Ecological Bulletins 53: 235–245, 2010

Broadleaved forest management for multiple goals in southern Sweden – an overview including future research prospects

Magnus Löf, Mattias Boman, Jörg Brunet, Mats Hannerz, Leif Mattsson and Mats Nylinder

Stands of temperate broadleaved tree species in southern Sweden are often small and scattered across the landscape. Competing land uses and a modern industrial demand for fast growing conifers has resulted in a conversion of the once dominant broadleaved and mixed forest types into farmland and conifer plantations. Today, the remaining broadleaved forests generate e.g. timber, biodiversity and recreational opportunities. This multi-functionality is, however, problematic, since one way of using the forest often affects the potential for other uses. There is, therefore, a need to develop management strategies that combine different interests. This paper provides an overview of the research conducted within the Sustainable Management in Hardwood Forests research program. The issues surrounding broadleaved forests are first outlined in a historical context, and are followed by a basic description of the relationships between different forest functions and the possibilities for combined use. We also summarize the achievements in the five different sub-fields of the program (multiple functions and welfare, wood properties and utilization, biodiversity conservation, silviculture, and communication with end-users). Finally we discuss future management and research prospects. The potential for combining timber production with outdoor recreation environments seems to be relatively promising, although more knowledge is needed about the relationships on different spatial and temporal scales. Combining timber production with biodiversity conservation will continue to be a major challenge. Another future challenge will be to adapt forest management to climate change. Research will be needed to address the impacts of climate change on trees, biodiversity and diseases, alternative silvicultural methods, new plant materials, habitat restoration and the migration of species. Sustainable approaches to management may be too expensive for the government to fund alone. In addition, approaches should be adopted which, among other things, consider economic aspects of privately owned forests. The knowledge base required for multifunctional management of broadleaved forests is indeed complex and interdisciplinary research will be required to underpin this knowledge.

M. Löf (magnus.lof@ess.slu.se), M. Boman, J. Brunet and L. Mattsson, Swedish Univ. of Agricultural Sciences, Southern Swedish Forest Research Centre, P.O. Box 49, SE-230 53 Alnarp, Sweden. – M. Hannerz, Skogforsk, Uppsala Science Park, SE-751 83 Uppsala, Sweden, (present address: Silvinformation AB, Kolonivägen 6B, SE-741 44 Knivsta, Sweden). – M. Nylinder, Swedish Univ. of Agricultural Sciences, Dept of Forest Products, P.O. Box 7008, SE-750 07 Uppsala, Sweden.

The areal extent of temperate broadleaved forests in southern Sweden has decreased considerably in the last thousand years, largely due to agricultural activities like land cultivation and heavy grazing, as well as timber harvesting (Lindbladh et al. 2000, 2007). This decline has accelerated during the past century, as an increased industrial demand for wood led to the transformation of broadleaved forests into coniferous ones (Löf 2001, Lindbladh et al. 2007). The 1960s was a decade of growing environmental concern internationally (e.g. Carson 1963), and forests came increasingly into focus in the Swedish debate about natural resources and environmental issues. The decrease in southern Swedish beech *Fagus sylvatica* forests became the focus of an official investigation in 1964. This led to an act of legislation in 1974 relating to the conservation of beech forests, requiring beech stands to be replaced by beech stands after felling (SOU 1971: 71, Statens Naturvårdsverk 1982). The concept of "multiple-use" forests was introduced (Hultman 1984), reflecting an increasing awareness of the importance of forests as a resource with different functions. In Sweden the Forestry Act of 1979 was the first one to acknowledge the importance of nature conservation and other public interests (SFS 1979: 429). As a consequence, forest management practices are now required to address different, and sometimes competing, goals (Samuelson 1976).

In 1984 the act pertaining to the conservation of beech forests was replaced by an act that also covered other "noble" and native temperate broadleaved tree species, i.e. ash *Fraxinus excelsior*, elms *Ulmus glabra, U. laevis, U. minor*, hornbeam *Carpinus betulus*, limes *Tilia cordata, T. platyphyllos*, maples *Acer platanoides, A. campestre*, oaks *Quercus robur* and *Q. petraea* and wild cherry *Prunus avium* (Statens naturvårdsverk 1982, SOU 1992: 76). In 1993 all these broadleaved tree species were included in the national Forestry Act (SOU 1992: 76). A basic principle in these acts was, and still is, that the harvest of broadleaved forests must be followed by reforestation with broadleaved trees. Forest owners can get subsidies to compensate for regenerations and stand treatments that are more expensive compared with those for coniferous tree species (SOU 1992: 76). The existence of these subsidies implicitly reflects a value that society attaches to the southern Swedish broadleaved forests, besides their value for forestry.

The forestry acts embody a societal wish to maintain and manage broadleaved forests, but research is required to ensure that we can successfully enact this wish. In order to make the most of both the timber and non-timber values of these forests, research into a broad spectrum of forest functions is required, at different spatial and temporal scales. A key issue is the current and potential value of broadleaved forests in southern Sweden. The general objective of the research program Sustainable Management in Hardwood Forests has been to "develop strategies for silviculture and conservation of 'noble' broadleaved forests with regard to their economical, ecological and social functions" (Löf 2010). In addition, the program has included considerable efforts to disseminate research results. The aim of this paper is to provide an overview of the research program, synthesize some of its major findings and discuss future research prospects.

The multiple-function problem

Temperate broadleaved forests in southern Sweden typically provide timber for the forest industry, as well as environments for outdoor recreation and biodiversity. Nevertheless this multi-functionality is problematic, since any one way of using the forest often affects the possibilities for other uses. Such effects, commonly called external effects (Tietenberg 1994), occur when the actions of one agent (a person or a firm) impact on another without permission or compensation (Kolstad 2000). The interaction and balance between different functions is an important issue in forest management and policy (Gregory 1955).

The conflicts of interest between forest users mainly result from negative external effects, since the possibilities for one use decrease as another increase. In the case of positive external effects, i.e. when the possibilities for one use are increasing as another use increases, the relationship between the different interests is harmonious, although there may still be an analytical problem to decide how to optimize the multiple use.

