On Trade-Offs Between Timber and Biodiversity

Claes Kindstrand
Faculty of Forest Sciences
Southern Swedish Forest Research Centre
Alnarp

Licentiate thesis
Swedish University of Agricultural Sciences
Alnarp 2008

ISBN 978-91-85911-29-5

Tryck: SLU Service/Repro, Alnarp 2008

Abstract

Kindstrand, C. 2008. On trade-offs between timber and biodiversity. Licentiate thesis.
ISBN 978-91-85911-29-5

For a long time the primary aim of forestry in Sweden has been the production of timber, but in recent decades other functions, such as biodiversity, have been increasingly recognised by society. Sweden has ambitious goals for forest management, aimed at serving public interests, providing valuable timber yields and preserving biodiversity. Achieving the level of various goods that forests shall provide, under such goals, is thus rather complex. This thesis focuses on trade-offs between production of timber and the maintenance of biodiversity in forests, and the effects of information on benefits, costs and biological traits.

In Paper I the benefit of forest land protection was estimated based on a nation wide contingent valuation survey. Paper II examined and compared, through survey data, the attitudes among private forest owners and forest officers. Papers III and IV used data from a field inventory in old growth forests (>110 years of age) of Norway spruce (*Picea abies* [L.] Karst.) in the county of Gävleborg, Sweden. In Paper III the relative importance of information about costs and biological traits in reserve selection was examined. In Paper IV the cost-efficiency of different strategies for setting aside forests, using different biodiversity targets, were analysed.

The thesis revealed a positive willingness to pay for forest land protection among Swedish citizens, and also a positive attitude among private forest owners to biodiversity as well as timber production. The views of forest owners and forest officers did not always coincide. Moreover, the relative importance of including data on costs and conservation benefits depended on how the conservation goal of the reserve network was formulated. There was also a difference in cost-effectiveness between different nature conservation strategies and biodiversity targets.

The results emphasise the importance of achieving cost-effective solutions in biodiversity conservation through the proper use of information about biological traits and costs, as well as considering values and attitudes held by different interest groups in society.

Keywords: attitudes, biodiversity, contingent valuation, cost-effectiveness, economics, forest management, private forest owners, reserve selection, timber

Author's address: Claes Kindstrand, Southern Swedish Forest Research Centre, SLU, P.O. Box 49, SE-230 53 ALNARP, Sweden.

Contents

Appendix

Papers I-IV

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

I. Boman, M., Norman, J., Kindstrand, C. & Mattsson, L. 2008. On the budget for national environmental objectives and willingness to pay for protection of forest land. Canadian Journal of Forest Research, 38: 40-51.

II. Kindstrand, C., Norman, J., Boman, M. & Mattsson, L. 2007. Attitudes towards various forest functions: a comparison between private forest owners and forest officers. Short communication. In press, Scandinavian Journal of Forest Research.

III. Perhans, K., Kindstrand, C., Boman, M., Boberg Djupström, L., Gustafsson, L., Mattsson, L., Schroeder, L. M., Weslien, J. & Wikberg, S. 2007. Cost-efficient reserve selection: relative importance of costs and benefits depends on the conservation goal. Under revision, Conservation Biology.

IV. Wikberg, S., Perhans, K., Kindstrand, C., Boman, M., Boberg Djupström, L., Gustafsson, L., Mattsson, L., Schroeder, L. M. & Weslien, J. 2007. Cost-effectiveness of implemented conservation strategies in economically important forests: selection of set-asides. Manuscript.

Introduction

Forests are an important natural resource which have many functions and provide a multitude of goods, such as timber, game, berries and recreational areas. Forests also sequester carbon dioxide, prevent wind erosion and harbour species. While timber production is considered an important national resource, and provides forest owners with an income, timber harvesting reduces old forests into scattered fragments in the landscape. This ultimately reduces the species associated with these forests and changes the species composition within these areas, changing the diversity. Some aspects of biodiversity are regarded by society as being scarce. Regulations and policy tools are thereby used to achieve sustainable levels of biodiversity, as well as the various other goods that forests provide. Sweden has ambitious goals for forest management. Forests must be managed so that in addition to serving public interests, they provide valuable timber yields and preserve biodiversity. Achieving the level of various goods that forests shall provide, under such goals, is thus rather complex.

Objectives

The focus of this thesis is the trade-offs between the production of timber and the maintenance of biodiversity in forests, and the effects of information about benefits, costs and biological traits. Paper I estimates the benefit to society of protecting forest land for biodiversity purposes. The attitudes towards timber production, biodiversity and recreation, among two groups representing land-owner and societal interests (forest owners and forest officers) are addressed in Paper II. The relative importance of information about costs and biological traits in reserve selection is examined in Paper III, and the cost-effectiveness of different strategies for setting aside forests, using different biodiversity targets, are analysed in Paper IV.

Background

Forestry has a long history in Sweden and in many ways forests have contributed to the utility of humans. They have, among other things, provided fuel wood and timber, they have been used for hunting game, cattle grazing and for slash and burn cultivation. The use of forests for agricultural purposes dominated during the 19^{th} century, but small scale industrial processing of raw material from forests also contributed to the income among farmers (Ekelund & Hamilton, 2001). The forest use has sometimes conflicted with the intentions of the authorities, which has led to different regulations where local interests have been subordinate to national interests (Eliasson & Hamilton, 1999). Oak, for instance, was used as building material for war ships, and until 1830, its use was regulated by law (Ekelund & Hamilton, 2001). The mining industry has also consumed substantial amounts of wood, which led to regulations aimed at securing their need for resources.

The view of what has best served society's interests has varied over time. During the 17th and 18th century the aim of forest policies was to regulate the consumption of forest products, which during the 19th century was replaced with regulations aimed at enhancing forest productivity (Schager, 1928). During the 20th century the forests became more important as an industrial resource, which was accompanied by enhanced central control (Eliasson & Hamilton, 1999). The national Forestry Act of 1903 had a strong focus on the reproduction aspects of forests, namely regeneration after final felling (Ekelund & Hamilton, 2001). A revision of the Forestry Act was made in 1923 and 1948, resulting in an even stronger focus on aspects of timber production. In 1923 it was stated that forest land should be used for forest production, and in 1948 that forest land should be managed in order to provide a satisfactory economic return at a sustained level (Ekelund & Hamilton, 2001). The Forestry Act from 1948 also implied a change in harvesting operations. Different forms of selective cutting of the most valuable trees were practiced during harvest, but according to the new Act it was forbidden (Bäckström, 2001). The aim with the new regulation was to secure an even flow of timber from the forests, and implied large interventions in the forest owners' right to decide about their forest (Eliasson & Hamilton, 1999). In 1974 other values, in addition to timber, were addressed through the recommendation that general consideration regarding nature conservation and recreation should be taken. A special act on the preservation of beech (*Fagus sylvatica*) forests was also introduced, which in 1984 was revised to include other selected valuable broadleaved trees (Anon., 1974; Anon., 1984). In the revision of 1979, regulations regarding nature conservation were introduced as a specific paragraph (Anon., 1988). The abandonment of selective cutting in 1948 implied that the clear-cutting system was fully introduced, and methods for harvest and forest management were improved to meet increased costs (Bäckström, 2001). Selective cutting was considered to degrade the quality of forests, and the advantage of a system with regeneration of a specific area was advocated already in the beginning of the 19th century (Wahlgren, 1928).

