Living coastal woodlands

Conservation of biodiversity in Swedish archipelagos

Coastal Woodlands

Karl-Olov Bergman

2006

Abstract

1. Introduction

1.1 The Baltic coastal woodlands from a national and international perspective

Almost half of the European Union's population lives within 50 kilometres of the sea and coastal regions are under constant pressure. In addition, the coastal zones contain some of Europe's most fragile and valuable natural habitats (European Communities 2002). The Baltic Sea is no exception. The pressure is high both on the water and the coastal areas.

The Baltic Sea is the world's second largest brackish water basin with a great variety of ecosystems and habitats. A large number of habitats are associated with the water. The salinity varies from low in the Bothnian Bay in the north, and increases to the south where salt water from the Atlantic flows in. Just a few of the habitats include bladder wrack (*Fucus vesiculosus*) belts hard and soft sea beds, shallow sea grass meadows and deep bottoms. There are also however, a number of unique terrestrial habitats in the Baltic Sea. Some areas of the coast consist of archipelagos with an equal variety of habitats as in the water. In summary it can be said that The Baltic Sea harbours a considerable biodiversity.

The coastal archipelagos in the Baltic Sea are unique and of great conservation interest from a national as well as an international point of view. The archipelagos consist of tens of thousands of islands, from small barren skerries to larger islands covered in woodland and agricultural areas. Despite the fact that the archipelagos have been populated for a long time, a considerable number of terrestrial and marine habitats and ecosystems have remained in a relatively undisturbed state. There are still areas of forests in a natural or near-natural state and rich semi-natural grasslands containing very old oaks and other deciduous trees. The rich coastal woodlands on the archipelagos of the Baltic Sea have few comparisons in the rest of Europe. Many other coastal woodlands have been logged, but it is still possible to visit almost virgin forest during a trip around the thousands of islands in the Baltic Sea. The area also has a high recreational value, which is closely connected to the high nature conservation values (Fig 1). In a national survey of valuable forest, the Woodland Key Habitat survey, a very high percentage of valuable forests were found in the archipelago. A Woodland Key Habitat is a part of the landscape where red-listed animals or plants exist or can be expected to exist. Compared with the whole of Sweden where about 1% was classified as Woodland Key Habitats (WKH), an average of 10% of the forests in the archipelago were WKH, and on some islands it reached up to 50 % (Thor and Gad Burgman 2004).

Biological characteristics of the archipelago of St Anna

The archipelago of St Anna in the County of Östergötland was chosen as the study area due to its high biodiversity. A detailed botanical inventory was carried out during 1979-80 by Lars-Åke Gustafsson in the archipelago of St Anna and the following description is based upon his studies (Gustafsson 1983). The archipelago can be separated into three parts, the inner, central and outer archipelago. The inner part consists of large islands with both deeper fertile soils and barren rocks with shallow soils. Despite that fact that coniferous forests (*Pinus sylvestris* and *Picea abies*) dominate in many parts which have shallow soils, the quantity of deciduous woodland (mainly *Quercus robur* and *Tilia cordata*) is considerable in the inner archipelago on the deeper soils. This is also where agriculture is most active. Fields are mainly situated on deeper soils near the deciduous forests. Many of the small fields however, have been abandoned and are becoming overgrown. Open, flower-rich semi-natural grasslands sparsely populated with oak and lime are an attractive feature of the inner archipelago.

The central archipelago consists of some larger islands but the majority of the islands are small. On the larger islands there are some deciduous forests and open grasslands but on the many smaller islands, pine forest dominates on the shallow soils. Further away from the mainland, the islands become more barren and birch (*Betula* sp.) dominates. Some islands only have bushes of *Juniperus communis*.

The outer archipelago begins beyond the islands with birch and pine. The outer archipelago consists of small barren islands without trees, of special importance for the bird fauna. This is also where grey seals are found.

During 1995-2002 a “WKH” survey was carried out in the archipelago of St Anna. The survey was carried out in two steps. First, the surveyor searched for potential key habitats by compiling information from a variety of sources, e.g. infrared aerial photographs, forest inventories and forest management plans. Potential areas were then visited in the field and assessed. The assessment was based on two criteria, the occurrence of red-listed and indicator species and the occurrence of key elements for red-listed species such as logs, old trees and hollow trees. The WKH survey clearly showed that two tree species hold the majority of the biodiversity in the St Anna archipelago. Scots pine constitutes 40% of the total tree volume and oak constitutes 29% of the valuable stands. None of the other tree species constitutes more than 13% of the tree volume. Oak and pine also dominate in the key elements (Fig 4), large old oaks are the most common key element. The species that were found during the WKH survey are also mainly dependent on old oaks and old pines (Table 1). Many national red-listed lichens and insects were found and indicated that the St Anna archipelago is a hot-spot for oak and pine species.

Due to the fact that the majority of the WKHs were associated with oak and pine this report focuses entirely upon these two habitats: old oak trees in semi-natural grasslands and old natural pine forests (Fig 2). The report begins with a general background description of oak biology and then discusses conservation in coastal woodlands at different scales, from landscape planning to single sites threatened by industry. The examples come from the island of Händelö and the archipelago of St Anna both located in the County of Östergötland (Fig 3). This report forms a part of the Coastal Woodland project, a European Union LIFE-environment demonstration project with focus on forests. The aim of the whole project is to develop useful models for integrated management and nature conservation for forests in coastal areas.

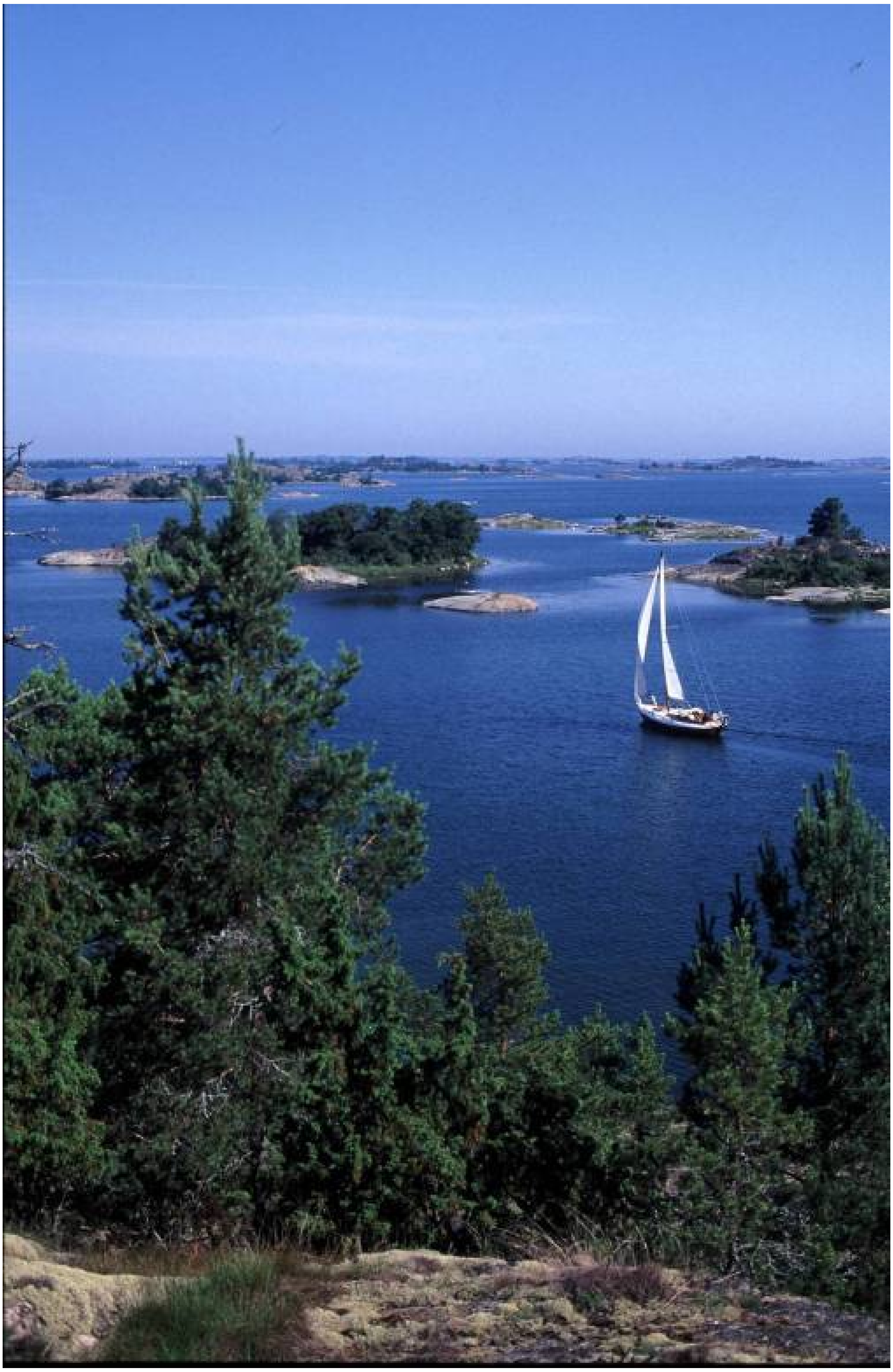


Figure 1. The archipelago has a high recreational value, which is closely connected to the high biodiversity. Photo: Karl-Olof Bergman.

