson 1979). Vole species fluctuate cyclically with a cycle length of 3 – 5 years in Fennoscandia (e.g., Hanski et al. 1991). When vole populations crash, generalist vole-eating predators (mainly mammalian, such as small mustelids and the red fox *Vulpes vulpes*) have to shift to an alternative prey, such as clutches and nestlings of birds. Thus, fragmentation increases nest predation of birds in forests through increased numbers of predators (Hansson 1979, Angelstam 1992, Huhta 1995).

Drainage of mires for tree production has considerable effects on biota. The drawdown of water level starts a secondary vegetation succession. Plant species of wet habitats are first to disappear, and the change in species' pool is quickest on wet nutrient-rich sites (Laine et al. 1995). In the postdrainage vegetation succession species of drier habitats spread first onto the site where original mire species still prevail. After this period forest species start to dominate the site (Laine et al. 1995).

The disappearance of mire species has a time lag, plant species usually disappear within 20 – 30 years after drainage. Thus, in a drained mire the alpha (α) diversity of plants (see chapter 10) can be higher for some time after the drainage compared with the diversity in undrained mire, as both mire and forest species can co-occur on a site for a while. However, mire drainage causes eventually the decrease of the gamma (γ) diversity of landscapes (see chapter 10) owing to the disapperance of true mire species in a longer term (Laine et al. 1995). The most specialized species of mires have become endangered and disappeared in several regions in Finland due to mire drainage. These include plant species in eutrophic fens, such as *Dactylorhiza incarnata* subsp. *cruenta*, *Saxifraga hirculus*, *Carex laxa*, *Microstylis monophyllos* (e.g. Heikkilä 1990). No species is known to be dependent on the occurrence of drained mires (Laine et al. 1995). For instance, draining of mires increases the numbers of already abundant generalist bird species, such as the willow warbler and the redwing, and decrease the numbers of mire-nesting species, such as waders (Väisänen and Rauhala 1983).

Drainage of mires has caused considerable changes in the biota of streams. Forest ditches increase the amount of inorganic material in the streams causing an impoverishment of moss-dwelling, benthic macroinvertebrate fauna (Vuori and Joensuu 1996). Increased sedimentation causes the disappearance or drastic decrease in several invertebrate groups, such as shedder-feeding stoneflies (Plecoptera). On the other hand, the density of tolerant species groups, such as simuliids, increases manyfold.

13 Systematic reserve selection

Protected areas comprise a reserve network at a larger, regional scale. The aim of a reserve network is to maintain ecosystems and species. Reserve network should be both representative and complementary (Pressey et al. 1993), which means that all habitat types of natural or semi-natural ecosystems should be represented in the reserve network. The reserve network should be large enough so that several populations or subpopulations of species are represented. During the past years numerical algorithms have been developed to identify the minimum set of areas in which all species of particular species groups are represented in a given region. Margules et al. (1988) identified the minimum set of wetlands in which all native plant species (98 species) are represented in the Macleay Valley floodplain, Australia. Based on numerical algorithm they found that 78% of the whole floodplain should be included if all the plant species were represented at least at five wetland areas. This means that most of the floodplain should be protected for maintaining all the native plant species.

In boreal regions a larger proportion of biota are habitat generalists, so they occur in several habitat types. Based on the similar procedure as Margules et al. (1988), Virkkala (1996) analysed the minimum set of areas needed to include all species of land birds (98 species) occurring in forests and on mires in a particular region, Kainuu (size 21 000 km^2), situated in northern Finland. The study was based on the information of Finnish bird atlas (Hyytiä et al. 1983) in which the presence of a species was recorded in 10 x 10 km squares (altogether 252 squares in the region, Table 3). In order to cover all the 98 bird species in at least five squares 13.5% of all squares should be included. Threatened species and declined species preferring old-growth forests (altogether 22 species) are particularly important in terms of biological diversity. In order to cover all these species in at least five squares 10.3% of all squares should be included (Table 3). The composition of the areal network is highly dependent on the rare species, as they are not observed in most squares in contrast with more common species. This approach shows that including all species of a particular species group in the areal network in a boreal region does not require most of the land area as in the Australian study of native wetland plant species (Margules et al. 1988). This is partly due to the fact that a larger proportion of species is habitat generalists not dependent on a specific habitat type. However, for the adequate representation of species in an areal network there is a threshold, which is approximately 10% of the land area.

Table 3. The number (n) and the proportion (%) of squares (10 x 10 km) in Kainuu (northeastern Finland) needed to include all forest and mire bird species (98 species, Virkkala 1996), and all threatened bird species and bird species preferring old-growth forests (22 species, Virkkala 1996) at least once, twice, three times, four times and five times. The total number of squares in Kainuu is 252.