Nowadays the most common harvesting system is clear-cutting which often is synonymous with the silviculture of pure even-aged stands. The forest stands have to reach a certain age before they legally are allowed to become harvested, which for e.g. Norway spruce (*Picea abies* [L.] Karst.) stands are between 45 and 100 years depending on site condition and the geographical location of the stand (Anon., 1993b). There are also regulations regarding how large proportion of a forest property that can be harvested at one time. The use of a minimum harvest age (implying protection of younger stands) in combination with rationing of the older forests, serves to secure the industries' future need of raw material (Håkansson, 2002). The present silvicultural methods imply that the trees are harvested when they are, from a biological perspective, relatively young. Today, about 3% of the total Swedish forest land area has forests older than 160 years (Anon., 2006b). The structure of forests has changed and old forests have been reduced into isolated and fragmented patches in the landscape, which has had a negative impact on biodiversity (Haila, 1999). Old growth forests are therefore rare and many species associated with this forest type are now threatened by extinction (Berg *et al*., 1994). Compared to the long tradition of timber production, environmental concern and the scarcity aspect of biodiversity has only recently been recognised in Swedish forestry. The current Swedish Forestry Act from 1994 has an environmental goal in addition to a timber production goal, both to be treated with equal importance (Anon., 1993a; Anon., 1994).

Environmental concern in forestry should also be viewed from the perspective of national environmental policies. In 1999 the Swedish Parliament decided on 15 national environmental objectives, which represent substantial components constituting the Swedish natural environment (Anon., 2000a). The intention is to reduce human impacts on the environment to a level that can be sustained in the long term. These 15 objectives encompass air quality, groundwater, lakes and watercourses, wetlands, sea, coastal and archipelago areas, forests, agricultural landscape, mountain areas, urban areas, eutrophication, acidification, toxic substances, radiation, greenhouse effect and depletion of the ozone layer. In 2005 a sixteenth environmental objective, "A Rich Diversity of Plant and Animal Life", was adopted by the Parliament (Anon., 2006a). The goal of the national environmental quality objectives is to promote human health; safeguard biodiversity and the natural environment; preserve the cultural environment and cultural heritage; maintain long-term ecosystem productivity; and ensure wise management of natural resources. The "Sustainable Forests" environmental objective specifically deals with forest land (Anon., 2000a) and is made up of four so-called interim targets. These targets focus on long-term protection of a quantified area of forest land, enhanced biological diversity, protection of cultural heritage, and action programmes for threatened species (Anon., 2004). "Sustainable Forests" is an interpretation of the comprehensive goals stated in the first section of the Forestry Act, with a long-term perspective, whereas the interim targets focus on short-term goals (Anon., 2005).

Theoretical framework

Basic microeconomic theory

The science of economics deals with the production, consumption and distribution of goods and services. A basic assumption is that all individuals are rational and seek to maximise their utility. In contrast to human needs is the fact that the resources of the Earth are scarce and inadequate to fulfil all the needs of all individuals. Economics is thus an important tool, which helps us choose the best way to use and manage our resources.

Goods and services are bought and sold on competitive markets through the interaction between consumers and producers. A competitive market determines how much is produced based on what people are willing to pay, compared to what must be paid to produce the good (Varian, 2003). In microeconomic theory the concept of a “perfectly competitive market” is commonly used, which requires a number of pre-requisites in order to be fulfilled. On a given market there exists a large number of small producers and consumers, each so small that their actions have no significant impact on others. These firms are price takers, which mean they have to accept the price that the market sets. The firms can buy or sell an unlimited volume of a good on the market. There is no co-operation between producers or between consumers which allows control over market prices, which means that no market cartels are possible. Specific goods and services are homogeneous, in the sense that they are perfect substitutes. Both consumers and producers have perfect and complete information about the actual market price of the goods. No seller can therefore charge a higher price on a good than the market allows. Firms may, at their own wish, enter or exit the market. Moreover, no externalities are present on a perfectly competitive market. The definition of an externality is that it is present whenever one agent’s action directly affects the utility of another agent, without any market transaction taking place between the two (Varian, 1992). On a perfectly competitive market there are generally no public goods. These goods are distinguished from private goods by two important features; public goods are non-rival and non-excludable. This means that one person’s consumption does not reduce the available amount of the good to other consumers, and no one can be excluded from the consumption of the good. For private goods the opposite is valid.

Examples of public goods are clean air, sunshine, biodiversity in forests or recreation, whereas timber is an example of a private good. The ordinary pricing system, or market, is often unable to provide an efficient level of a public good (Baumol & Oates, 1988), which is an example of a market failure (Bator, 1958). Efficiency in this case refers to Pareto-efficiency, which is an allocation where there is no way of making one agent better off without the other being made worse off (Varian, 1992). In the case of public goods, they are often associated with externalities and not well defined property rights. If property rights could be defined, in theory efficient outcomes could be achieved (Coase, 1960).

Biodiversity conservation from a policy perspective

An environmental policy should be beneficial to society, even though it may conflict with the interests of some individuals, or groups of individuals. The implementation of a public policy could therefore require the use of policy tools, or instruments, in order to fulfil the policy goal. An optimal choice of policy tool depends upon the nature of the environmental damage, the kind of harm it can cause, available control technologies, and the number and type of agents causing the problem (Richards, 2000). In this thesis three types of policy instruments are considered; economic incentives, "command-and-control" regulations (Kolstad, 2000), and voluntary measures. The first implies use of pricing mechanisms for regulation of the environmental damage. This can be contrasted with "command-and-control", which uses direct regulations.

Economic incentives

Taxes and subsidies

When markets fail it causes non-efficient market allocations of resources and goods. The presence of externalities calls for intervention from society, to which there is a variety of available methods for the control of externalities. One is corrective, or *Pigouvian,* taxes and fees, which were named after the British economist Arthur Cecil Pigou. In his paper 'The Economics of Welfare' (1920) he argued that in the presence of negative and positive externalities, governmental intervention is needed. Anyone causing a negative externality should be imposed with a tax on the generating activity in order to diminish it. An activity generating positive externalities should, on the other hand, be encouraged with subsidies. With a system of Pigouvian taxes (per unit of environmental damage) set equal to the marginal social damage, the causing agent will change her/his externality generating activity. This is only valid as long as the imposed tax is higher than the cost for the production change. A party with low marginal costs for changing the activity will reduce emissions to a large extent, whereas a party with high marginal costs for changing the activity will reduce emissions to a lesser extent. An optimal Pigouvian tax implies the determination of a reasonable estimate of the money value of the social damage, which may be difficult to obtain (Baumol & Oates, 1988).

Marketable emission permits

Another alternative approach is a system of marketable emission permits (Dales, 1968). The basic idea is that the regulating authority decides on a limited number of permits to perform the externality generating activity. These permits are offered for sale to the highest bidder. The allocation of the externality generating activity is thereby decided through market forces. If an optimal number of permits are released by the authorities, their price will bid up to the exact level of the Pigouvian tax (Baumol & Oates, 1988). By restricting the number of marketable permits offered by the authorities any target level can be met. All parties causing the externality will, on a market, meet the same price for the permits which will result in a cost-minimising behaviour by the firm. The use of marketable permits in policy settings has some advantages over fees (Baumol & Oates, 1988). First, they meet the desired goal with certainty, since the responsible authority sets the total quantity at the allowable level. Secondly, a system with permits will adjust itself, through market forces, to inflation and growth, with no increase in pollution. A system of permits can be very costly for the parties generating the externality if the permits are initially bought on an auction. If, however, these emission permits are freely distributed among the existing parties, based on their earlier levels of externality generation, the efficiency of the system is achieved without any added costs for those parties. This type of distribution of permits is also known as “grandfathering”.