Figure 2. Pictures of the two habitats that hold the majority f the terrestrial biodiversity in the coastal woodlands in the County of Östergötland: old oak trees in semi-natural grasslands and old natural pine forests. Left photo Jens Johannesson, Right photo Karl-Olof Bergman

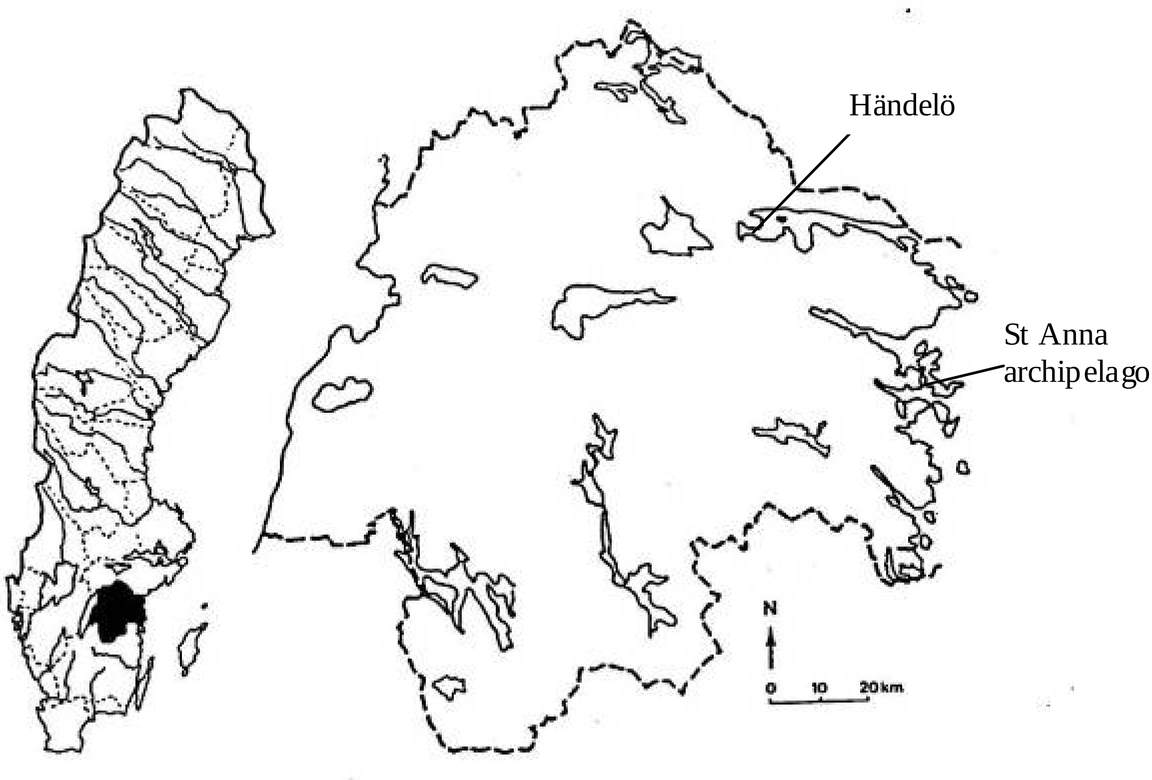


Figure 3. Location of the study area, the archipelago of St Anna and the island of Händelö.

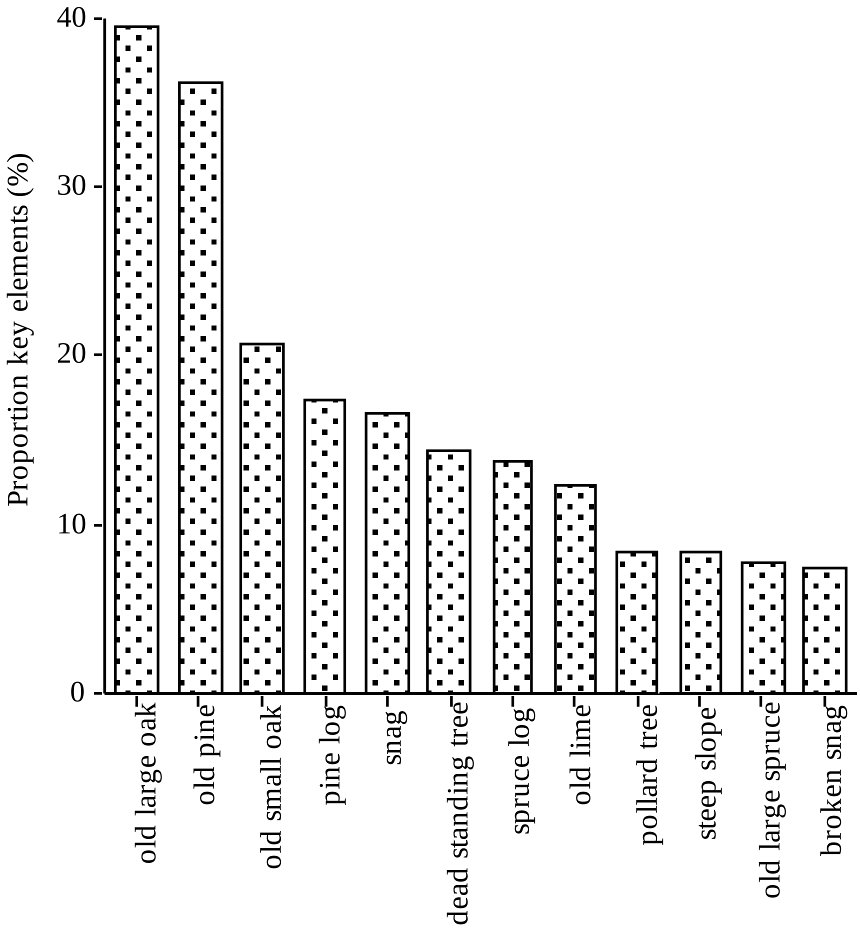


Figure 4. Distribution of key elements for woodland key habitats found in the St Anna archipelago.

*Table 1. The most common indicator species found during the woodland key habitat survey in St Anna archipelago. *=red-listed in Sweden. F=fungi, L=lichen, M=mosses, B=beetles, V=vascular plants*

Indicator species	**Number of WKHs**	**Proportion of WKHs with the species (%)**	**Habitat association**	**Organism group**
Phellinus pini	79	27.0	Scots pine	F
Calicium adspersum	64	21.8	Oak	L
*Lecanographa amylacea**	57	19.5	Oak	L
*Cliostomum corrugatum**	54	18.4	Oak	L
*Schismatomma pericleum**	37	12.6	Oak	L
*Schismatomma decolorans**	35	11.9	Oak	L
Antitrichia curtipendula	34	11.6	Steep slopes and boulders	M
Arthonia vinosa	34	11.6	Deciduous trees	L
*Anthaxia similis**	33	11.3	Scots pine	B
Chaenotheca phaocephala	32	10.9	Oak	L
Homalothecium sericeum	29	9.9	Deciduous trees	M
*Buellia violaceofusca**	28	9.6	Oak	L
Leocobryum glaucum	28	9.6	Wet forests	M
Microbregma emarginata	19	6.5	Norwegian spruce	B
*Caloplaca lucifuga**	19	6.5	Oak	L
Cardamine bulbifera	19	6.5	Deciduous forest	V
Tilia cordata	18	6.1	Deciduous forest	V
*Nothorina punctata**	18	6.1	Scots pine	B
*Dicerca moesta**	16	5.5	Scots pine	B
Hepatica nobilis	16	5.5	Deciduous forest	V
Hypogymnia farinacea	16	5.5	Scots pine	L
*Ramalina baltica**	16	5.5	Oak	L
Lathyrus niger	16	5.5	Deciduous forest	V
Lecanactis abietina	15	5.1	Norwegian spruce	L
Phaeolus schweinitzii	15	5.1	Scots pine	F