Species observed in at least	All species		Threatened species and species preferring old-growth forests	
	n	%	n	%
One square	7	2.8	4	1.6
Two squares	13	5.2	10	4.0
Three squares	20	7.9	16	6.3
Four squares	26	10.3	21	8.3
Five squares	34	13.5	26	10.3

In a smaller scale study of distribution patterns of rare vascular plants (65 species of the total of 242 vascular plants) in Helvetinjärvi National Park (southern Finland) in an area of 1300 ha, it was observed that to cover all rare vascular plant species in at least one site would require that 1% of the land area should be included. The area percentage for at least five sites per species was about 8% (H. Toivonen and S. Järvi, unpublished). Thus, these results in a smaller scale and in a different group of biota are parallel with the approach of land birds in larger geographic scale.

On the other hand, these results stress also the importance of edaphically and hydrologically favourable or specific sites for maintaining vascular plant diversity in a boreal forest-mire landscape. In the Helvetinjärvi area rare vasculars were concentrated on mesic and moist herb-rich forests, often along brooks, wooded mires, and also to some extent on rocky outcrops and cliffs. These sites are often small (only 0.1 – 2 hectares in size), which supports the importance of the 'key biotope' concept (see chapters 15 and 16).

In selecting individual reserves several aspects should be taken into account (Spellerberg 1994), including: (1) size and extent of the area, (2) diversity of species, communities and ecosystems, (3) naturalness, (4) rarity and commonness, (5) fragility. The larger the area the more species are included and the larger the population sizes of species. In addition, the negative impacts of surrounding habitats are smaller in large areas. However, some species and habitats occur in specific, small-scale sites, such as springs, brook margins and herb-rich forests. In such cases, the protection of small areas is well-founded. Diversity of species, communities and ecosystems is important, but species-poor habitats should be emphasized if they consist of rare and endangered species. The occurrence of rare and endangered species are commonly regarded as essential in founding reserves, but also declined species and ecosystems should be taken into account. It is important that species retain their functional significance in the ecosystem and do not decline and become endangered. Fragility of a habitat should be taken into account in founding reserves. Clear-cutting of an old-growth forest or drainage of a mire result in almost irreversible changes in the ecosystem, and recovering of these habitats to the state that occurred before the human-caused change takes a very long period and may require specific restoration measures.

14 Resolutions and forest conservation programmes for sustaining biodiversity

Ministerial Conference on the protection of forests in Europe in Helsinki in 1993 defined a resolution (H1) for 'General Guidelines for the Sustainable Management of Forests in Europe' and a resolution (H2) for 'General Guidelines for the Conservation of the Biodiversity of European Forests' (Ministry of Agriculture and Forestry 1995), which are particularly important in maintaining and enhancing biological diversity. The resolution of sustainable management (H1) stresses that conservation and appropriate enhancement of biological diversity in all types of forests is an essential element in the management of forests. Silvicultural practices should simulate natural dynamics, and practices contrary to sustainable management should be actively discouraged. This resolution also brings forth that fragile ecosystems such as primary and climax (old-growth) forests should be protected. The resolution of conservation of biodiversity (H2) suggests a specific proposal to establish a network of forests to be protected. The purpose of this resolution is to maintain both representative and threatened ecosystems in terms of biodiversity.

In order to evaluate sustainable forest management and enhancement of biodiversity it is important to identify criteria on which these concepts can be judged in practice. Criteria include both descriptive and quantitative indicators. Criterion 4 'Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems' is particularly important in terms of biodiversity, and it deals with such conception areas as representative, rare and vulnerable ecosystems, threatened species, and biological diversity in production forests (Ministry of Agriculture and Forestry 1995). The measured indicators of sustainable forestry have been applied in Finland (Ministry of Agriculture and Forestry 1997).

New Environmental Programme for Forestry in Finland was published by the Ministry of Agriculture and Forestry and Ministry of the Environment in 1994. This programme states that when promoting forest management and utilisation, increasing emphasis must be placed on attending to forest ecosystems in their entirety and to maintaining biodiversity (Ministry of Agriculture and Forestry and Ministry of the Environment 1994). As a target for the year 2005 the Programme stressed, e.g., the importance of founding an adequate network of protected forest areas in order to preserve the biodiversity in forest ecosystems and the use of commercial forests on a sustainable level in each region. Management of the forest landscape should aim at reducing the impact of forestry on the ecosystem and the landscape level.

The Ministry of the Environment (1994) has also published a strategy for sustaining biodiversity in Finnish forests. This programme stresses the importance of protecting old-growth forests and, in general, the need for increasing the amount of protected forest areas. Rare, site-specific habitats, such as specific herb-rich forests and eutrophic fens should all be preserved.