How to combine timber production, biodiversity and recreation in temperate broadleaved forests is a key issue. Should different forest uses be separated in space, so that a specific forest area is used only for one purpose, or should two or more uses take place in the same forest area? Answers to these kinds of questions can be illustrated – at a fundamental level – using production possibility frontiers between different goods (Saastamoinen 1984, Kolstad 2000). The concepts of "production" and "goods" have a broad meaning in this context, referring to output of timber as well as environments for biodiversity and recreation. The latter two non-timber goods can be produced by consideration measures being taken in forestry operations. Establishing a forest nature reserve can be seen as an action aimed at maximizing the production of non-timber forest goods. The analysis presented below provides an insight into the possible outcomes of combining forest uses.

In Fig. 1a and b the x-axes represent the intensity of timber production, while the y-axes represent the intensity in the production of two different non-timber forest goods. Both figures display a production possibility frontier (PPF), denoting how much a particular forest area can produce at most of one good (e.g. timber) depending on how much it produces of another good (e.g. environment for recreation) – and vice versa. Accordingly, a PPF illustrates the reciprocal interrelationship between the different goods produced, and represents the maximum possible output combinations. It should be noticed that combinations of the different forest uses may also be at points inside the PPF (not on it), but at those points the production possibilities are not fully utilized.

Figure 1a illustrates the possibilities to combine production of timber and production of environments for the kind of forest recreation that is most common in southern Sweden (as well as other parts of the country), i.e. the one based on the Right of Public Access. This recreation includes, for example, taking a walk in the forests (Bladh et al. 2008) in order to experience nature and/or get physical exercise (Norman et al. 2010b). For this kind of "everyday forest recreation" the demands are not focused on wilderness, but rather passability, views, mushrooms and berries (Mattsson and Li 1994, Lindhagen and Hörnsten 2000). The shape of the PPF indicates that a moderate intensity of timber production can support this kind of recreation, e.g. through forest roads and cuttings that are planned with consideration for recreational use, thus having positive external effects (Hodge 2000). The more intensive timber production becomes, the less is left for consideration to demands of the recreationists, and the external effects become increasingly negative. Conversely, the PPF indicates that it takes relatively much of production of environment for everyday forest recreation to heavily reduce the production of timber. A PPF shape like the one in Fig. 1a suggests that the specific forest area can be used simultaneously for everyday forest recreation and timber production. The exact combination to be chosen along the PPF depends on the societal preferences for timber production and recreation (Kolstad 2000).

In Fig. 1b the non-timber good is the kind of biodiversity that requires a continuous supply of old-growth structures. Examples are certain epiphytic bryophytes and lichens growing on old, senescent trees, and saproxylic fungi and insects depending on coarse woody debris (Brunet et al. 2010). The type of forest needed for such habitat specialists is old-growth. The shape of the PPF indicates that this "old-growth biodiversity" starts to decrease a lot already at a low intensity of timber production. Higher timber production intensities decrease the old-growth

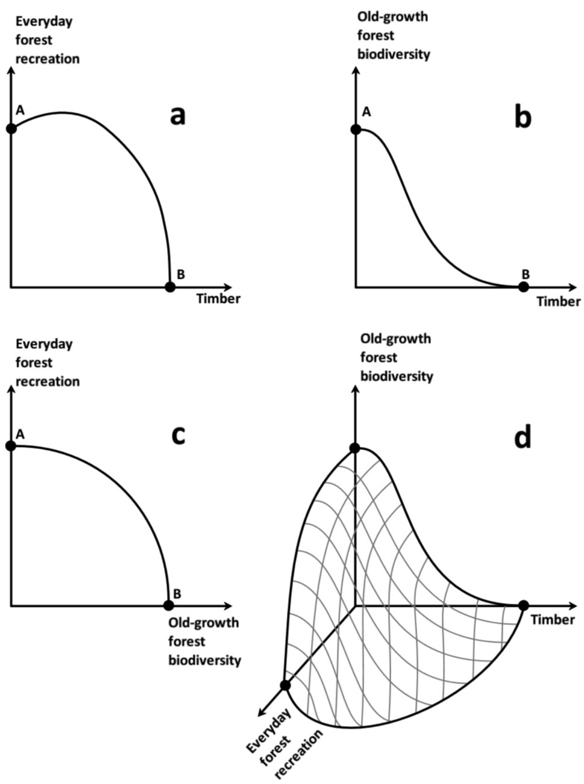

Figure 1a–d. Illustrations of reciprocal relationships between, and feasibility to combine, different forest uses. In each graph there is a production possibility frontier (PPF). In (a–c) the PPF is in the form of a PPF curve and in (d) in the form of a PPF surface. A PPF denotes how much a particular forest area can produce at most of one good depending on how much it produces of another good – and vice versa. At point A and B in (a–c), and at corresponding points in (d), the particular forest area is used for production of one good only, while between these points along the PPF the forest area is used for combined production.

biodiversity further, although there is less and less of this kind of biodiversity to be lost. Conversely, the PPF shows that production of old-growth biodiversity immediately reduces the timber production. In this case the negative external effects are more pronounced than in Fig. 1a. The PPF thus illustrates the difficulties in using a specific forest area simultaneously for production of old-growth biodiversity and timber, and that the two forest uses should be separated in space (except for the case of a low timber production).

Figure 1c illustrates the possibilities for combining the production of old-growth forest biodiversity with production of environments for everyday forest recreation. Individuals participating in such recreation prefer forests associated with moderately intense timber production, rather than unmanaged old-growth forests with large amounts of dead wood (Lindhagen and Hörnsten 2000, Boman et al. 2010). The PPF indicates that the possibilities for combining these two goods are somewhat less than for the case illustrated in Fig. 1a, but better than for that of Fig. 1b. In this situation a double forest use may also be feasible, with production of old-growth forest biodiversity and environments for everyday forest recreation in the same area. Measures taken to promote the passability in this kind of forest can improve the relationship between the two forest functions (the "Dalby Söderskog" reserve in the county of Skåne being a good example, Oheimb and Brunet 2007).

Most temperate broadleaved forests in southern Sweden are used for more than two purposes. Figure 1d illustrates the case of triple forest use. All three forest functions are included, so the PPF is in the form of a three-dimensional surface. Even this is a simplified illustration since, in reality, the forest functions are typically more than three-dimensional (Boman et al. 2010). Timber is not only raw material for the forest industry, but also wood for energy purposes (Nylinder et al. 2006). Forest recreation is not only everyday forest recreation based on the Right of Common Access, but also leisure activities like hunting forest game species (Mattsson et al. 2008). Biodiversity includes many more flora and fauna species than those typically dependent on old-growth conditions (Brunet et al. 2010). Carbon sequestration and water supply are other important forest functions (Boman et al. 2010).