2. The Swedish oak areas are important

The WKH survey showed that a large proportion of the biodiversity and nature conservation values were associated with old oaks in the coastal woodlands. But how important are the Swedish oak woodlands in comparison with the rest of Europe? Is it worth the effort to conserve oak woodland in a country in the far north of Europe? Areas with old deciduous trees are few and fragmented all over Europe due to forestry, intensified agriculture and urban development. Sweden however, still has relatively large areas containing old deciduous trees compared to other parts of Europe (McLean and Speight 1993). The County of Östergötland is especially rich in oak areas. More than 16 000 large (>1 m in diameter) and/or hollow oaks have been found in surveys. Östergötland therefore harbours one the few larger areas of oaks in northern Europe and is of international importance (Ranius et al. 2001). One of the largest populations of the hermit beetle (*Osmoderma eremita*) in Europe exists in Östergötland together with >200 other red-listed species associated with old oaks. The hermit beetle is protected by law and is a prioritised species in the EU Habitat directive annexe 2 (directive 92/43/EEG). The reason for the prioritisation of the hermit beetle is that it is associated with old deciduous forests with a large number of hollow oaks, a habitat that harbours a great number of other threatened species. Old deciduous forests have declined across the whole of Europe, and today there is only a fragment of its former distribution remaining, estimated as less than 2% (Hannah et al. 1995). The most acute problem is the lack of very old trees. In a survey in Belgium (Speight 1989), not a single oak, old enough to die of old age was found. This gives some perspective of the relative importance of areas with old oaks found in Östergötland.

2.2 The oak – why is it special?

Among old trees, the oak is exceptional. No other tree has so many associated species (Fig 5). Almost 1500 species of fungi, lichens, insects and other invertebrates have the oak as their main habitat (Hultengren et al. 1997). The reason for the species richness associated with the oak is that the oak contains an impressive number of microhabitats that varies between different individuals and over time in the same individual. It is of crucial importance to understand this variation and the dynamics to be able to analyse long term survival of organisms associated with old oaks.

The most long-lived tree in Sweden

The long life of the oak contributes to the impressive amount of species associated with it. It can live for as long as 1000 years, more than any other Swedish tree. During its life, the oak as a habitat changes and there is a succession of species. One example is the lichen flora on the bark that is completely different on young oaks compared with oaks of an age of 300-400 years old. Other things happen inside the oaks. Few organisms can live in the hard wood of young oaks but as the oak grows older, different fungi species start to develop, breaking down the oak wood to loose wood mould. One important species is *Laetiporus sulphureus* (chicken of the woods) that creates a perfect environment for many larvae of beetle species inside the oaks. The larvae live on the mycelium in the wood mould. With increasing age the oak becomes habitat for a number of organisms specialised on different stages in the decomposition process. The number of species increase until all of the wood inside the oak is broken down. This process may take several hundreds of years and the most species-rich trees are often >300 years old. This means that many species are dependent on trees that have been untouched by humans since the 18th century. The number of old trees in this age class has declined drastically in Sweden and the rest of Europe, something that has affected many species and put them on the red list of threatened species.

The oak as a habitat

The base of the oak has a fauna and flora of its own. The largest beetle in Europe, the stag beetle (*Lucanus cervus*), lives as larva in the roots of the oak for five years. Around 100 fungi species have a mycorrhizal association with the roots of oaks (Hultengren et al. 1997).

Different lichen species thrive on the bark. Specialist species with extremely high habitat requirements colonise oaks only at an age of 300-400 years old. A number of these are red-listed. Some thrive deep in the crevices of the bark, characteristic of really old oaks, like *Sclerophora coniophaea*, and others thrive on the top of the crevices like *Cliostomum corrugatum*. Some thrive on the hot sunny side of the tree and others on the shady side. The differences in temperature can be as much as 60°C during the summer.

Many organisms also live in the crown of the oak, like the beautiful light crimson underwing moth (*Catocala promissa*). In some years the crown can be totally invaded by larvae of the european oak leaf roller (*Tortrix viridana*) and the predators like *Xylodrepa quadripunctata* and birds thrive in these years.

On the branches there are specialised beetles and fungi. On Händelö the threatened fungi species *Pachykytospora tuberculosa* is found on the underside of the branches and causes white rot. The beetle *Scraptia fuscula* lives in branches with white rot.

It is however on the inside of the oak that the majority of the species live. Inside of a hollow oak there is a mix of all kinds of things such as fungi, wood, animal droppings, bird nests and dead birds. In this seemingly unpleasant environment a large number of threatened animals thrive; beetles, pseudoscorpions and hoverflies.

Figure 5. ***Among the old trees, the oak is exceptional. No other tree has so many associated species. Almost 1500 species of fungi, lichens, insects and other invertebrates have the oak as their main habitat Photo: Jens Johannesson.***

Every individual is unique…

At first glimpse all old oaks looks the same, but for their inhabitants there are a number of differences that are possible for a trained human eye to detect. Different fungi species give different kinds of rot, brown rot and white rot. Different types of rot give a slightly different fauna. Different degrees of sun exposure give a different fauna despite the fact that the majority thrive in full sun. One group of beetles that prefer shade however are those beetles associated with fungi. One of the species is the threatened beetle *Mycetophagus quadriguttatus* that has been found on Händelö.

Hollows in different successional stages also harbour different species. The saproxylic pseudoscorpion *Larca lata* prefers large hollows with a large amount of wood mould, while the pseudoscorpion *Allochernes wideri* prefers hollow oaks with smaller cavities and small amounts of wood mould (Ranius and Wilander 2000). Both of the species have been found on Händelö.

Hollow oaks inhabited by hornet wasps attract specialised species living inside the nest of the hornet. Hollow oaks inhabited by birds attract a partly different community of beetles than hollow oaks without birds and so on... Out of 30 hollow oaks maybe just five of these are suitable for a certain species, something that is important to keep in mind when trying to conserve the biodiversity associated with hollow oaks.

3. Händelö – conservation at a local scale
A conflict between conservation and industry on an island with high nature conservation values

Händelö is a 600 hectare island in the Baltic Sea situated just outside the city of Norrköping in the County of Östergötland. The island harbours both industry and areas of high nature conservation value. The vegetation on the island consists of agricultural fields, coniferous forests, old-growth deciduous woodlands and semi-open semi-natural grasslands with old oaks. New large establishments of industries and infrastructure are planned on the small island. Parts of the island have been classified as being of such value that that they have been included in the European network of protected areas, Natura 2000. Händelö harbours at least 26 nationally red-listed species of insects (Jansson 1996). This makes Händelö one of the prime areas in the County of Östergötland with regard to density of threatened insects associated with areas of oak. Of a total of 60 areas with oak studied in Östergötland, Händelö is the 4th with respect to species richness associated with old oaks. The areas of highest quality on Händelö are included in Natura 2000. One part of Natura 2000 is the Habitats Directive (92/43/EEC), one of the most important parts of nature conservation legislation in the EU. The Directive aims "to contribute towards ensuring bio-diversity through the conservation of natural habitats and of wild fauna and flora". To achieve this, areas in Natura 2000 should have "favourable conservation status" (Jones 2002). Conservation status of natural habitats means the sum of influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions as well as the long-term survival of its typical species within the territory.

The conservation status of natural habitats will be taken as favourable when:
i) its natural range and areas it covers within that range are stable or increasing, and
ii) the species structure and functions which are necessary for its long term maintenance exist and are likely to continue to exist for the foreseeable future, and
iii) the conservation status of its typical species is favourable as defined in Article 1(i).

The most important question for the conservation of the biodiversity on Händelö is how to ensure the long term survival of organisms associated with old deciduous trees, mainly oaks. To be able to analyse and understand the overall issue of long term survival, a number of other issues have to be discussed:

- What qualities should an individual hollow oak have to contain threatened species?
- How many old oaks do the threatened species on Händelö need to survive?
- How many old oaks can grow in a certain area without risking the recruitment of young oaks for the future?
- With respect to the dispersal ability of the species associated with old oaks, how close to each other should different areas with oak be?
- How are the species associated with old oaks affected by roads and industry?

