

## ОХОРОНА І СТАЛЕ ВИКОРИСТАННЯ ЛІСУ ТА ЛІСОВИХ РЕСУРСІВ

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### SUSTAINABILITY OF FORESTS AND WOODLANDS: THE NEED TO MATCH ECOLOGICAL AND MANAGEMENT DIMENSIONS AT THE LANDSCAPE LEVEL

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Realizing ecological sustainability requires an understanding of how landscape management can maintain ecosystem processes, and habitats that are sufficiently similar to those required for maintaining viable populations of native species, i.e. biodiversity. Protecting, managing and restoring biodiversity requires that both the range of natural disturbance regimes and the resulting forest and woodland environments (the ecological dimension) are understood, and that a corresponding range of different land management regimes exist (the management dimension). Finally, the management regime applied for a given forest environment should harmonize.

This paper summarizes knowledge about forest and woodland disturbance regimes to which species' populations have adapted, as well as the range of management methods that are applied both to forests and woodlands in Europe. Natural disturbance regimes are divided into 3 main groups: succession following large-scale natural disturbance such as fire and windfall, cohort dynamic after repeated low-intensity disturbance, and gap dynamic caused by mortality of trees in small patches. Forest management systems also form 3 groups: even-aged, multi-aged and uneven-aged. Additionally, pre-industrial cultural landscape management should be considered.

In principle there is good potential for emulating natural disturbance regimes by management both in forestry and cultural landscapes. However, a wider range of successional stages and tree species combinations need to be maintained compared with situations when wood production is the only objective. Most forest and woodland management practices are poor at maintaining coarse woody debris of different decay classes, very large and old trees.

I finally stress that stand-level management needs to be developed with an overarching landscape level strategy to satisfy the different aspects of sustainable forest landscape management. Building an international network of case study landscapes to develop partnerships locally, regionally and internationally would alleviate this.

*Key words:* Sustainable forest management, biodiversity, landscapes, spatial scales, a natural disturbance regime.

Sustainable development is a general vision for natural resource management (Sayer and Campbell 2004). The maintenance of ecosystem services, functionally

connected habitat networks and viable populations of species are prerequisites for attaining ecological sustainability. To maintain, and if necessary to restore, ecological sustainability in forests and woodlands one needs to understand the extent to which existing land use practices harmonise with the natural dynamics of the ecological past of the different tree-dominated environments. This requires that both the range of natural disturbance regimes and the resulting forest and woodland environments (the ecological dimension), as well as the range of different land management regimes that can be applied (the management dimension) are reasonably well known. It also requires that the management regime chosen for a given forest environment harmonise at the scales of trees and stands as well as landscapes and even regions. To implement ecological sustainability a landscape approach that integrates ecosystem and social systems is needed (Angelstam et al. 2003, Lazdinis and Angelstam 2004).

Forest management involves the use of forests to meet the objectives of the landowners and society at large. After a long history of focus on wood production we saw during the end of the 20<sup>th</sup> century a strong international policy trend towards multi-objective management including the maintenance of ecological processes and sufficient amount of habitat structures to maintain viable populations of species (Angelstam et al. 2004a). Simultaneously, however, rapid expansion of forestry into intact forest landscapes (Yaroshenko et al. 2001) and disappearance of traditional agricultural woodland systems due to socio-economic changes are taking place (e.g., Dömke and Succow 1998). These trends are major threats to the ecological sustainability of both naturally dynamic forests and pre-industrial cultural landscapes.

There is, however, considerable knowledge of how to encourage trajectories towards ecological sustainability of forests and woodlands. In the following I will give an overview of the different natural disturbance regimes that are characteristic of Europe's forests, as well as of the associated forest and agricultural woodland management systems. Finally, I discuss how effective development of regionally adapted approaches to implement the vision of ecological sustainability could be alleviated by establishing a network of landscape level case studies representing different trajectories of forest development and system for government and governance (Angelstam and Törnblom 2004a,b).

***Ecosystem management and the natural disturbance paradigm.*** In response to society's concern about the status of forests and woodlands, considerable attention has been drawn to deforestation, loss of species, and the need for sustainable forest management (Rametsteiner and Mayer 2004). Consequently there has been an increased focus on trying to understand the ecology of forests (e.g., Hunter 1999), and to develop management systems that emulate the natural dynamics of forests (Fries et al. 1997, Angelstam 2003). In North America the concepts of "New Forestry", "forest ecosystem management", "natural disturbance ecology" and "ecological forestry" (Hunter 1999) have been advocated. In practice this can be interpreted as "...manipulation of a forest ecosystem should work within the limits established by natural disturbance patterns prior to extensive human alteration of the landscape" (Hunter 1999). The key assumption behind the natural disturbance paradigm is that native species have evolved under natural disturbance conditions. Thus the maintenance of sufficiently similar conditions offers the best insurance for maintaining the functions, habitats and species of that ecosystem.