Command-and-control

This type of policy instrument involves a direct control approach, where the authority decides on acceptable levels (pre-determined standards) of environmental damage for each source. A direct control must, according to Baumol & Oates (1988), involve a directive to reduce the externality generating activity to levels that are lower than the ones specified by the legislator. The incentive to follow the regulation is that a violation of decided levels of emissions is accompanied with some form of punishment. Given complete information about the cost and benefit functions, the policy maker can reach an efficient solution either by taxes or regulation. The use of direct controls will, if effective, achieve the desired goal with little uncertainty (Baumol & Oates, 1988).

Voluntary measures

A forest stand generates a monetary value to the owner, but also constitutes a habitat for species. The value of the latter is, however, not shown in any market. The nature conservation authorities have limited economic resources for the purchase of habitats. It is sometimes assumed that an environmental policy can be implemented through voluntary participation of different agents. A voluntary approach to setting aside habitats has the disadvantage of sometimes being affected by problems like free-riding behaviour (Field, 1997). Nevertheless, voluntary participation does take place, and resources are devoted to the persuasion and education of forest owners (cf. Törnqvist, 1995). The goal is to get persons to voluntarily refrain from actions that degrade the environment, by appealing to their moral values or civic duty (Field, 1997). Based on this, an individual may take such measures that reduce her/his impact on the environment, simply because it is beneficial to her/him.

Application of biodiversity conservation in Swedish forests

About 56% of the Swedish land area (41.3 million hectares) is covered with forests (Anon., 2006b) and at the end of 1998, 865 000 hectares were legally protected (Anon., 2000a). The ‘Sustainable Forests’ environmental objective Interim target 1 states that 900 000 hectares of productive forest land, in addition to the levels in the turn of the year 1998 and 1999, should be protected by 2010 (Anon., 2004). About 500 000 hectares will be protected on a voluntary basis and 400 000 hectares will be legally protected. The legal protection will comprise of nature reserves (320 000 ha), woodland key habitats (30 000 ha), and nature conservation agreements (50 000 ha) (Anon., 2004). The authorities can use different approaches to reach these targets.

Economic incentives

Forests can be protected through nature conservation agreements between the authorities and forest owners, who are compensated monetarily. The compensation does not cover the total financial damage that the forest owners suffer, and can be compared with a subsidy. These agreements are only valid for a maximum of 50 years, due to legal constraints, and are based on an active and voluntary choice of forest owners. Forest owners can also receive subsidies for maintenance, restoration or re-creation of valuable nature and cultural environments. Another available subsidy is for the maintenance of existing stands of valuable broadleaf species such as ash (*Fraxinus excelsior*), beech (*Fagus sylvatica),* cherry (*Prunus avium*), elm (*Ulmus spp*), hornbeam (*Carpinus betulus*), lime (*Tilia spp*), maple *(Acer platanoides*) and oak (*Quercus spp*).

Command-and-control

Certain forest types are, due to their conservational values, forbidden to harvest and consequently legally protected. During the years 1993 to 1998, the National Board of Forestry conducted an inventory of so-called woodland key habitats (Nitare & Norén, 1992) on land owned by non-industrial private forest owners. The focus was to identify forests with high conservational value. Woodland key habitats are often found as fragments, or “island” habitats, in the surrounding landscape and are often remnants of old forest stands with long forest continuity. The conservational values in these forests were identified through a number of structural attributes and so-called indicator and red-listed species. The presence of these values implied that these forests were important to withdraw from forestry operations, as they constitute a significant part of the biodiversity in Swedish forests (Norén et al., 2002). The locations of these forests are registered at the Swedish Forest Agency, and the establishment of a woodland key habitat is conducted through a legal agreement between forest owners and the authorities. The forest owners are financially compensated for the full damage that they incur, and the forest area is no longer treated as productive forest land.

Forests can also be protected as nature reserves, which are regulated in the Environmental Code (Anon., 1998) and are established by the County Administrative Boards. Nature reserves are often larger areas (>20 ha) with high conservational values, but can also contain areas with lower values (max 30% of the area). These areas are either bought by the state or the land owners are compensated in other ways. The Swedish Forest Agency is responsible for the information about species and establish costs in both key habitats and nature conservation agreements. To combine the production goal with the environmental goal in practical forestry, the Swedish Forestry Act sets a qualitative standard or lowest level of environmental consideration. Forest owners are, according to §30, obliged to take "general consideration" at final felling. In practice this means leaving habitats, favouring red-listed species and biodiversity in general, intact (e.g. areas around streams, wells, bogs, rocks, cliffs, old trees and dead wood) (Anon., 1994). The decision of what to leave is made by the forest owner at time of harvest.

Voluntary measures

In the end of 1998, 230 000 hectares of forest land were voluntarily protected (Anon., 2000a). According to Interim target 1 an additional 500 000 hectares of productive forest land will be voluntarily protected by 2010 (Anon., 2004). These forests should contain higher conservational values in comparison to normal production forests, and the goal should be achieved through voluntary participation from all forest owners. Another voluntary measure is so-called green forest management plans, which are provided by both the Swedish Forest Agency and by different forest companies and forest owner associations. These management plans focus on environmental values, in addition to timber production, and they identify stands with higher conservational values, which is a good support tool for forest owners in managing their forests. Some of these stands will be voluntarily protected according to Interim target 1, thus constituting an important part of the 'Sustainable Forests' environmental objective.

Green forest management plans are also mandatory if the forest property is certified according to certification schemes such as the Forest Stewardship Council (FSC) (Anon., 2000b) and Pan European Forest Certification (PEFC). Certification is rather common amongst forest owners today. FSC, for instance, requires that 10 trees per ha are retained (Anon., 2000b), which could, for example, result in small groups of trees (usually <0.5 ha) remaining on clear-cut areas. The identification and delimitation of retention areas is based almost exclusively on structures and is done by forest owners at the time of harvest. Certification schemes are a voluntary complement to the general considerations stated in the Forestry Act. The Forest Agency is aiming to achieve higher levels of consideration than those stated in §30 of the Forestry Act. This has been achieved through information to and education of the forest owners.

Estimation of benefits and costs associated with public goods

Enhancement of biodiversity levels in forests implies restrictions on forestry activities. In order to reach efficient solutions, we seek to maximise the benefit and minimise the costs. Costs are straightforward and are often measured in a monetary unit. In order to measure the economic benefit, there has to be a connection between the change in the good (e.g. number of species) and the achieved utility of the good. Given an equivalent monetary value, a comparison between benefits and costs (cost-benefit analysis) is possible, which from an economic perspective is useful when deciding whether or not a public project should be carried out. A necessary condition for the efficient provision of a public good is that the marginal benefit should equal the marginal cost of the public good (Varian, 2003). Knowledge about costs and benefits is also important when a legislator wants to implement an environmental policy with the use of economic policy tools. Uncertainty about costs and benefits will result in policies that are not socially optimal (Baumol & Oates, 1988).

Economic benefits and empirical valuation methods

Empirical methods to value environmental goods and services are classified as either indirect or direct (Garrod & Willis, 1999). Indirect methods use market prices, through the connection between environmental qualities and market priced goods or services. The value of a forest for recreational purposes can, for instance, be measured through the travel costs associated with visits to the forest. Another method is hedonic pricing, which measures the economic value of ecosystem or environmental services that affect market prices of real estate. An example is the use of differences among house prices, located in different areas which possess different environmental traits. Indirect methods use the observed behaviour of individuals to value the environment but do not account for non-use values, such as the mere existence of natural resources. A resource can be considered as valuable to people, simply through their knowledge of its existence, even though they may never experience the resource in question (Krutilla 1967).