How many old oaks do the threatened species on Händelö need to survive?
Beetles dependent on hollow oaks with wood mould is the dominant group of red-listed species on Händelö. It is therefore of crucial importance to understand how many hollow oaks are needed for the long term survival of these species. Other studies have shown that the probability of finding a certain species increases with increasing number of hollow oaks in a single site. The probability of finding the click beetle *Elater ferrugineus* is very low until the number of hollow oaks is up towards 100. The hermit beetle occupied 60% of all hollow oaks in sites with lots of hollow oaks. In sites with only 1-3 hollow oaks, the occupancy was only 20%. The pseudoscorpion *Larca lata* occupied only 0-3% of the hollow oaks in sites with fewer than 11 hollow oaks. In sites with >11 hollow oaks the occupancy rates increased to around 20% (Ranius 2002). These results are in line with both empirical and theoretical work that suggests that a minimum of 15-20 sites are necessary for a species to survive (Thomas and Hanski 1997). Results of modelling on the hermit beetle based on empirical data showed that 20 hollow oaks were the minimum required for long term survival (Ranius and Hedin 2004).

Calculation of the minimum number of hollow oaks and the minimum area that is necessary for long term survival
Empirical and theoretical results suggest that a minimum of 20 suitable hollow oaks are necessary for long term survival. A mix of data from two of the more sensitive species, *Elater ferrugineus* and the hermit beetle was used, as models for further calculations. The principles for the calculations are summarised in Fig 6.

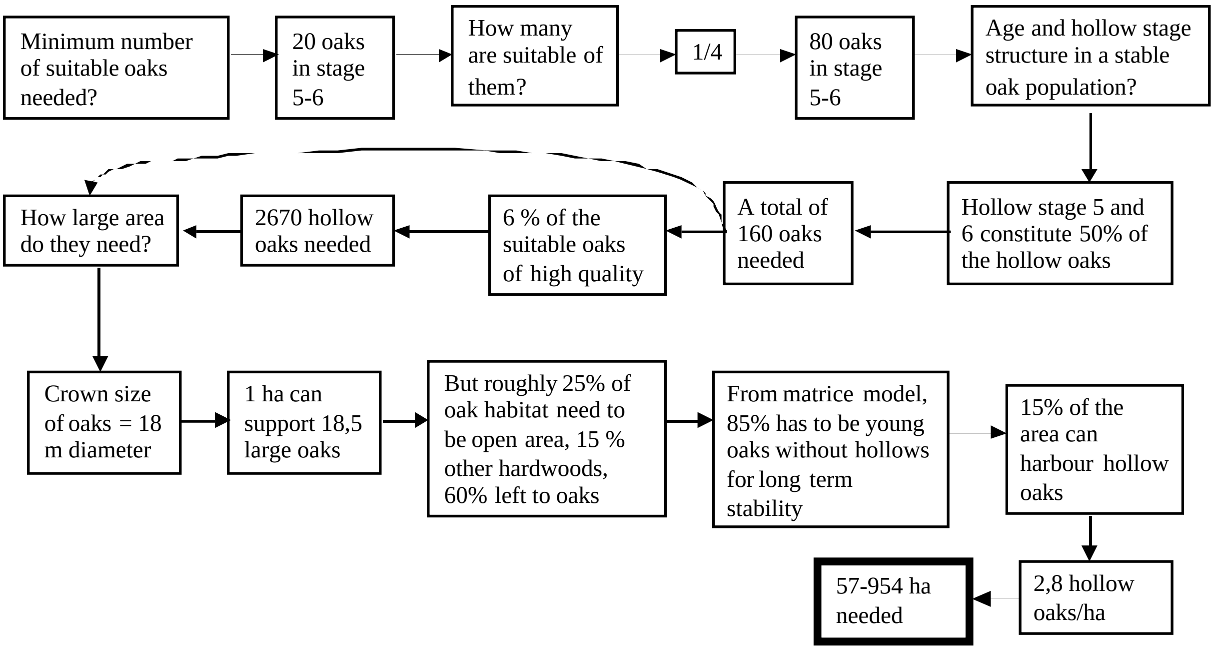


Figure 6. The principles for the area requirement calculations for the long term survival of beetles depending on old hollow oaks. The figures are based on data from two of the sensitive species, Elater ferrugineus *and the hermit beetle combined with data from Box 1 and field data.*

Elater ferrugineus only occurs where there are sites which contain 100 hollow oaks. Results from sieving wood mould (which is an effective method for detecting the species) from 53 oaks showed that the species occurred in only 26% of the hollow oaks. This low figure was true even in the best areas with many hollow trees where it would be expected that all suitable trees would be occupied (Ranius and Jansson 2002). The reason is probably that only one quarter of all hollow oaks are actually suitable for the species. This means that there needs to be 80 hollow oaks for 20 suitable ones. The hollow oaks however, go through a succession over time and only certain stages contain enough wood mould to be included among the 80 oaks. In the survey done by the County Administrative Board in Östergötland (Jansson and Claesson 2001) oaks were classified into five classes (Fig 7). Classes 5 and 6 contain enough wood mould to be taken into account.

A stable oak population over time
The next step in the calculation was to estimate how large a part of the population could be old hollow oaks if the population should be stable over time in the long term. An area can contain many old hollow oaks at a given time but it is clear that as time passes and the old oaks die, there will be a shortage of old oaks in the next generation. For an area to be suitable in the long term it is clear that a certain proportion of the population has to be made up of young oaks. An estimation of a stable oak population was made using data from the survey of a large part of Östergötland which found 16 418 hollow and/or large (>1 m in diameter) oaks. This snapshot of the oak population given by the 16 418 individual oaks was used as a substitute for following a cohort of oaks through time. The prerequisite for this was the assumption that oaks in different hollow stages or diameters have the same chance of being cut down, something that is probably true because no active selective logging has taken place to seek particular qualities of oak. By using

matrices and the probabilities of the tree entering the next hollow stage and diameter class the stable oak population could be calculated (see Box 1).

The amount of hollow oaks in stages 5 or 6 in a stable population is 50% according to the calculations. Since 80 hollow oaks in stages 5 or 6 were necessary for 20 suitable ones the total number of hollow oaks has to be 160 in stages 4-7 for long term survival.

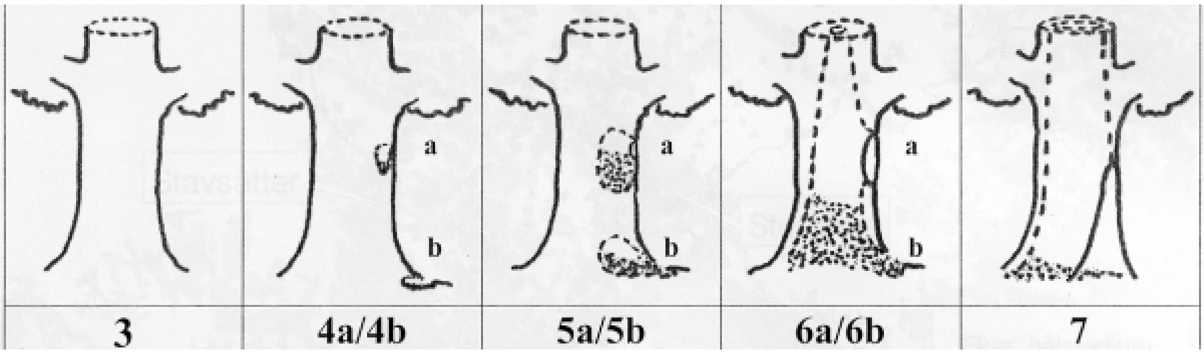


Figure 7. The classification of oaks into different stages of hollowing in the survey by the County Administrative Board in Östergötland. Hollow stage 3 included all oaks with no hollowing and >1 m diameter (from (Jansson & Claesson 2001).