Thus the PPF illustrations give only a very rough guide of how to deal with a multi-functional resource like the temperate broadleaved forests in southern Sweden. However, the stylized examples can help researchers, as well as end-users, to appreciate some fundamental aspects of the complexities involved. Our research program has dealt with only a fraction of these aspects. This is primarily because temperate broadleaved forests have, for many decades, received little interest from Swedish forest researchers (Löf 2001) and, consequently, much of the research in the program had to start more or less from basics, including collection of empirical data.

Achievements in different sub-fields

Multiple functions and welfare

The importance of timber production in economic terms is relatively well known. Therefore, the research in this subfield of the program was primarily focused on forest functions about which we know less. In this research, which is to a large extent about welfare aspects, comparisons are essential. These comparisons might involve different geographical regions, tree species, forest functions or groups of people – as described below.

Our empirical research shows that southern Swedish forests are important for outdoor recreation based on the Right of Public Access (RPA). For example, in the southernmost counties, i.e. Skåne and Blekinge, the welfare economic value per forest visit is about three times higher than that for the county of Västerbotten in northern Sweden (Norman et al. 2010b). Results from an investigation of the publicly owned "Region Skåne" forests suggest that the recreation value of these forests is at least four times higher than the timber production value (Mattsson 2008). Temperate broadleaved tree species are important in this context. The findings suggest that in the counties of Skåne and Blekinge the recreational value increases at a decreasing rate with the areal share of temperate broadleaved trees. Accordingly, if the areal proportion of the broadleaved trees was double the current one (with the proportion of other tree species being correspondingly less), the recreational value would be considerably higher, whereas if the proportion was half of what it is today the recreational value would be much lower (Norman et al. 2010b). In addition, hunting, which is not included in the RPA, is also an important leisure activity in southern Sweden, where the annual welfare economic recreation value for the average hunter is almost double the corresponding value for his or her counterpart in northernmost Sweden (Mattsson et al. 2008).

Our research on the Skåne and Blekinge forests indicates that the RPA-based recreation, especially in temperate broadleaved forests, is of importance for public health. Among women visiting the broadleaved forests, a longer distance from home to the forest was associated with a higher level of stress in daily life. Among men visiting the broadleaved forests a longer time per visit was associated with a lower level of stress. In contrast, for visitors to coniferous forests, distance and time did not contribute to explain the level of stress (Annerstedt et al. 2010). For visitors to temperate broadleaved forests the mere experience of nature in the forest (without any specific activity in mind) was a more important reason for visiting the forest than it was for visitors to coniferous forests (Annerstedt et al. 2010). Our comparative studies on RPA-based forest recreation in Skåne and Blekinge, hunting in all of Sweden, and all kinds of outdoor recreation in all of Sweden, indicate that retaining the recreational activities have a significant effect on self rated health. The magnitude of the effect was found to be intermediate for forest recreationists in southern Sweden, in comparison to hunters and outdoor recreationists in the whole of Sweden (Norman et al. 2010a).

According to our research, non-industrial private forest owners express different views about forest functions than forestry officers in organizations serving the forest owners. This was the case especially in southern Sweden, where the proportion of forest owners who considered recreation and biodiversity to be very important functions of their forests was ten times the proportion of forest officers who thought so (Kindstrand et al. 2008). Moreover, we analyzed the harvesting decision problems encountered by forest owners who produce timber as well as various non-timber forest goods. We synthesized existing empirical research results and analyzed two cases, a beech stand and, for comparison, a spruce stand (Boman et al. 2010). It was shown that the output of many of the goods varies considerably over a rotation period, and that the differences between beech and spruce in this sense were primarily with respect to berries. Such dynamics are significant for the optimal rotation age, when considered from an economic perspective.

Together with our empirical research, we contributed to the development of methods for economic valuation of non-market priced goods. We focused especially on contingent valuation (Mitchell and Carson 1989, Carson 2004), where the data is typically collected by means of questionnaires sent to a random sample of a population. The reliability of value estimates from such surveys is always a major concern. One main conclusion was that the subjective uncertainty experienced by respondents answering hypothetical valuation questions should be explicitly taken into account in question format design, as well as in the analysis of data (Boman et al. 2008, Boman 2009, Ellingson et al. 2009).

Wood properties and utilization

The work within this part of the program focused on information regarding utilization. The overall idea was to compile and spread information about valuable hardwood resources to the industry, forest management organizations and society, so that such resources might be viewed in a more objective way. One result of our work is the book "Noble hardwood – properties and utilization" (Nylinder et al. 2006). From literature studies and interviews with employees in the industry, we compiled up to date knowledge on wood characteristics, the physical, chemical and technical properties of wood, available wood resources and its consumption and utilization. In addition, we have been running innovation projects on wood utilization. The idea was to show the potential and unique properties of hardwoods to innovators and businessmen, with the purpose of finding new products and increasing the demand and value of the wood.

Despite an increase in standing volume, the utilization of hardwoods does not seem to have developed in the same way (Woxblom and Nylinder 2010). The pulp and paper industries, which are the main consumers of hardwoods in Sweden, have increased their consumption of timber during the last decades. They import large volumes of birch and beech due to difficulties in getting enough wood from Swedish forests. It is difficult to gather enough wood from the scattered and often small stands of broadleaved trees in the southern Swedish landscape.

The potential for utilization is still the main factor for forest owners when choosing tree species for forest regeneration. With the growing hardwood resource in mind, it would probably be an advantage for forest owners if a new modern industry could be developed. A new system of sawing was tested, and it seems to have potential for very valuable hardwood and for specialized products where the orientation of the annual rings is important (Johansson and Sandberg 2010). The orientation of the annual rings has a strong influence on shrinkage, strength and other wood properties. Further development of this technique could perhaps result in new uses and increase the demand for valuable hardwood.

Wood quality varies much more in hardwood than in softwood and has more influence on the raw material prices (Nylinder et al. 2006). As southern Sweden is located on the northern limit for several broadleaved tree species the quality issue has often been raised. One of the most important factors is colored heartwood. The cause of this has been investigated in beech, ash and birch, and it appears to be related to growth conditions, treatment and especially stem damage and branch breakages, rather than latitude (Hörnfeldt et al. 2010). A more ambitious silvicultural approach in these types of stands could improve wood quality and value.

Biodiversity conservation

Society is in agreement that all native forest species should be maintained in viable populations. Biodiversity research within the program focused on beech forest, which is the most common temperate forest type in southernmost Sweden (counties of Blekinge, Halland and Skåne), and because other recent research efforts in Sweden were mainly concerned with the biodiversity in oak forest ecosystems (e.g. Götmark 2009).

