Silviculture Adapted to Multiple Goals in Swedish Small Scale Forestry – methods for choosing practices, biotopes, stands and events.

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Abstract

During recent decades a new type of private forest owner has appeared in Sweden, with forestry goals other than simply generating money from wood production; these goals include hunting, maintaining biodiversity, cultural aspects and historical values. However, multiple goals often conflict with each other, leading to a problem of finding practices that can deliver several goals at the same time. Recently, there has been an increasing move to continuous cover forestry and other systems or practices that are considered more likely than clear cutting to fulfil multiple goals. However, an additional problem is that much of what is said about the suitability of different practices is partly based upon beliefs rather than on sound data, so more research is needed in this domain. Finally, identifying stands that are suited to specific practices represents another challenge.

The main objective of the research presented in this thesis was to identify tools that can help foresters to select appropriate practices and suitable forest stands that will allow them to achieve the multiple goals of small-scale forest owners.

Silvicultural practices were identified through a literature search and their appropriateness and value was determined using matrices summarizing the results of published studies. The results indicated that thinning and successive felling were most suitable for delivering the goals considered. Passive practices were less well adapted.

Further literature reviews were undertaken to find criteria relevant to six different situations. In order to determine the link between management practices and results, checklists were created for field-testing.

Checklists were also intended to be useful in other situations, and two additional lists, 'Optimizing natural regeneration of Scots pine (*Pinus sylvestris* L.)', and 'Avoiding false heartwood in ash (*Fraxinus excelsior* L.)', were proposed as further examples of useful checklists.

Keywords: Clear cutting, group system, multiple goals, multipurpose forestry, small scale forestry, selection system, scarification, silviculture, two-storied forest, uniform system.

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Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Hörnfeldt, R. & Ingemarson, F. 2006. **Evaluation of Silvicultural Practices from a Multipurpose Perspective.** Baltic Forestry. Journal of Forest Science in Lithuania, Latvia and Estonia. 2006. Vol.12, No1, 82-93.

II. Hörnfeldt. R. 2013. Methodology for assessing the suitability of forest stands for Silviculture with multiple goals (Manuscript).

III. Hannerz, M., Almqvist, C. & Hörnfeldt, R. 2002. **Timing of seed dispersal in *Pinus sylvestris* stands in Central Sweden.** Silva Fennica, 36(4), 757-765.

IV. Hörnfeldt, R., Vincenza Chiriacò, M. & Hu, B. 2012: **Optimum timing of soil scarification for the natural regeneration of *Pinus sylvestris* in Central Sweden.** Scandinavian Journal of Forest Research, DOI:10.1080/02827581.2012.657669

V. Hörnfeldt, R., Drouin, M. & Woxblom, L. 2010. **False heartwood in beech *Fagus sylvatica*, birch *Betula pendula*, *B. papyrifera* and ash *Fraxinus excelsior* – an overview.** Ecological Bulletins 53: 61–75.

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Abbrevations

AG	Advance growth
CCF	Continuous Cover Forestry (syn. Clear Cutting Free Forestry)
CNFMP	Close to Nature Forest Management Principles
FMP	Forest Management Plan
GTR	Green Tree Retention
MPF	Multipurpose forestry (treated here as a synonym of SAMG)
NFE	Natural regeneration at Forest Edges
NGO	Non-Governmental Organization
NIS	Natural Regeneration under Irregular Shelter
NUS	Natural Regeneration under Uniform Shelter
PF	Protect the Forest (NGO)
SAS	Statistical Analysis System
SFA	Swedish Forest Agency
SAMG	Silviculture adapted to multiple goals
SKOGF	Skogforsk ((the Forestry Research Institute of Sweden)
SNFA	Swedish National Forestry Act
SNFI	Swedish National Forest Inventories
SSNP	Swedish Society for Nature Protection

Definitions

Advance growth: Seedlings naturally regenerated in situ without any special regeneration measures; particularly common in stands containing shade tolerant species (Anon. 1969)
Brownheart (Blackheart): False heartwood with brownish–blackish colour in ash (*Fraxinus excelsior* L.)
Candidate stand: A stand that is apparently suitable for SAMG.
Checks: Ruptures in the wood (and stem) along the grain (Brown, Panshin & Forsaith 1949)
Continuous cover forestry: umbrella term that covers all methods but traditional clear cutting, i.e. clear cutting followed artificial regeneration (Syn.: Clear cut free forestry).
Coupe: An area of forest that has been clear felled (Hibberd 1991)
Crown density: The **relationship between** the surface that is covered by the horizontal projection of the tree crowns in a stand and the total area of the stand; generally expressed in tenths, where 1.0 means that the **entire** forest area is covered **by tree** crowns (Anon. 1969).
Dwarf shrub type: Moss-rich coniferous forest with dwarf shrubs, such as bilberries and cowberries (Anon 1969).
Dwarf shrub type with low herbs: Moss-rich coniferous forest with dwarf shrubs, and with low herbs, such as wood anemone (*Anemone nemorosa* L.) and wood sorrel (*Oxalis acetocella* L.) (Anon.1969).
False heartwood: Coloured wood in the central core in tree species such as ash (*Fraxinus excelsior* L.) and beech (*Fagus sylvatica* L.), which do not form 'normal' heartwood. 'Normal' heartwood forms under the control of endogenous, hereditary factors, and can be found in species, such as pine (*Pinus sylvestris* L.) and oak (*Quercus robur* L.). In contrast, the formation of false heartwood is induced by diverse exogenous factors, including various kinds of injuries or stresses that damage the tree (Kohler 2006). A common

cause of stress is drought, but heavy compacted and waterlogged soils can also have the same effect. Other stresses include branch breakage, incidents which create wounds or stem and root injuries.

Forestry: 'The science, business and art of managing and conserving forests and associated lands for continuing economic, social, and environmental benefit' (Matthews 1989 p.61).

Forest management: The task of forest managers to carry out forestry on a tract of land and to conduct the enterprise 'so that work and labor are in balance and financial targets are met' (Matthews 1989; p 49–50).

Gley (gleysols): Type of soil found in wetlands with changing and sometimes high water table, which exhibits more or less vertically orientated rust red streaks or spots (Lundmark 1986). One problem among others with glay is that the repeated wetting and drying creates an unfavourable root environment (Driessen & Dudal 1991).

Heat sum: The sum of daily mean temperatures over +5 ºC (∑(daily mean – 5 ºC)) during the vegetation season (Lundmark 1986).

Ironpan: Found on sites where water rich in iron and humus enters from the surroundings. The soil particles form a kind of concrete that can be a problem for forest trees because it impedes water drainage and restricts the growth of roots (Lundmark 1986).

Mesic dwarf shrub type: Compare with 'dwarf shrub type'!

Modified clear cutting: Coupes where measures have been undertaken to soften negative aspects of the clear cutting system, such as leaving retention trees, limiting the clear cut area, avoiding steep terrain etc.

Objective: Sometimes used as synonym of goal, e.g. in Paper I

Redheart: False heartwood in beech (*Fagus sylvatica* L.); in general with a reddish to salmon red colour, but there are many other nuances from grey or grey–beige to almost brown (Kohler 2006).

Scarification: Here performed carefully by just uncovering the mineral soil in patches or in ranges (disc trenching with a low pressure) or by mounding. Ploughing is excluded.

Selection stand: An 'un-even aged irregular type of forest in which all age and size classes are mixed together over every part of the area' (Matthews 1989). This includes both single tree selection and group selection stands.

Shelterwood (Matthews 1989)**:**

Uniform shelterwood: The shelter trees are left distributed more or less evenly all over the regeneration area. This leads to an even aged young crop already present at the start of the rotation. The number of seed trees left may vary from less than 50 to 150 or more per ha. In the first case (and according to Swedish vocabulary) the term *seed tree stand* is used, and all the seed trees are cut at the same time. In the second case the shelter trees are harvested in two or more steps.

Irregular shelterwood, where scattered gaps are opened in the canopy. The two variants are related since the young crops in both cases develop more or less under the influence of adult trees during the regeneration phase, and in both cases the objective is to create even aged stands. The regeneration phase of the irregular shelterwood starts by searching for 'natural' gaps in the stand, especially those with promising groups of advanced growth. As a complement, new gaps are created artificially in denser parts of the canopy. As soon as regeneration has begun in all gaps, the gaps are widened in several steps until they coalesce and the entire stand is regenerated. The young crop at that stage is more and less uneven aged, but through appropriate management the stand will become even aged, or at least consist of trees of the same size. The silvicultural system for this kind of stand is (*shelterwood*) *group system* (Matthews 1989).

Silviculture involves the regeneration, tending and harvesting of trees and forests at the stand level (Compare with 'Forest management'!).

Silvicultural practice refers to techniques for managing forest stands, such as felling, tending, regeneration, etc." (Matthews 1989)

Silvicultural system is defined as "the process by which the crops constituting a forest stand are tended, removed, and replaced by new crops, resulting in the production of stands of a distinct form" (Matthews 1989, p. 3).

1 Introduction

The claims on today's Swedish small scale forest owners are high. Nowadays it is not enough to manage the forest in a way that secures the estate economically; there are pressing external demands with respect to biodiversity, cultural, historical, aesthetic and other values enshrined in the Swedish National Forestry Act (Anon. 1999), and by Non-Governmental Organizations (NGOs) and the general public. In addition, since the 1980s, a new category of forest owner has emerged, with somewhat different ambitions than former generations (Ingemarson 2004). They are, of course, still more or less interested in economic returns from their forests, but they also have other goals, such as 'Conservation', 'Utilities' and 'Amenities' (Hugosson & Ingemarson 2004). For them, as well as forest owners in general, Silviculture Adapted to Multiple Goals (SAMG) may be an interesting alternative.

Multi-functionality is a 'principle invented by Nature' (Schütz 1997); in fact a habitat is rarely used only by a single species. Forests are no exception and have always? been 'multiple-use resources' globally (McArdle 1954). Unfortunately this has often led to 'potentially conflicting goals' (Löf et al. 2010, Gustafsson et al. 2012). There are many examples in Swedish history, such as conflicts between the Crown's right to harvest wood in any location for the navy and landowners' rights, shifting agriculture and mining, reindeer herding and agriculture etc. (Nylund & Ingemarson 2007).

From the middle of the 19th century, there was a rapid increase in the demand for timber by the forest industries. Harvesting doubled between 1850 and World War 1 (Sjöberg 2012). However, for many private owners the forest was more important for grazing and collection of winter fodder than for wood production, which resulted in almost no planned new regeneration after harvesting. In 1904, to reverse the situation, the Swedish parliament enacted legislation that made it compulsory to regenerate after harvesting; however, the law was ineffective as long as there were still cattle grazing in the forest. The question of forbidding all grazing in forests had been discussed for several decades, and was still debated in the Swedish parliament as late as the 1930s (Kardell 2004), without any definitive solution. However, the problem disappeared successively with urbanization and the rationalization of cattle husbandry after World War 2.