In addition, this programme suggested a categorization of forests into separate types according to their use for different purposes. The most valuable forest areas in terms of biodiversity should be preserved but managed forests should be classified into different groups: those in which nature conservation is particularly important ('luonnonarvometsät') and those in which timber production is the most important aim ('talousmetsät'). In managed forests of high conservation value tim-

ber production should be carried out with low-intensity (for further discussion, see chapter 16). This categorization of forests could also mean that the distinction between protected and managed forests would not be so clear, and the maintenance of biodiversity in forests would include a continuum of different areas in terms of forest use from fully protected to managed forests.

In order to develop a reserve network some national protection programmes have been approved by the Finnish government during the past ten years. These include, e.g., programmes of herb-rich forests (436 sites, total land area 53 km^2) and old-growth forests (513 sites, total land area 3400 km^2) both in southern and northern Finland.

In developing the Finnish network of nature conservation areas also the Habitat and Bird Directives of the European Union must be taken into account. The Habitat Directive stresses the so-called favourable conservation status of habitats and species with a special interest on the level of the European Union. To fulfill the demands of the Directives, an ecological network of special areas of conservation shall be set up under the title Natura 2000 in each member state. As boreal forest types are poorly represented in the habitat directive, new boreal habitat types have been presented by Finland and Sweden to be included in the habitat directive (Appendix 1). These include forest habitats typical to Fennoscandia, such as hemiboreal natural old broad-leaved deciduous forests, natural forests of primary succession stages of landupheavel coast, herb-rich forests with *Picea abies*, coniferous forests on glacifluvial eskers, subalpine forests with *Betula pubescens* ssp. *czerepanovii*.

15 Legislation reform

A reform of nature conservation and forest legislation has just been carried out in Finland. The new Nature Conservation and Forest Acts came into force at the beginning of 1997. The goal of the new Nature Conservation Act is to maintain and enhance biodiversity in Finland. The Act takes into account the demands of the European Union's Habitat and Bird Directives. The Nature Conservation Act, e.g., stresses the favourable conservation status of natural habitats and of wild fauna and flora. In the Nature Conservation Act, the favourable conservation status will be reached by creating nature reserves, protecting species and their specific sites of occurrence, by protecting specific, rare habitat types (see Appendix 2) and by other regulations of land use.

A general guideline of the Forest Act requires the simulation of natural dynamics of forests in management practices. Forest harvesting should be carried out by taking into account the specific characters of a given site. There is also a statement dealing with specific small-scale 'key biotopes' in which special caution should be applied when managing these habitats (see Appendix 2). It has been estimated that key biotopes presented in the Forest Act cover 0.5 – 1% of the forestry land in privately owned forests of Finland (Niemelä and Arnkil 1997, 1998). The total proportion of all kinds of key biotopes and other valuable habitats (such as shoreline woods) was estimated to be 4 – 5% of total forestry land in privately owned forests (Niemelä and Arnkil 1997, 1998). It should, however, be noticed that moderate silvicultural procedures are allowed in most key biotope sites.

Means of sustaining biodiversity in forests

16

Forest conservation priorities have to be seen against the biogeographic background. Preserving representative forest and mire ecosystems of western Eurasian taiga is without doubt one of the main contributions of Finland to the nature conservation in the European and global context.

The basic argument in sustaining biodiversity in Finnish forests is that it is impossible to maintain all the characteristics of a natural forest landscape and forest structure in intensively managed forests. For this reason, the foundation of nature reserves is of utmost importance (see Esseen et al. 1997). Without the foundation of new reserves, several species and ecological groups will disappear, or decrease so much that they loose their functional significance in the forest ecosystem. Viable populations of species having specific habitat and area requirements, such as those preferring decaying wood and contiguous, old-growth forests, could be sustained only by an adequate reserve network.

For the whole country the proportion of protected forests is about 3% of productive forest land (tree growth >1 m^3/ha/yr), and the new conservation programmes of forests would increase this figure to about 5%. The proportion of protected forests comprises 0.5 – 3% of productive forest land in the different forest vegetation zones and their sections excluding the northernmost Finland, Forest Lapland (section 4c in Fig. 1), where reserves cover about 40% of forest land (Ministry of the Environment 1994). After the foundation of protected areas in the conservation programmes, the proportion of protected forest land in hemiboreal, southboreal and midboreal forest vegetation zones would vary between 1 and 3%.