One fact that further complicates the calculations is that the quality of the suitable trees for a species can also vary substantially. Results from the hermit beetle studies show that only a few trees are of really high quality. Of the total number of hermit beetles, between 43-65% were found in only 6% of the trees that were occupied (Hedin 2003). These results suggest that only one tree out of twenty occupied is of really high quality. This means that small sites with a limited number of trees are very vulnerable to stochastic changes in the tree composition. There is a large risk that high quality trees are totally absent in areas with a limited number of hollow oaks. The conclusion is that the estimated minimum number of 160 hollow oaks is an absolute minimum if sensitive species should be conserved in a site. A site containing 20 high quality trees in stages 5 or 6 (if 6% of the suitable ones are of high quality) results in a total of 2670 hollow oaks. This can be regarded as the upper limit in the calculations for fulfilling the requirements for the most sensitive beetles.

How many old oaks can grow in a certain area without risking the recruitment of young oaks for the future?

What area is required for 160 hollow oaks without risking the recruitment of young oaks for the future? To be able to calculate this it is necessary to look at the habitat preferences of the species associated with old oaks. In order to become a high quality oak, sun exposure is important. With high sun exposure an oak can develop into a wide-crowned, short tree with a large diameter, highly preferred by wood-living beetle species. The number of beetle species is higher on oaks with high sun exposure and 90% of the Swedish beetle fauna associated with oaks is estimated to be favoured by sun exposure (Gärdenfors and Baranowski 1992). An estimation of the crown diameter of old sun exposed oaks revealed figures between 15-21 metres.

A good site does not only contain sun exposed old oaks. In combination with the old oaks, sunny glades surrounded by bushes are needed to create shelter from wind, something that is important for many insects. In addition some bushes and flowers in the glades provide the essential resources like pollen and nectar for adult beetles. One example is the red-listed beetle *Globicornis rufitarsis* that has been found on Händelö. Its larvae lives in hollow oaks with nests (for example birds or wasps) but the adult beetles are dependent upon nectar and pollen. This species therefore requires both hollow oaks and open glades.

An estimation of the proportion of open areas and old oaks that can satisfy the needs of the above species is that 25% of the area should be open and 75% can be covered by trees. It is preferable however, that there are also some other species of deciduous trees growing in the area to increase the heterogeneity for the total biodiversity. Several beetle species can also utilise species other than oaks, so even although other tree species are often only suitable for a shorter period of time, they can contribute to the survival of the species. It is estimated that oak can grow in 60% of the area. With a mean crown size of 18 m for an old oak, one hectare can support 18.5 oaks. An area cannot however, support only fully-grown oaks. Parts of the area have to contain young oaks to avoid catastrophic gaps in the supply of old oaks for the beetle species. One example of where the management of a very valuable oak area failed is the nature reserve Halltorps hage where no young oaks were able to germinate due to the shady conditions. There is now a gap in age structure that will be extremely difficult to overcome and several species are at risk of extinction from the reserve. From these estimations of the stable age structure, 15% of a given area will be hollow oaks and 85% will be young or old oaks without hollows. If hollow trees make up more than 15%, there is a risk that there will be a gap in the amount of hollow oaks in the next phase or generation.

The figure of 15% hollow oaks in one hectare amounts to 2.8 hollow oaks growing in a stable population. A comparison with empirical data from some of the best oak areas in Östergötland (Jansson 1998), shows a variation of 0.6-6.8 hollow oaks per hectare, so the estimation of 2.8 oaks seem to be reasonable. As well as the 15% hollow oaks another 15% are estimated to be more than 200 years old but without hollows. In total, one hectare will thus support 5.6 old and/or hollow oaks.

With 2.8 hollows oaks/ha and 160 hollow oaks necessary for the long term survival, the minimum area needed is 57 ha. The upper limit for the most demanding species will be 954 ha, based on the figure of 2670 hollow oaks.

Age structure on Händelö

Random sampling of the diameter of oak from four sub-sites on Händelö shows large differences between the areas with regard to age structure (Fig 8). In several of the areas there are gaps in the age distribution of the oaks. Area “b” has the largest number of old and hollow oaks, 59 on 6.2 ha. This number is over the calculated number of old and hollow oaks (35 oaks) in a stable age distribution on 6.2 ha. It is however, out of the question to cut down valuable old oaks in the area. The alternative solution is to connect several areas with different age structures, for example with area “d” which consists mainly of young oaks. In the long term there will be a dynamic over the whole area, with different sub-sites having old oaks at different times.

In several areas there is also a gap in the age distribution in the youngest class, those below 10 cm in diameter, probably as a result of competition for light due to high canopy cover. The acorns need at least 30% direct sunlight to germinate so an area with too many oaks will soon lose its generation of young oaks.

Spatial structure of areas of oak with regard to dispersal ability of beetles

Alongside estimates of the area requirements and age structure, it is important to take into consideration the spatial structure of the sites (Fig 9,11). How far apart can oak sites be and still be connected to one other? The beetles are the dominating group among the red-listed species in oak woodland. Planning should therefore focus upon this group.

Studies from the Netherlands showed that species with a low dispersal ability had decreased more than species with good dispersal ability since 1880 when the fragmentation of the landscape was most acute (Turin and den Boer 1988). "Newly established" planted oak forests in Great Britain with oaks 200-300 years old are species-poor compared to oak forests with a longer history. Speight (1989) concluded that the source populations that could have colonised these new forests were too far away to allow colonisation. Once the species have disappeared from a site, colonisation is unlikely without high quality sites in the immediate vicinity.

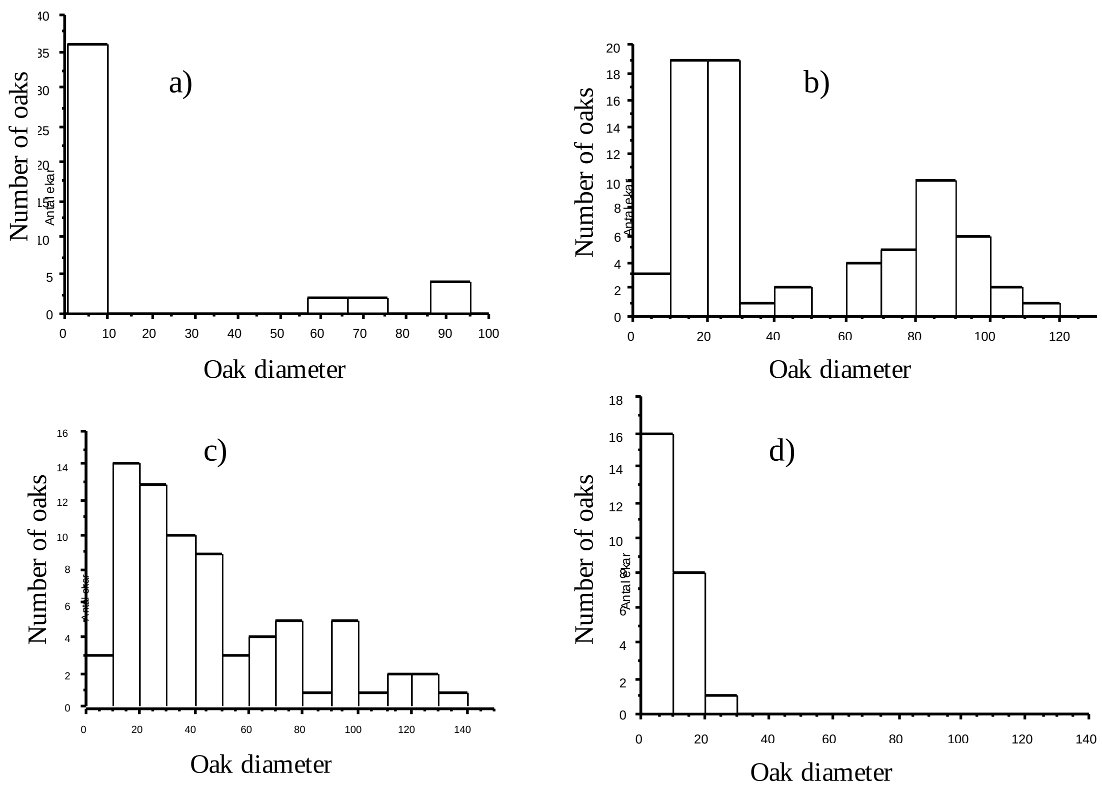


Figure 8. Distribution of oak diameters from four different areas on Händelö. One random sample has been taken from each area where all oaks in a sub-site were measured. See the map below for the position of each area.

Figure 9. One of the largest hollow oaks on Händelö. In the wood mould inside the oak, threatened beetles live side by side with nesting birds. Other beetles use the branches and in the spring a number of insects will use the leaves for food.