Similar ideas have been put forward also in Europe. In both western (e.g., Peterken's (1996) "natural approach") and central Europe (e.g., Remmert's (1991) "mosaic cycle concept") the natural dynamic of forests have been proposed as sources of inspiration for forest and woodland conservation. In Scandinavia biodiversity maintenance became a

management objective in the 1970's, mainly as a response to large clear-felled areas and reduced amount on natural forest legacies. During the 1990's the natural disturbance regime concept became an accepted approach to argue for applying an increased range of silvicultural methods in boreal forests (Fries et al. 1997, Angelstam and Pettersson 1997, Angelstam 1998). Still, however, clear-felling methods dominate completely.

To describe the idea that landscape management that builds on natural forest disturbance regimes can maintain ecological sustainability, words such as emulate, imitate and mimic, have been used. In most cases, however, landscapes should harbour a wide range of goods and services other than ecological ones. Often, a full imitation of the natural disturbance regime would seriously conflict with the interests in economically essential commodities. To strike a balance between all these interests means that the idea of maintaining the full range of variability is usually not feasible. Rather, maintenance of biodiversity in managed landscapes is a matter of letting management be sufficiently similar to the natural disturbance regimes, but still within the range of natural variability. If this is not the case, part of the landscape must be used to establish functional networks of protected areas, or be managed with the explicit objective of maintaining forest biodiversity. This stresses the urgent need for quantitative targets about "how much is enough" of different structural elements ranging from dead trees and logs to protected areas and processes of forests across spatial and temporal scales (Fahrig 2002, Angelstam et al. 2004b). It also requires development of tool to monitor the status and trends of the components of biodiversity (Noss 1990, Angelstam and Dönz-Breuss 2004) as well as efficient communication between policy, science and practise.

**Natural disturbance regimes.** A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment. A prerequisite for biodiversity maintenance in managed landscapes is to understand and emulate closely the natural disturbance regimes to which different species have adapted (Hunter 1999).

The diversity of forest types in a landscape is determined by the interaction between non-biotic and biotic factors. Climate, topography, soils, and access to nutrients and water determine the range of possible compositions of tree species (Ellenberg 1996). The composition and structure of trees are modified by different kinds of interactions and disturbances. These range from non-biotic (e.g., fire, wind, water) to biotic (e.g., grazing, browsing, predation) and anthropogenic (e.g., clearing, livestock grazing).

Different combinations of non-biotic, biotic and anthropogenic landscape trait layers create characteristic disturbance regimes. Disturbance regimes vary along a continuum from large-scale disturbances, such as fire, wind, floods, and insect outbreaks to small-scale or localized disturbances such as gap formation caused by fungi, insects and single tree fall. In the following I divide the forest formation processes into three groups: even-aged, uneven-aged, and all-aged (for details see Johnson 1992, Oliver and Larsen 1996, Angelstam 2003, Angelstam and Kuuluvainen 2004). To stress the dynamic characteristics of each group, I use the words successional, cohort, and gap dynamics.

**Successional dynamics.** Trees of a single age class, or cohort, proceeds from life to death through a series of developmental stages. Large-scale disturbances such as fire or wind initiate succession and allow forests to regenerate over large areas simultaneously. Due to spatial and temporal heterogeneity of disturbances the structural complexity of age classes within a landscape increases with age. However, if viewed over longer time spans, successional stages are usually ephemeral at a particular locality. Thus, to persist in the landscape, species specialising in a particular successional stage must be able to disperse from areas with suitable but degrading habitat in order to colonise new sites where the

habitat conditions are good or improving. A critical requirement of many species is therefore that a stable patch dynamics is maintained within the landscape, and with a sufficiently large variation in patch size and distance between patches. Because species have different area requirements, the size of a landscape can be viewed as species-specific.

At the scale of a stand that has resulted from a large-scale disturbance event, succession produces gradually ageing cohorts with a more or less narrow age distribution. Empirical data from boreal and temperate forest show that the maximum possible range of all the different steps in the succession usually exceeds well over 250 years (Jahn 1991, Johnson 1992).

The development of a single cohort of trees following a disturbance event can be divided into several stages. In managed forests, the terms harvested, young, thinning and final felling are useful as they link the development of the stand to the silvicultural operations. In addition, later developmental stages of particular importance for forest biodiversity need to be included. In the following six stages are used.

**1. Stand initiation.** The type and severity of disturbance together with pre-disturbance stand structure fundamentally affects the initial conditions for succession. Structural legacies from the previous generations, such as standing and down coarse woody debris and living trees strongly affect the density, species composition, growth, survival and spatial pattern of regeneration. A number of the trees damaged may die during some years after disturbance. There is also a variable mosaic of forest floor microsites, which often leads to high spatial variation in abundance and species of the tree regeneration. Immediately following extensive disturbances such as fire, wind-throw and large-scale insect outbreaks the environmental conditions are often unique. As an example, many species of insects have adapted to this by using the burned or sun-exposed dead wood as a substrate. Similarly, the germination of some plants is enhanced by heat.

