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Ecological and Landscape Considerations in Forest Management

Kristoffer Jasinski

SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES

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Abstract

A major challenge for the forestry sector is to adapt forest management to better sustain and promote biological diversity. In this thesis some aspects of such considerations on different spatial and temporal scales are studied and discussed. The dynamics of a natural forest landscape in Russia were studied by analysing peat cores. The forest landscape could roughly be divided into two types: one affected by fire at a regular basis and one type that can be regarded as a fire-free refuge. There was evidence for a site-related mosaic of forest dynamics in the landscape that had probably persisted in many thousands of years. The presence of such strongly contrasting disturbance regimes in the same landscape affects the distribution of plants, fungi and lichens.
Another study showed that estimating the relative occurrence of charcoal bands in peat probes is a simple and practical method to assess past fire history in a landscape where surface signs are scarce or missing. Furthermore, vegetation groups with different relative fire intervals were distinguished.
In a third study a different perspective was applied by studying how a management plan for a forestry estate needed to be adapted when using the capercaillie *Tetrao urogallus* as a target species. Around known leks (display areas) the management was adapted to suit the bird's needs. The result was that set-asides had to be increased with more than 100 ha., and the total cost for this management was estimated to 5% of the net present value.
In the fourth study the usefulness of different regional classification systems as aids in planning for nature management in a landscape perspective were compared. The classifications showed a degree of similarity between the divisions of vegetation types a specific landscape. However the regional classifications referred to all have some shortcomings. Firstly an attempt is made to impose discrete boundaries on continuums of the earth's surface. Secondly, there is a need to complement the descriptions of the regions with details about dynamics.

Different perspectives and approaches can be taken in ecological considerations. Depending on the conditions of a specific area, some are better suited than others. However, the complexity of the problem is so great that a precise scientific system for such considerations is unlikely to be constructed. Instead, regional and local experience, coupled with sound scientific knowledge, seems to be the best foundation for good ecosystem management.

Keywords: landscape mosaic, fire, capercaillie, regional classification, management aids.

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Kristoffer Jasinski
Department of Forest Management and Products
Uppsala

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Author's address: Kristoffer Jasinski, Department of Forest Management and Products, P.O. Box 7060, SE-750 07 Uppsala, Sweden.

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Appendices

Paper I-IV

This thesis is based on the following papers, which are referred to by their Roman numerals.

I. Jasinski, K. and Angelstam, K. Long-term differences in the dynamics within a natural forest landscape – consequences for management. Accepted paper – Forest Ecology and Management.

II. Angelstam, P. And Jasinski, K. Natural-fire archives as a guide for biodiversity restoration planning in managed boreal forest – a test in a pristine landscape in Russia. Submitted manuscript.

III. Jasinski, K., Pettersson, M. and Dahlin, B. Consequences of Capercaillie *Tetrao urogallus* as a Target Species in Forest Management Planning. Manuscript.

IV. Jasinski, K. Regional classification: the significance for forest landscape management. An example from the Boreo-nemoral zone of Sweden. Manuscript.

Paper I is accepted for publication and is reprinted with kind permission from Forest Ecology and Management, (Foreco 5550) (in press); Paper II is submitted and is published with permission.

Introduction

The History of Nature Conservation Within Forestry

Historically, concern for economic profit led forest management in Sweden to favour high production of primarily two conifer species; Norway spruce *Picea abies* and Scots pine *Pinus sylvestris*. A result of this is a patchy landscape consisting largely of even aged, even sized and regularly spaced stands, often almost totally dominated by one of these species. On the other hand, habitats such as wet-site forests and stands containing high proportions of broadleaf species mix and old trees have become ever more fragmented, resembling islands in an otherwise less accommodating environment (Esseen et. al. 1992, Östlund 1993, Östlund *et al.* 1996, Kouki *et al.* 2001). As a consequence a large number of species have become endangered (Berg *et al.* 1994).

Forest managers now weigh and consider production aspects with maintenance of biological diversity, recreational use and even sustainable development. The maintenance of biodiversity, a term that was first used in scientific literature in the 1980's (Haila & Kouki 1994), has become a focal point in environmental issues (United Nations 1992). Consumers of forest products have become aware of the impact of forestry on nature and have started to demand "green-label" products (Upton & Bass 1995, Viana *et al.* 1996). At the same time the latest Forestry Act (Anon. 1994) has set maintenance of biodiversity on par with production aspects. As a consequence, strategies must be found and implemented by forest managers that rest upon a deeper understanding of forest ecosystems and knowledge of how human interventions and use of forest resources can be achieved, while guaranteeing a healthy forest stock (Ryding 1994).