Special emphasis was put on epiphytic lichens and bryophytes, and on saproxylic beetles, which are expected to be strongly affected by timber harvesting (cf. Fig. 1b). These groups are also frequently used as indicators when assessing the conservation value of forests (Nilsson et al. 2001).

Our results show that the current retention measures applied in managed beech forests usually provide sufficient habitat for most species with good dispersal capacity and broad ecological amplitude (Brunet and Isacsson 2009a, b, 2010, Fritz et al. 2009a, b). However, red-listed species of beech forests often have more specialized habitat requirements and a lower dispersal capacity than other forest species (Fritz et al. 2008, 2009a, b, Brunet and Isacsson 2009a, b, 2010, Fritz 2009, Fritz and Heilmann-Clausen 2010). The combination of these traits means that the conservation of the remaining fragments of old-growth beech forest should have high priority. Many of these fragments are too small to support viable populations in the long-term. Habitat restoration close to old-growth fragments that contain threatened species is therefore necessary.

Species of the red-list categories nearly threatened (NT) and vulnerable (VU) often survive in beech forests with fewer old trees and less coarse woody debris than is found in old-growth beech forests, as long as there is a continuous supply (Fritz et al. 2008, Brunet and Isacsson 2009a, b, Hultberg et al. 2010). Protected stands and retained old trees that can maintain a supply of at least 20 m^3 ha^{-1} of dead wood at the landscape scale will facilitate the persistence of most of these species (Brunet and Isacsson 2009a). In practice, this can be achieved by a combination of medium sized reserves (10–100 ha), protected woodland key habitats (1–5 ha) and tree retention in managed stands. Active measures to provide a continuous supply of habitat may be necessary in protected forests with a discontinuous age structure (Churski and Niklasson 2010, Drobyshev and Niklasson 2010, Fuentes et al. 2010). This may include induction of senescence in living trees or the creation of high stumps and logs (Brunet and Isacsson 2009a, Fritz and Brunet 2010). Field experiments are needed to develop effective methods of habitat restoration for epiphytic and saproxylic species.

Furthermore, our results indicate that the occurrence of the most threatened species, i.e. red-list categories endangered (EN) and critically endangered (CR) species, depends on a continuous occurrence of relatively large amounts of suitable habitat both spatially and temporally (Nilsson and Baranowski 1997, Fritz et al. 2008, 2009a, b, Brunet and Isacsson 2010). This means that relatively large beech forest reserves (>100 ha) are necessary to maintain these species. The work on protecting the largest core areas of old-growth beech forest in southern Sweden, including active measures to restore beech habitat lost in these areas in the past, is therefore of great importance for reaching the goal of maintaining all native beech forest species (cf. Fig. 1b).

When comparing species groups, we found that epiphytic lichens and bryophytes are most sensitive to the dry and sunny micro-climate induced by shelterwood cutting in beech forest (Fritz et al. 2009a, Brunet et al. 2010, Fritz and Brunet 2010). A combination of conventional shelterwood beech forestry and the conservation of red-listed epiphytes is, therefore, not possible at the stand level (cf. Fig. 1b). The structure and micro-climate of multi-layered beech forests managed using single tree selection or group felling is more similar to the gap dynamics of natural beech forests (Brunet et al. 2010). Trees retained for epiphytes in such forests are probably much more valuable than retention trees in shelterwood stands. The relative importance of old-growth beech forests as a habitat for epiphytic lichens and bryophytes has increased during the past 20 yr as a result of disease-induced high mortality in oak, ash and elm in southern Sweden (Brunet and Oheimb 2008, Fritz 2008).

We conclude that the current strategy, involving conservation measures at different spatial scales – from retention trees in managed stands to forest reserves larger than 1000 ha – is generally well suited to provide long-term maintenance of the existing biodiversity in southern Swedish beech forests. The specific levels of tree retention and number and extent of reserves needed to avoid species extinctions are, however, still unknown.

Silviculture

Although subsidies are available, the costs of timber production in temperate broadleaved stands are still higher than in conifer stands. There are therefore few forest owners in southern Sweden who invest in new stands of temperate hardwood trees, the exceptions being some large private forest estates with a long management tradition of broadleaved forest, and several public forest owners. This situation motivated a research focus within the program towards alternative regeneration and timber production methods. In addition, during the last two decades, two other issues connected to temperate broadleaved forests in southern Sweden have arisen. First, stands of Norway spruce, which is the most common forest type, have suffered from frequent storm-felling (Löf et al. 2010). New subsidies have been made available for the conversion of Norway spruce stands into stands containing broadleaves, in order to increase sustainability and adapt managed forests to climate change. This is a major silvicultural challenge, especially since the regeneration cost is much higher than that for conventional planting of Norway spruce (Löf et al. 2004). Secondly, stands of ash, elm and oak, which are three important temperate broadleaved tree species in the region, have suffered from ash dieback, Dutch elm disease and oak decline (e.g. Martin et al. 2010, Sonesson and Drobyshev 2010), with economic as well as ecological consequences for both society and private forest owners. Both of these issues have been addressed in the program.

Large differences in survival between different tree species were found during the conversion of Norway spruce to temperate broadleaves through planting on clear-cuts (Löf et al. 2004, 2010). The best survival was found in oak, while the survival rate in ash *Fraxinus excelsior* was very low, probably as a consequence of newly widespread ash dieback, in which the hyphomycete *Chalara fraxinea* is involved. Nurse trees of birch *Betula* sp., alder *Alnus glutinosa* and hybrid larch *Larix* x *europleptis* did not control competition from the ground vegetation and naturally regenerated trees of other species (Löf et al. 2004, 2010), although we believe that they will positively influence future stem form in any simultaneously planted temperate broadleaved tree species. Using Norway spruce shelterwoods for underplanting temperate broadleaved tree species was found to be effective for beech *Fagus sylvatica* and small-leaved lime *Tilia cordata* when the shelterwood density was relatively low. Both ground vegetation and the natural regeneration of other tree species were controlled by the shelterwoods (Löf et al. 2007). However, we also found that such shelterwoods were storm-felled during major storm events. Damaging insects, e.g. pine weevils *Hylobius abietis*, did not feed on planted temperate broadleaves, so that insecticides are not needed for plant protection (Löf et al. 2004). Disc trenching, the most commonly used site preparation technique, did not influence survival and growth in planted oak (Bergquist et al. 2009). More intensive site preparation methods, such as inverting or mounding, were necessary to influence both growth and survival positively (Löf et al. 2006, Bergquist et al. 2009). At all sites fences proved to be unreliable for controlling browsing by larger herbivores, and needed to be checked and maintained regularly to be effective (Löf et al. 2010).