**2. Young forest.** The growth of the trees and gradual closing of the canopy leads to changes in conditions on the forest floor: the amount of light and wind speeds decrease, and humidity increases. In this phase the typical herb, shrub and tree layer vegetation starts recovering, often after a phase of herb-rich pioneer ground vegetation. After natural disturbance, there are often large amounts of coarse woody debris as well as living trees and patches of trees left as legacies from the previous stand. Dead remnants from the previous stand start to decay. It should be noted that even a severe stand-replacing fire usually does not consume more than about 20 % of the standing biomass of the burned stand (e.g. Johnson 1992). Moreover, considerable proportions of the disturbed area are often left intact as groups and stands of trees.

**3. Middle-aged forest.** In this phase of the stand development, or towards the end of the previous stage, severe competition among trees typically leads to stem exclusion (self-thinning), where some trees die from lack of light or soil moisture, a process called competitive suppression. However, this may not happen if the regeneration has been sparse and the trees are widely spaced. Later the light-demanding tree species genera that first colonised the disturbed area may gradually be replaced by shade-tolerant species. However, once established as dominants light demanding species are able maintain their position for a long time on sites that are suitable for them. At this phase trees totally dominate the site and many light demanding plant and animal species disappear from the understorey vegetation.

**4. Mature forest.** In this phase the trees regenerated after disturbance approach their final height. The term mature is used to denote that it is during this phase that trees are usually mature for final felling within sustained yield forest management. The amount of coarse woody debris is at its lowest, as the dead wood created in the disturbance has largely

decayed but significant amounts of new coarse woody debris has not yet been created (Siitonen 2001). The importance of competition induced mortality decreases, and mortality due to other causes such as fungi and insects starts to increase. At this phase light-demanding species start to show signs of decreased vigour, and become important substrates for many specialised species. The forest may gradually start to acquire a multi-storey structure.

These four first developmental stages in the succession after severe disturbance have their equivalents in most managed forests. However, due to various silvicultural practices the tree species composition, the vertical and horizontal vegetation structure as well as the amount and types of dead wood are being manipulated with the aim to remove undesired forest components.

**5. Ageing forest.** In this stage scattered trees that previously were successful become more and more vulnerable to damage or death due to senescence, insects, fungi, snow-break, wind, falling trees or other factors. Trees from different canopy layers are dying and forming dead wood structures. Dead wood also starts to accumulate, but this may not happen if the trunks of dominant trees decompose fast. Unless a new disturbance occurs, the ageing and opening stand increasingly differentiates in its vertical and horizontal structure. The gaps in the canopy allow more light and moisture to reach the forest floor. As a result of increasing light the understorey vegetation starts to develop, and an advance regeneration of shade-tolerant species emerges. In this phase, shade-tolerant tree species are becoming older and start to develop diameters of interest for the largest primary nest excavators, bark texture becomes suitable for different specialised lichens, and trees can carry the nests of large birds. The vertical and horizontal vegetation structures become more complex.

**6. Old-growth forest.** After one to three centuries, depending on tree species and geographic region, in the absence of complete or partial stand-replacing disturbance, most trees that regenerated after the initial stand-replacing disturbance have died. The stand is generally rather open due to the formation of gaps in the canopy as large trees or groups of trees die and fall down. Coarse woody debris is abundant and different types and sizes of dead wood is formed continuously all over the forest. The opening of the canopy creates a diverse horizontal understorey vegetation mosaic. Gap sizes and characteristics vary creating vertical and horizontal structural heterogeneity in the tree layer. The tree age distribution is dominated by old trees but with young cohorts appearing both in gaps and as an additional vegetation layer. The relationship between the size and the age of the trees is becoming less and less obvious. Finally, it must be stressed that an old-growth forest is not a static end-point of stand development, but a dynamic changing system itself. Thus, there is great variation in old-growth forest structures depending on the characteristics and duration of the developmental history.

**Cohort dynamics.** Several tree species show adaptations to low intensity disturbances. Scots pine (*Pinus sylvestris*) and fire provide a good example in the European boreal zone. Scots pine forests on dry sites are often characterised by frequent low-intensity fires that produce stands with multiple aged cohorts of trees (Sannikov and Goldammer 1996). A Scots pine tree becomes less sensitive to fire damage with increasing age due to its thick bark and to the long distance between the ground and the fuel in the canopy. As a consequence, Scots pine forests often have several distinct age cohorts of living trees and standing snags, both of which eventually produce a continuous supply of dead wood in different stages of decay on the ground. Such a forest often has a park-like appearance, although in many areas the understorey layer may be quite dense. In natural Scots pine forests there are typically 3-5 distinct cohorts that range over at least 200-300 years of age

(e.g., Sannikov and Goldammer 1996). Sometimes, due to the absence of fire for longer time periods, and to the associated accumulation of nutrients, the site type may develop towards a more productive one.