To include existence values of a natural resource, one can use direct methods such as experimental markets or hypothetical markets by surveying people's preferences and valuations (Brännlund & Kriström, 1998; Garrod & Willis, 1999). These methods study how people choose between different alternatives in an experimental or a hypothetical situation. One method that accounts for the total value of a natural resource, non-use values included, is the Contingent Valuation Method (CVM) (Mitchell & Carson, 1989). In CVM-studies preferences are assessed directly through survey questions, where people express their willingness to pay (WTP) for an environmental change. The construction of a contingent market involves a structured questionnaire with a scenario description that is theoretically consistent, policy relevant, truthful and easy for the respondent to understand (Brännlund & Kriström, 1998). The method does, however, have some disadvantages, mainly that the survey scenario involves a hypothetical situation. Moreover, there is the possibility of respondents expressing sympathies rather than WTP ("warm-glow"), or valuing a part of a project as high as the whole project ("part-whole" bias). WTP may also vary due to payment method and amount of information (Mitchell & Carson, 1989).

The determination of costs

The cost of environmental concern in forestry can be looked upon as the net revenue of foregone timber production or the opportunity cost. At the stand level, the opportunity cost of an action to increase biodiversity in forests is the difference between the maximum net present value that can be obtained from the stand (based on the optimal choice of rotation period, regeneration method, thinning etc.) and the net present value obtained as a result of an action to preserve biodiversity. The classic forest economics problem is the selection of optimal harvest time, or the optimal choice of rotation period, of an even-aged forest stand. The correct formulation of the problem was made by Faustmann (1849), and was correctly solved some years later by Pressler (1860). Many years later Bertil Ohlin, at the age of eighteen, independently presented a correct solution to the rotation problem (Ohlin, 1921). The solution to the rotation problem, under the assumption that foresters are maximising the forest land's present discounted value, is that a forest stand shall be harvested when the rate of change of its value with respect to time is equal to the interest on the value of the stand plus interest on the value of the forest land. The net present value, Π, of a forest stand from an infinite number of rotations with optimal harvesting age T, is calculated as:

$$\Pi(T) = pV(T) + L \qquad (1)$$

where p is the net price of timber, V is the standing volume and L is the land expectation value, *i.e.* the expected value of an infinite series of rotations. Put differently, a stand shall be harvested when the marginal benefit of harvesting now is equal to the forgone marginal benefit of waiting (*i.e.* the marginal cost).The solution to the problem is well-defined provided that there is a perfect capital market (one can lend and borrow any amount at the prevailing interest rate, and the future interest rates are known), the future price of timber is known, forest land can be bought and sold in a perfect market and the future technical lumber yields are known (Johansson & Löfgren, 1985). The optimal rotation period changes with the price, costs or interest rate. Higher prices and/or lower costs and higher interest rates shorten the rotation period. We have so far only assumed that no other values than timber can be derived from the forest. The forest does, however, provide values from other services and goods. Accounting for additional values yields another solution to the rotation problem. Hartman (1976) extended the model of optimal rotation to determine when to harvest a forest if non-timber benefits and multiple-use aspects are considered. Hartman used recreation value as an example and showed that the presence of other services provided by a standing forest have an important impact on whether and when a forest stand should be harvested. In some cases a standing forest provides a significant flow of valuable services, which model (1) does not take into account. Today non-timber benefits, such as biodiversity and recreation, play an important role in forest management, and it is important to account for these values as well as for timber values. The question is to what extent this should be done?

Biodiversity

Biodiversity can be described as "the diversity of life", an expression that goes beyond species to genetic and ecosystem components of life on earth (Hunter, 1999). Genetic diversity among organisms exists at different levels: within a single individual, between different individuals of a single population, between different populations of a single species (population diversity), and between different species (species diversity). Species richness, defined as number of species in a given taxon in a chosen assemblage (Magurran, 2004), is sometimes used as a measurement of biodiversity. Species do, however, differ in abundance and a second component of diversity, evenness, is often used for description of biodiversity. Evenness is based on the relative abundance of species and is a measure of how similar species are, which also has to be accounted for when sampling species. Diversity among species in a habitat is known as α-diversity, whereas the compositional diversity among habitats is known as β-diversity, and diversity on e.g. landscape level is known as γ-diversity (Whittaker, 1972).

It is important to have a large scale perspective regarding biodiversity, especially when evaluating effects of biodiversity management (Hunter, 1999). The following will serve as an example (*sensu* Hunter, 1999): A regeneration of a forest creates new habitat that attracts many new (and common) species, which adds to the overall biodiversity of the tract (α-diversity). In comparison with the neighbouring and unharvested forest stand (assuming that they are different habitats) the newly harvested stand differs in species composition (β-diversity). As a result of the conversion of late successional habitats into early successional habitats, species associated with old forests lose suitable habitats and are possibly reduced. This results in a decreasing number of species in the landscape and, consequently, reduced γ-diversity. The diversity of the landscape is decreasing due to the lowering of evenness (common species become more abundant and uncommon species rarer) and the species richness will decline if species become locally or regionally extinct.

The measurement of diversity is based on the assumption that all species are equal. Sometimes the status of species and their conservational value is of interest, which implies weighting of the species and their importance. The classification of species according to the Red List (Gärdenfors, 2005) is an analysis of the state and relative risk of extinction of a number of species, according to criteria established by the International Union for Conservation of Nature (IUCN, 2001). The Red List uses five criteria, or "alarm signals", for the assessment of a species status. These alarm signals are: a) the size of the population is rapidly reduced, b) the population has limited geographical range, is declining, is fragmented, and is extremely fluctuating, c) the population is small and declining, d) the population is very small, and e) a quantitative analysis shows a specific probability of extinction within a defined time frame (Gärdenfors, 2005). Even though the Red List does not directly measure biodiversity, it can be used as a tool for nature conservation purposes, through its highlighting the levels of threat that certain species face. If looked upon from the perspective of "all species have a right to exist", the more red-listed species that are protected, the higher the biological benefit that is achieved.

Conservation Value Scores are calculated by summing up the amounts of biological attributes in different areas. These attributes are structures, such as old trees, dead wood from coniferous and deciduous trees, but also the presence of red-listed species and so-called indicator species. Indicator species, or signal-species, are used for localising and distinguishing forests with high conservational value. These species are useful in field inventories because they are easy to find and their presence indicates that other demanding species, that are not found as easily, could also be present in the area (Nitare, 2000). The use of conservation value scores is similar in construction to the Swedish woodland key habitat inventory (Nitare & Norén, 1992). The higher conservation value from the different biological attributes, the higher biological benefit that is achieved.