Although the protected forests in the northernmost Finland are ecologically valuable, they cannot compensate the need for protection in more southern areas having also more productive forests. At present the reserve network is not representative, because most of the protected forests are situated in the very northernmost Finland. In addition to productive forest land a great deal of unproductive forestry land (scrub land) in terms of tree growth (tree growth 0.1 – 1.0 m^3/ha/yr) has been protected, about 25% of the total land area of scrub land. Unproductive scrub land includes, e.g., rocky areas, sparsely wooded mires and sparse forests (including mountain birch woods) near the northern forest line. About 75% of the protected scrub land is situated in the northernmost Finland (Forest and Mountain Lapland, sections 4c and 4d in Fig. 1). Scrub land does not compensate the need for protection of productive forest land. About 7% of the combined land area of forest and scrub land is protected in Finland.

The present reserve network should be enlarged, and the level to be reached should preferably be at about 10% of forest land protected in each of the forest zones and sections (see Virkkala 1996). The given proportion of forest land to be protected is based on the recent knowledge of critical thresholds of habitat fragmentation, on the systematic reserve selection to consist of all species in a particular group (land birds), on the minimum proportion of old-growth forests in the forest landscape and on the predictions of ecological models (see chapters 8 and 10-13; Virkkala 1996). In areas with a high proportion of natural forests (such as in eastern and northern Finland) forest protection should play a more important role than in areas with a high level of degraded forests (see UNEP 1996b), such as in

southern and western Finland, where the proportion of forest land to be protected might be lower (Virkkala 1996). The main argument for this is the need for protection of larger source populations of taiga species in eastern and northern Finland.

In a longer term protected forest areas should cover about 10% of forest land also in southern Finland, but besides protection of existing forests this requires larger restoration actions. In a short term, the proportion of the forest land to be protected in southern and western Finland might be lower, e.g. 5% of forest land. However, whether this reasoning holds true, further analyses are needed. In general, the balance between the use of in-situ conservation (protected forests) and ecosystem management (forest management guidelines) is influenced by the land use history in each region (UNEP 1996b, Angelstam and Pettersson 1997). This knowledge is crucial in assessing forest protection means, especially in southern Finland. In these regions political constraints against conservation of larger forest areas are also more severe than in northern and eastern part of the country.

In general the protected forest areas should be large enough, preferably over 10 km^2 in size. Several species of natural and old-growth forests prefer such large contiguous forest areas, for instance, resident bird species, like capercaillie, tree-toed woodpecker, Siberian tit, and Siberian jay (Virkkala 1990, 1996). It is important that the source populations of species in their optimal habitats are being preserved. In addition, the protection of large forest areas is well-founded, as natural disturbances and natural dynamics of forest landscape operate at a relatively large scale. The operation of natural disturbances can be possible only in larger protected areas. The early successional stages of natural disturbance regime (e.g. young regenerating stages after forest fire) are very rare in Finland. As a consequence, several species associated with forest fires have become threatened (see e.g. Niemelä 1997).

The foundation of reserves has priorities. Firstly, the biologically important areas of old-growth forests, mainly situated in northern and eastern Finland should be preserved. Secondly, in areas in which old-growth forests and other valuable forest ecosystems in terms of biodiversity no longer exist, the protection and restoring of ecosystems should be carried out. These areas include southern and western Finland. Restoring of already managed forests in protected areas should include, e.g.: (1) increase of decaying wood by killing individual trees, (2) burning of a forest, (3) cutting of small areas (some ares) in homogeneous, managed coniferous stands to increase the amount of broadleaved deciduous trees (which usually start to grow in the openings) and dead trees. These felled trees should be left in the forest to increase the amount of decaying wood on the ground. The purpose of the small-scale cuttings is to create openings and, thus, to simulate gap dynamics (windthrow) of natural forests. In protected deciduous forests and in herb-rich forests felling individual spruces is recommended in managing the habitat.

In Sweden, Angelstam and Andersson (1997) studied the need for new protected areas based on gap-analysis, which identifies the deficiencies in representation of biological diversity (see Scott et al. 1993). They concluded that based on their analyses 9 – 16% of forest land should be protected in the different regions of Sweden outside the mountain forests. In both the Swedish boreal zones (south and north) the calculated need for protected forests was about 9% of forest land. In Sweden, forest use and management resemble those in Finland. Thus, the amount and proportion of forests in need of protection seem to be similar both in Finland and in Sweden.

In addition to foundation of forest reserves, forest management practices should take into account the demands of sustaining biodiversity (UNEP 1996b). The important aspects include, e. g., leaving dead trees, large trees and broad-leaved deciduous trees (particularly large aspens) on the felled area. This could enable the continuity of trees on a given site. However, this kind of practice does not make it possible for several species to have viable populations in the managed forests as,

at least at present, only a few per cent of trees are left on the felling areas. Prescribed burning should be used more often in the regeneration of managed forests, as several endangered species, beetles in particular, are dependent on the occurrence of fires (Muona and Rutanen 1994).