Another issue that was discussed during the early decades of the 20th Century was the right to pick berries on private forest owners' land (Sandström & Sténs 2012), but the political parties that supported the idea of banning this activity, mainly conservatives, never succeeded in achieving a majority. One reason for that was the strong belief in universal rights', which has deep roots in Sweden. On the whole, landless people have been able to continue their traditional use of forest resources, such as free access to private forests for picking berries and mushrooms. On the other hand, there was probably no question of changing forestry practices to deliver the eventual demands of the public. Until the 1960s, the thinking among European foresters was dominated by 'die Kielwassertheorie' (German for 'wake theory'; Diedrich 1941), which states that delivering the production goal would automatically supply all other functions of the forest (Schütz 1990).

However, things changed radically in Scandinavia from the 1950s with the introduction of 'modern forestry', characterized by clear cutting, artificial regeneration in monocultures, use of herbicides, artificial fertilizing etc. An urbanized population, visiting their former home district during their vacations, as well as the remaining rural population, reacted gradually to seeing ubiquitous large clear cut areas and frequent monocultural afforestation of agricultural land. This resulted in many demonstrations and other actions, often initiated by NGOs, against Swedish forestry companies and the managers of public forests during the 1960s, reaching a peak in the early 1980s. Swedish foresters had been caught off guard and were not prepared for the suddenness, disbelief and persistence of the criticism (Enander 2012), and it took some time for many of them to realize that wake theory was no longer valid. However, partly as a consequence of this 'new thinking', the current Swedish Forestry Act was enacted in 1993, with two equal goals – forest production and the environment, with the intention of sustained biodiversity (Egnell 2000) – but also incorporating cultural, aesthetic and social values.

Multiple goals

Another sign of new thinking was that 'new' phrases and expressions gradually came into common use at the turn of the century, such as silviculture for 'multi use' (Hartman 1976), 'multiple objective', 'multipurpose ', 'joint goals' (Pröbstl 2008)' and 'multiple goals'; this was particularly noticeable after the Rio Conference in 1992. Such terms could be considered synonyms even though there may be doubts in some cases, e.g. between 'multiple uses' and 'multiple goals/objectives'?

However, it is not within the scope of this thesis to analyse the terminology and throughout the rest of this work the phrase 'Silviculture Adapted to Multiple Goals' (SAMG) is used, sometimes with 'Multipurpose Forestry', as a synonym. The multiple goals (syn. 'multiple objectives') that are discussed, consisting of timber values and non timber goods and services, are defined in a model presented by Hugosson & Ingemarson (2004), describing in detail the multiple objectives of private forest owners in Sweden (Table 1):

Table1. Small-scale forest owners' multiple goals according to Hugosson and Ingemarson (2004)

Conservation	**Utilities**	**Amenities**	**Economic efficiency**
Nature Conservation	Game Production	Forestry Tradition	Yield of Capital
Cultural Conservation	Berry Production	Challenge of Silviculture	Liquidity reserve
Water/Soil Conservation	Mushroom Production	Aesthetics	Tax Planning

1.1 Practices and systems, considered suitable for SAMG in literature

1.1.1 Continuous cover forestry

According to Mason et al. (1999), there has been a worldwide move towards continuous cover forestry during recent decades, defined as '*the use of silvicultural systems whereby the forest canopy is maintained at one or more levels without clear felling*, *due to a belief of that this system is more fitted for multipurpose forestry than clear felling systems'*. Like clear cutting and shelterwood systems, harvesting wood is one objective of this approach. However, the intention is not to remove too many trees in order '*not to disturb the wider system*' (Mason et al. 1999). This principle is considered '*common for all forests managed for multi-purpose objectives*' (Ibid 1999), and includes different kinds of selection and shelterwood systems, but excludes clear cutting and, in general, seed tree systems.

An almost identical interpretation of the meaning of *'continuous cover forestry'*, and what silvicultural treatments could be included in it, is given by a project run by the Swedish Forestry Agency (SFA), 'Continuous forests' and 'clear cut free forestry' (Dahlberg 2011). Both phrases are defined as '*umbrella terms that contains anything but traditional clear cut forestry, i.e. clear cut followed by artificial regeneration'*, including selection cutting, natural regeneration in gaps and shelterwood (Bengtsson & Rosell 2012), in the latter case provided that at least 20–50 seed trees per ha are retained in the new stand. Although the SFA project mainly seems to focus on biodiversity, some attention is paid to other goals, such as protection of soil and water, social and cultural values, economic efficiency, supporting reindeer breeding etc. For most of these goals, with exception of the economic ones, keeping continuous forest cover is considered more appropriate than clear cut forestry (Bengtsson & Rosell 2012).

Keeping a continuous forest canopy allows many different organisms, often red listed species with low regeneration potential, (Dahlberg 2011), to survive and decreases the risk of water run-off and soil erosion. However, the continuous canopy of large old trees in itself is not the only important factor. Keeping continuous forest cover must be combined with interventions in the form of either single tree selection- or group selection felling in order to create irregular stand structures with trees of different ages and sizes, unequally scattered across the stand. This establishes a multitude of ecological niches for many different organisms; these habitats remain for short periods as transitional states in the untended forest (Schütz 1997). Constant forest cover with some large old trees retained makes the forest look 'eternal' in the eyes of an observer, and the harvesting of single trees or small groups of trees will probably not cause the same trauma as clear cutting. In addition, the irregularity of such a forest is considered aesthetically attractive by the public (Matthews 1989). These different aspects of diversity create opportunities to combine many goals.

Continuous cover is defined differently in different European counties (Ek 2013). In Germany, Switzerland (Schütz 1997) and the UK (Mason et al 1999) shelterwood is unequivocally considered to be 'continuous', even if cutting is permitted as soon as regeneration is secured. In Sweden the same treatment is considered to represent clear cutting (Ek 2013). In several of the federal states of Germany it is permissible to make small clear cuts (< 3 hectares), and for the forestry still to be considered 'clear cut free'.

1.1.2 Different forms of natural regeneration

Different forms of natural regeneration are often mentioned as examples of practices that are suitable for forest management with several goals (Mason et al 1999, Hörnfeldt & Ingemarson 2006). However, in addition to questions of whether natural regeneration of Scots pine (*Pinus sylvestris* L.) in uniform shelterwood could be considered to represent continuous cover forestry or not, there are doubts about shelterwood combined with soil scarification (Sahlin & Säfve 2011). Burschel & Huss (1997), however, claim that, on the whole, the uniform shelterwood system is positive for biodiversity, allowing both light demanding and shade tolerant species to survive in the stand. Shelterwood maintains the number of species at the pre-treatment level, but the cover of shade tolerant plants may decrease (Vahna-Majamaa & Jalonen 2001), and the number of light demanding species increase (Kardell & Lindhagen 1998). Even scarification has some positive effects on biodiversity; the number of naturally regenerated seedlings of both silver birch (*Betula pendula* Roth.) and downy birch (*Betula pubescens* Ehrh.) is considerably higher in scarified than in non-scarified areas (Folkesson & Johansson 1981), at least on mesic and moist ground (Fries 1985). So, shelterwood systems may deliver many aims other than wood production, including production of game and berries, maintaining biodiversity and, to a certain degree, aesthetics (Hörnfeldt & Ingemarson 2006) and could be supposed to limit the disturbance of '*the wider system*' (Mason et al. 1999). Thus, uniform shelterwood systems can, from many perspectives, be considered suitable for multipurpose forestry, even if they do not meet all objectives. However, no single silvicultural system or practice can deliver all objectives simultaneously.

1.1.3 Broadleaved tree species

Broadleaved species are important for multiple use forests (Andersson & Andersson 2005, Löf et al. 2009). They are valuable for biodiversity in pure as well as in mixed stands (Schütz 1997). In addition, several species can produce valuable timber (Woxblom & Nylinder 2010) and/or game fodder. The fact that broadleaved forests often are considered aesthetically attractive by the public makes them especially suitable for recreation (Norman et al. 2010), e.g. they have a positive influence on human health, with respect to stress relief (Annerstedt et al. 2010) and are 'immensely important' for cultural history (Löf et al. 2. 2010.) In addition, one of Sweden's national environmental goals is to increase the total area of broadleaved species (Anon 2005).

Table 2 summarizes the suitability of silvicultural systems, practices and tree species for delivering multiple forestry goals, based on published information.

Table 2. Are specific silvicultural systems/practices and species suitable for delivering multiple forestry goals?

Continuous forest cover (e.g. selection- and group selection systems)…..	Yes
Group system (Irregular shelterwood system)…………………………….	Yes
Broadleaved species……………………………………………………..	Yes
Uniform shelterwood…………………………………………………..	Yes?
Seed tree system…………………………………………………………	No?
Clear cutting system…………………………………………………….	No

1.2 Presentation of problems

- Table 2 is based upon only a few references, and sometimes the data in them relates to 'beliefs' (Mason et al. 1999, Rosell 2012). More research is needed on how to evaluate different ways of tending the forest from a multipurpose perspective, at least when it comes to small scale forestry.

- Not all forests are suitable for the practices, systems and species compositions discussed above (Matthews 1989, Lundqvist 2012). According to Mason et al. (1999) '*the choice of alternative systems should be based upon an understanding of species requirements, site potential, climatic limitations*'…etc. This is also valid in the reverse sense – the choice of practice must be appropriate for the stand. There is little chance of succeeding with a single tree selection system in a Scots pine stand on poor soil, at least not if one of the goals is to meet a production target, such as it is expressed in § 10 of the Swedish Forestry Act (Anon.1999). Even with a more suitable species for the selection system, e.g. Norway spruce (*Picea abies* (L.) Karst.), it is hard to find suitable stands in Sweden (Lundqvist 2012). For a long time, checklists have been used for different purposes in forestry (Paper II), but perhaps not particularly frequently for matching silvicultural practices and stands. However, there have been some attempts, e.g. an assessment of suitable objects for continuous cover forestry (Rosell 2012) and an assessment of forest biodiversity potential (Drakenberg 2004), but more research is needed in order to examine other examples.

- Failures happen even in cases where a stand is suitable for a particular practice, due to bad timing of the intervention. Within the shelterwood system, it is crucial that scarification is undertaken when rich seed falls are expected, so sound data on predicting good seed years is important (Karlsson et al. 2009). However, some aspects have been little studied, for example the timing of seed dispersal and of scarification (Hannerz et al 2002).

2 Objectives

- To present a method for evaluating different silvicultural practices and assessing their suitability for multiple goals.

- To present checklists for identification of stands and biotopes suitable for delivering multiple goals.

- To present examples showing that not only matching of silvicultural practice and stand/biotope is important, but so is appropriate timing of interventions; for example the natural regeneration of Scots pine.

3 Overview of papers

Figure 1 gives an overview of the five papers that form this thesis, their approaches, roles and connections to each other.

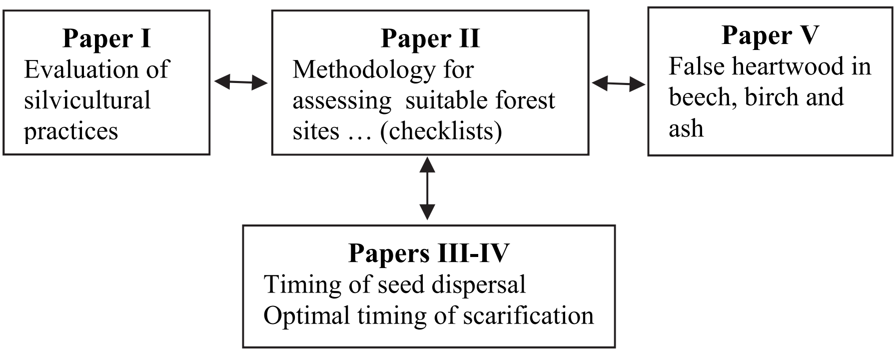


Figure 1. Overview of the five papers.