**Gap dynamics.** While cohort dynamics are driven mostly by external abiotic disturbance often operating on larger areas, gap dynamics is caused mostly by biotic or autogenic disturbances operating at the scale of individual trees and tree groups. Hence, in the absence of large external disturbances, the death of single tree or groups of trees mainly due to biotic disturbance agents drives forest dynamics by forming gaps in which more or less shade tolerant trees can regenerate. A relatively even, both temporally and spatially, process of mortality and regeneration determines the stand dynamics. The age/diameter distribution of trees within a stand conveys no information of the typical age structure. The internal age distribution can be characterised as all-aged or consisting of multiple cohorts. Note however that the relationship between the size and age of trees is often poor because small trees can become very old when they grow in the shade of older trees.

In naturally dynamic landscapes stands with gap dynamics often form corridors, networks or clusters in the wet and moist parts of the landscape. Typically, these forests have a relatively moist and stable microclimate and a continuous supply of dead wood in different stages of decay. This type of dynamics also occurs in large extensive areas where the climate is moist and fire cycles are long enough for this stage to develop, such as at high latitudes and altitudes. The tree species involved include shade tolerant coniferous and deciduous tree species.

#### ***Silviculture and other tree management systems***

**Silvicultural systems.** Trees are the main components that affect the distribution and abundance of other forest species, directly and indirectly. As trees can also be found in other vegetation types not traditionally called forests, not only forestry but also agriculture and other forms of land use that include trees as components have a joint responsibility for the biodiversity associated with trees (for details see Matthews 1989, Angelstam 2003).

Foresters group different silvicultural systems using the gradient between even-aged and uneven-aged systems. There are three general types of age-class structures that are managed for: even-aged, stands with two age classes, and uneven-aged. Even-aged systems (1) include clear-felling or seed tree systems, the intermediate double-cohort systems (2) include shelterwood systems, and finally uneven-aged systems (3) include single tree and group selection.

**Even-aged management with clear-felling systems.** In even-aged stands all trees germinate, sprout or are planted at about the same time. While the tree size will increasingly vary as the stand ages, the calendar age of the trees is about the same when it is time to regenerate the stand. Because of a definite beginning and end it is often relatively easy to characterise stands just by the stand age (similar to or slightly shorter than time since disturbance) as well as to guide decisions about treatments and harvesting of the stand. It is also easy to manipulate the genetic makeup by planting or seeding. There is a wide range of terms applied and the following three methods are commonly used. The smallest recommended stand size ranges from 0.5 ha to tens of hectares, but clear-felling may also cover thousands of hectares.

**Clear-felling/coppice:** This is the most common silvicultural regime. It implies the removal of the entire stand in one cutting. Coppice can be viewed as a special case of clear-felling, which is dependent on vegetative regeneration of sprouting broad-leaved species such as *Populus*, *Corylis*, *Carpinus* and *Fraixnus*.

**Seed tree method:** This method involves removal of the old stand in one cutting,

except for a number of seed trees left dispersed or in small groups to ensure the recruitment of a future tree generation. When a new tree generation has been secured, the seed trees are removed, usually with a considerable addition of valuable diameter growth.

Variable retention: In response to criticisms to clear-felling, considerations to both visual values and biodiversity maintenance have been developed. Retention of trees during harvest may include both dispersed trees and patches or clumps of trees. Compared with the seed tree method the aim is, however, different. For visual reasons the shape and manner of harvesting can be designed to avoid the visual impression of almost complete harvesting. For biodiversity the retention trees usually include forest components typical of old-growth stands (e.g. large/old trees, snags, coarse woody debris), and buffer zones along streams and wetlands.

***Double-cohort management with shelterwood systems.*** In this system the removal of the old stand takes place in a series of cuttings, which extend over a relatively short part of the successional development. The establishment of the next cohort takes place under the partial shelter of the seed trees, or under trees of other species. These double-cohorts represent an intermediate category in which the presence of both cohorts can be temporary or continuous.

Shelterwood cutting: Shade-tolerant species are often regenerated under a protecting canopy of remnant trees from the previous stand. The aim is to reserve the best trees, which have large crowns and strong boles. Such trees are considered both windfirm and with the health and vigour that lead to good seed production.

Coppice with standards: This system includes the combination, in the same area, of short-rotation coppice growth with scattered older trees (standards). The standards are often species that may be of seedling origin. While the generation time of the coppice is only a few decades the standards may be harvested at ages exceeding a century or more. A common combination in Central Europe is *Fraxinus/Carpinus/Corylus* as coppice and *Quercus* as standards (Kirby and Watkins 1998).