This individual is isolated from other oaks and its fauna may have difficulties in dispersing to other hollow oaks when this giant dies. Photo Karl-Olof Bergman.

Empirical data from the hermit beetle regarding dispersal ability
One beetle species associated with hollow oaks, the hermit beetle, has been intensively studied. It has been studied using the mark-recapture technique over five years (Ranius and Hedin 2001). The studies show that even short distances can be a problem in the world of the hermit beetle. From 839 marked individuals, not a single one moved to a tree in another site other than the natal one. The furthest move was 190 m inside the same site. From 901 recaptures, 892 were from the same hollow oak as they were first marked. Out of 74 radio-tagged hermit beetles, eight moved from their natal hollow oak. Five of them moved to the nearest hollow tree, one to the second closest, one to the third closest and finally one to the seventh closest (Hedin 2003). Not one moved further than 190 m. It is probable that the limited dispersal ability of the hermit beetle is representative of other organisms associated with hollow oaks.

An oak is a stable ecosystem for as many as 50 generations of insects. To move from an oak is risky and very few hermit beetles move from their natal oak. The chance of reproduction is much higher if they stay safe inside their hollow than if they try to locate a new hollow oak on a risky trip through the landscape. Those individuals that do move however are very important for the long-term survival of the species. Without colonisation of new hollow oaks, the population will slowly become extinct as the old oaks die. Each oak has a population with a limited number of individuals. The mean number of hermit beetles per oak is only 11 individuals (Ranius 2001). With this low population there is a risk of extinction of the local populations in each hollow oak. Dispersal between oaks to repair extinctions is therefore crucial.

Dispersal between populations is also important to prevent inbreeding. Studies of the butterfly *Melitaea cinxia* showed that the probability of extinction increased with increased inbreeding. The inbred individuals had a shorter lifespan, lower survival as larva and their eggs had a lower hatching rate (Saccheri et al. 1998).

Clearly, the hollow oaks need to be situated close to one other to allow dispersal between them. It is therefore recommended that the oaks should ideally be in the same site, with small distances between them, at most 50-100 m for frequent dispersal.

Box 1

What does a stable age structure in an oak population look like?

By using matrices it is possible to calculate a stable age and hollow stage structure over time in an oak population. To be able to estimate a stable age structure, data on survival and growth are needed. A survey of oak carried out by the County Administration Board in Östergötland provides the possibility to make such calculations. All oaks with a diameter above 100 cm and all hollow oaks without regard to diameter have been surveyed. The hollow stage and diameter were recorded for each oak. This snap-shot of diameter and hollow stage may also give a good picture of survival rates and hollow stage distribution over time. For example, the probability of survival from diameter 1.0-1.25 to 1.26-1.5 m is estimated to 2563/7942 (number of oaks with1.26-1.5 m diameter/number of oaks with 1.0-1.25 m diameter). That means that 32.3% survive to diameter class 1.26-1.5 m from 1.0-1.25 m. The probability of survival between hollow stages was calculated in a similar way. The calculations are based on data from 16 418 oaks.

Diameter	Hollow stage 3	Hollow stage 4	Hollow stage 5	Hollow stage 6	Hollow stage 7	Sum	Probability of survival to next diameter stage
<1,0m		2696	1049	725	289		
1,0-1,25m	5875	917	557	396	197	7942	
1,26-1,5m	1506	311	359	266	121	2563	32,3% (2563/7942)
1,51-1,75m	367	98	132	122	74	793	30,9 % (793/2563)
1,76-2,0m	82	36	37	51	38	244	30,8% (244/793)
>2,0m	28	9	19	33	28	117	48,0% (117/244)
Sum	7858	4067	2153	1593	747	16418	
Probability of survival to next hollow stage		28,9% (2271/7858)	52,9% (2153/4067)	74.0% (1593/2153)	46,9% (747/1593)		

The table below shows the distribution of age and hollow stages in a stable oak population based on the oak data above. The diameters were roughly translated to ages to make it possible to make estimations. It is estimated that the first hollows appear when the oak reaches the age of 100 years. One result showed that 84.8% of the oak in one area in a stable population are without hollows and that 75% of the oak in one area are less than 200 years old. These figures are rough estimations but are the best available data we have.

Age (year)	No hollow	Hollow stage 4	Hollow stage 5	Hollow stage 6	Hollow stage 7	Sum age classes
0-100	0.3768	0	0	0	0	0.3768
100-200	0.3184	0.0271	0.0153	0.0108	0.0053	0.3769
200-300	0.1149	0.0198	0.016	0.0116	0.0056	0.1679
300-400	0.0286	0.0064	.0078	0.0064	0.0034	0.0462
400-500	0.0067	0.0022	0.0026	0.0028	0.0019	0.0162
500-600+	0.0026	0.001	0.0015	0.0024	0.0019	0.0094
Sum hollow stage classes	0.848	0.0565	0.0432	0.034	0.0181	

The history of the oak in Sweden

The oak has a long history as an important tree in Sweden, something that is intimately connected to the rich biological life associated with the oak. With knowledge about the history it may be possible to make more informed decisions regarding which areas to conserve. As early as 1347 there was a ban on logging oak trees stated in the law of the Swedish King Magnus Eriksson. The oaks belonged to the Crown as they were needed for e.g. ship construction (Hultengren et al 1997). All oaks were included except oaks on the land belonging to the nobility. The prohibition of the logging of oak lasted until 1789 when some land owners were allowed to cut oaks which were of no use to the Crown. The ban on cutting oak was lifted for all landowners in 1875. The oak forest decreased rapidly as a consequence, as the logging provided income and land owners "hated" the oaks after the long ban on cutting oaks on their own land. On land belonging to the nobility however, the oaks were left in peace, something that is clearly seen in the landscape today. As a result of the history of oaks, there are now very valuable small stands which were once part of a much larger stand only 100 years ago. They may still contain relict populations of animals dependent on large stands, animals that may be possible to save by restoring land nearby.

Restoration of land which is nearby areas with high nature conservation values is the most efficient conservation effort when compared with restoring random sites in a landscape.

An example of historical oak decline

The existing areas with oak are in many cases only a fragment of the historical distribution. The animal life in the fragmented areas of oak has developed in a landscape which only 150 years ago had an abundance of old oaks. One example from the parish of Vårdnäs in Östergötland clearly shows the oak decline (data from Tommy Ek, County Administration Board of Östergötland). The parish of Vårdnäs had a large population of oaks according to the inventory of oaks carried out in 1749. A total of 38 495 oaks were found. The oaks were classified into three classes:

1. Young and fresh oaks that could be embraced with the arms (24 398 individuals).
2. Fresh oaks that could not be embraced (8 641 ind).
3. Hollow, top damaged or stem damaged oaks (5 456 ind).

The farms belonging to the church were not surveyed and it is estimated that an equal number of oaks could have been found on their land. This gives approximately 11 000 hollow or damaged oaks and 17 000 oaks that were too large to be embraced. According to the recent survey of all old oaks in the parish of Vårdnäs, there are only 159 hollow oaks remaining, 1.5% of what was found in 1749.

A historical look at Händelö

Maps from 1871 (Fig 10) show that areas with deciduous woodland (probably with a large amount of oaks) in total covered 279.8 ha. An area that is today situated outside of Händelö, but which was originally a part of a large meadow with deciduous trees is also included in these figures. Today there are 71 ha of oak woodland on Händelö, 25% of the original cover. In spite of this decline in area, the oak woodlands on

Händelö have one of the most species-rich faunas in Östergötland. The reason is likely due to the fact that historically the area with oak was much larger 130 years ago. Many of the old hollow oaks that we can see today existed 130 years ago, but surrounded by much larger oak woodlands most probably with many more hollow oaks than today.

In a study by Hedin (2003), the occurrence of the hermit beetle was better correlated with the historical number of old and hollow oaks per village than with the number today. A similar situation has been shown for vascular plants in semi-natural grasslands (Lindborg and Eriksson 2004). It must be concluded therefore that to be successful in conserving the large number of species that still exist in the small fragments, the areas and the number of hollow oaks have to increase. The situation on Händelö is similar with a rich fauna in areas that were much larger historically. The high number of species found today is probably “a relict” from the past. The likelihood of the species surviving through this bottle-neck with a low number of oaks is better if the number of oaks can increase. The area has a good potential for the future if the organisms associated with hollow oaks can survive the next 100-200 years, until there are new and more hollow oaks in restored areas.