Paper I compares the suitability of different silvicultural practices with respect to the multiple goals of small-scale forest owners. The results of Paper I influenced the choice of cases and the methodology for evaluating the literature examined in Paper II.

Paper II. A methodology is presented for identifying suitable biotopes and stands for forestry practices adapted to multiple goals. The stand and practice must be compatible; if not the risk of failure is high.

Paper III. 'Timing of seed dispersal', is fundamental for paper IV.

Paper IV. 'Optimal timing of scarification'. Together the two papers (III and IV) show that sometimes it is not enough to ensure goal ↔ practice ↔ stand compatibility; timing of activities may also be important. The vertical arrow between Papers II and III–IV indicates that the methodology developed in

Paper II is more widely applicable. This is discussed in more detail under ‘General remarks and applications’.

Paper V. The same applies to the horizontal arrow between Paper II and V. Similarly, the arrow between Papers II and V indicates the applicability of checklists to the study of false heartwood’.

4 Details of the paper

4.1 Evaluation of silvicultural practices from a multipurpose perspective. Paper I.

4.1.1 Objective

The main objective of this study was to compare the suitability of different silvicultural practices with respect to the multiple goals of small-scale forest owners. In addition, a method for evaluating the results of research within the field is presented.

4.1.2 Material and methods

A theoretical model (Hugosson & Ingemarson 2004), describing the objective of private forest owners was used to compare different silvicultural practices (Table 1). A more detailed description of the objectives is presented in paper I.

The practices considered were: Clear cutting, successive felling (corresponding to 'uniform felling' (Matthews 1989), achieved in two steps), no felling, scarification, burning, planting, sowing, natural regeneration under uniform shelter (NUS), natural regeneration under irregular shelter (NIS), natural regeneration at forest edges (NFE), cleaning, no cleaning, thinning and no thinning.

A literature review was conducted, the relationships between practices and forest owners' objectives were analysed and summarized in the form of matrices, with the clusters of objectives on one axis and silvicultural practices on the other. One matrix was constructed for each cluster of objectives, i.e. conservation, amenities, utilities and economic efficiency. Each cell was allocated a level of adaptation and the levels were summarized using the following variables: A indicated 'adapted' (1); P indicated 'partly adapted' (0); and N indicated 'not adapted' (-1).

Following Gustafsson (1998), a system for reviewing the references was used, allocating asterisks according to their validity:

*** Refereed articles or monographs
** Scientific reports and textbooks
* Articles/reports not peer reviewed

The asterisk system maps documented knowledge for the area under consideration, so that areas lacking research are obvious in the matrices.

The suitability of each practice was analysed at forest stand level over a period of twenty years. This period was chosen for several reasons. First, the owners of properties tend to change during such a period: on average, a Swedish owner keeps and area of forest for about twenty years (Eriksson 1989). Second, this period is a time suitable for surveying: after twenty years the forest has developed into a new age class and a new silvicultural practice is often necessary. Over a longer period of time it would be difficult to gain an overview. If the period considered were a rotation, the analysis would have been at the systems level, rather than examining practices. Studying systems was not within the scope of this study, but a rough outline, with a comparison between two silvicultural systems is presented in the discussion of Paper I. The stands referred to were assumed to have a history and pre treatment such that the practices could be implemented without severe risk. The tree species were limited to Scots pine and Norway spruce in their natural habitats: other species could be kept in the stand for biodiversity purposes. Although the emphasis was on the most common practices related to clear cutting and uniform shelterwood systems (Matthews 1989), other practices, related to silvicultural systems in Central Europe that could be adapted to Scandinavia, were also discussed.

4.1.3 Results

In Paper I, the result of each cluster of objectives, namely ‘Conservation’, ‘Utilities’, ‘Amenities’ and ‘Economic efficiency’ is presented in detail in the form of matrices for each of the clusters; here, there is only a short verbal summary, however, Table 3 is a matrix summarizing all the objectives.

Conservation

Natural regeneration under irregular shelter (NIS) and Natural regeneration at forest edges (NFE) appeared to be suitable for conservation purposes (Paper I). Clear cutting, successive felling and an absence of tending produced low scores with respect to delivering conservation objectives. In general, the sum for the column ‘Culture conservation’ was low; this is not surprising considering that cultural conservation in forests is often associated with opening up areas, i.e. removing vegetation, in order to allow prehistoric graves, old ruins etc. to become visible within the landscape (Andersson 2000, Gustavsson 2000), thus preventing damage by roots and stopping trees from covering the area. Therefore, maintaining forest cover and undertaking forestry activities are, in general, unlikely to benefit cultural conservation.

Utilities

Thinning was the only practice that delivered all three objectives (production of ‘game’, ‘berries’ and ‘mushrooms’) in the cluster (Table 2, Paper I). Successive felling and cleaning were also useful, but inactivity was less appropriate, e.g. ‘no thinning’ could only deliver on the objective of mushroom production.

Amenities

Successive felling, the main regeneration practices (especially different forms of shelter) and active tending were appropriate in supporting the objectives of the amenities cluster (Table 3, Paper I). Clear cutting and passive practices were not of value in this respect.

Economic efficiency

Successive felling, regeneration under different shelters, cleaning and thinning were well suited to economic efficiency (Table 4, Paper I). Not cleaning had no economic efficiency benefits.

Summary

Table 3 below summarizes the level of suitability of each of the activities considered for all the multiple objectives of small-scale forest owners. Horizontally, the summation includes the scores for each individual practice. Vertically, the summation of practices demonstrates their suitability for each individual objective.

The results indicate that thinning and regeneration in gaps (NIS) appeared to be most suitable. Regeneration by a uniform shelterwood (NUS) was a little less well adapted and ‘passive practices’, such as no thinning, were poorly adapted to the multiple objectives of private forest owners.

Table 3. A summary of the level of suitability of various practices for the four clusters of objectives

	Conservation	Utilities	Amenities	Economic efficiency	Sum:
Clear cutting	-1	1	-2	1	-1
Successive felling	-1	2	3	3	7
No felling	-1	-1	-1	-1	-4
Scarification	0	1	-1	0	0
Burning	0	1	1	-1	1
Planting	0	1	1	-1	1
Sowing	0	1	2	-1	2
NUS	0	1	3	3	7
NIS	2	1	3	2	8
NFE	2	1	2	2	7
Cleaning	1	2	2	2	7
No cleaning	-1	1	-2	-3	-5
Thinning	1	3	3	3	10
No thinning	-1	-1	-2	-1	-5
Sum	1	14	12	8	35
Non peer reviewed reports/articles (%)	2,0	26,2	14,3	28,6	Mean: 17,9

4.1.4 Discussion

Low scores for passive practices

The fact that 'passive practices', such as, 'no thinning' and 'no felling', and no cleaning generally received low scores, and were found to be inappropriate for delivering the multiple objectives of private forest owners, was perhaps a little surprising. Whilst it is relatively easy to understand that passive practices are not 'adapted' to economic efficiency, it is harder to accept that such practices are only 'partly adapted' to the conservation cluster. No tending leads to free development of the forest and is often considered particularly suitable for conservation purposes (Sahlin & Säfve 2011). The explanation is that the cluster 'Conservation' contains not only 'Nature conservation', but also 'Culture conservation' and 'Water/Soil conservation' (Paper I). Untended ('virgin') forest obscures historic monuments and, in general, is not opened up in a controlled way (Buschel & Huss 1997). The absence of felling and tending in a stand may be appropriate for water and soil conservation, but not if this causes forest degeneration (Lanier 1994). In addition, passive practices are only 'partly' adapted to 'Nature conservation'; an absence of cleaning, thinning and felling is, in part, beneficial for biodiversity (especially mosses, lichens, fungi and insects), but it can be detrimental for some herbaceous plants and tree species. A crown density approaching 1.0 is not recommended (Ingelög 1981), unless only shade-tolerant species are required.

Analysis of a longer period

The time frame of the analysis was limited to twenty years, and this influenced the results: it is a short period for changes within the forest. However, analyses over a longer period demand consideration of complete silvicultural systems, which was not the aim of this study. Despite the limitations, it is necessary to begin at the stand level in order to evaluate different systems, e.g. clear cutting and selection systems. The technique could be applied when a forest owner, with a specific profile, requests an evaluation of a complete silvicultural system for a stand over a whole rotation period. Below is an example in which a forest owner with an ecological and nature-oriented profile might leave the stand free to be influenced by natural processes. This hypothetical owner is interested in studying how certain practices affect nature and water/soil conservation, in collecting edible mushrooms, in encouraging game and in tax planning. In Alternative 1 (Table 4), the owner chose to avoid active management during the whole rotation and to employ burning. In Alternative 2, a more active and traditional strategy was chosen.

Table 4. Two examples of interactions between several practices in silvicultural systems (Scores from Tables 1-2 in Paper I)

Alternative 1.	**Nature con.**	**Water/Soil con.**	**Mushr. prod.**	**Game prod.**	**Tax planning**	**Sum**
No felling	0	0	1	-1	0	
Burning	1	0	0	1	1	
No cleaning	0	0	1	1	1	
No thinning	0	0	1	-1	0	
Sum:	1	0	3	0	2	6
Alternative 2.						
Clear cutting	0	-1	-1	1	1	
Planting	0	1	0	1	1	
Cleaning	0	1	1	0	1	
Thinning	0	1	1	1	1	
Sum:	0	2	1	3	4	10

Alternative 1 appears inferior in all respects except for the production of edible mushrooms. The first alternative is, perhaps, extreme, but the example demonstrates that it is possible to examine the suitability of a large number of different silvicultural systems with a range of objectives.

An evaluation at stand level may not provide sufficient information for decision-making at the estate level. The composition of the stands, their structure and prior tending, all influence the outcome of favourable practices at the estate level. A complete evaluation of the optimal choices of practices for a large number of stands at estate level would be complex, especially if it is extended to encompass a whole rotation. A computerized system would facilitate the right choice of practice and could be used to consider the relative importance of the different objectives to the individual forest owner.

Different forest owners – different values

There are large numbers of forest owners, representing a wide variety of values, and for whom the different objectives assume different levels of importance. This is not taken into account in the summed values resulting from the matrices. In practice, a forest owner may consider, for example, that 'nature conservation' and 'mushroom production' were twice as important as the other objectives. The relative positions could be taken into consideration by allocating higher scores to the most important objectives, perhaps double those allocated to other objectives. This would make the two alternatives in Table 4 equally valuable. Thus it is possible to adapt the choice of practices to the different relative importance of each objective.