***Uneven-aged management with selection systems.*** In uneven-aged stands there is no definite beginning or end in time of stand development. Trees in a given area vary by age as well as size, and contain, depending on the ecoregion, one or several different shade-tolerant species. Throughout their lives the trees compete for light or moisture with larger or taller trees nearby. Uneven-aged stands are in principle composed of small even-aged cohorts of different ages located in gaps of different size in the stand. As each little even-aged group becomes older competition reduces the number of trees, first rapidly and later more slowly.

For some management purposes a distinction is made between balanced and irregular uneven-aged stands. In a balanced uneven-aged stand there are three or more age classes, each occupying an equal area. Irregular uneven-aged stands do not contain all age classes and will therefore not ensure that trees will arrive at a certain time at an even rate. In the contemporary Central European and old Scandinavian literature the terminology on uneven-aged silvicultural systems is very diverse. Following Mayer (1992) I include only two types, the single-tree and group-selection systems.

Single-tree selection: In the classic form of the selection system every even-aged cohort of the uneven-aged stand occupies a space about equal to that created by the removal of a single tree. Stands, or whole forests, are characterised by these scattered gaps with small even-aged groups of trees, which are thinned as they grow. The types tree species that are perpetuated with this system are shade-tolerant (e.g. *Fagus*, *Abies*, and *Picea* on good sites).

Group-selection system: If the regeneration openings are made larger, the

ecological requirements of a range of other tree species will be satisfied. A special case of the group-selection system is strip-selection (Saumschlag in German). Here the components of the uneven-aged stand are created in slowly advancing strips. Advantages are that the harvested wood can be transported through the old stand and the strips can be arranged so the front of progressively taller trees faces the prevailing winds.

**High-grading.** Although not a silvicultural system, harvesting of the most valuable trees and stands usually forms the first phase of forest usage in any region. As a consequence, the diameter of the trees is gradually being reduced, as well as the area of old forest in general, and large intact areas in particular. Subsequently, there is usually a need to restore the wood supply by introducing forest management of some kind based on the principle of sustained yield of wood.

**Old cultural landscape management regimes.** Clearing and cultivation of forested land, a major impact on forests for millennia, has caused a dramatic reduction and fragmentation of the once naturally dynamic primeval forests. Nevertheless, in some regions, forest biodiversity has to some extent been rescued by management methods practised in the old cultural landscape. To maintain summer and winter fodder for cows, sheep and other domestic animals, land was managed using fire, mowing, clearing, tree and water management (Kirby and Watkins 1998). This range of cultural disturbances often resulted in forest biodiversity being maintained because of the presence of large and special trees in a landscape dominated by grazing and/or agriculture. Today such habitats usually remain as small isolated patches in a managed matrix. However, in parts of Europe pre-industrial management regimes are still in use. This applies to remote valleys in mountainous areas, as well as in regions to which the agricultural revolution with intensive management has not yet reached.

The ancient practice of pollarding and lopping whereby branches of trees are cut but the tree itself is not, does maintain large trees that are growing slowly. Coarse woody debris on the ground was often limited but dead wood was available in the crowns of large trees, which were left to shade the ground. As a consequence, suitable substrate both on the outside of the trees, as well as inside if hollow, will provide habitat for many forest species ranging from shade-intolerant vascular plants, lichens and insects to large birds nesting in cavities and large trees. Similar trends in the development of the composition and structure of domesticated trees (e.g. olive and fruit trees) have occurred both in Central Europe and the Mediterranean.

**Do natural disturbance and management regimes harmonise?** The development of different management systems has been inspired by natural disturbance regimes (e.g., Mayer 1992). Hence, as shown in the summaries of natural disturbance and management regimes above, there is a basic similarity between the two suites. But there are also major differences. In this section I focus on discussing to what extent the two dimensions differ. For each forest and land management system I analyse the similarities and differences compared with the different natural disturbance regimes and their subtypes. The reasoning rests on the underlying assumption that maintaining biodiversity requires the maintenance of the different developmental stages in succession and the characteristic habitat features of all the different disturbance regimes both at scale of stands and landscapes.

**Even-aged management vs. natural disturbance regimes.** Succession: Because silviculture aims at maintaining a high yield of wood, stands are as a rule harvested at a point when the increase in volume growth starts to diminish. Consequently, the amounts of ageing and old-growth stands will decline with increasing time of application of even-aged forest management under the sustained yield paradigm. Moreover, in the absence of stand-replacing disturbances such as fire and wind blowdown also very early successional stages



are missing. This prohibits the presence of species requiring burned wood, bare soil associated with the rootplates of fallen trees, and heat to allow germination. It should be noted that natural forest systems might include a high proportion of other, both younger and older age classes. To favour biodiversity different systems of variable retention cutting have been developed. For example, in Sweden the amount of residual trees left after final harvesting increased from 2 % in the mid 1980's to 13% in the 1990's (Angelstam and Pettersson 1997). While this certainly improves the quality of the future stands, logging of old and ageing stands continues and causes reduction in both the total amount and individual patch size of such forests.