Efforts are now continually made to alleviate the damage to biodiversity caused by forestry. Nature conservation has traditionally been approached through three strategies: conservation of endangered species populations, conservation of biotopes and conservation of areas of high biodiversity. The limitation of these approaches is that structures rather than processes are preserved in the long-term, too little area is protected and the prevailing management paradigm is often one of managing the individual landscape segments, more or less in isolation from surrounding segments (Hansson & Angelstam 1991, Hobbs *et al.* 1993, Angelstam & Andersson 2001).

Consequently, it has been realised that relying on small patches alone is not sufficient as the surrounding matrix can negatively affect these. Many the nature and soil conservation problems that are encountered have to be tackled at both regional and landscape level and have clear spatial and temporal aspects (Pickett & Thompson 1978, Noss & Harris 1986, Noss 1990, Hunter 1991, Norton 1999). Disturbance for example has long been recognised as an important factor affecting community structure and dynamics and may affect different levels of organisation from individuals to ecosystems to landscapes, and the consequences and mechanisms of disturbance are different at each hierarchical level (Rykiel

1985, Pickett *et al.* 1989). Ecologists, therefore, recommend complementing traditional conservation approaches with concerted efforts taken in the managed landscape to ensure maintenance of biodiversity which consider both the spatial and temporal aspects (Brussard 1991, Clark 1991, Oliver 1992, Hansen et. al 1993). As a result, different approaches to systematic conservation planning have been proposed (e.g. Noss *et al.* 1997, Margules & Pressey 2000).

Over the last decades ambitious education and information campaigns to improve nature maintenance during forestry operations have been undertaken by the Swedish forestry sector. During the late 80's the Board of Forestry initiated the "Richer Forest" campaign, where the need for nature maintenance was emphasised and study circles for forest owners were held all around the country (Anon 1990). Then during the 90's the idea of landscape planning was introduced. Industrial forest companies, whose objective is to balance high timber production with the maintenance of biological diversity, were readily attracted by the notion of landscape planning (Fries *et al.* 1997, Peters *et al.* 1997).

Landscape ecological models

The general consensus amongst ecologists is that disturbance is an important factor in the creation and maintenance of diversity. Disturbance is neither rare nor totally unpredictable and it can express itself at any number of hierarchical levels from disturbance of an individual to disturbance on a landscape scale affecting whole communities and their dynamics (Pickett *et al.* 1989, De-Grandpre & Bergeron 1997, McCarthy 2001). The insight that conservation management should take into consideration potential changes in the physical environments has led to another possible approach to biodiversity maintenance. The idea is to establish the disturbance regimes of the landscape and quantify the structures and processes initiated by the various disturbances. In the case of forestry this knowledge can then be used to identify stands which can set aside for nature rehabilitation or else utilised for production by mimicking processes, structures and dynamics of nature (Pettersson 1991, Lindhe and Drakenberg 1992). The naturalness approach is based on the concept that the biodiversity will be enhanced if there are suitable natural conditions and consequently management should mimic natural processes blending these into production forests (Liljelund *et al.* 1992, Angelstam 1996, 1997, Fries *et al.* 1997). At landscape level management should aim at maintaining or establishing natural patterns of stand types and succession stages. Where fire has been the dominating disturbance factor arrangements and temporal distribution of stands should be based on mimicry of fire (Bergeron *et al.* 1999, 2001).

A landscape can also be managed bearing in mind the requirements of a selected "target" species, for example a woodpecker or to take an example from the New World, the Northern spotted owl *Strix occidentalis caurina.* This, fine-filter approach focuses on learning the needs of species at risk and then providing for the needs, often through intensive management (Noss 1987). A planning strategy can then be applied to the landscape whereby the life history of the species and

suitable habitat is quantified and subsequently alternative management models of the landscape can be tried against each other and the most suitable alternative implemented.
A further example of a model for landscape planning is the key habitat – corridor model. This model is founded on, island biogeography (MacArthur and Wilson 1967) and on landscape ecology (Forman and Godron 1986). The general idea of the species approach is to identify areas in which threatened species occur, and then protecting these "keystone habitats." The "keystone habitats" are the basis for this model where the landscape is viewed as a matrix with patches that may or may not be linked by corridors. Although there are few scientific studies to prove the importance of corridors there are ecologists who believe that they are of value in ecological landscape planning (Gustafsson and Hansson 1997, Hansson 2001, Niemelä 2001). Additionally, outside the forest, there is a need to maintain biodiversity in the cultural landscape (Rackham 1986, Peterken 1996, Angelstam and Pettersson 1997). A suitable model for this kind of landscape may be the multiple aspect approach that is based on the view that there are elements and features in the landscape that, although they are not necessarily of biological value, are defined as important and support landscape planning (Lucas 1991, Fries *et al.* 1998). This approach has evolved in regions where there has been a considerable impact on the landscape and values such as cultural heritage, recreation and aesthetic are important.