4.1.5 Conclusions

- Thinning appears to be the most useful forestry practice for private forest owners.
- Different forms of natural regeneration and cleaning are also appropriate. Passive practices seem to be unsuitable for the multiple goals of private forest owners.
- The silvicultural practices examined here were not well suited to delivering conservation goals, especially not to the conservation of cultural features.
- The results indicate that the practices evaluated provide opportunities for forest owners to adapt their forestry to multipurpose goals. The matrix system could be computerized, but for it to function efficiently, it is important to continue to include supporting evidence.
- Although the results are essentially restricted to Sweden, the method for evaluating the results of research within the field may have broader applications for the forestry sector in general.

4.2 Methodology for assessment of forest stands, suitable for silviculture with multiple goals. Paper II

A forest owner with a local knowledge of a small estate may have ideas about where to find suitable stands/sites, but also in such cases it is advantageous to study the question more systematically, e.g. by means of a checklist.

4.2.1 Objectives

Overriding objective

To find a method that gives guidance to the decision maker for identifying forest stands and biotopes suitable for silviculture to deliver multiple goals.

Sub goals

- To find criteria and data on criteria from the literature
- To present preliminary checklists to help in the identification of suitable stands in the field

Limitations

The checklists are designed to function mainly at stand level. The intention is that they could be used for identifying important criteria to be met, and not that they should include detailed descriptions of future treatments in the stands or economic analyses of the different cases.

4.2.2 Material and methods

A literature overview was accomplished (Paper II) by searching criteria and data on suitable stands with a focus on the following six cases:

1.) Selection system.
2.) Natural regeneration of Norway spruce in gaps (Shelterwood group system).
3.) Natural regeneration of Norway spruce under low shelterwood of birch.
4.) Natural regeneration of ash (Fraxinus excelsior L.)
5.) Natural regeneration of Pedunculate oak (Quercus robur L.) in coniferous stands
6.) Production of valuable black alder saw logs (Alnus glutinosa L.) and high biodiversity.

Criteria and facts about the criteria that were mentioned by the authors were collected and summarized (Paper II, Appendix 1).

Criteria and facts were then summarized in separate lists for each of the cases (Example: Table 5 below).

For reviewing references, the approach described by Gustafsson (1998, p.11) was used.

Finally facts relating to the criteria were transformed into questions and presented in checklists for each of the six cases (Example: Table 6).

4.2.3 Results

Selection of criteria and facts about criteria; evaluation of references and interpretation of facts

Table 5 shows a selection of criteria and facts for identifying stands/sites, suitable for two of the six cases, Case 1 ('Selection system') and Case 2 ('Natural regeneration of Norway spruce in gaps'). The criteria are grouped under four headings: 'Stability of mother stand', 'Vitality of mother stand', 'Suitability of the site for natural regeneration' and 'Stand structure and vitality of trees/plants', the latter just concerning Case 1. Because of limited space here, only two of the six cases are presented. The remaining four cases (3–6) can be found in Paper II (Appendices 2–5). For the same reason, only a few examples of references are mentioned in the third column. Descriptions of criteria and facts that were not precise had to be interpreted, e.g. 'the soil should be mixed with stones' (Söderström 1971) was interpreted as 'a till is preferable'. Some criteria, such as 'soil', have been 'double-checked', i.e. considered from more than one viewpoint. For instance, the criterion 'Soil' is found under heading 1 ('Stability of mother stand'), where the risks of wind throw in an old stand are considered, but also under heading 3 ('Suitability of the site for natural regeneration'), with focus on the establishment of new trees. About 13 % of the references were not peer reviewed.

*Table 5. Criteria, facts, evaluation of references and interpretations for Case no 1 'Selection system' (Headings 1-4) and Case no 2 'Natural regeneration of Norway spruce in gaps' (Headings 1-3). (***Refereed articles or monographs; **Scientific reports and textbooks; *Reports/article not peer reviewed)*

Criteria	Facts	References (including evaluation)	Interpretations
1. Stability of mother stand			
Soil	Should be mixed with stones	Söderström 1971 **	A till is preferable
Depth of the soil	Deep and with no iron pan, gley or pseudogley	Lundmark 1988, Otto 1998 **	Deep and without any impenetrable layer
Hydrology	Wet sites not suitable	Ebert 1994 **	No wet sites
Exposure	The risk of wind throw should be low	No ref. *	The stand should be in the lee of stands or hills
Stems per ha in the mother stand initially	Maximum 400 Maximum 500	Burschel & Huss 1997 Norén & Ståhl 1994 **	400–500 per ha and the latest thinning done>5 years ago
Standing volume	30% higher than stated in §10 of the Swedish Forestry Act	Rosell 2012, Anon. 1999 *	>30% over the threshold in §10
Tree height /diam. DBH	< 0.8	Burschel & Huss 1997 **	h / d < 0.8
Previous treatment	Thinned > 5 years ago	Ebert 1994 **	Well thinned, but not during the last 5 years
2. Vitality of mother stand			
Age of the stand	60–65 years Closer to 60 than to 80	Norén & Ståhl 1994 Schütz 1997 **	About 60–70 years old
Ring width	No starvation wood!	Eriksson 1966 **	Sum of latest 10 years >10mm
Crown length / tree height	>0.33 > 0.4	Schütz 1997 **	Length of green crown is 0.3–0.4 of tree height
Frequency of root rot	Low frequency of root rot	Norén & Ståhl 1994 ? **	No visible traces
Freshly injured trees in	The frequency of	Anon.1999	< 5 m³ per ha

the stand	recently wind thrown and injured trees should be < 5 m³ per ha	*	
Closest stand with severe insect damage	> 300 m away?	Lindberg 2012 *	> 300 m from the stand
	> 1 km away?	Dueli et al. 1997 **	> 1 km from the stand
3. Suitability of the stand/site for natural regeneration			
Location	Forest edge bounded by an open area	Schütz 1997 **	Bounded by an open area but the trees will resist storms
Vegetation/vegetation type	Low herb type (with *Wood anemone* and/or Wood sorrel*)*	Lundmark 1988, Troedsson 1961 **	Dwarf shrub type with low herbs
Advanced growth	Many seedlings in gaps	Troedsson 1961 **	Seedlings in gaps positive
Allelopathic species	Often an obstacle	Lundmark 1988 **	Should not be abundant
Site index	Suitable for spruce	Lundmark 1988 **	Site index G24 at least
Soil	Fine textured	Lundmark 1988 **	Silty
Humus layer	Humus layer at least 5 cm	Lundmark 1988 **	Depth 5 cm
Hydrology	Mesic to moist, not wet	Burschel and Huss 1997 **	No wet site
	Flowing water table	Gemmel et al 1997 **	Flowing water table
Topography	Slope	Lundmark 1988 **	Stand on a slope
Mixture of tree species	Positive with a mixture of tree species, e.g. pine and birch	Lundmark 1988, Schütz 1997 **	Presence of other species than spruce is positive
Potential seed trees per ha	At least 25 – 100	Söderström 1971 **	25–100
Presence of gaps	Important	Matthews 1989 **	Important
4. Stand structure and vitality (Concerns only the selection system)			
Tendency to stratification of the trees in several layers	'Partly stratified' stands are in general suitable for the selection	Schütz 1997 **	Partly stratified (although not 'perfectly' stratified)

	system		stands are suitable
Number of trees per ha to maintain the forest canopy during the transition faze	40-60 vital and middle sized trees (Spruces but also some pines, birches)	Schütz 1997 **	Number of vital (middle sized trees should be about 40-60 ha◌1 (Spruce and other specie)
Vitality of advanced growth	Length of top shoot 75% about of lateral shoots	Schütz 1997 **	Length of top shoots at least 75% of lateral ones

Reports/ articles not peer reviewed: 12.9 %

Checklist

Table 6 is an example of a preliminary checklist adapted to the cases 'Selection system' (Headings 1–4) and 'Natural regeneration of Norway spruce in gaps' (Headings1–3). Criteria under headings 1–3 are considered valid for both cases. In the case of regeneration in gaps there is no need to have a stand with uneven storeys to start with. In the case of transformation to a selection stand, there should be a tendency towards stratification of the stand, (heading 4; 'Stand structure'… etc.) that makes possible a successive transformation to a selection stand. The criteria have been derived from a starting point in Table 5 by transforming the interpretations (Table 5; Column 4) into questions. The assessment is supposed to be accomplished by direct observations in the field, answering yes or no to the questions, where a 'yes' generates 1 point and a 'no' or 'insufficient information' 0 points. Check lists for cases 3–6 are presented in Paper II; Appendices 2–5.

Table 6. Preliminary checklist for the cases 'Selection system' (Headings 1–4) and 'Natural regeneration of Norway spruce in gaps' (Headings 1–3) ***Yes = 1p; No (or insufficient information) = 0p***

Criteria	**Questions**	**Yes = 1 p**
1. Stability of mother stand		
Soil	Is the soil a till? (Stones or boulders are visible at the surface?)	
	Does the soil seem to be deep? (e.g. no substantial rock outcrops)	
	Is the soil free from an iron pan or similar layers?	
	Is the soil mesic to moist and not wet?	
Exposure	Is the stand in the lee of surrounding stands or hills?	
Stems per ha at start	Not more than 400–500?	
Tree height /diam. DHB	Is the h/d < 0.8? (height in m; diameter DHB in cm)	
Previous treatment	Has the stand been thinned more than 5 years ago?	

2. Vitality of mother stand		
Stand age	60–70 years or less?	
Ring width	Is the sum of the latest 10 years >10 mm?	
Green crown length	Is the green crown length / total tree height at least 0.3–0.4 on average?	
Root rot	Is there green foliage, trunks/roots without old injuries, resin flow and no swollen roots?	
Freshly injured trees	Is the frequency of recently wind thrown and injured trees < 5 m³ per ha?	
Severe insect damage	Is the closest stand with severe insect damage more than 300 m away?	
	Is the closest stand with severe insect damage more than 1 km away?	
3. Suitability of the stand for natural regeneration		
Location	Is the stand bounded by an open area but with a forest edge that will withstand storms?	
Vegetation type	Is it a dwarf shrub type with low herbs?	
	Is there substantial advanced growth in the stand?	
	Is there conspicuous advanced growth in gaps?	
	Are there few allelopathic species[2] in the stand?	
Site index	Is the site index G24 or higher?	
Soil	Is the soil fine textured (silty)?	
	Is the humus layer at least 5 cm deep?	
Topography	Is the stand on a slope and does it have a flowing water table?	
Mixture of tree species	Are there several trees of species other than spruce? Several trees of other species than spruce?	
	Are there substantial numbers of other species?	
Seed trees of spruce	Are there at least 25–100 potential seed trees of spruce per ha?	
[1]Good signs: Presence of wood anemone or wood sorrel; [2]such as bracken, crowberry, bilberry etc Sum (1-3):		
4. Stand structure and vitality of trees/plants (Concerns only 'Conversion to selection stand')		
Stratification	Is the stand partially stratified, with trees growing in different strata, although not necessarily perfectly stratified with a J-shaped distribution of tree sizes, e.g. lack of middle sized trees?	
Number of vital trees	At least 40–60 vital co- and sub-dominant spruces (pines/birches) per ha?	
Advance growth (AG)	Length of apical shoots of AG > 75% of lateral shoots?	
Sum (1-4):		

4.2.4 Discussion

Use of the checklists

The checklists are basically intended to be used to find suitable stands by visiting them and making assessments in the field. The assessor is supposed to make observations by means of the checklist in a number of representative areas all over the stand; how many depends on the homogeneity of the stand. Heterogeneous stands require 'many' observations. The scores are summarized and divided by the number of observation areas to produce a result for the entire stand. A remaining problem is to establish a minimum score for the 'suitable stand'. A way to avoid the problem would be to examine many stands and choose the best of them. However, there is no guarantee that 'the best' is suitable. For the moment there is no exact resolution to this problem; further research and follow-up in a large number of different stand types is required. At present, the answer can only be that a stand which achieves a low score is probably unsuitable and a stand that is allocated points for the majority of the criteria is likely to be suitable. Making the lists functional also demands verifying whether the questions relating to the criteria are intelligible or not; they may be interpreted and understood in different ways by different people. The questions must be clear and distinct and this requires numerous tests involving a large number of individuals.