Cohort-dynamics: Clear-felling with residual seed-trees is superficially similar to cohort dynamic where the stand is dominated by younger cohorts. The obvious difference is the lack of dead wood, both snags and coarse woody debris, in different dimensions and decay stages. However, with long-term consistent retention of trees at every harvest event, a certain amount of dead wood in different stages of decay, and several cohorts of different living trees could be restored over long time.

Gap dynamics: The even-aged silvicultural systems are not appropriate for gap dynamics.

***Double-cohort management vs. natural disturbance regimes.*** Succession: Following large-scale disturbances associated with surviving remnants of the previous stand the establishment of the new stand can lead to a structure similar to a shelterwood system. This could for example be a combination of oak with a turnover time of 100+ years and coppice; i.e. the typical Central European Mittelwald.

Cohort-dynamics: This kind of dynamics can to a large extent be emulated in forest management with repeated retention of trees and dead wood, and the use of fire as a biodiversity management tool. The restoration of a dry pine forest where clear-felling with seed tree regeneration could be achieved in the following steps. Instead of harvesting the seed trees when the regeneration of a new stand has been secured, a proportion of the seed trees should be left to develop into a cohort of old trees. During the following rotation the procedure should be repeated. The restoration of dead wood could either be active by leaving high stumps, or passive by leaving wind-blown trees.

Gap dynamics: Not appropriate.

***Uneven-aged management systems vs. natural disturbance regimes.*** Succession: Opening gaps for generating a new tree generation is in principle the beginning of succession. However, this approach would not ensure a sufficiently wide distribution in patch sizes to satisfy the area requirement of many of the species. Gap formation would also often be a too weak disturbance, and therefore exclude many species. Uneven-aged management systems could, however, to some extent maintain the composition and structure of the final old-growth phase in the succession. However, to succeed, the restoration and maintenance of dead wood of different types would also be needed.

Cohort-dynamics: Uneven-aged group-selection management systems could potentially be useful for stands, which naturally have a range of age classes. One example is *Pinus ponderosa* forests that naturally are subject to repeated low-intensity fire episodes.

Gap dynamics: The continuous application of single and group selection harvesting in forests with shade-tolerant tree species such as *Fagus sylvatica*, *Abies alba* and *Picea abies* on fertile soils leads to a multi-layered vegetation structure. Near-to-nature forestry (Naturnahe Waldwirtschaft in German) was developed with the aim of maintaining this forest structure. In spite of this apparent good match between the silvicultural system and the natural disturbance regime, traditional uneven-aged near-to-nature silviculture does

not emulate all components of the natural gap phase dynamics. The absence of dead wood is the most striking difference. But also the absence of large old trees is evident.

***Old cultural landscape management systems vs. natural disturbance regimes.***

**Succession:** A characteristic feature of agriculture is land abandonment. This may take place at all spatial scales. Small fields or whole land holdings may be abandoned due to individual preferences, family events and disputes. Villages, and whole regions, may be deserted as a consequence of famine, disease and changed economic conditions for the current land use. As a result, in spite of active management, certain successional stages in the development from abandoned pastures, meadows and fields have a chance of being dynamically present in the landscape.

**Cohort-dynamics:** The maintenance of wooded meadows and pastures can allow the long-term presence of large old trees in a landscape for a very long even if that is not considered a forest. However, for the maintenance of forest biodiversity, such a landscape can provide a crucial rescue effect for a number of species. For example, in Extremadura (Spain) combined sheep, pig and cork production can host large raptors and carnivores.

**Gap dynamics:** The low tree density and limited number of age classes will not host gap phase dynamics unless the area is converted to forest again.

**Exploitation.** Often the early phases of the utilisation of forest resources can be described as tree mining (e.g. Yaroshenko et al. 2001). Only certain species, and/or dimensions are harvested, and the timber resource is viewed as infinite. From a biodiversity point-of-view this is not necessarily a problem in the short term if sufficient residual structure is left at multiple spatial scales. However, in the long term there will be a decline in the area of intact stands and landscapes. It is of paramount importance that functional networks of such unexploited areas are maintained, both for the maintenance of biodiversity, and as benchmark to learn about natural forest dynamics.

**Discussion.** Matching ecological and management dimensions at multiple levels.

There is large variation both among different natural disturbance regimes as well as the management systems in forestry and pre-industrial cultural landscapes. Considering the maintenance of forest biodiversity, some combinations between ecological and management dimensions provide an acceptable match. The comparisons between management systems and natural forest disturbance regimes also show that there is not one "near-to-nature" land management or silvicultural system that is universally suitable. Instead different methods should be adopted in different combinations and contexts, depending on both the forest ecology, local land use history and the management goal for the landscape (cf. Mayer 1992, Hunter 1999, Angelstam 2003). Moreover, there are usually several deficiencies that need to be mitigated by special considerations such as variable retention of live and dead trees and tree groups, or by not utilising parts of the landscape at all.