An important aspect of a more ecological forestry is the consideration of key biotopes, i.e. valuable, small-scale habitats or biotopes of high natural values that should either be left untouched or managed with special care (Meriluoto 1995, Meriluoto & Soininen 1998, see chapter 15).

However, key biotopes are according to the present recommendations supposed mostly to be extremely small, usually less than one hectare (Meriluoto 1995). Thus, adoption of the key biotopes approach does not compensate the need for preserving large forest areas but key biotopes may ease species' dispersal within managed forest landscape. For species of old-growth or natural forests, key biotopes may act as 'ecological corridors' or 'stepping stones' between larger protected forest areas. Also for species occurring in edaphically and hydrologically specific sites, such as several vascular plants (chapter 13) and mosses, protecting small-scale key habitats is important.

The scientifically verified knowledge about the effects of the new forest management recommendations on biota are scanty, as yet. The information dealing with these new management recommendations will increase in the next years (e.g., Raivio 1995, 1997). In Sweden, Carlson (1994) studied the significance of trees left on the clear-cuts (size 3 – 6 ha) for cavity nesting (hole-nesting) birds. He observed that the frequency of occupied cavities on the clear-cuts was highest near the forest edge, less than 50 m from the edge. At a distance of over 50 m from the forest edge the proportion of occupied cavities rapidly declined. This was due to the fact that tits and the pied flycatcher *Ficedula hypoleuca*, which were the most common cavity nesters, foraged in the forest and thus avoided breeding far away (>50 m) from the forest. Cavity trees left in the central parts of even a relatively small clear-cut (e.g., >3 ha) have thus minor significance as a potential nesting trees.

Kaila et al. (1997) studied the significance of dead trees left in clear-cuts for saproxylic beetles. They concluded that these dead trunks are important not only for generalist beetles but for many beetle species specialized to warm, sun-exposed environments.

However, in spite of the new management recommendations fragmentation of forest landscape will continue under the present logging practices. Therefore, the construction of new forestry roads causing additional fragmentation of forest areas should be considerably reduced, particularly in forest areas, where they, as yet, do not exist.

The different activity patterns of the new forest management recommendations should be represented in every region, and these schemes should be carried out by regional forest planning. However, as private people own 63% of forest land in Finland, and as much as 75% in southern Finland, this kind of planning is largely dependent on the land owners willingness to follow these recommendations.

In regional forest planning different needs should be taken into account, such as wood production and maintaining forest biodiversity, as also economic objectives and other environmental values. In the Finnish Forest and Park Service the compiling of such multiple-needs plans has started some years ago, and they should cover all state-owned land (representing about 25% of all forest in Finland) in a next few years. An essential part of multiple-needs plans is so-called landscape ecological planning (Hallman et al. 1996). This planning is the overall consideration of nature values in a relatively large area (50 – 500 km^2). This plan includes mapping of important key biotopes for biota, mapping of other nature, landscape and cultural values, maintaining ecological corridors and stepping stones for the biota and structural characteristics of forests to simulate natural dynamics, and definition of

areas of being restored or improved in terms of biodiversity. The purpose of ecological corridors and stepping stones (small patches of valuable habitats) is to maintain dispersal possibilities for species between larger areas of, e.g., old-growth forests. Landscape ecological planning should ensure the maintenance of biodiversity in a landscape of predominantly managed forests.

Although landscape ecological planning approach is basically an adequate framework for forestry of large areas, the quality of existing forest landscape management plans varies considerably. In some cases these plans have slightly increased the proportion of old-growth forests intended to be preserved, but using selected cases Mönkkönen & Reunanen (1998) concluded that the planned corridor networks are more aesthetic constructions buffering water courses against negative effects of forestry than true dispersal corridors for forest associated species. Corridors are too narrow (25 – 100 m) for many forest specialist species or corridors are not forest at all, but various wetland habitats along watercourses (Mönkkönen & Reunanen 1998).