Boreal and hemi boreal forests and land-use history

The major part of forests in Sweden belongs to the boreal zone. The southern most part of Sweden belongs to the nemoral zone, and the transition region between these zones is called the boreo-nemoral or the hemi-boreal zone (Sjörs 1965, Ahti *et al.* 1968).
The majority of forest sites in the boreal zone have been affected by fire (Kohh 1975, Zackrisson 1977, Tolonen K. 1983, Engelmark 1984, 1987, Tolonen M. 1985, Niklasson and Granström 2000), although wind, fungi and insect pestilence, flooding and browsing have also played important roles (Syrjänen *et al. 1994,* Peterken 1996). Large and intensive fires tend to homogenise the vegetation units throughout the landscape, but there may also be highly variable consequences due to different fire behaviour. At high intensities the subsequent stands tend to be even aged, and with a large proportion of broadleaf tree species present in the beginning of the succession. The vegetation can also be correlated to fire-probability patterns - mires and lakes creating effective firebreaks (Engelmark 1984, Grimm 1984). However, not all disturbances in boreal forests are large-scale and caused by fire. Small-scale gap disturbance and regeneration are common in boreal forests that have escaped fire for great periods of time. Typical examples for forests where gap regeneration occurs are the spruce dominated forests that can be found in the moister parts of the boreal landscape. In general there is a great variety in both size of gap and the temporal distribution of gap causing episodes (Kuuluvainen 1994, Hörnberg 1995).

Vegetation in the boreo-nemoral zone is described as consisting mainly of Norway spruce *Picea abies* and Scots pine *Pinus sylvestris*, with an admixture of birch *Betula sp.*, aspen *Populus tremula* and on wetter sites alder *Alnus spp.* and pockets of broadleaf forests composed of "ädel" or "noble" broadleaf species (Engelmark & Hytteborn 1999). The term "ädel" (noble) refers to species that have a relatively high demand for nutrients and temperature and have greater economic importance than "trivial" species such as birch *Betula sp.* or aspen *Populus tremula.* The species classified as "ädel" according to the Forestry Act (Anon. 1994) are common ash *Fraxinius excelsior,* elm *Ulmus glabra,* Norway maple *Acer platanoides*, small-leaved lime *Tilia cordata*, oak *Quercus spp.,* wild cherry or Gean *Prunus avium* and common beech *Fagus sylvatica.* The presence of deciduous species within this zone often depends on climatic and edaphic conditions (Diekmann 1994). In their natural state noble deciduous forests are, like many spruce forests in the boreal zone characterized by small scale gap disturbance, often due to wind throws, browsing and grazing and flooding (Falinski 1986, Röhrig 1991, Schnitzer 1995, Bradshaw and Mitchell 1999). However it is likely that human activity over thousands of years should be regarded as the major factor affecting the forest landscape in the boreo-nemoral zone, with large extents of deciduous forest being cut down and transferred into arable land (Berglund 1969, Behre 1988, Lindbladh and Bradshaw 1998).

Objectives

General

The general objective of this thesis is to translate some ecological principles into suitable forest ecosystem management and suggest how management of the ecosystem could be adapted depending on from what perspective the landscape is viewed.

In paper I this is done by seeing how stands in a landscape where natural boreal forest dynamics still occur, were affected by different dynamics, how they were distributed in the landscape and how the vegetation had developed through time and finally the implications of this for forest biodiversity management.

In paper II the relationship between fuel characteristics of vegetation found on different forest site types and fire, are used to predict the relative fire frequency among boreal forest site types. The implications of the distribution of different fire frequencies among site types for forest biodiversity management by emulation of natural forest disturbance regimes is discussed.

In paper III an assessment is made of the adaptation of a management plan where the capercaillie *Tetrao urogallus* is used as a target species. Furthermore the consequences of the adaptation of the management plan for production are examined and alternative strategies for production and the maintenance of biodiversity are discussed.