Direct seeding of beech and oak is an alternative regeneration method with the potential to reduce regeneration costs drastically. The success of direct seeding was, however, threatened by granivorous rodents, and competition between small seedlings and herbaceous vegetation (Löf and Welander 2004, Madsen and Löf 2005). Our results suggest that a combination of measures is needed to control seed predation by rodents. Regeneration areas should be large and free from suitable rodent habitats such as shelter trees, forest edges, slash and patches of vegetation (Birkedal et al. 2009). Site preparation methods such as mounding may reduce predation on acorns and facilitate early growth of oak seedlings (Birkedal et al. 2010). Moreover, we found that mink *Mustela vision* excrement and chilli pepper *Capsicum* sp. could be developed as efficient repellents against granivorous rodents, although more research is needed on how best to implement their application (Birkedal 2010).

Our results indicate that the mast year interval in beech has decreased during recent decades (Övergaard et al. 2007), which might facilitate natural regeneration of beech in the future. This change is probably influenced by climate change. Natural regeneration of beech is a low cost regeneration method and commonly used in Swedish beech forests, although there are problems on less fertile sites (Övergaard et al. 2009). Liming might improve the regeneration on such sites, but our results were not consistent (Övergaard et al. 2010). Our research also indicated that site preparation, e.g. disk trenching, is not always needed. Instead, utilizing several mast years without site preparation might be an alternative to reduce regeneration costs further (Övergaard et al. 2009).

If the predicted climate change occurs, the growth of temperate broadleaved tree species in southern Sweden, such as beech and oak, will probably increase (Bergh et al. 2010). However, the production of other tree species, e.g. Norway spruce and birch, may well increase simultaneously. It is therefore difficult to foresee any future advantage of climate change for temperate broadleaved tree species, in terms of the economics of timber production. Instead, for increased profits, the stand treatments need to be more efficient. The quantity of stems with good stem form (large, straight and unbranched lower parts of the stem) is most important for the overall economics of beech and oak stands. Our results suggest that fewer but more intensive thinnings do not affect these quality aspects negatively in beech (Karlsson et al. 2006). Furthermore, adding Norway spruce to beech plantations could significantly improve the economics of timber production, as long as the Norway spruce is not storm-felled (Karlsson et al. 2006).

In southern Sweden, symptoms of oak decline (e.g. crown defoliation and dead trees) increased during the 1990s and peaked around 2000 (Sonesson and Drobyshev 2010). Thereafter these visible symptoms have decreased. Low soil fertility, low pH values in the soil and also, in some cases, outbreaks of leaf damaging insects, seem to be involved in the damage (Sonesson and Drobyshev 2010). The fungus *Phytophthora quercina* was present in approximately half of the damaged stands that were studied in our research (Jönsson et al. 2005). However, our results indicate that extreme weather events, such as cold winters and dry summers, are more important for explaining oak decline than the other factors mentioned above (Drobyshev et al. 2007, Sonesson and Drobyshev 2010). In contrast to oak decline, the Dutch elm disease in the region is more devastating and caused by the vascular fungus *Ophiostoma novo-ulmi* Brasier (Martin et al. 2010). Similarly devastating damage on ash trees is caused by ash dieback, and has been observed during the last five years.

Communication with end-users

A large research program like Sustainable Management in Hardwood Forests produces a large amount of information (Löf 2010), which is intended for eventual use in practical forest management. A challenge for the researchers is to disseminate the results via channels that will reach those who make the final management decisions, i.e. the forest owners who own most of the temperate broadleaved forests in Sweden. The program has used seminars, courses and articles in forestry magazines as tools to inform foresters about the results and conclusions (Löf 2010). The activities have been targeted mainly at forestry professionals, who are the main advisors of the forest owners. As a complement, a decision-support tool was produced for the internet. The tool "Forestry with temperate broadleaves" was built as a section of the knowledge-system "Knowledge Direct", aiming to help forest owners with management decisions (Hannerz et al. 2005, 2007). The decision-support tool functions as a direct link between the researchers and the end-users of the information.

Although many recent studies have addressed the communication needs of forest owners (e.g. Mattsson et al. 2003a, Hujala et al. 2009), there has been a lack of research into the role of the internet as a tool for capacity-building among private forest owners. Based on a questionnaire sent to forest owners in southern Sweden, we concluded that the internet has an increasingly important role in the communication process (Hannerz et al. 2010). Despite this, personal advice, printed information in magazines and newsletters, and courses and excursions were more important for all groups of forest owners. The internet was considered a lower ranking information channel for the average forest owner. There were, however, large differences among the groups of forest owners. Owners up to the age of 50 yr, and owners with at least a secondary school education, put more emphasis on the internet as a channel. Of the forest owners up to the age of 50 yr with a university degree, 70% considered the internet as an important channel for competence-building in forestry. Owners living off their properties also tended to be keener on using internet for their forest information. In contrast, owners older than 65 yr, and those with only primary school education, had less access to the internet and considered it less important for forestry purposes.

The results indicate that using the internet as a main platform for information dissemination creates a "digital divide" between the young, well-educated owners and the older, less computer-literate owners. The traditional channels, such as personal advice, courses and excursions, and printed material, are therefore still important for research dissemination, in addition to the internet.

Future prospects

Since several interests are involved, future management of temperate broadleaved forests in southern Sweden will continue to be a difficult and complex task. Any particular way of using the forests may affect the possibilities for other uses, and different stakeholders will emphasize different uses. Probably, forest owners will continue to focus on profitable timber production, whereas other interest groups such as environmentalists and recreational users will focus on the conservation of biodiversity and environments for outdoor life. The most pressing science and policy issues often occur where there are conflicting interests. More research is therefore needed to find ways of combining different land uses and reducing the conflicts of interest. For example, a combination of timber production with environments for outdoor recreation seems to be relatively manageable, although our understanding of temporal and spatial external effects is not well developed. Combining timber production with the conservation of biodiversity will continue to be a major challenge, and we need to know more about the cost-effectiveness of environmental policies linked to forestry. The economic valuation of non-market priced forest goods is an evolving research discipline (for an overview, see Mattsson et al. 2003b), and there is a need for more empirical work and method development.