In regional forest planning an important issue is to ensure that different forest types are represented in appropriate proportions (Haila 1994). For instance, spruce forests have considerably decreased in northern Finland during the past decades as a consequence of forestry. This is because spruce forests have largely been regenerated by pine. In order to restore missing characteristics of a managed forest landscape several procedures should be carried out. Forestry should try to simulate the effects of natural dynamics as much as possible (Haila et al. 1994, Angelstam and Pettersson 1997, Angelstam 1998). For example, in natural conditions there usually is not a complete turnover of tree individuals in a given site as a consequence of fires or storms: in general, part of the trees survive these disturbances causing continuity of tree generations within a forest. It should also be noticed that when a disturbance kills all the trees it causes a very large amount of dead wood in the area. In managed forests, on the contrary, clear-cutting of a forest removes all or a great majority of trees in a given site. Thus, to better ensure tree continuity, selective cutting should be preferred, whenever possible. Small-scale key biotopes already presented by several forest programmes should be left untouched. The use of longer rotation cycles should also be considered. Increasing the amount of decaying and deciduous wood in managing forests is clearly a task that should be carried out. This means also that systematic removal of wind-fallen trees should be avoided.

In Sweden a so-called ASIO model has been developed for forestry to better mimic the disturbance dynamics of different forest types (Angelstam et al. 1993, Angelstam 1997, 1998). This model is based on the intensity and significance of fire occurring in different types of forests. Forests are divided into those which burn almost never (A), seldom (S), intermediately (I) and often (O). Different forestry practices should be carried out in these four fire frequency classes.

However, there is still little information available about the positive effects of these new harvesting methods on forest biodiversity. Thus, before such studies have been conducted these forestry methods should be regarded as 'working hypotheses' (Niemelä 1997). Clearly, research into the feasibility of these methods should be encouraged.

As forests are utilized at a large scale in Finland also in the future, one way to minimise the negative effects of forestry on biota would be to concentrate timber production more clearly to certain areas. This would mean that there are different types of forests: first, managed forests with high management intensity ('talousmetsät', Ministry of the Environment 1994), second, managed forests with low management intensity and high biological and conservation value ('luonnonarvometsät', Ministry of the Environment 1994) and, third, protected forests. So, if the

total cutting volume remains the same, logging activities should be increased in certain areas and decreased in other areas. For instance, drained mires which have largely lost their natural characteristics could mainly be used for intensive tree production. The valuable old-growth forests and other natural forests that are not to be protected should be managed with special care by using selective cutting to ensure the continuity of trees.

17 Research priorities

Scientifically valid reviews on the biodiversity of various forests are insufficient, see however, Haila (1994) and Haila et al. (1994). The need for more knowledge applies not only to protected areas, rare and endangered species, but also to managed forests, and to the impacts that forest management practices have to biodiversity.

In general, there is an urgent need to study in detail the effects of forestry practices on biota. These studies should include both local scale, intensive research within a forest stand; and a larger, regional scale, which covers extensive scientific work within a landscape perspective. The important topics to be studied include ecological and structural components of biodiversity (e.g. amount of decaying wood, old-growth trees and broadleaved deciduous trees) available and needed within the managed forests, and the amount of old-growth forests needed at the landscape scale.

A study of the dispersal of species is of utmost importance, as several species preferring old-growth forests probably have a poor dispersal ability. Consequently they are susceptible to habitat fragmentation. The effects of habitat fragmentation on different groups of biota should also be studied. This information is important for the landscape ecological planning. As forest ecosystems are rather complicated systems, research on species' interactions should be encouraged.

The significance of key biotopes (see chapter 15) for biota should be studied properly. Key biotopes are taken into account in managing forest habitats but due to their extremely small size (0.1 – 1 ha) their importance for sustaining biodiversity in the long run is uncertain. Better knowledge on the importance of ecotones and transition zones in forest landscapes is requested, e.g. for assessing ecological corridors and stepping stones in the context of landscape ecological planning.

The network of protected areas in Finland should be analysed from the viewpoints of biogeographic complementarity and urgency for conservation measures to discover the deficiencies in the network. This includes the analysis of the impact that surrounding areas have on a protected site. For instance, many protected mires are actually parts of larger ditched mire areas. Often the drained mire margins affect detrimentally the hydrological regime, and consequently the biota of the protected part of the mire. The evaluation of the Finnish reserve network is currently (1997 – 2000) being carried out in the Finnish Environment Institute.

The restoration methods and practices should simulate natural disturbance regimes of forests, i.e. by creating structural elements characteristic to natural forests. Part of structural features of a natural forest or mire habitat can be created in some tens of years. Resilience of species diversity on restored habitats is, however, widely unknown. Evaluation of restoration and management experiments is therefore highly requested.

Determining and monitoring biodiversity of forests should be connected to measurable parameters. There is also a need to develop methods for assessing the conservation value of different types of habitats and areas.

A monitoring system is required to yield information on the state and changes of biodiversity in forests. In general, monitoring of changes both in the structure of forests and in the species and habitat diversity is essential. Monitoring of popula-

tions and forests should be carried out in areas remaining natural (protected areas) and in managed forest landscapes to detect the effects of changes, both detrimental and favourable, in sustaining biological and structural diversity of forests.