Some regional vegetation classification schemes that are relative to ecosystem management planning are reviewed in paper IV and compared as an aid for nature maintenance planning in a specific landscape.

Summary of papers

Long-term differences in the dynamics within a natural forest landscape – consequences for management

This study was carried out in a boreal forest landscape where natural dynamics still occur. The aim of the study was to see how stands affected by different fire regimes were distributed in the landscape, and how the vegetation may have developed through time. Using the historical archive consisting of charcoal and pollen accumulated in peat it was seen how the two main forest types, dry *Pinus sylvestris* and wet *Picea abies* differed with respect to fire disturbance. At a landscape level low-resolution studies were carried out in the field by visual examination for charcoal presence in cores of peat retrieved with a Russian peat corer from peat deposits. At a stand level, high-resolution studies were carried out at two sites representing each of the two main forest types where the vegetation history of different stand types was studied by analysing the pollen found in peat cores retrieved from the two peat deposits.
The low resolution study of charcoal remains in the peat deposits suggest that the landscape studied can roughly be divided into two types; one affected by fire at a regular basis and one type which can be regarded as a fire-free refuge. The pollen studies, which indicated that there was little to suggest any anthropological influence on the landscape, strengthened the charcoal band evidence for a site-related mosaic of forest dynamics in the landscape that had probably persisted in at least 2500 years.
The conclusion of this study are that the presence of such strongly contrasting disturbance regimes in the same landscape affects the distribution of plants, fungi and lichens, which could be an important base for biodiversity management in forestry and reserve design.

Natural-fire archives as a guide for biodiversity restoration planning in managed boreal forest – a test in a pristine landscape in Russia.

Management of forest biodiversity requires understanding of past natural disturbance regimes. In this study the possibility of further resolution in fire frequency index related to site type in a naturally dynamic boreal forest was studied. Using the Russian pristine boreal forest in the Pechoro-Ilych Strict Reserve (57° E, 62° N) as a reference for European boreal forest biodiversity management, we studied fire as a site-specific factor affecting forest dynamics. Observations of macroscopic charcoal in peat and fire scars on trees covered six main boreal site types with different fuel characteristics ranging from wet tall herb dominated by Norway spruce *Picea abies* to dry lichen with Scots pine *Pinus sylvestris*. Firstly the aim of this paper was to evaluate the usefulness of macroscopic charcoal bands found in peat deposits in the boreal landscape for obtaining indications to relative fire frequency in different site types when surface sign on trees and stumps are not present. Secondly the relationship between the fuel characteristics of the vegetation on different forest site types and fire was used to predict the relative fire frequency among different forest site types.

The average number of charcoal bands for each peat deposit and the frequency of visible signs of fire on trees were strongly related to the surrounding site type and to each other. This allowed the conclusion to be drawn that estimating the relative occurrence of charcoal bands in peat probes is a simple and practical method to assess past fire history in a landscape where surface signs are scarce or missing. Furthermore three groups with different relative fire intervals were found. (1) On dry *Cladonia* lichen sites fire had occurred often. (2) On mesic sites with *Vaccinium spp*. and ombrotrophic peat *Ledum palustre* sites fire had occurred at intermediate frequencies. (3) On moist sedge types fire had occurred seldom.

This clear trend in relative fire frequency among sites with different fuel characteristics can provide inspiration for maintenance and restoration of biological diversity in managed forest by sufficient emulation of natural forest disturbance regimes. The data could be said to be in accordance with the ASIO-natural disturbance model (after the relative frequencies Absent, Seldom, Intermediate and Often) used in Fennoscandia where three silvicultural systems matching three main disturbance regimes are suggested. On dry sites where low intensity fires predominate, the goal is to create and maintain multi-layered cohorts of pine trees. For sites with fire-adapted communities on mesic sites where stand-replacing fires were common, clear-cuts with varying degrees of green tree and patch retention are considered to be ecologically proper. In site types with natural gap-phase dynamics, selective cutting systems and set-asides are promoted.

Consequences of Capercaillie *Tetrao urogallus* as a Target Species in Forest Management Planning.