To maintain forest biodiversity it is insufficient to include only the maintenance of commercially valuable tree species. Moreover, the traditional inclusion of age classes only up to final harvesting needs to be complemented by a continued, albeit dynamic, presence of both ageing and old-growth phases as well as recently disturbed phases in the successional development. For all management systems it is essential that status as well as variance of different forest components and structures should be maintained at a range of spatial scales from that of trees in stands to landscapes in regions (Angelstam et al. 2005).

Contrary to common belief of many stakeholder groups, the maintenance of viable populations of forest and woodland specialists is not only a challenge for sustainable forest management, but also to several forms of pre-industrial agriculture and pastoralism. The reason is that many of the components of forest biodiversity have been rescued, or locally

even introduced and maintained, by ancient traditional management methods that were practised in the pre-industrial cultural landscapes. Europe with its wide range of environments and management traditions provides a good example of this. At present the forest cover in Europe is expanding. If the expansion takes place on low productive agricultural land with a traditional land use this may actually be a threat for many species highly valued by the public and by conservationists as elements of those landscape types perceived as authentic. To conclude, in spite of the relatively good match between the ecological and some of the management dimensions, conservation areas with both protection and active management strategies are necessary parts of a comprehensive approach to maintain and restore ecological sustainability in forests and woodlands.

It should also be noted that although an ecologically appropriate silvicultural system may create the relevant habitat structures and dynamics at the local stand level, this will not automatically provide for the spatial needs of viable populations at the levels of landscapes, and for large species even regions. It is therefore recommended that suites of area-demanding umbrella species are identified for different forest ecosystems (Roberge and Angelstam 2004), the quantitative requirements of which can be used in the planning process within forest landscape management units (Angelstam et al. 2004c). Similarly, it may be necessary to balance both natural processes such as browsing by large herbivores, fungal and insect outbreaks as well as anthropogenic processes such as airborne pollution and the development of transport infrastructures.

***Current forest landscape management challenges.*** Management gradually changes forest landscapes over time. This is particularly evident where the history of land management is long, such as in Sweden. A naturally dynamic landscape has a mixture of disturbance regimes ranging from succession to cohort and gap-phase dynamics (Angelstam and Kuuluvainen 2004). The resulting average age distribution in a large area over long time thus included age classes from recently disturbed to mature as well as 40-60% of different types of old-growth stands (see Figure 1, left). By contrast, the present Swedish age distribution in managed landscapes includes less than 5% old-growth stands. Moreover, the advent of clear-felling practises about 40 years ago forms one peak of younger forests, and one of forests mature for final felling (see Figure 1, middle), both of which with very altered internal stand structure (e.g., little dead wood and limited vertical layering). The present trends with (1) gradually lowered ages for final felling amounting to 60-90 years depending on ecoregion and tree species, and (2) set-aside of about 10% of forests for the conservation of species including variable retention in final-felling stands, riparian corridors and protected areas, will lead to a bimodal age distribution within the coming 50-100 years (see Figure 1, right). As a consequence, there will be severe decline in the kind of mature forest people find attractive for walks and picking blueberries and mushrooms.

At least three different silvicultural approaches can be used to mitigate this trend, and thus gradually transform the age distribution towards one that includes the full range of age classes found in a naturally dynamic landscape.

(1) Continuous cover forestry methods that emulate gap-phase and cohort forest dynamics, and the wooded grasslands of the pre-industrial agricultural landscape, partly for nature conservation aiming at less specialised species, and partly for social reasons in urban landscapes and close to settlements.

(2) Active restoration engineering of natural forest legacies within managed stands such as dead wood, deciduous proportion and vertical stand structure in young and middle-aged stands, mainly for satisfying nature conservation objectives in both terrestrial and aquatic ecosystems.

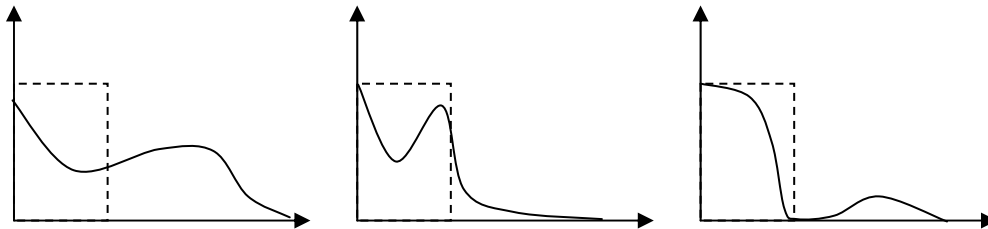


Figure 1. Schematic illustration of how the Swedish forest landscape age distribution has changed from its naturally dynamic structure (left) until today (centre), and what forecasts of the future age distribution looks like (right) (see Pennanen 2002, Angelstam 1997, National Board of Forestry unpubl.). The rectangular age distribution used in regulated sustained yield forest management, and with a final felling age of 100 years is shown for comparison.