The checklists could also be used for a preliminary desk-based rough selection to identify 'candidate stands', by means of 'traditional sources', such as forest management plans (FMP), geological maps and aerial photos (Paper II). The candidate stands could then be assessed in the field, and suitable stands selected. To date, information from traditional sources relating to the criteria is limited. FMPs need to be more detailed than they are at present if they are to become really useful for this purpose, e.g. it would be valuable if they included information on the number of trees per ha, stand structure and vegetation class.

Modern technology, e.g. satellite imaginary, digital aerial photos and laser scanned pictures, unlocks new possibilities (Klingström 2007). It is very likely that soon, forest management plans will contain considerably more detailed information than they do at present, and this will improve the opportunities to undertake more thorough desk-based assessments. However, before this can happen, there is still much that can be achieved with field studies of reference stands.

Should the lists be graded?

The criteria used in the checklists are ones that have been mentioned in the literature, but the fact that a criterion is not referenced does not mean that a forest manager can always ignore it. The criterion ‘topography’ in terms of ‘slope’ has been emphasized as important in the case of ‘Natural regeneration of ash’. However, it is well known that more or less all tree species are favoured by growing on slopes, at least on moderate ones. This could justify also taking into account ‘slope’ in cases when this criterion has not been mentioned as important in the literature, not withstanding a lower degree than in the case of ash. One way to implement this would be to introduce some kind of grading system. However, this would make the lists and assessments more complicated. However, the fact that some of the criteria may be more important than others might justify some kind of grading. In some cases it would even be possible to discern essential criteria’, e.g. severe damage by bark beetle in the neighbourhood of a ‘candidate- stand’ should disqualify it from conversion to a selection forest. However, it is possible that the risk of insect damage is reduced by the fact that the trees in the stand are extremely vigorous and that the answers to the majority of other questions on the list support conversion. In such cases the final choice is probably best made by the decision-maker examining the stand. Trying to decide in advance by introducing complicated scoring systems may make the list more of a ‘drawing-board product’ than is necessary.

Accuracy of facts

In some cases the references consulted provide precise facts, such as ‘the soil should be sandy’ or ‘the number of future seed trees’ should be 10–20 per ha. In other cases the ‘data’ are expressed in more general terms, such as site index should be ‘suitable for spruce’ (Lundmark 1988), which could be interpreted as ‘at least G24’. Of course it would have been preferable to collect only objective and quantitative data. However, much information that is not quantified precisely could still be useful in practical forestry.

References not peer reviewed

About 13% of the references for cases 1 and 2 were from literature that was not peer reviewed, such as instruction manuals, internal reports and articles in newspaper. Is such data appropriate to include in a checklist? Much of this information is based upon ‘general knowledge’ from practical forestry and could be useful. Thus, it would perhaps be an error to exclude such information at an early stage from a preliminary list, although the sources are not to be considered ‘scientific’.

4.3 Timing of seed dispersal in *Pinus sylvestris* stands in central Sweden. Paper III

In central Sweden, it is common to scarify seed tree stands of pine in the autumn, well before the expected seed fall. The main argument for this is a fear that the seed fall could occur very early in the spring or even in late winter, when scarification is prevented by a snow cover (Jäghagen & Sandström 1994, Enström 1996, Enström et al. 2005). This fear may be exaggerated and dispersal of pine seeds on the snow happens mainly in the northern latitudes of Fennoscandia (Heikinheimo 1932, 1937). However, there have been few relevant studies, especially in south Scandinavia. This justified our research.

4.3.1 Objective

To describe the variation in timing of seed dispersal from Scots pine seed trees in central Sweden.

4.3.2 Material and methods

Seeds were collected in traps at two locations: Garpenberg (lat 60˚ 16´N, long 16˚ 11´E, 170m a.s.l) and Knivsta (lat. 59˚43´N, long. 17˚49´E, 30m a.s.l.). The former was a Scots pine dominated mixed stand (93% Scots pine, 7% Norway spruce) with mature trees (120 years old) at a density varying between 100 and 250 trees per ha. The stand in Knivsta was dominated by Scots pine (80%), but also contained Norway spruce (5%) and some broadleaved species (15% aspen and birch). The total stand density in Knivsta was 120 trees per ha and the average age of the pine seed trees was 130 years at breast height. The recordings were carried out over four years at Garpenberg (1993–1996), and in three years at Knivsta (1996–1997 and 1999). The traps were emptied from March to August each year at 1–2 week intervals during the main period of seed dispersal. Weather data were collected from the meteorological stations in Ultuna, Uppsala, located 20 km from Knivsta, and in Falun, 50 km from Garpenberg.

4.3.3 Results

The seed fall started in mid to late April, shortly after the heat sum had started to increase, and the snow cover had disappeared. In general the most intensive seed fall took place in early to mid May, with the exception of Garpenberg in 1995, an extreme outlier, with seed dispersal occurring one month later than in the other years (Table 2; Paper III) The variation in timing among the years seems to be mainly due to climate factors – high temperatures promote seed fall and high precipitation retards it; for instance, during April 1995 the mean temperature in Garpenberg was much lower than ‘normal’ (Table 1; Paper III), defined as the average for April during the reference period 1961–1990, and the monthly precipitation was double the norm. Mean temperature in May 1995 was somewhat lower, and precipitation 50% higher, than normal. All this probably explains why the start of seed dispersal was considerably delayed in 1995 compared to the other years. The most intensive seed fall for 1995 occurred in mid June, when the mean monthly temperature was higher than normal.

In 1996, the only year when observations were carried out at both Knivsta and Garpenberg, the timing of seed dispersal was identical (Figure 1; Paper III), although the two localities are situated about 150 km apart and at different altitudes (Garpenberg 170m a.s.l; Knivsta 30m. a.s.l.).

4.3.4 Conclusions

The data suggest that scarification no later than mid May would generally create a good seed bed for most of the current years' seeds, whereas scarification in late May or June would bury a large proportion of this cohort.
The results may be useful for planning the time of scarification to optimize natural regeneration of Scots pine.

4.4 Optimal timing of scarification. Paper IV

The previous study (Paper III 'Timing of seed dispersal') may provide information on factors that promoted seed dispersal of pine, and thus provide some rough guidance on the timing of successful natural regeneration of Scots pine. However, there are many other factors that influence emergence and early establishment of seedlings, and there have been few comparisons of the effects of scarifying in autumn and at different times during the spring. This justified more studies in the field (Hannerz et al. 2002).

4.4.1 Objectives

The objectives were:

- to compare the effects of scarifying in autumn and at different times during the spring on the emergence and early establishment of Scots pine seedlings.
- to evaluate the impact of micro-topographical changes caused by soil compaction on seedling emergence.

4.4.2 Materials and methods

The study was conducted between 2005 and 2008 in two Scots pine shelterwood stands (Table 7), located close to each other 10 km south of Uppsala, and designated Stand 1 and Stand 2.

Table 7. Description of stands (Paper IV; Hörnfeldt et al. 2012)

Stand No.	**Site* index**	**Soil class**	**Slope**	**Veg. type**	**Area ha**	**Age years**	**Stems per ha**
1	T26	sand	flat	mesic dwarf shrub	8.0	85	110
2	T28	sandy silt	flat	mesic dwarf shrub; low herbs	6.0	100	140

* Dominant height at 100 years of age. T stands for 'tall' = the Swedish word for Scots pine.

Weather data were obtained from the Ultuna climate station, situated 5 km from the studied stands. Monthly mean temperatures were similar during the April–June period in the three study years (Paper IV; Figure 1). In all three years, the monthly precipitation values from April to September were close to the 1961–1990 monthly means, with some deviations for individual months. There was very low rainfall during May 2008, amounting to only half of the long-term average. June rainfall was close to average, but July was drier than usual in all three study years. In May 2008, there were fewer days with precipitation than in May 2006 or 2007. In June, the number of rainy days was similar in each of the three years.

Scarification was applied on several occasions in Stand 1 during 2005–2006 and Stand 2 during 2006–2007, being undertaken on similar dates (Table 8). However, due to an early spring in 2007, an additional scarification treatment was applied on 30 March in that year. In 2008, scarification was undertaken only once, in Stand 2 on 2 April. For practical reasons the scarification treatments were conducted by hand with a hoe and in limited patches to control the process and not influence previous scarification events by the movement of machines.

Table 8. Scarification events (Paper IV; Hörnfeldt et al. 2012)

Stand	**Autumn**	**March/April**	**Mid April**	**Early May**	**Mid May**
1	November 2005	–	20/4 2006	5/5 2006	22/5 2006
2	December 2006	30/3 2007	23/4 2007	7/5 2007	21/5 2007
2	–	2/4 2008	–	–	–

Starting in Stand 1 in autumn 2005, the experiment consisted of 50 blocks, with four treatments (scarification events) in each block. For practical reasons they were undertaken in five areas, spread across the stand, with 10 blocks in each area (Figure 2). Numbers of seedlings were counted in each patch in October 2006. The experiment was intended to be analysed as a randomized block design with 50 blocks of four treatments (scarification events). Starting in autumn 2006, the experiment was repeated in Stand 2, in the same area.

In order to test whether soil stabilization had an impact on seedling emergence, a third study was performed in Stand 2 during 2008. In each of the 33 areas of the stand, paired patches located close to each other were scarified on 2 April 2008. Both patches in each pair were scarified with a hoe, but one was also flattened and compacted with a spade, to create conditions similar to those of a stabilized autumn-scarified patch. Seedlings were counted in August 2008.

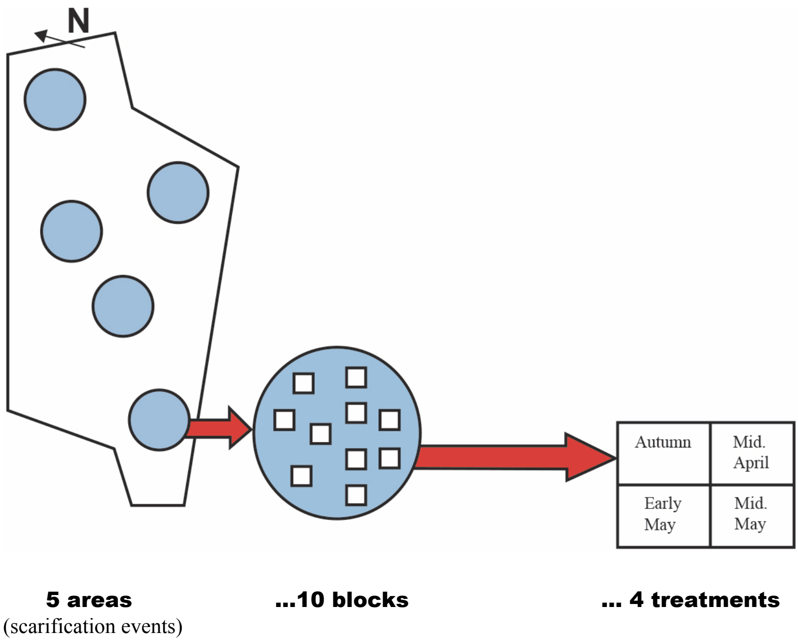


Figure 2. Design of the experiment in Scots pine stand 1. The 50 experimental blocks are located in five areas (10 blocks per area), and each block consists of four treatments (scarification events).