In order to promote high-quality research on biological diversity the Finnish Biodiversity Research Programme (FIBRE), a six-year programme, started in 1997. FIBRE is funded by a broad range of end users of biodiversity data and knowledge: the Academy of Finland, different Ministries, foundations and other organizations. FIBRE includes altogether 59 scientifically-based projects of which 23 are concentrated on forest sector. In FIBRE interdisciplinary approaches are emphasized. FIBRE focuses both on basic and applied biodiversity research, e.g, for forest management. For instance, the scientific, ecological basis of landscape ecological planning is studied in many projects.

18 Concluding remarks

It should be stressed that native species of boreal forests have adapted to natural dynamics and natural disturbances. Therefore, it is of crucial importance that forest management should simulate natural dynamics. Intensively managed forest landscape is a new ecological situation to which many species are not adapted. It should be noticed, however, that Fennoscandian boreal forests have been under continuous change during the past 10 000 years also without human influence. But the important issue is that environmental conditions in the forest landscape have never changed so rapidly as presently due to human influence: e.g., within the past 50 years the forest landscape has changed thoroughly in the whole of Finland. The relatively slow natural change in a period of thousands of years, for instance, in tree species composition in Fennoscandia (see chapter 4), is highly different from human-caused, rapid change in tens of years.

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Appendix 1

Forests of boreal and temperate Europe based on European Union's Habitat Directive. The new habitat types presented by Finland and Sweden are in asterisk.

Boreal habitat types:

Western taiga

* Fennoscandian hemiboreal natural old broad-leaved deciduous forests (*Quercus, Tilia, Acer, Fraxinus* or *Ulmus*) rich in epiphytes
* Natural forests of primary succession stages of landupheavel coast
* Nordic subalpine/subarctic forests with *Betula pubescens* ssp. *czerepanovii*
* Fennoscandian herb-rich forests with *Picea abies*
* Coniferous forests on, or connected to, glaciofluvial eskers
* Fennoscandian wooded pastures
* Fennoscandian deciduous swamp woods

Temperate habitat types:

Tilio-Acerion forests of slopes, screes and ravines
Old acidophilous oak woods with *Quercus robur* on sandy plains
Bog woodland
Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*

Appendix 2

Key biotopes according to the Forest Act and Nature Conservation Act in Finland

Key biotopes of the Forest Act:

Small herb-rich woodlands
Herb-rich and fern-rich wooded peatlands and marshes
Rich fens (except Lapland)
Natural springs, brooks and small ponds with their surroundings
Small wooded mineral islands in mire areas
Exposed rocks and rock cliffs, with their basement woodlands
Rocky crevices and gorges
Sparsely wooded mires and shore marshes
Sparse woodlands on sands, rocky outcrops and boulder fields

Wooded key biotopes of the Nature Conservation Act:

Natural woods of valuable broad-leaved trees (oak, elm, ash, lime)
Hazel woods
Black alder swamps
Sparsely wooded sand dunes

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Abstract

This paper deals with patterns of biological diversity in Finnish forests and processes, both natural and human-caused, affecting this diversity. Ecologically relevant issues in relation to maintenance of biological diversity, such as problems in measuring biodiversity, implications of ecological models, habitat fragmentation and systematic reserve selection are introduced. The work presents an overview of means of maintaining biological diversity in Finnish forests.

Forests in boreal zone were originally modified by natural disturbances, such as forest fires and storm fells. The native species of boreal forests have largely adapted to natural disturbances and successive natural dynamics. At present, almost all forest land outside protected areas is subject to systematic silvicultural practices. Intensive forest management changes the structure of forests and regional distribution and proportion of forest types in a way to which all species are not adapted.

Because it is impossible to maintain all the characteristics of natural forest landscape and forest structure in intensively managed forests, the foundation of nature reserves is of utmost importance. The present reserve network should be enlarged, and the minimum level should be at least 10% of forest land protected in each biogeographic forest zone in a long term. Forest management practices should take into account the demands of sustaining biodiversity, such as preserving small scale key biotopes. In general, forestry should simulate natural dynamics of forests as much as possible. Effects of forest management on biota and adequacy of reserve network in preserving biodiversity are essential future research priorities.