The capercaillie *Tetrao urogallas L.* is suggested as a suitable target species for forest ecosystem management planning. The reason for this being that the species has specific, yet diversified requirements as regards its environment, it is vulnerable to environmental degradation, being amongst the first species to disappear when habitats are adversely affected and a forest inhabited by a capercaillie population is likely to include features and properties that are otherwise scarce in Scandinavian boreal forests.
The aim of this study was to see how a management plan for a forestry estate needed to be adapted when using the capercaillie as a target species. Furthermore the forestry estate had ambitions to achieve “green label” certification standards

and an assessment was made of how well these standards can be met on the basis of capercaillie-adapted management.
The management plan to promote the capercaillie was drawn up on a 5000 ha. forest estate in central Sweden. Around three known leks, display arenas, the forest composition within a 500 m and 1000 m radius was studied. The amounts, proportions and juxtaposition of mature forest, older thinning stands and low productive forests were estimated and the management plan was adapted to fulfil the known requirements of the species.
It was found that the territory used by capercaillie at the time of the study was limited and given the present situation capercaillie management would be applied to 20% of the total area. This would require, apart from care being taken in actual forestry operations, also an increase of more than 100 ha. set-asides. In a landscape perspective, and also to meet "green label" certification targets, capercaillie management is sufficient to meet goals regarding the amount of set-aside that should be found in a landscape. However, the capercaillie management needs to be complemented with additional measures, such as preservation and reconstruction of old broad-leaf stands to meet goals regarding amounts of broadleaf admixtures in the landscape. The cost of capercaillie management for forestry was estimated to be less than 5% of the net present value compared with the original management plan.

Regional classification: the usefulness for forest landscape management. An example from the Boreo-nemoral zone of Sweden.

Based on the fact that classification of land into units can have significance for use of resources and nature maintenance and therefore may provide a basis for ecosystem management planning, a review was made of the different schemes that are relevant to conservation in forestry in Sweden. Furthermore, a comparison between the classification schemes was made when they were applied as a base for assessment of a landscape in the boreo-nemoral region of southwestern Sweden.
This study indicated that regional classification could be an aid to the forest manager in planning for nature management and production in a landscape perspective. Using the descriptions of the regional classification there was a degree of similarity between the divisions of vegetation types in the landscape. However, from the point of view of the forest manager or forest estate owner the regional classifications referred to in this paper all have shortcomings. Firstly, to different degrees, limited to being descriptions of regions. The regional classifications did not succeed very well in promoting an understanding of factors that delineate different regions and landscapes within regions. Information was supplied about the landscapes that can be expected within the regions without

information about what factors cause delineation between the units. An example of this is the description of the boreo-nemoral region where the vegetation is dominated by coniferous forest with pockets of noble deciduous species.
Secondly, an attempt is made to impose discrete boundaries on continuums of the earth's surface. Furthermore, the forest manager needs to complement the descriptions of the regions with details about dynamics and processes expected in the units within the regions and obviously the most suitable model for management.

Discussion

The landscape can be perceived and analysed in many different ways.
Often landscape ecology has emphasized patches and matrices in a landscape as perceived from a human point of view (Forman and Godron 1986). The landscape in Pechoro-Illych Zapoviednik was studied by examining how a specific ecological process, fire disturbance, has affected it and the scale of perception is human. Ecologists agree that disturbance is an important factor in the creation and maintenance of diversity (Pickett *et al.* 1989). Here the use of analysis of pollen from peat samples recovered from the area of interest, in combination with C-14 dating, gave a reasonably accurate account of the local forest stand history. Use was also made of the fact that forest fires often leave traces in peat in the form of charcoal, which can be regarded as a fossil indicator of fire (Patterson III *et al.* 1987). The charcoal bands found in the ubiquitous peat deposits found in the landscape sufficed to give a reasonable indication of the relative fire frequency in the landscape.
However, from a general ecosystem management point of view more is needed to be known about the past dynamics and structures of forests in different regions. Although the studies indicate that there has been a long-term stable site-related mosaic in the Pechoro-Illych landscape, fire regimes differ in different regions and have changed through the effects of climate and human impact. There is controversy in the idea of applying silvicultural methods that mimic disturbance and in how to gather and evaluate data regarding disturbance, especially fire (Angelstam 1998, Bergeron *et al.* 1999, Granström 2001).
The landscape can also be perceived from the point of view of separate species. The ecological needs of species dictate the perception of the landscape. In the case of the capercaillie it's ecological needs showed that there should be a certain range of habitat types available within a certain distance from leks and the juxtaposition of these habitats was important. However, patches, boundaries and corridors in a landscape matrix are perceived in different ways by different species and species to species interactions such as competition and predation may cause changes in behaviour and habitat choices, resulting in problems when integrating species in landscapes (Wiens 1989).
The problem of perception is important when considering the usefulness of a target or indicator species for monitoring the quality of a habitat or biotope. An

indicator species perceives and exploits specific habitats that usually do not match human-perceived habitats or landscapes (Landres *et al.* 1988). The concern about selecting one species as an indicator or target species can be alleviated by selecting a "management guild" (Wilcove 1989, Jansson 1998). Finally indicator and target species may not be associated equally well to natural mosaics and processes in a landscape as other species in a whole community. Many important changes in communities and landscapes may take place long prior to a species abandonment of a landscape.