Monitoring seed fall

To monitor seed dispersal in relation to the timing of scarification events in 2005–2006, seed fall was studied using one seed trap (catch area=0.14 m²) in each of the five areas in Stand 1. The traps were installed before seed dispersal had started, and the seeds were collected once a week until the beginning of July.

In 2006–2007 and in 2008, two seed traps were installed in Stand 2 and monitored as in Stand 1.

Seed dispersal

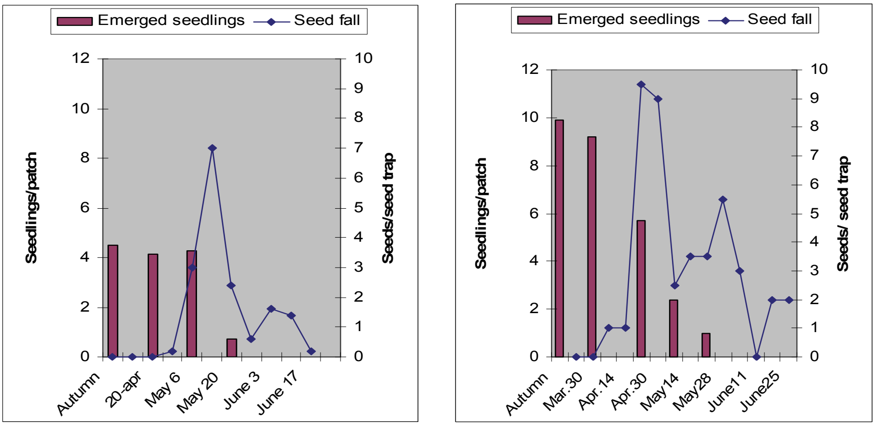
Seed dispersal peaked in mid-May in 2006 (Fig. 3), but the peak was several weeks earlier in 2007. Seed dispersal in 2008 followed a similar pattern to that recorded during 2006, but started earlier and ended later. Patches scarified in autumn 2005 and 2006 were exposed to most of the year's seed fall. This was also the case for patches scarified on 30 March 2007 and in mid-April 2006, since no seeds were found in the seed traps until after these events. By mid-April 2007, seed dispersal had already started and a considerable number of the seeds that fell during the year had already been released. During the following period, there were some differences between years. By early May 2007, the main peak of the seed dispersal had ended, but by early May 2006, it had just started. Thus, scarification events in early May 2006, and to some extent the one in mid-April, were better matched with seed dispersal patterns than the corresponding events in 2007. In both years, seed dispersal had declined considerably by mid-May. The single scarification event on 2 April 2008 should have exposed patches to most of the year's seed dispersal.

Statistical analyses of the number of emerged seedlings

The data were analysed using a generalized linear model as implemented in the SAS statistical package (SAS Inc., 2006). Tukey's test was used for multiple comparisons and treatment effects were considered significant if $p < 0.05$.

4.4.3 Results

For 2006 and 2007 the results indicate that the timing of scarification in relation to seed dispersal explains much of the variance in seedling emergence and establishment (Figure 3). Two of the scarification events during the spring of 2006 before the peak of seed dispersal were associated with about the same number of seedlings per patch as in the patches scarified in autumn 2005, i.e. 4 seedlings per patch. The patches scarified in mid May 2006 (22^{nd} of May; table 8), when the seed fall had decreased considerably, produced only about 1 seedling per patch on average. Because of a very early spring in 2007, only scarification on the 30 March was carried out early enough to benefit from 'all' of the year's seed fall, and compared with scarification in the autumn 2006, the number of seedlings was relatively low for scarification in mid-April (23^{rd} of April) and early May (7^{th} of May). The number of seedlings per patch was, in general, higher for scarification events during 2007 than during 2006, with the exception of scarification in early May.



2005–2006 *2006–2007*

Figure 3. Number of collected seeds per trap on different dates and number of emerged seedlings in the patches scarified at different times during the two first seasons of the study.

Results of significance tests

A significant difference was observed between seedling establishment in plots scarified in the autumn and those scarified in the following late spring, but not between plots scarified in autumn and early spring. The timing of scarification in relation to seed fall seemed to be an important determinant of seedling densities, and possibly the level of seed production. However, during 2008 a promising seed fall did not result in good seedling establishment, although scarification was completed before seed dispersal had started. This was probably because of drought, and the difference in numbers of seedlings that established between compacted and uncompacted patches was not significant.

4.4.4 Discussion

The more abundant seed fall in Stand 2, compared with Stand 1, was mainly due to better seed years, especially during 2007 (Anon, 2007), partly resulting from a higher number of seed trees and a higher site index (Karlsson et al., 2009). The annual seed fall in the stands amounted to between 1.2 and 3 million seeds/ha. Beland et al. (2000) recorded seed falls of 2.9–4.3 million seeds/ha in shelterwood in southern Sweden. However, there was a higher density of seed trees in the stands which they examined, 160–200 trees/ha, compared with 120–140 trees/ha in the stands examined in the present study. It should be emphasized that the seed fall study was not designed to measure the total abundance of the annual seed rain, which would have required a higher number of seed traps. The main purpose was to monitor the timing of seed dispersal and to estimate when it started, peaked and ended. Previous research has indicated that a few traps, systematically spread out in a very homogeneous shelterwood stand are sufficient for this purpose (Hannerz et al., 2002). However, estimates of total seed fall per ha, based on these figures should be interpreted with caution.

4.4.5 Conclusions

The optimum timing of soil scarification for regenerating Scots pine in central Sweden is before the seed fall begins. The results from 2005–2006 show that, for a single year, scarification as late as early May can be quite successful and result in good establishment of seedlings. However, the results for 2006–2007 also show that the most intensive seed fall of the year may occur much earlier than the beginning of May, which suggests that the optimum timing of soil scarification for regenerating Scots pine in central Sweden is from autumn through to mid-April (early spring).

4.5 False heartwood in beech, birch and ash. Paper V

This study focused on wood colorations found in beech, birch and ash. The term "false heartwood" is used throughout this work as a general term to express all variants of wood coloration found in these trees as opposed to normal heartwood coloration, which beech, birch and ash do not produce (Shigo 1986).

False heartwood is generally treated as a wood defect (Seeling & Becker 2002). However, the false heartwood concept encompasses many variants (Kohler 2006), one of which, 'redheart' of European beech (*Fagus sylvatica* L.), has long been marketed for its attractive aesthetic qualities (Koch 2004). Thus, there is a dilemma for foresters. On the one hand, false heartwood may be considered to be undesirable, and thus to be avoided, implying that we should attempt to minimize its formation, by carefully matching appropriate species and provenances to sites in terms of edaphic and climatic factors, adjusting silvicultural measures and targeting breeding programs accordingly. If, on the other hand, false heartwood is likely to be commercially attractive in the future, it would be of more interest to study issues related to marketing this unique kind of wood, and to develop new silvicultural programmes, probably quite different from traditional practices, to deliver specified volumes of such wood.

4.5.1 Objective

This study aimed to find answers to the following questions regarding false heartwood in beech, birch and ash:

- What are the differences between false and 'true' heartwood?
- What are its origins?
- What impact does false heartwood have on the quality, price and uses of wood?
- How can its formation be avoided it in the forest?
- Is false heartwood a problem or an asset?

4.5.2 Material and method

A literature overview was undertaken to compare false heartwood in beech, birch and ash with normal heartwood, discussing its induction, the impact it has on wood quality and use, and the possibilities for avoiding the formation of false heartwood by appropriate silvicultural practices and choice of the 'right' site for the species.

4.5.3 Results

Origin of false heartwood and its impact on wood quality

Normal heartwood forms in trees under the control of endogenous, hereditary factors. In contrast, the formation of false heartwood is induced by diverse exogenous factors, including various kinds of injuries or stresses that damage the tree, triggering a succession of processes (Kohler 2006). The extent of both normal and false heartwood increases when the tree ages. One common cause of stress is drought; others include branch breakage, incidents which create openings in trees or stem and root injuries, thereby exposing injured cells to the atmosphere. In all cases, similar reactions to those that occur when normal heartwood is formed are triggered, i.e. cells from the inner parts of the stem are emptied of their living contents and energy reserves, vessels and tracheids are plugged and conductive capacity is diminished. Initial chemical changes occur at this time and theses may result in discoloration of the wood. Microorganisms such as bacteria and non-decay fungi may subsequently invade, causing further alterations. The induced colouring can be explained by oxidation of the phenolic substances catalysed by various enzymes produced by the microbes present in the affected area. At that stage, only the aesthetic qualities of wood are affected. However, due to difficulties in visually distinguishing altered wood from rotten wood, false heartwood is considered a defect when grading wood, resulting in price reductions.

Silviculture

In the forest it is difficult to detect false heartwood by looking at the outside of a tree. Stems with deep checks and large numbers of dead branches are likely to contain considerable amounts of false heartwood (Seeling and Becker 2002), as well as trees with forked stems (Kohler 2006). Branch scar features are a sign of red heartwood in beech (Wernsdörfer et al. 2005a, b, 2006). The age of the stand also gives some hints; Seeling and Becker (2002) found a statistically significant positive correlation between tree age and the frequency of false heartwood.

The treatment required to avoid false heartwood is very similar for ash, beech and birch. Shorter rotations reduce the incidence of false heartwood. Young trees have higher vitality than old ones, and the higher the vitality, the greater a tree's resistance to various kinds of abiotic and biotic stresses. The key is to increase the trees' vigour through maintaining ample water and nutrient supplies. In a tree that has enough water and nutrients, the percentage of sapwood will be higher than in a tree with a lower water and nutrient supply. If water is abundant, trees can support large crowns, and thus produce more assimilates that can support the growth of the root system and annual rings, thereby keeping the tree in a "younger" state than a tree growing under poor conditions. One way to ensure this is to provide the individual tree with abundant space by active thinning. However, excesses of any kind can also stress trees (Kohler 2006). Therefore, thinning should not only be heavy, but frequent and regular to avoid sudden changes. The likelihood of trees being stressed due to drought or lack of nutrients is highly dependent on site conditions and excessively dry as well as waterlogged sites should be avoided. In stands growing on slopes, the frequency of false heartwood may be higher in the upper parts of the stand than further down towards the valley floor. One way to reduce the risk of false heartwood is to carry out heavier thinning on the upper parts of slopes than on lower parts, when treating an existing stand (Kohler 2006), another is to choose a more resistant species when creating a new stand.