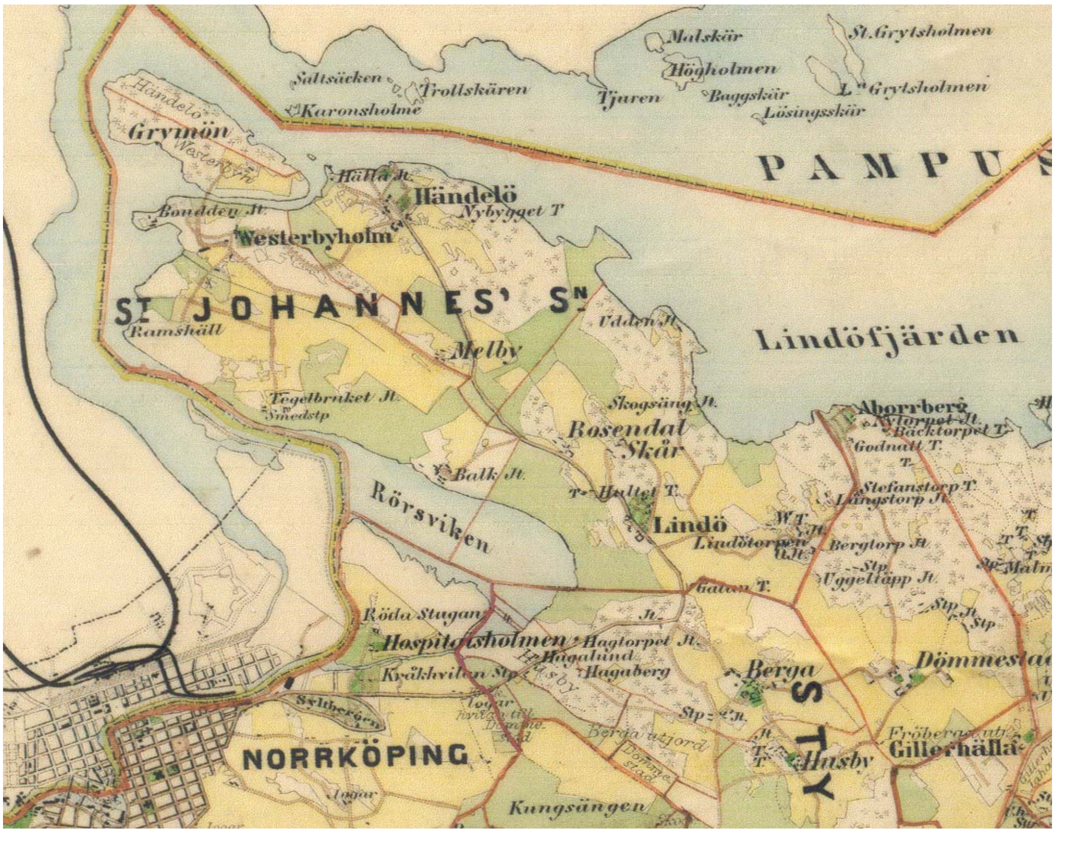


Figure 10. Historical map of Händelö from 1871. green = meadows, white = forest (stars = coniferous forest, circles = deciduous forest), yellow = arable fields. Note the large meadows that probably contained many old oaks.

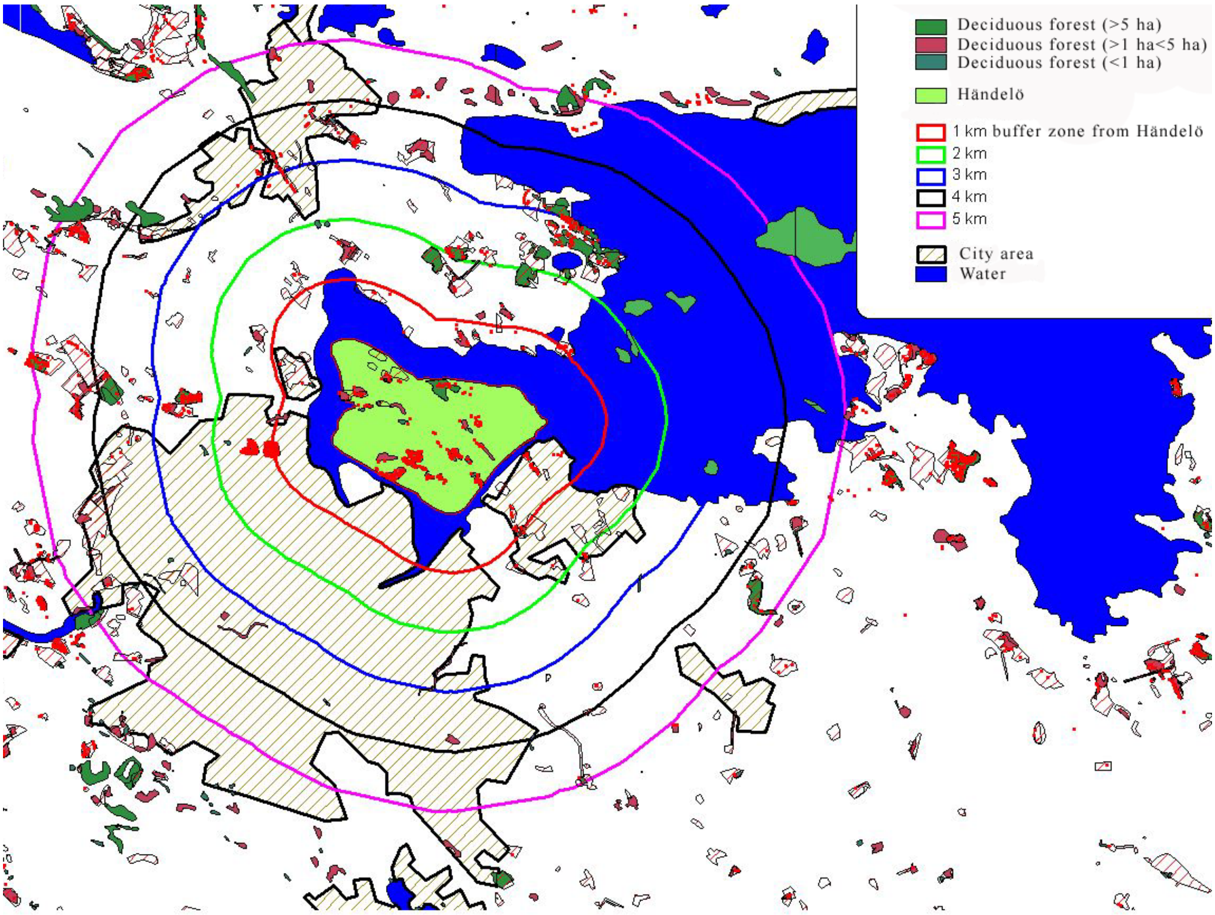


Figure 11. The distribution of areas with oak in the vicinity of Händelö. No larger systems of areas with oak exist within 2 km of Händelö. The red dots show single oaks and are not shown according to scale.

What are the effects of buildings and roads on the threatened fauna of oak?

Crucial for the survival of the rich fauna of Händelö is the creation of suitable conditions for new old hollow oaks and the facilitation of dispersal between different areas. Possible barrier effects and other disturbances that can affect the dispersal of the oak fauna are therefore important to estimate. Buildings and roads create six different types of barriers or disturbances. These will affect different species in different ways (Table 2):

- noise
- street lights
- air pollution
- scents
- blocked views
- practical problems of keeping grazing livestock

Lichens are very sensitive to air pollution. A lichen is a dual organism consisting of a symbiosis between a fungi and an algae. This symbiosis is sensitive to air pollution from for example traffic (Lindqvist and Nyberg 1989). Hedges of bushes and trees along the roads can to a certain extant mitigate the effects of air pollution. Established wood-living fungi like bracket fungi do not seem to be affected by air pollution. The establishment of the fungi on the oak by spores may however be sensitive.

Many bird species are sensitive to noise. Decreased densities of breeding pairs, and decreased survival rate of chicks close to roads have been shown (Reijnen et al. 1995; Kuitunen et al. 2003).

Table 2. Effects of buildings and roads on different organisms.