The spatial pattern of landscape elements and ecological objects, the flow between elements and the changes in the spatial pattern are the focuses of landscape ecology (Forman and Godron 1986, Forman 1995). Viewing the landscape as spatial elements affected by factors such as climate, soil and bedrock types, topography etc. has relevance in the principles of island biogeography. There is relevance from the point of view of isolation in fragmented landscapes (Harris 1984, Franklin and Forman 1987, Jansson and Angelstam 1999). Knowledge about the expected distribution of landscape types and forms, as well as processes throughout regions could supply important indications as to the biodiversity that could be expected in the region and enable an analysis of the deficiency in ecological systems to be carried out.

In the schemes most commonly referred to in relevance to nature conservation in forestry, there are shortcomings in that the descriptions are too general and cover too broad an area (e.g. Sjörs 1965, Ahti *et al.* 1968). Furthermore the placement of boundaries is inherently subjective. A boundary may be placed where the changes in climate-soil-vegetation conditions appear significant and a line is drawn showing where most changes occur. However local variations may only become obvious in areas mapped with greater detail.

In most studies vegetation serves as an indicator of climate and the geographical distribution of vegetation serves as the criteria for regional delineation. Although changes can be very abrupt in some cases, usually variation in vegetation is along a continuum (Bailey 1983).

Finally not all of the regional schemes take into consideration human impact. Knowledge about human impact and land-use history would greatly aid an analysis of the deficiencies in a region.

As mentioned earlier pollen analysis can result in a reasonable interpretation of a landscapes history but this can also be deduced with the aid of historical documentation or dendrocronological cross-dating (Rackham 1986, Östlund 1993, Niklasson 1999).

Knowledge about the anthropogenic transformation of the landscape supplies us with information about the changes in processes in a landscape in both time and space. For example in Sweden the history of anthropogenic change varies from the transformation of nemoral forest into arable land from about 5000 BP (Berglund 1991) to the commencment of colonisation in the northern parts of Örebro county, in the boreal/ boreo-nemoral transition zone, during the 16th century (Angelstam 1997).

This has bearing on the management of different landscapes with different land use histories. There have been structural changes in landscape components and remnant habitats have declined and been reduced in size (Stannes and Bourdeau 1995). From the point of view of nature maintenance the changes in structure are important to consider. Although the amount natural forest was seriously reduced in some regions, large proportions of the landscape were covered by wooded meadows and pastures. Here, large trees could be found that offered many forest–living species suitable habitats (Berg *et al.* 1994, Gustavsson and Ingelög 1994). When comparing the development over time of landscape it becomes evident that land use history has to be considered in ecosystem management.

As seen in paper IV the delineation of regions is quite subjective. This has to do with the perspective taken when examining the landscape and the way the landscape analysis is approached. Even though several schemes have been proposed to the regionalisation of Sweden with respect to abiotic, biotic and historic components there still remains much to be done. A thorough examination needs to be carried out to decide the relevant layers for establishing regions of ecological value and with similar conditions that are of relevance for forest ecosystem managers.

Amongst parameters that are of importance at regional and landscape scales can be named:

- Climatic - Temperature, mean annual, variability, range; Precipitation, mean annual, seasonal; Evapotransporation
- Geological – Bedrock, lithology, drainage and moisture
- Anthropogenic - Culture and land use history
- Geographic/topographic - Latitude, longitude, altitude, distance from sea
- Disturbance - Fire history, winds, harvesting, wildlife

Furthermore testing of regional delineation needs to be carried out; otherwise there is a risk that the divisions lack ecological validity and purpose.

A suggestion for testing the delineation of regions could be carried out by

- Comparing the vegetation, structures and processes on all landforms across all the regions
- Comparing the vegetation, structures and processes on all landforms within the different regions
- Comparing the regions by using all landform types.

Comparisons i) and ii) would be a direct test of the hypothesis that broad areas are different in important ways whilst comparison iii) would delineate the regions by differentiating broad areas containing similar or combinations of similar landform types.

The final conclusion is that landscape ecosystem management is not an exact science with standard solutions for all landscapes but rather an art based on thorough scientific ecological knowledge and social and historical understanding.

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