Materials and methods

In Paper I, the value of environmental goods was estimated. A CVM study was employed to measure Swedish citizens' willingness to pay (WTP) for attaining the national environmental objectives, or the "environmental budget". Five "green" indicators, chosen for Sweden with respect to emission levels and the state of the environment, formed a policy relevant basis for the formulation of CVM scenarios and WTP measurement in the survey. A representative sample of 600 Swedish citizens, aged 18-75 years was approached with the survey, which was equally divided between four versions. One survey version (called "General") involved a monthly environmental budget WTP question, for attaining the national environmental objectives, followed by a disaggregation of the budget on a subset of five green indicators through a rating question. These indicators included the greenhouse effect, acidification, urban air quality, eutrophication and biodiversity in the forest. Within the environmental budget, the value of a change in a specific environmental good was also estimated. Three additional survey versions (called "Bio 1", "Bio 2" and "Bio 3") contained the same environmental budget WTP question and a second WTP question asking the respondent about the WTP (as a part of her/his environmental budget) for a specified level of forest land protection. These versions were distributed to 150 persons each, and the respondents were asked to assess their WTP to avoid deterioration from a reference level to the levels in the different Bio versions of the survey. The reference level would secure the survival of species in the long run, whereas two of the alternative levels would not secure species survival and one would secure survival in the short-term. This study also considered the effects on value estimates when respondent uncertainty was explicitly introduced, and respondents who were not in the market for environmental objectives and forest land protection. Uncertainty in WTP was elicited by giving each respondent a table with a range of monetary amounts, or bids, asking for willingness to contribute with each of the amounts on the scale: "Definitely Yes" - "Probably Yes" - "Uncertain" - "Probably No" – "Definitely No". The bid vector comprised of the amounts 5, 10, 20, 50, 100, 150, 200, 300, 500, 1 000 and "2 500 or more" SEK per month. The WTP questions were preceded by so-called spike questions eliciting whether the respondent would be willing to pay anything at all. The response rate was 50.3%, corresponding to 302 partially or completely filled in questionnaires.

Paper II examined the attitudes of non-industrial forest owners regarding the following forest functions: production of timber, environment for biodiversity and environment for recreation. About half of the total Swedish forest area is owned by non-industrial private forest owners, and their attitudes about different forest functions are important to consider from a forest policy perspective. The owners' attitudes were compared with how forest officers understand them. Data was obtained through a mail survey investigation, which focused on forest owners and forest officers, and how they considered the importance of different research areas (Mattsson, Boman & Kindstrand, 2004). The questions analysed in this study were parallel for forest owners and forest officers. The forest owners were asked about the importance *up to now* and *in the future* of the different functions. The questions to the forest officers were the same, except that they stated their understanding, or estimation, of the importance of different functions to private forest owners in general. This study focused on the share of respondents who selected the response alternatives “Very important” and “Much more important than up to now”. The study included 2 000 forest owners from south, central and northern Sweden, randomly drawn from a register handled by Statistics Sweden. All forest officers in the same regions with direct contact with forest owners, in total 357, were selected from lists of employees found on web sites of forest owners associations, regional forestry boards and Skogssällskapet AB. All these organisations serve private forest owners in the management of their forests. The final response rates were 65 and 77%, respectively.

Papers III and IV used data from a field inventory in old growth forests (>110 years of age) of Norway spruce (*Picea abies* [L.] Karst.) in the County of Gävleborg, Sweden. The forest was of a bilberry (*Vaccinium myrtillus* L.) type, situated on mesic to moist soil. Sites 50 x 50 m (0.25 ha) having at least 70% Norway spruce were randomly selected from a satellite map of forest types, classed according to dominant tree species and stand age (Angelstam *et al*., 2003). Data on bryophytes, lichens, wood-living beetles, and structural characteristics in forests, as well as data on stand characteristics, was gathered in circular plots in each stand. The cost of a forest stand was expressed as opportunity cost, *i.e.* the net present value (NPV) of foregone timber production. The standing volume per hectare for each plot was estimated using growth functions by Ekö (1985). These functions were based on vegetation type (Hägglund & Lundmark, 1977), site quality index (Hägglund, 1981), stem number (ha^{-1}), basal area ($m^2\ ha^{-1}$), stand age, latitude and altitude (registered by GPS), and thinning history (thinned within the last ten years or not). The trees were also classed according to timber quality. The NPV of each site was calculated using the Visual Basic computer program Plan 33 (Ekvall, 2001) where simulations of stand management were made in order to maximise the NPV with an interest rate of 3%. Price lists in Plan 33 for different timber classes of Norway spruce and Scots pine, and prices of pine, spruce and birch pulpwood as well as costs for silvicultural measures (regeneration, pre-commercial thinning, harvesting etc.) were obtained from Mellanskog, a non-industrial forest owner co-operative (cf. Ekvall, 2001; Ranius *et al.*, 2005). The price of pine pulpwood was 220 SEK/ m^3, spruce pulpwood 240 SEK/ m^3 and birch pulpwood 250 SEK/ m^3. All other deciduous tree species in the calculation were treated and priced as birch pulpwood.

Paper III focused on the importance of information about costs and biological benefits when selecting reserves. Three different conservation goals were formulated and applied to the same data set, and the performance of selection schemes with and without information about costs were investigated. According to the first conservation goal, sites were selected according to the maximum number of species, and sites containing a high number of species were systematically chosen first. The second conservation goal aimed at maximising the total species richness in the reserve network, and the sites were thus chosen depending on each other. The third conservation goal was based on conservation value scores given to each site. For each of the three conservation goals, site selection models were applied, containing information about biological benefits alone (B-selection), costs alone (C-selection) and biological benefits and costs integrated (BC-selection). Each of the conservation goals were then analysed according to the cost-efficiency of different site selection models, together with the variability in both costs and biological benefits for each goal, as well as the correlation between costs and biological benefits.

The intention of Paper IV was to analyse how cost-efficient four strategies of identifying set-aside areas in old spruce forest were, in terms of biodiversity targets in relation to opportunity costs. Currently, three strategies to identify set-aside forests in Sweden are used, i.e. retention areas, key habitats and nature reserves, all representing different biodiversity targets and levels of information about the biological benefits associated with the targets. A hypothetical strategy where areas with old spruce forest were selected at random from the satellite map "wRESEx" (Angelstam *et al*., 2003) was also examined. The four different strategies were compared, with respect to how cost-efficiently they include each of nine biodiversity parameters (number of species in three species groups, number of red-listed species in three species groups, and volume of three tree structures). The cost-efficiency for tree structures was calculated as the ratio between the amount of a structure and the opportunity cost. For species, accumulation curves were used and the number of sites on the x-axis was multiplied by the average opportunity cost for the plots. This allowed for comparisons of cost-effectiveness of the different strategies, based on the average number of species that were included at different budgets. This was also done for the mixed strategies. The number of beetle species was not recorded per plot but per 2.5 m^2 bark area. The average net present value per plot was divided by the average amount of bark per plot and multiplied by 2.5 in order to determine the net present value of a forest area containing 2.5 m^2 bark in the different strategy types. These values were then multiplied with the number of sites on the x-axis of the species accumulation curves to get a species-investment curve for beetles. An analysis of how information costs influence the result was also made through a repeated cost-effectiveness analysis, with data on information costs added to the opportunity costs.

Results

On the budget for national environmental objectives and willingness to pay for protection of forest land (I)

Neither socioeconomic characteristics of the respondents nor the result from the follow-up questions to non-respondents indicated the presence of unit nonresponse bias. Respondents to the “General” version of the survey were approached with budget questions regarding environmental objectives on a national level, and a disaggregation of their budget on green indicators. The respondents were willing to allocate 16.63% of their monthly environmental budget on the green indicator protection of forest land, which corresponds to a mean WTP of 22.60 when using the mean environmental budget estimate of 135.92 SEK (“definitely yes – definitely no” model). This estimate allows maximum respondent uncertainty and takes respondents not in the market into consideration. Accounting for respondents not in the market implies a more representative sample of respondents, which should reflect the citizens WTP. The mean budget share for biodiversity protection from the “General” subsample was similar to the marginal WTP estimates from the “Bio” subsamples, where the respondents were presented an explicit scenario for forest land protection. The estimates in this case were 17-21 SEK, depending on functional form. The level in “Bio 3” corresponds to the actual Swedish policy goal regarding protection of forests, so these estimates represent WTP for the current level of protection of forest land.