A major future challenge is the adaptation of forest management to the expected climate change. For southern Sweden, it is predicted that temperatures will increase by 2–6°C by the end of this century (Holgersson et al. 2007). In addition, the weather is expected to become more extreme, although we do not know if this includes increases in wind speed. With a warmer climate, temperate broadleaved tree species will probably be able to establish further north and may become more ecologically competitive than previously, although other tree species may be able to increase their growth as well (Koca et al. 2006, Smith et al. 2007, Bergh et al. 2010). Forest policies have, so far, predominantly concentrated on protecting the few valuable temperate broadleaved forests that still remain in southern Sweden, since they harbor unique biodiversity and provide recreational environments preferred by many people. At present, our knowledge of the population ecology of many species is too limited to predict whether the planned levels of protection, restoration and retention measures are sufficient. In the future, more research is therefore needed in areas such as climate change impacts on species and habitats, extinction thresholds, habitat restoration and species migration. Appropriate adaptation strategies will also need to be developed, including new plant material and increased stress tolerance in trees (Bolte et al. 2009).

It may be too expensive to rely solely on governmental resources for sustainable approaches. In addition, approaches which consider economic and other aspects of privately owned forests should be adopted (Löf et al. 2008). For example, there is considerable potential for promoting profitability by making better use of wood from broadleaved tree species. New products may be developed, along with methods for efficiently gathering small amounts of broadleaved timber. In the long run this would probably also be beneficial for recreation and biodiversity conservation, especially if it leads to the establishment of more temperate broadleaved stands. Other options for improving the profitability include finding alternative, efficient and cost effective silviculture and regeneration systems for broadleaved species. Promising progress was made concerning the planting and direct seeding of oak, as well as the regeneration and stand treatment of beech, and this needs to be followed up. Improving our knowledge about the risk, management and prevention of various diseases could also lead to increased profitability. In particular, the ecology of various biotic factors in relation to ash dieback, Dutch elm disease and oak decline requires further research. The recent increased interest in biotechnology may well help in developing countermeasures against these diseases (Martin et al. 2010). However, political solutions are also needed for future management of broadleaved forests. One example is the effect of high game populations on regeneration costs (Bergquist et al. 2009). In this case there is a need for joint management of game and forests, instead of policies that are isolated from each other. There is also a need for policy solutions that provide clear incentives for the implementation of sustainable approaches with respect to all of the functions of broadleaved forests. In that context it is of particular importance that forest owners are provided with appropriate incentives, which, in turn, requires more knowledge about their preferences and valuations.

Communication with the end-users of research is important for effective future forest management, and could also be developed further. Choosing the most appropriate communication methods is important for impacting the rate of change of the attitudes and behavior of forest owners and forest managers. Communication is not only a means to disseminate results, but also a new important research field in itself. The role of new and innovative communication platforms is an emerging area of research.

The knowledge base required for forest management, both today and in the future, is indeed complex, and interdisciplinary applied research is needed to provide that base. Such research is not simple to conduct, since it requires considerable efforts from researchers to understand each other across disciplinary boundaries. Most of the research in our program has been carried out using an intradisciplinary approach, i.e. "discipline by discipline". Nevertheless there is a common view among the researchers regarding basic relationships between different forest functions and possibilities for combining different forest uses and management goals. Accordingly, there is a base of experience that can be used to develop further interdisciplinary research in the field. Just like in everyday life, cooperation between researchers begins and ends with the will and ability of people to communicate with each other. In our view, this has worked exceptionally well within our program. It is our intention to exploit this ability further in the future, by making it an integral part of our continued research efforts relating to the management of broadleaved forests.

Acknowledgements – We thank Filip Hannerz for technical assistance with the figures and Sees-editing for linguistic improvements. This study was financially supported by the research program Sustainable Management in Hardwood Forests.

References

Annerstedt, M. et al. 2010. Finding stress relief in a forest. – Ecol. Bull. 53: 33–42.