Avoiding stress is especially important when growing ash (Lanier 1994), which has a lower range of site tolerance than beech and birch. Hence it is important to identify inappropriate sites for ash production, especially very poor arid and shallow soils (Götmark et al. 2006). The opposite extremes, heavy, compacted and waterlogged soils, are also to be avoided (Evans 1984). Ash seedlings may invade such sites in abundance, since they only need a few cm of well-drained soil during the regeneration phase, but periods of drought generally lead to small later increments (Savill 1991), and the risk of false heartwood ('brownheart') development is increased. Brownheart in ash appears when the tree is 60–80 years old. In Sweden, a rotation of 60–70 years on better sites is recommended for ash plantations (Almgren et al. 2003). With an active thinning programme, starting at a height of 10 m (Evans 1984), and an age of 30 years, keeping the crowns of the main stems free by crown thinning every five years (Lanier 1994), it should be possible to advance final felling to a time before the frequency of brownheart becomes too high.

4.5.4 Discussion

False heartwood – an asset?

In Europe there have been attempts to launch false heartwood of beech ('redheart') on the market for furniture and cabinet making. This trend may open new opportunities for false heartwood. Consequently, silvicultural practices may become quite different from those proposed above. Rotations might become longer, and in some regions in Germany there are even claims that selection cutting represents a suitable silvicultural system (reference?). However, one condition for successful marketing of an "exclusive wood" is that it should remain "exclusive". Thus, there is no guarantee that successful marketing and production of redheart "en masse" would remain sustainable. Increasing traded volumes could lead to price reductions in the long term. Thus, it is probably better to keep the available volumes of wood with redheart at present levels. The potential for selling redheart also depends on transient fashions, generally lasting very brief periods. For these reasons it may not be a good idea to increase the supply of redheart by tending forest stands in ways that promote higher volumes of altered wood. The volume of such wood produced "involuntarily" may be more than sufficient. Further persistent marketing problems may be associated with persuading buyers that redheart, in its early stages, has "nothing to do with decay". At least it always remains a doubt, and strenuous efforts will be required to educate prospective clients, especially since sound redheart and decayed wood are often present in the same saw log (Kohler 2006).

4.5.5 Conclusions

- Normal heartwood forms in trees under the control of endogenous, hereditary factors.
- False heartwood is induced by diverse exogenous factors, including various kinds of injuries or stresses.
- In the early stage of false heartwood formation, only the aesthetic qualities of the wood are affected.

- Due to difficulties in visually distinguishing between altered wood and rotten wood, false heartwood is mainly considered a defect when grading wood.
- Young trees have higher vitality than old ones.
- The higher the vitality, the higher a tree's resistance to various kinds of stresses.
- Shorter rotations reduce the incidence of false heartwood.
- Heavy thinning should be applied to ensure that trees reach valuable dimensions at an early age.
- Excesses of any kind can also stress trees. Thinning should not only be heavy, but frequent and regular to avoid sudden changes.
- The key is to avoid trees being stressed, and this is highly dependant on site conditions, e.g. excessively dry as well as waterlogged sites should be avoided.
- Ash has a lower range of site tolerance than beech and birch.

5 General remarks and applications

5.1 Modification of practices

In Table 3 ('A summary of the level of suitability….etc.'), clear cutting received low scores and was not considered suitable for multiple goals in small scale forestry. However, clear cutting in this case referred to the 'original form', i.e. no Green Tree Retention (GTR) after harvesting (Paper I, p.4). GTR provides an opportunity to preserve continuity, keeping key habitats for birds, insects and fungi etc. (Gustafson et al. 2012). However, it also provides for ecosystem services (Kronnäs et al 2012), increases public acceptance of harvesting (Gustafson et al. 2012), and even brings aesthetic benefits. This possibility was not discussed in Paper I. A modified approach to clear cutting could, perhaps, be adapted to multiple goals (Table 9). There follows an attempt to examine this:

Clear cutting in its original form received low scores especially in the clusters 'Conservation' and 'Amenities'. In the 'Conservation' cluster ('Culture-, Nature- and Water/Soil conservation'), clear cutting received low scores mainly because the practice was not found to be suitable for Water/soil conservation (score -1). For Culture- and Nature conservation, clear cutting was only 'partly adapted' (0), and the sum of scores for the whole cluster was -1 (Table 9). However, by modifying the practice – i) limiting the clear cut area to just a few hectares; ii) using the practice only on flat terrain; iii) leaving retention trees and iv) avoiding destruction of historical monuments through better planning – clear cutting could perhaps achieve a score of +3 instead of -1.

Table 9. Suitability of the practice of clear cutting to deliver conservation objectives, comparison with 'modified clear cutting'

	Culture conservation	Nature conservation	Water/Soil conservation	Sum of scores:
Clear cutting, 'original form' (Def. Paper I, p. 4. Scores from Paper I, Table 1)	Partly adapted (0)	Partly adapted (0)	Not adapted (-1)	0+0-1=-1
'Modified clear cutting'(Small area+ retention trees etc.)	Adapted (+1)	Adapted (+1)	Adapted (+1)	1+1+1 =3

When it comes to the 'Amenities' cluster (Forestry tradition, Silvicultural challenges and Aesthetics), clear cutting received even lower scores, because of the low scores for Silvicultural challenges (-1) and Aesthetics (-1). The 'modified clear cutting', described above, would provide both 'challenges' and opportunities to bring 'aesthetic benefits' to the forest owner, which makes it possible to transform the score from -2 to at least +2. Adding the new scores of the two clusters increases the overall score from -1 to +7 (Table 10), which indicates that modifications to a 'not adapted' forest practice can turn it into an 'adapted' practice. This also suggests that it may be possible to use the technique presented in Paper I to identify 'new' practices, better adapted to different goals. Taking the practices presented in Paper I as a starting point, it would be possible to examine why a certain practice was 'not adapted' to different goals, and then to determine how the practice could be improved so that it does deliver the relevant objectives.

Table 10. A summary of the level of suitability of clear cutting for the four clusters of objectives. (Scores from Paper I, Table 3.) Comparison with 'Modified clear cutting', i.e. small clear cut + flat terrain + leaving retention trees.

	Conservation	Utilities	Amenities	Economic efficiency	Sum:
Clear cutting ('original form' Table 5)	-1	1	-2	1	-1
Modified clear cutting	3	1	2	1	7

5.2 Matching the practice to the stand (Paper I in combination with Paper II)

In the discussion of Paper I a comparison was made between two forest owners with two different profiles and strategies. One of them, representing a traditional forest owner, chooses a quite conventional strategy (Table 4, Alternative 2), i.e. clear cutting→ planting→ cleaning→ thinning. However, in Table 4 the practices were chosen in a routine way, and no account of the stand/biotope was taken. Starting from Alternative 2, let's see what happens if stand- and site factors are also borne in mind (Table 11.):

Table 11. Two examples of interactions between several practices in systems when stand- and site factors are borne in mind

Spruce stand (Alt. 2. in Table 4; scores table 4)	**Nature cons.**	**Water/Soil cons.**	**Mushr. prod.**	**Game prod.**	**Tax planning**	**Sum**
Clear cutting	0	-1	-1	1	1	
Planting	0	1	0	1	1	
Cleaning	0	1	1	0	1	
Thinning	0	1	1	1	1	
Sum:	0	2	1	3	4	10
Pine stand/ suit. site for natural regeneration of pine.(Scores Paper I)						
NUS	0	1	0	1	1	
Scarification	0	1	1	0	1	
Cleaning	0	1	1	0	1	
Thinning	0	1	1	1	1	
Sum:	0	4	3	2	4	13

If the stand is an 'ordinary overripe spruce stand', monoculture, suitable neither for NUS (Natural regeneration under Uniform Shelter), nor NIS (Natural regeneration under Irregular Shelter), the optimal programme would probably remain the same as in the example presented in Table 4, i.e. clear cutting→. planting→ cleaning →thinning. However, if the stand is a mature pine stand, and the combination of stand and soil is suitable for natural regeneration, the right choice of practices could change. In that case, it is likely that there will be higher scores for the sequence (NUS)→ scarification→ cleaning→ thinning (The scores in the 'pine alternative' are from Tables 1 and 2 in Paper I). A spruce stand (suitable for NIS after assessment using the checklist presented in Table 6) would perhaps produce another option.

So, the optimal silviculture adapted to small estates is much a question of matching goals, practices, stand (including site factors) and events. Figure 4 is an attempt to illustrate this.

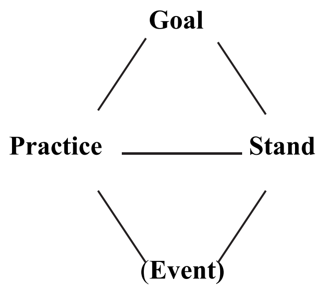


Figure 4. Matching goals, practices, stands and events.

Practices and the forest owner's profile (as expressed by the goals) must fit together and so must the relationship between practices and stands, because even in cases when the goal matches the practice and vice versa, it is not guaranteed that the practice and stand can be combined successfully. The connections between 'Stands'↔ 'Goals' and 'Stands'↔ 'Events' are less clear, but there are sometimes opportunities to modify a stand to become better adapted to the goal or the event by appropriate tending.

Example: A forest owner, with a 'nature oriented profile', wants to introduce the selection system all over the estate. This is a realistic option in a spruce stand that is suitable for the selection system based on the checklist in Table 6. Goal, practice and stand all match each other. However, if the forest owner wants to use selection cutting in a dense spruce stand that has been even aged since the regeneration phase, there will certainly be some problems. It is true that the goal and the practice still match, since the forest owner has a predilection for the selection system, but the stand is not adapted to selection cutting (Matthews 1989, Schütz 1997). There will be problems, such as wind thrown trees and insect damage. In addition, the goal (introduction of the selection system) and the stand do not match. In this case it is possible to 'stabilize' the stand through several careful thinning operations (Schütz 1997), but this will take time and it may be more efficient to continue to treat the stand as being even aged until the end of the rotation and start the change to the selection system only after final felling.

The connection between ‘event’ and ‘practice’ tends to happen ‘occasionally’, e.g. when there are good seed years. This is indicated by the use of parentheses – ‘(Event)’ – in Figure 4. Soil scarification is matched to the event (seed year → scarification) when undertaken in association with a good seed year and the timing of scarification is appropriate for the seed dispersal period, i.e. accomplished either during the autumn before, or in early spring (Paper IV). The converse, i.e. that scarification would ‘lead’ to a good seed year is of course not possible. However, the good seed year could be induced by thinning the stand 4–5 years before the scarification is carried out. The link between the event and the stand is that the seed must be produced in a suitable stand, in this case a Scots pine shelterwood. A good seed year for Scots pine is of little value in a stand dominated by Norway spruce. A good adaptation to the event is to observe in advance that a good seed year will occur in a shelterwood. Other practices, such as clear cutting, may be less dependent on adaptation to ‘the right event’, and still be successful.