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Tiivistelmä	Tässä julkaisussa tarkastellaan metsiemme biodiversiteettiä ja siihen vaikuttavia prosesseja. Työssä tutkitaan sekä luonnon dynamiikan että ihmistoiminnan vaikutuksia metsiemme monimuotoisuuteen sekä tuodaan esille toimenpiteet, joiden avulla monimuotoisuus voidaan tulevaisuudessa säilyttää. Julkaisussa tarkastellaan mm. metsiemme ja lajistomme erityispiirteitä, ekologisia malleja ja niiden tarjomia mahdollisuuksia arvioitaessa lajistomme säilymistä sekä ekologisesti relevantteja toimenpiteitä ylläpitää biologinen monimuotoisuus. Boreaaliseen metsäluontoon on aiemmin vaikuttanut ns. luontainen häiriödynamiikka, kuten metsäpalot ja tuulenkaadot. Boreaalisten metsien lajit ovat sopeutuneet metsäluonnon häiriöiden olemassaoloon ja metsäluonnon dynamiikkaan. Nykyisin kuitenkin lähes kaikki metsät suojelualueiden ulkopuolella pyritään hoitamaan puuntuotannon tavoitteiden mukaisesti. Intensiivinen metsätalous muuttaa metsien rakennetta ja metsätyyppien alueellista koostumusta tavalla, mihin osa lajeista ei ole sopeutunut. Koska luonnonmetsämaisemaa ja luonnonmetsien rakennetta ei voi säilyttää intensiivisesti puuntuotantoa varten hoidetuissa metsissä, suojelualueiden perustaminen on välttämätöntä. Nykyistä suojelualueverkkoa tulisi laajentaa ja tavoitteena tulisi olla, että pitkällä aikavälillä vähintään noin 10 % metsämaasta olisi suojeltu kussakin metsäkasvillisuusvyöhykkeessä. Metsänhoidon tulisi ottaa huomioon biodiversiteetin ylläpito talousmetsissä, kuten ns. avainbiotooppien ja muiden arvokkaiden luontokohteiden säilyttäminen hakkuiden yhteydessä. Metsätalouden vaikutus lajistoon sekä suojelualueverkon riittävyys monimuotoisuuden säilyttämisessä ovat keskeisiä tulevaisuuden tutkimustarpeita.	
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Sammandrag

I den här publikationen granskas den biologiska mångfalden i våra skogar samt de prosesser som påverkar den. I arbetet undersöks såväl den naturliga dynamiken samt människans inverkan på den biologiska mångfalden i våra skogar. Härtill presenteras åtgärder som gör det möjligt att bevara mångfalden i framtiden. I publikationen granskas bl.a def finska skogarnas och arternas särdrag, ekologiska modeller och de möjligheter dessa erbjuder för att uppskatta bevarandet av arter.Ytterligare granskas ekologiskt relevanta åtgärder for att upprätthålla biologisk mångfald.

Den boreala skogsnaturen har tidigare påverkats av naturliga störningars dynamik såsom skogsbrand och vindfällen. De boreala skogarnas arter har anpassat sig till skogsnaturens störningar och dess dynamik. Numera strävar man emellertid att sköta nästan alla skogar utanför skyddsområden så att trädproduktionens mål uppfylls. Intensivt skogsbruk förändrar skogarnas uppbyggnad och den regionala sammansättningen av skogstyper på ett sätt som en del av arterna inte har kunnat anpassa sig till. Eftersom skogslandskap och naturskogars uppbyggnad inte kan bevaras i skogar som sköts enligt den intensiva trädproduktionens principer är det nödvändigt att skapa skyddsområden.

Det nuvarande nätverket av skyddsområden bör utvidgas och målet borde vara att man på långsikt bevarar minst 10% av skogsmarkerna i samtliga skogsvegetationszoner. Vid skogsbruk borde man beakta bevarandet av biologisk mångfald i ekonomi-skogar såsom nyckelbiotoper och andra värdefulla biotoper i samband med avverkning. De mest väsentliga forskningsteman i framtiden är hur skogsbruket påverkar artsammansättningen och hur väl nätverket av skyddsområden kan bevara den biologiska mångfalden.

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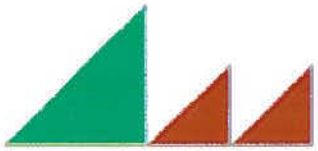

NATURE AND
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Maintaining biological diversity in Finnish forests

Forests are highly important for the Finnish economy and for the welfare of Finnish people. However, intensive exploitation of forests will eventually cause a decrease in biodiversity of forests, for which reason the use of forests should be on a sustainable basis also in terms of ecology of boreal forests.

This report presents an overview of processes and patterns affecting biodiversity in Finnish forests. The specific Finnish features, both natural and human-caused, having an influence on present biota in forests are introduced. An important and essential issue is, how to maintain biological diversity in forests also in the future.

This report provides information to all, who are interested in biodiversity of Finnish forests or boreal forests in general.

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