Attitudes towards various forest functions: a comparison between private forest owners and forest officers (II)

The attitudes of forest owners and how forest officers understand them does not always coincide. Regarding the timber production function and its importance *up to now*, a significantly larger share of the forest officers ticked “Very important” than the corresponding share of forest owners, in all regions. Amongst the forest owners, 35.4-39.9% considered timber production to have been a very important function whilst 62.1-73.2% of the forest officers estimated it as being very important to the forest owner. The share of forest owners who ticked “Very important” for the biodiversity and recreation functions were significantly larger than the share of forest officers, in all regions. Between 9.7 and 15.8% of forest owners considered biodiversity to have been a very important function. The corresponding share for the recreation function was 21.9-28.3%. Amongst the forest officers these functions were estimated as very important *up to now* for the forest owners by 0.0-2.3% and 1.1-1.8%, respectively. Regarding *the future* importance of forests 15.4-17.7% of the forest owners estimated that timber production would become much more important to the owner. Among the forest officers 6.9-8.0% estimated the importance to increase much for the owner. The difference between the two groups was significant in southern Sweden. No significant differences between forest owners and forest officers regarding *the future* importance of biodiversity and recreation could be found.

Cost-efficient reserve selection: relative importance of costs and benefits depends on the conservation goal (III)

Accounting for heterogeneous costs of sites generally increases the cost-efficiency in systematic reserve selection. The selections based on both biological benefits and costs (BC-selection), implied selection of sites that were ranked due to their diminishing cost-efficiency and were, consequently, always more cost-efficient in each step. However, the relative importance of information about costs and information about biological benefits depends on how the conservation goal of a reserve network is formulated. When the goal was to maximise species records, the selection based on costs (C-selection) was almost equally efficient as the selection based on biological benefits and costs (BC-selection). The selection based on biological benefits alone (B-selection) was less efficient. When the goal was to maximise the total number of species in a reserve network, all the selection models were initially performing equally. After approximately 450 species, the BC- and B-selections performed better than the C-selection. As a comparison the C-selection needed all 60 sites to be selected before all species in the network were included, whereas the BC-selection and B-selection included all species in 45 sites. When the goal was maximum conservation value scores, the C-selection was generally more efficient than the B-selection, except for higher levels of cumulative biological benefits.

The difference in efficiency between the B-selection and the C-selection was also determined through the construction and comparison of an efficiency index for each conservation goal. When the goal was to maximise the number of species in each site, the C-selection was on average 13% more efficient than the B-selection. Regarding the goal to maximise the number of species in a reserve network, the C-selection was 33% less efficient than the B-selection. For the third goal, maximising conservation value scores, the C-selection performed slightly better than the B-selection, though the difference was small (3%). It is not possible to compare the cost-efficiency of the selection models between the different conservation goals, as the biological benefits are measured in three different units. The costs were negatively correlated with species number in sites. A separate analysis of bryophytes, lichens and beetles, showed that only bryophytes were significantly correlated with costs. No significant correlation between costs and conservation value scores was found. To quantify the costs and variability in each biological benefit type, the Gini-coefficient of variability was used. The benefit variability was largest in the conservation goal to maximise the total number of species in the reserve network. The variability was lowest in the goal to maximise species records, while variability in conservation value scores and costs were intermediate.

Cost-effectiveness of implemented conservation strategies in economically important forests: selection of set-asides (IV)

The biodiversity targets used were structures (large-diameter trees, deciduous trees and dead wood), species in general and red-listed species. The species groups examined were wood-living beetles, bryophytes and lichens. Consequently, nine biodiversity parameters were examined *i.e.* number of species in three species groups, number of red-listed species in three species group, and volume of three tree structures. For the biodiversity target structures, large diameter trees in retention groups were significantly less cost-effective than in key habitats and nature reserves. For deciduous trees nature reserves were more cost-effective than satellite identified areas, the other strategies being intermediate. For dead wood there was no significant difference in cost-effectiveness between the four types. Regarding the biodiversity target species, retention groups (R) and key habitats (K) were the most cost-effective strategies. They contained the highest number of species, in all groups, at any given cost and the lowest cost at any given number of species. The difference in the lichens species group was, however, small. For red-listed species, the key habitat strategy was the most cost-effective for all three species groups. The cost-effectiveness of mixes between two types was generally intermediate between them, except for red-listed bryophytes where a mix of 10 nature reserves and 10 satellite identified areas (NS) was slightly more cost-effective, and for red-listed lichens, a mix of retention groups and satellite identified areas (RS) was less cost-effective than either single strategy. The cost-effectiveness of the different strategies was also tested by adding information cost to opportunity cost. This did not, however, influence the cost-effectiveness of the different strategies or change their relative order.

Conclusions and discussion

For a long time the primary aim of forestry in Sweden has been the production of timber, but in recent decades other functions, such as biodiversity, have been increasingly recognised by society. Biodiversity is a public good for which no market exists that can reflect its value. Such market failures require intervention from the authorities, in the form of different policy tools. Sustainable Forests are one of the sixteen environmental objectives decided by the Swedish parliament, indicating what features in forests are considered as scarce by society. This objective deals with the long-time protection of forest land, and about 400 000 hectares will be protected through the purchase of land (Anon., 2004). According to the Swedish Environmental Council (Anon., 2004) this requires an estimated 1 516 million SEK per year until the year 2010. To investigate whether this investment is profitable or not, and to account for the benefit of this project, a CVM study can provide useful information. One must, however, bear in mind that the result depends on how the valuation scenario is described to and interpreted by the respondents.

According to Paper I, the estimated mean willingness to pay (WTP) for protection of forest land is 22.60 SEK per month, based on the rating question and 21.47 SEK based on the marginal WTP estimate. A WTP of 22 SEK per individual and month results in an annual WTP of 264 SEK per year. Aggregated over the surveyed population (6 290 773 individuals between 18 and 75 years of age in 2002) the total mean WTP is 1661 million SEK. The benefit of this project outweighs costs by about 10%. Another interpretation of the respondent uncertainty would, however, yield a different result for the WTP for protection of forest land. Even though findings from CVM studies are good support tools in the evaluation of public projects, it must, once again, be stressed that the results must be interpreted in terms of the survey scenario, and not out of context.

Biodiversity conservation implies restrictions in forestry, and private forest owners are affected by these regulations. Privately owned forest land comprises about half of the forest area in Sweden, and the actions of these forest owners could have a large impact at the national level. Paper II revealed diverging attitudes among forest owners, and the interpretation of the importance of forest functions made by the forest officers. A possible explanation was that forest owners express attitudes, whereas the forest officers report what they observe amongst forest owners, both their attitudes and their actions. A central component in the implementation of Swedish forest policy is the use of complementary measures such as education of forest owners, and forest officers are in this case used as vectors of information and methods. The implementation of the “Sustainable Forests” environmental objective depends to a large extent on the voluntary contribution from forest owners, and so also the implementation of a higher level of general consideration than stated in §30 in the Forestry Act. Although forest owners express attitudes which are in line with our current Forestry Act, the existence of diverging attitudes between the two groups is unsatisfactory from a policy implementation perspective.