(3) Intensive forest management, especially close to the wood-processing industry, to compensate for reduced wood production at the landscape scale due to application of continuous cover forestry, ecosystem restoration, and set-aside of forests in protected area networks.

To implement these measures there is, however, a need for understanding the following.

(1) The natural potential for applying each of these and other management approaches at the scale of landscapes in regions. (2) The extent to which new approaches are needed based on how the history of land use has reduced the actual amount of different types of forest and woodland dynamics, and natural legacies within them. (3) The knowledge about, ability and interest of different forest owners to apply the different silvicultural methods with an over-riding landscape level strategy that results in functionally connected networks of different disturbance regimes, and to satisfy socio-cultural objectives.

**Partnerships for sustainable landscapes.** To conclude, because of a gradually widened set of values to be satisfied within the framework of sustainable forest management (Rametsteiner and Mayer 2004), there is a need for applying silvicultural approaches with a landscape perspective to satisfy a range of objectives such as:

- Sustainable wood production with general considerations towards basic nature conservation (satisfying the needs of generalised species) and socio-cultural and multiple use needs (hunting, fishing).
- Maintaining viable populations of specialised forest and woodland species using protection or specially adapted management at different spatial scales. This sometimes requires integration of forestry and woodland management in agriculture within rural landscapes. Some of these areas should be made easily accessible to the public to learn about forest ecology and the need for functional habitat networks at the landscape scale.
- Protection against hazards such as flooding and avalanches.
- Recreation in urban landscapes including forests that are made available to a wide range of users.
- Intensive forest management to compensate for reduced overall productivity due to the above restrictions.

Accommodating this wide range of ecological, economic and socio-cultural values means that managing forests and woodlands only at the scale of trees in stands is insufficient. Consequently, it becomes necessary to work also at the scale of landscapes in regions and to include effects of forest management outside what is forest, the vision being to develop sustainable landscapes. An important consequence of such a landscape level approach is that it often becomes necessary to zone and schedule forest management of different kinds to maintain sufficiently connected networks of different forest ecosystems. While the idea of landscape zoning appears novel in Western Europe, there is a long tradition in many East European countries of applying planning approaches based on zoning of a landscape to satisfy different dimensions of sustainable forest management (Lazdinis and Angelstam 2005). This is consistent with the generally accepted idea that to assess the level of ecological sustainability there is a need for formulating performance targets (Ekins et al. 2003, Angelstam et al. 2004b). Such targets can be used for assessing the status and trends of ecosystems, and in landscape and regional planning to maintain functional habitat networks (Angelstam and Bergman 2004).

How this kind of spatial integrated natural resource planning for sustainability could be achieved in practice at multiple spatial and temporal scales throughout rural and urban landscapes, are critically important areas of research and development. Even if much research remains to be done, it is clear that a landscape approach encompassing both social systems and ecosystems is needed to develop sustainable forest management in practice (Lazdinis and Angelstam 2004, Angelstam and Törnblom 2004a,b). This is a challenge to the whole society including businesses, public agencies and the education system.

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**СТАБІЛЬНІСТЬ ЛІСІВ ТА ЗАЛІСНЕНИХ ТЕРИТОРІЙ: НЕОБХІДНІСТЬ  
ПОСДНАННЯ ЕКОЛОГІЧНИХ ТА УПРАВЛІНСЬКИХ АСПЕКТІВ  
НА РІВНІ ЛАНДШАФТУ**

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Підсумовано знання про збудуючі природні режими лісу та заліснених територій, а також про низку методів менеджменту, що застосовано до лісів та заліснених територій в Європі.

Природні збудуючі режими поділяють на три основні групи: сукцесії після великомасштабних природних збудуючих процесів (таких, як пожежі та вітровали), динамічні процеси після повторювальних слабоінтенсивних порушень і динаміку

пробілів, спричинену відмиранням дерев на невеликих ділянках. Системи лісового менеджменту також поділяють на три групи: одновіковий, багатовіковий і різновіковий. Також необхідно врахувати доіндустріальний менеджмент культурних ландшафтів.

Наголошено, що менеджмент необхідно розвивати в рамках ландшафтної стратегії для задоволення різних аспектів сталого менеджменту лісових ландшафтів. Слід побудувати міжнародну мережу ландшафтних полігонів для розвитку місцевого, регіонального і міжнародного партнерства.

*Ключові слова:* сталий лісовий менеджмент, ландшафт, природний збурюючий режим.

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