Bergh, J. et al. 2010. Impact of climate change on the productivity of silver birch, Norway spruce and Scots pine stands in Sweden and economic implications for timber production. – Ecol. Bull. 53: 185–195.
Bergquist, J. et al. 2009. Effects of roe deer browsing and site preparation on performance of planted broadleaved and conifer seedlings when using temporary fences. – Scand. J. For. Res. 24: 308–317.
Birkedal, M. 2010. Reforestation by direct seeding of beech and oak: influence of granivorous rodents and site preparation. – Acta Universitatis Agricultural Sueciae, Doctoral thesis no. 2010: 13, Faculty of Forest Sciences, Alnarp.
Birkedal, M. et al. 2009. Rodent impact on establishment of direct seeded beech and oak on forest land. – Scand. J. For. Res. 24: 298–307.
Birkedal, M. et al. 2010. Effects of granivorous rodents on direct seeding of oak and beech in relation to site preparation and sowing date. – For. Ecol. Manage. 259: 2382–2389.
Bladh, G. et al. 2008. Vara i naturen – varför eller varför inte? Delresultat från en nationell enkät om friluftsliv och naturturism i Sverige. – Rapport nr 2, Forskningsprogrammet Friluftsliv i förändring, in Swedish.
Bolte, A. et al. 2009. Adaptive forest management in central Europe – climate change, strategies and integrative concept. – Scand. J. For. Res. 24: 473–482.
Boman, M. 2009. To pay or not to pay for biodiversity in forests – what scale determines responses to willingness to pay questions with uncertain response options? – J. For. Econ. 15: 79–91.
Boman, M. et al. 2008. On the budget for national environmental objectives and willingness to pay for protection of forest land. – Can. J. For. Res. 38: 40–51.
Boman, M. et al. 2010. Forest amenity values and the rotation age decision: a Nordic perspective. – Ecol. Bull. 53: 7–20.
Brunet, J. and Oheimb, G. von 2008. Elm disease and hungry slugs: drastic vegetation changes in Dalby Söderskog, a south Swedish deciduous forest. – Sv. Bot. Tidskr. 102: 27–38, in Swedish with English abstract.
Brunet, J. and Isacsson, G. 2009a. Influence of snag characteristics on saproxylic beetle assemblages in a south Swedish beech forest. – J. Insect Conserv. 13: 515–528.
Brunet, J. and Isacsson, G. 2009b. Restoration of beech forest for saproxylic beetles – effects of habitat fragmentation and substrate density on species diversity and distribution. – Biodivers. Conserv. 18: 2387–2404.
Brunet, J. and Isacsson, G. 2010. A comparison of the saproxylic beetle fauna between lowland and upland beech forest in southern Sweden. – Ecol. Bull. 53: 131–139.
Brunet, J. et al. 2010. Biodiversity in European beech forests – a review with recommendations for sustainable forest management. – Ecol. Bull. 53: 77–94.
Carson, R. 1963. Silent spring. – Hamish Hamilton, London.
Carson, R. T. 2004. Contingent valuation – a comprehensive bibliography and history. – Edward Elgar, Cheltenham.
Churski, M. and Niklasson, M. 2010. Spatially and temporally disjointed old-growth structures in a southern Swedish beech dominated forest landscape. – Ecol. Bull. 53: 109–115.
Drobyshev, I. and Niklasson, M. 2010. How old are the largest southern Swedish oaks? A dendrochronological analysis. – Ecol. Bull. 53: 155–163.
Drobyshev, I. et al. 2007. Temporal mortality pattern of pedunculate oaks in southern Sweden. – Dendrochronologia 24: 97–108.
Ellingson, L. et al. 2009. Valuation uncertainty and maximum willingness to pay: a nonparametric comparison between elicitation formats. – In: Anon. (ed.), EAERE 2009, the 17th Annual Conference of the European Association of Environmental and Resource Economists. Book of abstracts, Amsterdam.
Fritz, Ö. 2008. Unique lichen flora in avenues at Sperlingsholm, southwestern Sweden. – Sv. Bot. Tidskr. 102: 5–18, in Swedish with English abstract.
Fritz, Ö. 2009. Vertical distribution of red-listed epiphytes emphasizes the importance of old beeches in conservation. – Biodivers. Conserv. 18: 289–304.
Fritz, Ö. and Brunet, J. 2010. Epiphytic bryophytes and lichens in Swedish beech forests – effects of forest history and habitat quality. – Ecol. Bull. 53: 95–107.
Fritz, Ö. and Heilmann-Clausen, J. 2010. Rot holes create key microhabitats for epiphytic lichens and bryophytes on beech (*Fagus sylvatica*). – Biol. Conserv. 143: 1008–1016.
Fritz, Ö. et al. 2008. Does forest continuity matter in conservation? A study of epiphytic lichens and bryophytes in beech forests of southern Sweden. – Biol. Conserv. 141: 655–668.
Fritz, Ö. et al. 2009a. Tree age is a key factor for the conservation of epiphytic lichens and bryophytes in beech forests. – Appl. Veg. Sci. 12: 93–106.
Fritz, Ö. et al. 2009b. Interacting effects of tree characteristics on the occurrence of rare epiphytes in a Swedish beech forest area. – Bryologist 112: 488–505.
Fuentes, M. et al. 2010. Tree mortality in a semi-natural beech forest in SW Sweden. – Ecol. Bull. 53: 117–129.
Götmark, F. 2009. Experiments for alternative management of forest reserves: effects of partial cutting on stem growth and mortality of large oaks. – Can. J. For. Res. 39: 1322–1330.
Gregory, R. 1955. An economic approach to multiple use. – For. Sci. 1: 6–13.
Hannerz, M. et al. 2005. Knowledge direct – an internet-based guide for foresters. – Results from Skogforsk no. 2.
Hannerz, M. et al. 2007. Knowledge direct – high-value hardwoods. – Results from Skogforsk no. 4, in Swedish with English abstract.
Hannerz, M. et al. 2010. The role of internet in knowledge-building among private forest owners in Sweden. – Ecol. Bull. 53: 225–234.
Hodge, I. 2000. Agri-environmental relationships and the choice of policy mechanism. – World Econ. 23: 257–273.
Holgersson, B. et al. 2007. Sverige inför klimatförändringarna – hot och åtgärder. Slutbetänkande av klimat- och sårbarhetsutredningen. – Statens Offentliga Utredningar, SOU 2007: 60, Chapter 3.5, Stockholm, in Swedish.
Hörnfeldt, R. et al. 2010. False heartwood in beech *Fagus sylvatica*, birch *Betula pendula*, *B. papyrifera* and ash *Fraxinus excelsior* – an overview. – Ecol. Bull. 53: 61–75.
Hujala, T. et al. 2009. Family forest owner's perception towards decision support. – Scand. J. For. Res. 24: 448–460.
Hultberg, T. et al. 2010. Forest in a cultural landscape – the vegetation history of Torup in southernmost Sweden. – Ecol. Bull. 53: 141–153.
Hultman S. G. 1984. Multiple-use forestry in Sweden: undefined – and non-existent? – In: Saastamoinen, O. et al. (eds), Multiple use-forestry in the Scandinavian countries. Comm. Inst. For. Finn. 120: 27–32.
Johansson, J. and Sandberg, D. 2010. Improved use and production of hardwood with the PrimWood method. – Ecol. Bull. 53: 51–59.