A working model for optimal choice of practices adapted to the forest owner’s goals could include the following steps:

Step 1		Step 2		Step 3		Step 4		Step 5
Goals? ↑ Forest owner’s profile?	↔	What practices are suitable for the goals?	↔	Do the practice, stand (and goal) match?	↔	Is a choice of event necessary?	→	Final choice of practice stand and event
		Method of Paper I		Checklist Papers II and V		Checklist Papers II–IV		

5.3 Stand level – estate level?

The discussions above refer to combining several goals at the stand level. The most realistic situation for an ‘ordinary’ estate in Sweden is that there should be no difficulty in identifying stands that are unsuitable for multiple goals, e.g. established and tended for a single purpose, such as wood production. For the ‘multiple-goal-minded’ forest owner there is then another approach available: utilizing suitable stands for multiple purposes and the others for more specific goals, but at the same time trying to create variation by using multiple management at the estate level to form a mosaic of stands.

5.4 A wider use of checklists – some examples

Optimizing natural regeneration of pine

The recommendations in Paper III were solely based upon the study of seed dispersal. Whilst it is possible to state that the most intensive seed fall is over by mid May and that scarification should be undertaken before then. However, this is not enough, since the optimal timing of scarification is not only driven by the timing of seed dispersal; it should also take into account many other factors affecting seedling establishment, such as timing of good seed years, soil fertility, the number of years following release cutting, competition from weeds during the establishment phase etc. A checklist could be useful for 'optimizing' natural regeneration. Table 12 is an example of how such a list could be presented by utilizing the same methods as in Paper II and drawing on information from the literature study presented in Paper IV.

Table 12. Example of a preliminary check list for optimizing natural regeneration of Scots pine under a seed tree stand

Criteria	**Questions**	**Yes = 1p**
Number of years after release cutting	Is it more than 2 years since release cutting? (Site index< T22)	
	Is it less than 1 year since release cutting? (Site index>T22)	
Cone prognostics	Do the prognostics (Skogforsk and SNFI) look favourable?	
Number of cones in seed trees	Are there > 200 cones per seed tree? (In case you intend to scarify this autumn or early next spring)	
Site index	Is the site index T24 or less?	
Altitude	Is the altitude < 400 m a.s.l.?	
Temperature sum	Is the temperature sum > 900 day degrees?	
Hydrology	Is the site dry–mesic?	
Topography	Is the site on a slope?	
Soil	Is the soil coarse textured?	
Humus layer	Is the humus layer < 3cm?	
Vegetation	Is the ground flora a dwarf shrub type (or lower)?	
Competition	Will the competition from weeds probably be low?	
Game	Is the game population low?	
Insect and other predators, e.g. snails	Do insect/herbivore populations seem to be low?	
Stability of seed trees	Do the seed trees have green crown lengths> 1/3 of the tree height?	

	Is the area protected from wind (surrounded by hills, tall stands)?	
Earlier treatment	Was the stand managed for saw timber (about 300–400 stems per ha) during the 5–15 years before release cutting?	
Basal area	Is the basal area about $20m^2$?	
Actual number of trees per ha	Are there 80–100 seed trees (SI<T22)?	
	Are there > 100 seed trees? (SI>T22)	
Stand age	Has the stand attained the lowest permitted age for final felling according to the forest act?	
Sum :		

Avoiding false heartwood

The same technique as above can be used in other cases. Table 13 provides some guidelines for a forest manager who is seeking stands with low frequencies of false heartwood, in this case stands of ash. If affirmative answers to the questions dominate, it is likely that the trees in the stand will have small amounts of false heartwood. The criteria are from the list for ash presented in Paper II, with some modifications and additional criteria from Paper V. (The checklist could also be utilized in reverse by a manager who is interested in harvesting wood with brownheart, i.e. low scores indicate a high likelihood of finding that valuable wood.).

Table 13. Example of a preliminary check list for 'Avoiding false heartwood (brownheart) of ash' by choosing the right stand

Criteria	**Questions**	**Yes = 1p**
Vegetation/ vegetation type	Is the vegetation type 'tall herb type'?	
Site/Site index	Is the site index G26 or higher?	
Soil/ soil type	Is it a silt- to light clay? (not a heavy clay!)	
Soil depth	Is the soil depth >60cm?	
pH	Is the soil pH in the range 5–7? (not under 4.4)	
Hydrology	Is the site moist but well drained, with a flowing water table?	
	Is the site free from waterlogged areas?	
Topography	Is the site on a slope?	
	If so, is the site situated in the middle of a slope, rather than at the top or bottom of it?	
Exposition	Is the site within a shelterwood or is there a forest edge in the neighbourhood?	

Stand age	Is the site younger than 40–60 years?	
Earlier treatment	Has the stand has been thinned heavily and regularly (stumps from thinning visible?)	
Crowns of main trees	Are the green crowns well developed > ½ of total tree height?	
Increment	Is the increment of the main stems high, with relatively high mean diameters for the trees' age?	
Presence of alder	Are there alders present in the stand?	
Mixture of tree species	Does the stand contain a mix of ash, alder, aspen, birch, larch or pine?	
Shelter from the side	Is the stand protected from the side by another stand?	
Health of the trees	Does the stand, on the whole, seem to be free from die back of ash, cankers, checks or other injuries on the stems?	
Dead branches	Do the trees have few dead branches or branch scars on the bottom logs?	
Forked stems	Is the frequency of forked stems low?	
Soil compaction	Are there few traces of heavy vehicles in the stand?	
Game	Are there very few signs of game damage in the stand?	
Sum:		

Choice of tree species

The choice of tree species in an area is often made roughly and in a routine way in Swedish forestry, and is frequently based upon only a few criteria, e.g. soil fertility and access to water. Low fertility and a limited water supply generally leads to the choice of pine; high fertility and an abundant water supply leads to spruce. However, as has been shown in Paper II, there are many other factors to take into account when choosing tree species for a site, and checklists could be developed for species other than those presented in Paper II.

Checklists as 'handbooks'

The primary intention with the checklists described in Paper II was that they should serve to identify suitable stands. However, examining a stand in relation to various criteria can also help a manager to identify what is 'wrong' with the stand, what eventually could be 'repaired', thus providing some guidance on suitable future silvicultural interventions.

6 Conclusions and further research

Practices such as thinning and natural regeneration in gaps and under shelterwood were found to be adapted to multiple goals in small scale forestry, even if there were some doubts about the latter, especially when combined with soil scarification. Passive practices, such as ‘no thinning’ and ‘no felling’ did not deliver the goals (Paper I).

Forests with continuous cover, such as single- and group selection stands were considered to be adapted to multiple goals in the literature studied. This is very likely since the practices that were considered ‘adapted’ in the study described in Paper I are practices commonly used within those systems. Creation of broadleaved forest stands was also found to be adapted to multiple goals in the literature.

There are possibilities for improving ‘not adapted’ practices by modifying them. This was examined in the case of clear cutting, and could also be done for other practices or systems considered not to be adapted, such as scarification, planting, the seed tree system etc.

The chances of succeeding with continuous forest cover, broadleaved forest stands, and natural regeneration in gaps and under shelterwood were highest on very specific sites, according to the literature.

There was a lack of peer reviewed studies about the regeneration of oak in coniferous stands (Paper II), and also, to a certain extent, about natural regeneration of spruce under birch shelter, suitable stands for the selection system and regeneration of spruce in gaps. Information about natural regeneration of ash was well documented (Paper II). The information on production of high quality alder timber was adequate, but very few parameters were found (Paper II); the latter was also the case for the regeneration of oak in coniferous stands, which was not surprising since the question has been little studied. Another weakness is that most information on criteria was mainly found in textbooks and scientific reports, and very seldom in refereed articles in scientific journals. However, this may also be because, in general, textbooks focus on 'how to implement' to a higher degree than scientific articles.

A tool for assessing suitable stands and biotopes was presented in the form of six checklists. In their present state the checklists are only preliminary. Creation of functional lists demands numerous comparisons in the field, involving many forest stands. The lists need to be revised after having been tested.

Making the lists functional also requires verification of whether the questions relating to the criteria are intelligible; they may be interpreted and understood in many different ways by different people. The questions on the lists must be unambiguously clear and distinct and this demands numerous tests involving lots of people.

The 'checklist method', might be useful in many other cases than the six presented in Paper II. Two additional checklists ('Optimizing natural regeneration of Scots pine' and 'Avoiding false heartwood in ash') were presented as examples of other ways that checklists could be used. Such developments would require further literature studies to find information relating to specific new cases.

Checklists give information on the present state of forest stands, and could therefore be useful when choosing future silvicultural measures.

Both Papers III and IV conclude that the optimum timing of soil scarification for regenerating Scots pine in central Sweden is before seed fall begins. According to Paper III, the most intensive seed fall generally occurs during early May, so scarification no later than mid May would generally create a good seed bed for most of the current years' seeds. However, additional observations in 2007 (Paper IV) show that intensive seed fall may occur much earlier than that, i.e. mid to late April. As a result of this new information, 'the optimal scarification season' was shortened by two weeks (Paper IV). This can of course be modified in the future if spring arrives even earlier than in 2007.

The recording of the seed dispersal was undertaken in six years for Paper III and three years for Paper IV, giving a total of nine years of recordings. This is a very short time in the context of the life of a forest. Weather statistics from the Ultuna climate station (Karlsson & Fagerberg 1995) may make it possible to obtain complementary information about variations over longer periods. The climate station has collected daily records of temperature and precipitation since 1896. Seed dispersal commences shortly after the temperature rises above 5˚C and the heat sum starts to accumulate (Paper III). Detailed studies on temperatures during the days and weeks after 'the start day', should give access to data on the timing of seed dispersal for long periods. This could lead to more accurate recommendations about the optimal timing of soil scarification, although the recommendations would only remain retrospective.

Finally and in a wider perspective: Things are rarely either black or white in nature, but furthermore 'in between' and you can't obtain all the truth only by putting a number of criteria and facts 'in little boxes'. This is a weak side of the methodology proposed in Paper II; still the checklist gives the user an opportunity to confirm that key criteria are met. This provides valuable guidance when identifying suitable forest stands for silviculture with multiple goals. However, the decision-maker must be aware about the limits of the checklists, and there is no omnipotent silvicultural system or practice that can deliver all objectives simultaneously. Within (large scale) industry forestry they have tried to solve this problem by modifying the clear cutting system, e.g. leaving high stumps, protection zones, retention trees etc. This is also common within small scale private forestry. 'Modified' clear cutting has been very successful when it comes to improvement of the biodiversity (Gustafsson et al. 2012), and perhaps also for other conservation objectives, at least according to Table 9, but what about the other goals presented in Table 1? Clear cutting has many advantages, e.g. easy to administrate, suitable for large scale operations etc. However, to what degree can modified clear cutting meet other goals, such as 'forestry tradition', 'challenge of silviculture' and 'aesthetics'? Clear cutting is often considered as a stereotypic practice, and will probably be considered so by many forest owners' for a long time from. For that reason there will probably always be a demand for alternative silvicultural practises, such as selection felling, regeneration in gaps etc. One problem is that there are a lot of risks in connection to those alternatives, especially systems and practises that are not commonly used in Sweden; risks for storm felling, outbreaks of severe insect damage and insufficient regenerations leading to production losses. How avoiding that? The answer could perhaps more research about alternative silvicultural systems/practises and more education. That's the reason why many of the questions in the checklists (e.g.Table 6) are dealing quite a lot about minimising risks.

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