The current environmental objective implies legal protection of forests, thus investment in nature reserves, woodland key habitats and nature conservation agreements. In Paper III the importance of information about biological values and costs in reserve selection was addressed. The estimation of costs is based on classical forest economic theory, and is reasonably easy to obtain through ordinary forest taxation. How we use the information about costs and species, and how detailed the conservation goal is will affect the result of the reserve selection. When the goal is to maximise number of species per site, joint information on costs and biological benefits, or information on costs alone, is more efficient than information on biological benefits alone. A more detailed goal, such as conservation value scores, is most efficient when using information on both benefits and costs in the selection process. When the goal is to maximise number of species in a network, the efficiency can be enhanced when using information about both benefits and costs. In the practical selection of forest sites for conservational purposes in Sweden, structural elements are important features, and consequently biological value is the most important information in the selection process.

Biodiversity in forests is often protected as woodland key habitats or nature reserves. These types of legal protection of forest land are also found to be cost-effective regarding structural elements, such as large trees and deciduous trees, according to Paper IV. The intention with these areas is the conservation of biodiversity, and consequently the identification process is aimed at finding important structural elements and red-listed species. Woodland key habitats are also most cost-effective regarding red-listed bryophytes and lichens. Retention groups are a part of the so-called general consideration, as stated in §30 of the Forestry Act. These areas are identified by the forest owner (or contractor) and left remaining at final harvest. Retention groups have a significantly lower opportunity cost per hectare, which is natural when assuming that forest owners seek to maximise their harvesting net value. As a consequence they are not cost-effective for large diameter trees due to this lack of structure. On the other hand, they were found to be cost-effective regarding species in general, but less effective in including red-listed species. The intention with retention groups, however, is not to save red-listed species but to increase structures important to biodiversity conservation in the developing production stand. The low volume of large diameter trees implies a future lack of this structure. The different strategies complement each other, but with a completely different focus. Retention groups represent forestry practices with a higher environmental concern, whereas the main purpose of reserves and woodland key habitats are to conserve species.

This thesis focuses on the trade-offs between production of timber and the maintenance of biodiversity in forests, as well as the effect of information on benefits, costs and biological traits. Apparently, there is a positive willingness to pay for protection of forest land among Swedish citizens. Among private forest owners, there is a positive attitude to biodiversity as well as timber production. Protection of forest land does, however, render costs to forest owners regardless of whether it is performed on a voluntary basis or based on society's positive willingness to pay for it. It should be noted that this thesis does not attempt to examine the extent to which forest owners' interests should coincide to the interests of society. However, if society wishes to protect forests, it should be done at the lowest possible cost. Such an approach implies lowest possible alternative costs for the forest owners and lowest possible use of public funding, a scenario most preferable to both parties. Cost-effective solutions can be achieved in the practical selection process through the proper use of information about biological traits and costs.

An important topic for future research relates to the approach used for biodiversity area selection (Papers III and IV). We treat conservation of biodiversity in a static manner, which implies saving species that are present in a specific forest area, with limited consideration to the dynamic processes in nature. Creation of important structures such as dead wood and large diameter trees is commonplace in current forestry practices, recognising the dynamics of natural processes. A dynamic approach could imply the use of methods which create valuable forests for future conservational purposes. Leaving harvested forest areas for free development is one example of such an approach. This line of thinking could be useful in a landscape management perspective when striving to reach cost-effective biodiversity conservation solutions.

References

Angelstam, P., Mikusinski, G., Eriksson, J.A., Jaxgård, P., Kellner, O., Koffman, A, Ranneby, B., Roberge, J.-M., Rosengren, M., Rönnbäck, B.-I., Rystedt, S. & Seibert, J. 2003. *Gap analysis and planning of habitat networks for the maintenance of boreal forest biodiversity in Sweden - a technical report from the RESE case study in the counties Dalarna and Gävleborg.* Department of Natural Sciences, University of Örebro and Department of Conservation Biology, Forest Faculty, Swedish University of Agricultural Sciences.

Anon. 1974. Lag om bevarande av bokskog (SFS 1974:434). Stockholm. (In Swedish.)

Anon. 1984. Ädellövskogslagen (SFS 1984:119). Stockholm. (In Swedish.)

Anon. 1988. *Skogsvårdslagen: handbok.* 2:a upplagan*. (Handbook of the Forestry Act,* 2nd edn.*)* Skogsstyrelsen, Jönköping. 111pp. (In Swedish.)

Anon. 1993a. Skogsvårdslag (SFS 1979:429). Stockholm. (In Swedish.)

Anon. 1993b. Skogsstyrelsens författningssamling (SKSFS 1993:2). Skogsstyrelsens föreskrifter och allmänna råd till skogsvårdslagen (SFS 1979:429). ISSN 0347-5212. (In Swedish.)

Anon. 1994. *Skogsvårdslagen: handbok (Handbook of the Forestry Act)*. Skogsstyrelsen. Jönköping. (In Swedish.) 66 pp.

Anon. 1998. Miljöbalken. (1998:808), Stockholm. (In Swedish.)

Anon. 2000a. De facto: Environmental objectives – our generation's responsibility. Swedish Environmental Protection Agency, Stockholm. ISBN 91-620-1208-8.

Anon. 2000b. *Svensk fsc-standard för certifiering av skogsbruk*, 2nd edn. Svenska FSC-rådet, Sweden. (In Swedish.)

Anon. 2004. De facto: Sweden's environmental objectives – are we getting there? Swedish Environmental Protection Agency, Stockholm. ISBN 91-620-1238-x.

Anon. 2005. Nationella skogliga sektorsmål. Skogsstyrelsen, Jönköping

Anon. 2006a. De facto: Sweden's environmental objectives – buying into a better future! Swedish Environmental Protection Agency, Stockholm. ISBN 91-620-1251-7.

Anon. 2006b. Skogsstatistisk årsbok. Skogsstyrelsen, Jönköping. (In Swedish.)

Bator, F. M. 1958. The Anatomy of Market Failure. *The Quarterly Journal of Economics 72:3*, 351-379.

Baumol, W.J. & Oates, W.E. 1992.*The theory of environmental policy. Second Edition.* Cambridge University Press, Cambridge. 296 pp.

Berg, A., Ehnström, B., Gustafsson, L., Hallingbäck, T., Jonsell, M. & Weslien, J. 1994. Threatened plant, animal, and fungus species in Swedish forests - distribution and habitat associations. *Conservation Biology 8*, 718-731.

Brännlund, R. & Kriström B. 1998. *Miljöekonomi*. Studentlitteratur. Lund. 307 pp. (In Swedish.)

Bäckström, P.-O. 2001. Några erfarenheter av svensk skogspolitik. In: *Skogspolitisk historia*. Skogsstyrelsen. Jönköping. (In Swedish.)

Coase, R. H. 1960. The Problem of Social Cost. *Journal of Law and Economics 3*, 1-44.

Dales, J.H. 1968. *Pollution, property and prices*. University of Toronto Press, Toronto. 111 pp.

Ekelund, H. & Hamilton, G. 2001. *Skogspolitisk historia.* Jönköping: Skogsstyrelsen. Rapport 2001-8A. ISSN 1100-0295. (In Swedish.)

Ekvall, H., 2001. Plan 33 – A tool for economic analysis of timber production in the forest company. Licentiate thesis. *Swedish University of Agricultural Sciences, Department of Forest Economics. Report No. 123*. ISSN 0348-2049. (In Swedish with English abstract.)