Jönsson, U. et al. 2005. Relationships between health of *Quercus robur*, occurrence of *Phytophthora* species and site conditions in southern Sweden. – Plant Pathol. 54: 502–511.
Karlsson, M. et al. 2006. Establishment and early growth of mixed beech and spruce stands. – In: Book of abstracts from IUFRO conference Beech silviculture in Europe's largest beech country, 4–8 September 2006, Poiana Brasov, Romania. Papers available at Univ. of Brasov, Fac. of Silviculture and Forest Engineering, pp. 70–72.
Kindstrand, C. et al. 2008. Attitudes towards various forest functions: a comparison between private forest owners and forest officers. Short communication. – Scand. J. For. Res. 23: 133–136.
Koca, D. et al. 2006. Modelling regional climate change effects on potential natural ecosystems in Sweden. – Clim. Change 78: 381–406
Kolstad, C. D. 2000. Environmental economics. – Oxford Univ. Press.
Lindbladh, M. et al. 2000. Pattern and process in south Swedish forests during the last 3000 years, sensed at stand and regional scales. – J. Ecol. 88: 113–128.
Lindbladh, M. et al. 2007. Forest history as a basis for ecosystem restoration – a multi-disciplinary case-study in a south Swedish temperate landscape. – Restor. Ecol. 15: 284–295.
Lindhagen, A. and Hörnsten, L. 2000 Forest recreation in 1977 and 1997 in Sweden: changes in public preferences and behaviour. – Forestry 73: 143–153.
Löf, M. 2001. Uthålligt skogsbruk i ädellövskog: förslag till forskning och utveckling. – Sveriges Lantbruksuniversitet, Skogsvetenskapliga fakulteten, Rapport 19, in Swedish with English abstract.
Löf, M. 2010. Uthålligt skogsbruk i ädellövskog: slutrapport från ädellövprogrammet 2003–2009. – Sveriges Lantbruksuniversitet, Inst. för sydsvensk skogsvetenskap, Arbetsrapport 42, in Swedish with English abstract.
Löf, M. and Welander, N. T. 2004. Influence of herbaceous competitors on early growth in direct seeded *Fagus sylvatica* L. and *Quercus robur* L. – Ann. For. Sci. 61: 781–788.
Löf, M. et al. 2004. Herbivory by the pine weevil (*Hylobius abietis* L.) and short-snouted weevils (*Strophosoma melanogrammum* Forst. and *Otiorhynchus scaber* L.) during the conversion of a wind-thrown Norway spruce forest into a mixed-species plantation. – For. Ecol. Manage. 190: 281–290.
Löf, M. et al. 2006. Mounding site preparation for forest restoration: survival and short term growth response in *Quercus robur* L. seedlings. – For. Ecol. Manage. 232: 19–25.
Löf, M. et al. 2007. Growth and mortality in underplanted tree seedlings in response to variation in canopy closure of Norway spruce stands. – Forestry 30: 371–383.
Löf, M. et al. 2008. Restoration of broadleaved forests in southern Sweden – some thoughts about a new management concept. – Sv. Bot. Tidskr. 102: 43–51, in Swedish with English abstract.
Löf, M. et al. 2010. Conversion of Norway spruce stands to broadleaved woodland – regeneration systems, fencing and performance of planted seedlings. – Ecol. Bull. 53: 165–173.
Madsen, P. and Löf, M. 2005. Reforestation in southern Scandinavia using direct seeding of oak (*Quercus robur* L.) – Forestry 78: 55–64.
Martin, J. et al. 2010. Ecological factors in Dutch elm disease complex in Europe – a review. – Ecol. Bull. 53: 209–224.
Mattsson, L. 2008. Utredning angående möjligheterna att vidareutveckla verksamheten vid Fulltofta naturcentrum och på berörda stiftelsers marker. – Rapport från utredning på uppdrag av Region Skåne, in Swedish.
Mattsson, L. and Li C. Z. 1994. How do different forest management practices affect the non-timber value of forests? – J. Environ. Manage. 41: 79–88.
Mattsson, L. et al. 2003a. Privatägd skog: Värden, visioner och forskningsbehov. – Rapport från Sufor/Brattåsstiftelsen, in Swedish.
Mattsson, L. et al. 2003b. Miljöekonomisk skogsforskning. – In: Lundgren, L. J. (ed.), Vägar till kunskap: några aspekter på humanvetenskaplig och annan miljöforskning. Symposium, Stockholm, pp. 149–165, in Swedish.
Mattsson, L. et al. 2008. Jakten i Sverige – ekonomiska värden och attityder jaktåret 2005/06. – Adaptiv förvaltning av vilt och fisk, Rapport nr 1, in Swedish.
Mitchell, R. C. and Carson, R. T. 1989. Using surveys to value public goods: the contingent valuation method. – Resources for the Future, Washington DC.
Nilsson, S. G. and Baranowski, R. 1997. Habitat predictability and the occurrence of wood beetles in old-growth beech forests. – Ecography 20: 491–498.
Nilsson, S. G. et al. 2001. Biodiversity and its assessment in boreal and nemoral forests. – Scand. J. For. Res. Suppl. 3: 10–26.
Norman, J. et al. 2010a. Influence of outdoor recreation on human health: comparing three categories of Swedish recreationists. – Scand. J. For. Res. 25: 234–244.
Norman, J. et al. 2010b. The value of forests for outdoor recreation in southern Sweden: are broadleaved trees important? – Ecol. Bull. 53: 21–31.
Nylinder, M. et al. 2006. Ädellöv – virke och förädling. – Sveriges Lantbruksuniversitet, Inst. för skogens produkter och marknader, Uppsala, in Swedish.
Oheimb, G. von and Brunet, J. 2007. Dalby Söderskog revisited: long-term vegetation changes in a south Swedish deciduous forest. – Acta Oecol. 31: 229–242.
Övergaard, R. et al. 2007. Effects of weather conditions on mast year frequency in beech (*Fagus sylvatica* L.) in Sweden. – Forestry 80: 555–565.
Övergaard, R. et al. 2009. A method for natural regeneration of beech (*Fagus sylvatica* L.) practiced in southern Sweden. – Stud. For. Suec. 128: 1–30.
Övergaard, R. et al. 2010. Effects of liming on site properties and natural regeneration of European beech *Fagus sylvatica* in southern Sweden. – Ecol. Bull. 53: 175–183.
Saastamoinen, O. 1984. Product transformation in multiple-use forestry. – In: Saastamoinen, O. et al. (eds), Multiple useforestry in the Scandinavian countries. Comm. Inst. For. Finn. 120: 119–125.
Samuelson, P. A. 1976. Economics of forestry in an evolving society. – Econ. Inquiry 14: 446–492.
SFS 1979: 429. Skogsvårdslagen. – Jordbruksdepartementet, Stockholm, in Swedish.
Smith, B. et al. 2007. Modellering av vegetationsförskjutningar i Sverige under framtida klimatscenarier. – In: Anon. (ed.), Sverige inför klimatförändringarna – hot och åtgärder. Slutbetänkande av klimat- och sårbarhetsutredningen. Statens Offentliga Utredningar, SOU 2007: 60, Stockholm, Appendix B 23, in Swedish.
Sonesson, K. and Drobyshev, I. 2010. Recent advances on oak decline in Sweden. – Ecol. Bull. 53: 197–207.

SOU 1971: 71. Bokskogens bevarande. – Riksdagen, Stockholm, in Swedish.
SOU 1992: 76. Skogspolitiken inför 2000-talet. – Riksdagen, Stockholm, in Swedish.
Statens naturvårdsverk 1982. Ädellövskog: förslag till skydd och vård. – SNV, PM 1587, Statens naturvårdsverk, Solna, in Swedish.
Tietenberg, T. 1994. Environmental economics and policy. – Harper Collins College.
Woxblom, L. and Nylinder, M. 2010. Industrial utilization of hardwood in Sweden. – Ecol. Bull. 53: 43–50.