Ekö, P.M. 1985. A growth simulator, for Swedish forests, based on data from the national forest survey. *Swedish University of Agricultural Sciences, Department of Silviculture. Report No. 16*. ISSN 0348-8969, ISBN 91-576-2386-4 (In Swedish with English summary.)

Eliasson, P. & Hamilton, G. 1999. "Blifver ondt att förena sigh"- några linjer i den svenska skogslagstiftningen om utmark och skog. In *Skogshistorisk forskning i Europa och*

Nordamerika. Ed. Pettersson, R. Skogs- och lantbrukshistoriska meddelanden nr 22. Kungliga Skogs- och Lantbruksakademien, Stockholm. 358 pp. (In Swedish.)
Faustmann, M. 1849. Berechnung des Wertes welchen Waldboden sowie noch nicht haubare Holtzbestände fur die Waldwirtschaft besitzen. *Allgemeine Forst- und Jagtzeitung* 15: 441-455. English translation in Gane, M (*eds*.) & Linnard, W (*transl*.): "Martin Faustmann and the evolution of discounted cash flow: two articles from original German of 1849." Commonwealth Forestry Institute, University of Oxford, Institute paper 42, 1968. Republished with permission in: *Journal of Forestry Economics 1*, 7-44. Reprinted 1995.
Field, B.C. 1997. *Environmental economics. An introduction.* Second Edition. McGraw-Hill, New York. 490 pp.
Garrod, G. & Willis, K. 1999. *Economic valuation of the environment – Methods and case studies.* Edward Elgar Publishing, Cheltenham, UK. 400 pp.
Gärdenfors, U. (ed.) 2005. *Rödlistade arter i Sverige 2005- The Red List of Swedish Species*. ArtDatabanken, SLU, Uppsala.
Haila, Y. 1999. Islands and fragments. In *Maintaining Biodiversity in Forest Ecosystems*. Ed. Hunter JR, M.L. Cambridge University Press. Cambridge, UK. 698 pp.
Hartman, R. 1976. The harvesting decision when a standing forest has a value. *Economic Inquiry 14:1*, 52–58.
Hunter JR, M.L. 1999. Biological diversity. In *Maintaining Biodiversity in Forest Ecosystems*. Ed. Hunter JR, M.L. Cambridge University Press. Cambridge, UK. 698 pp.
Håkansson, S. 2002. *Räntefördelningen och dess påverkan på skogsbruket*. Licentiate thesis. Acta Wexionesia No.16/2002, Växjö University Press, Växjö. 238 pp. (In Swedish.)
Hägglund, B. & Lundmark J.-E. 1977. Site index estimation by means of site properties: Scots pine and Norway spruce in Sweden. *Studia Forestalia Suecia*. 138, 1-38
Hägglund, B. 1981. Forecasting growth and yield in established forests – An outline and analysis of the outcome of a subprogram within the HUGIN project. *Swedish University of Agricultural Sciences, Department of Forest Survey*. *Report No. 31.* ISSN 0348-0496.
IUCN. 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.
Johansson, P.O. & Löfgren, K.G. 1985. *The economics of forestry and natural resources*. Basil Blackwell, Oxford.292 pp.
Krutilla, J.V. 1967. Conservation Reconsidered. *The American Economic Review 57:4*, 777-786.
Kolstad, C. 2000. *Environmental Economics*. Oxford University Press, 400 pp.
Magurran, A. E. 2004. *Measuring biodiversity*. Blackwell Publishing, Malden, MA., USA
Mattsson, L. Boman, M. & Kindstrand, C. 2004. *Privatägd skog: Värden, visioner och forskningsbehov. [Privately owned forest: Values, visions and research needs]*. Rapport från Sufor/Brattåsstiftelsen. (In Swedish)
Mitchell, R.C. & Carson, R.T. 1989. *Using surveys to value public goods: the contingent valuation method.* Resources for the future, Washington D.C. 488 pp.
Nitare, J. & Norén, M. 1992. Woodland key habitats of rare and endangered species will be mapped in a new project of the Swedish National Board of Forestry. *Svensk Botanisk Tidskrift 86*, 219-226. (In Swedish with English summary.)
Nitare, J. (ed.) 2000. *Signalarter. Indikatorer på skyddsvärd skog: Flora över kryptogamer. [Indicator species for assessing the nature conservation value of woodland sites: a flora of selected cryptogams].* Skogsstyrelsen, Jönköping, Sweden (In Swedish), 384pp.
Norén, M., Nitare, J., Larsson, A., Hultgren, B., & Bergengren, I. 2002. *Handbok för inventering av nyckelbiotoper.* Skogsstyrelsen, Jönköping, Sweden. (In Swedish.)
Ohlin, B. 1921. Till frågan om skogarnas omloppstid. *Ekonomisk Tidskrift 23,* 89-113. (In Swedish.)
Pigou, A.C. 1920. *The economics of welfare.* Transaction Publishers, New Brunswick. 876 pp.
Pressler, M.R. 1860. Aus der Holzzuwachlehre (zweiter Artikel). *Allgemeine Forst- und Jagtzeitung* 36: 173-191. English translation: Löwenstein, W. & Wirkner, J. R. 1995. For

the comprehension of net revenue silviculture and the management objectives derived thereof. *Journal of Forestry Economics 1,* 45-87.

Ranius, T., Ekvall, H., Jonsson, M. & Bostedt, G. 2005. Cost-efficiency of measures to increase the amount of coarse woody debris in managed Norway spruce forests. *Forest Ecology and Management 206,* 119-133.

Richards, K.R. 2000. Framing environmental policy instrument choice. *Duke Environmental Law and Policy Forum.* Vol. 10, No.2, 221-282.

Schager, N. 1928. Skogspolitik och skogslagstiftning i nyare tid. In *Sveriges skogar och huru vi utnyttja dem.* Eds. Wahlgren, A. & Schotte, G. Lars Hökbergs förlag, Stockholm. 1682 pp. (In Swedish.)

Törnqvist, T. 1995. Skogsrikets arvingar: En sociologisk studie av skogsägarskapet inom privat, enskilt skogsbruk [Inheritors of the Woodlands. A Sociological Study of Private, Non-Industrial Forest Ownership]. *Swedish University of Agricultural Sciences, Department of Forestry-Industry-Market Studies, Report 41*. ISSN 0284-379X. (In Swedish with English summary.)

Varian, H. 1992. *Microeconomic analysis*. Third edition. W.W. Norton. New York. 506 pp.

Varian, H. 2003. *Intermediate microeconomics*. A modern approach. W.W. Norton. New York. 688 pp.

Wahlgren, A. 1928. Skogsskötseln, dess utvecklingsgång och nuvarande ståndpunkt. In *Sveriges skogar och huru vi utnyttja dem.* Eds. Wahlgren, A. & Schotte, G. Lars Hökbergs förlag, Stockholm. 1682 pp. (In Swedish.)

Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon.* 21, 213-251.

Acknowledgements

Many thanks to all of you who have helped me with the completion of this thesis. In particular, my main supervisor Mattias Boman and associate supervisor Leif Mattsson are hereby gratefully acknowledged, as well as all members in the research project “Biodiversity & Economy”. This thesis was financed by Formas (the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning).

All my colleagues at the Southern Swedish Forest Research Centre, none mentioned and none forgotten, do also deserve a sober applause for their contribution to the everyday life at the office.

To my family and friends – you all know how much you mean to me.