- = no or small effects
↓ = negative effect
↓↓ = strong negative effect
↓? = possible negative effect, lack of knowledge
↓* = negative effect on condition that the spores are dispersed by beetles

	Beetles	Lichens	Wood living fungi	Birds
Noise	-	-	-	↓
Street lights	↓?	-	-	-
Air pollution	-	↓	↓	-
Scents	↓↓	↓*	↓*	-
Blocked views	↓↓	↓*	↓*	-
Practical problems of keeping grazing livestock	↓↓	↓↓	↓	↓

There are a number of studies into the effects of roads on animals (Forman and Alexander 1998). Roads of a width of 6-10 m decreased the dispersal of small mammals by 90%. Out of 742 carabid beetles that were studied over two years, only one individual crossed a 6 m wide road (Mader 1984). Several of the beetle species found on Händelö are active at night and there are no studies as to how they are affected by street lights.

Buildings surrounding the oak woodland sites have an effect on dispersal (Fig 12). Movement of insects is a complicated process involving many different stimuli to the central nervous system of the insect. Different combinations of stimuli may encourage or deter movement (Zhang 2001). Insects associated with trees orientate with the help of sight and/or by their sense of smell. Positive stimuli that encourage movement involve silhouettes of trees against the horizon and weak scents of trees infected by fungi. These stimuli help the insects to find their way to a tree were they can lay eggs and their larva can find the right food for successful development.

Scent is an important part of the communication and orientation system in many insects, something that can be hard to understand from a human point of view. Scent is for many insects as important as visual contact for us. Strong odours from industry may affect the ability of the beetles to find partners and suitable trees for egg laying.

One possibility to mitigate the effects of industry is to create corridors of oak, bushes and flowers between sites of oak woodland to reduce the distances between the oaks.

Figure 12. Small sites of oak that are surrounded by buildings will lose species when they become isolated from other sites. Photo: Karl-Olof Bergman

The effects on the beetles will be most serious in oak woodland sites that are totally surrounded by buildings. Urban areas may in the worst cases completely isolate populations from one another. The buildings will block the sight-lines between the oak sites, and as a consequense fewer individuals will leave to find a new area, The weak scents from oak with fungi that lead the females to suitable trees, may be at risk of dilution if industries with strong odours are established in the area.

Even insects in sites partly surrounded by buildings may be affected. An individual that tries to find a new site is risking death or will return to the original site if it does not find new oaks in the surroundings. A study of the fauna in 40 oaks in areas with different levels of urbanisation in the city of Linköping provides some information (Karlsson 2003, Karlsson unpublished). The number of species was positively correlated with the number of hollow oaks in the stand and the proportion of oak areas in the area to the next stand with hollow oaks. (Table 2). Species richness was negatively correlated with increasing distance to the next stand and the proportion of buildings 200 m from the stand. These results show that buildings affect the oak fauna negatively. However, areas with many hollow oaks which are connected with other areas maintain a richer fauna, something that can be used when planning on Händelö.

Table 3. Factors that affect the number of beetle species in old hollow oaks in the urban environment. The results are based on 40 oaks (Karlsson 2003).

Positive factors	**Negative factors**
• Large entrance hole (= large volume wood mould) • Large number of hollow oaks in the site • Large area of oak sites with hollow oaks within 1000 m • Large area of oak sites within 200 m • Proportion oak dominated sites in between to the next oak site	- Entrance hole directed to the east (low sun exposure) - Large distance to nearest oak site - Number of years that the oak site has been isolated by buildings - Proportion of built area within 200 m

If buildings are to be established in the vicinity of oak stands, a wide sun exposed edge should always be left intact. These sun-exposed edges are important habitats for many birds and insects. Sun exposure is crucial for many threatened species. A sun path diagram gives the opportunity to calculate how buildings may affect sun exposure (Fig 13). Ranius and Jansson (2000) discuss that sun exposure early in the spring is important for larval development. There are no studies of how the temperature affects the larval growth. The fact that 90% of the species are favoured by sun exposure shows however that temperature is important. Full sun exposure from 1st April may therefore be a guiding principle.

A 15 m tall building should not be closer than 32 m from an edge if it is to have sun from 8 am to 4 pm.

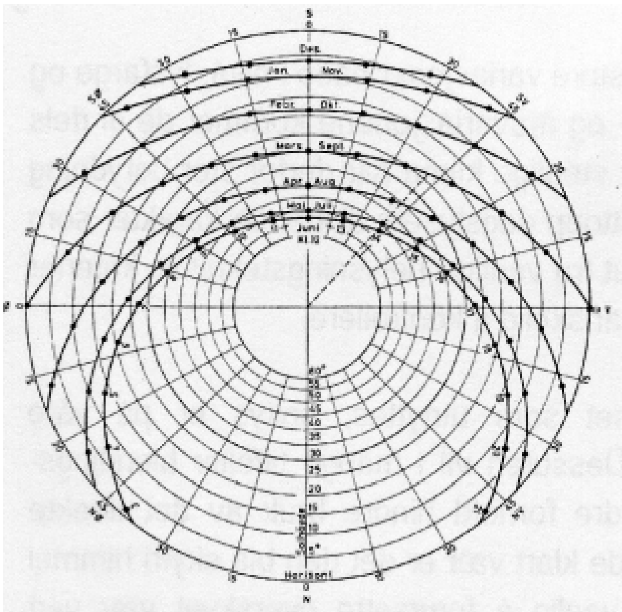


Figure 13. Sun path diagram for the 60th parallel. It can be used to calculate the shade caused by a building. The length of a shadow = height of the building/tangent of the sun angle.

Where and how much?

The real conservation challenge is how to ensure the fauna on Händelö survives in the long term. Where should the areas of oak be situated and how much is needed? Today, the areas with oaks on Händelö are fragmented into a number of smaller and larger sites. Each hollow oak harbours one population of its inhabitants of beetles. In a system like that, consisting of many small populations, some of them will become extinct due to natural and/or random reasons. These extinctions have to be repaired by colonisations from other oaks in the area. Some individuals have to move between oaks to colonise new suitable hollow oaks. If the contact between oaks in the system decreases, there is a risk that the whole system collapses, and species will become extinct throughout the whole system.

Today there is a rich fauna on Händelö, but the total area of oak is probably too small for the long term survival of all of the species. As discussed earlier, the rich fauna is probably a remnant from the past, when there were much larger areas of oak on Händelö. The fauna can survive however, if the area of oak can increase. High quality areas with old hollow oaks are located mainly in the south. Most of the areas with oak in the south should be managed as open semi-natural grasslands. In the north, areas with conservation values connected to shadier forests exist and they should continue to be managed in the same way, to best conserve the fauna.

The goal for the total area of oak on Händelö should be somewhere between 57-280 ha of well connected sites. The low figure is based on the estimation that 160 hollow oaks is a minimum for long term survival, and that there can be 2.8 suitable oaks/ha if there is to be a functioning regeneration of new oaks. The higher figure is based on historical data from the map from 1871, and is the landscape that the fauna was established in. The lower figure of 57 ha is a minimum area. The minimum area is however not a safe figure for long term survival due to uncertainties in basic data used in the estimations. For both figures of 57 and 280 ha however, arable fields need to be restored to oak habitats. The new oak habitats should also consist of areas with flowering bushes for feeding grounds for those beetles that use pollen as food. The establishment of feeding grounds quickly enhances dispersal. A good new habitat should contain oak seedlings which originate from Händelö, heterogeneous topography, creation of soil low in nitrogen by removal of the top soil in the fields thus creating suitable conditions for a herb-rich vegetation and flowering bushes like *Prunus sp*. Areas suggested as being suitable for restoration and of priority to create an area of 80 well connected hectares are given in Fig 14. This should provide a reasonable chance for long term survival.

Connecting the large Natura 2000 areas with the small areas of oak located to the east and north east is of particular importance. The restored areas should be wide enough to contain sheltered glades, something that is important for many species. Studies of corridors 1-45 m wide showed that the proportion of bird and mammal dispersed trees and bushes increased over wind dispersed species as the width of the corridor increased (Sarlöv Herlin and Fry 2000). That means that more animals move in wider corridors. With increasing number of animals, the diversity of trees and bushes increases which gives a positive feedback for the species diversity. With increasing number of birds, the probability of nesting in hollow oaks also increases, which favours the beetle species that live in the nest material. The hermit beetle had a higher probability of occurrence in hollow oaks with birds nests in a study in Bjärka-Säby and Sturefors (Ranius and Nilsson 1997).

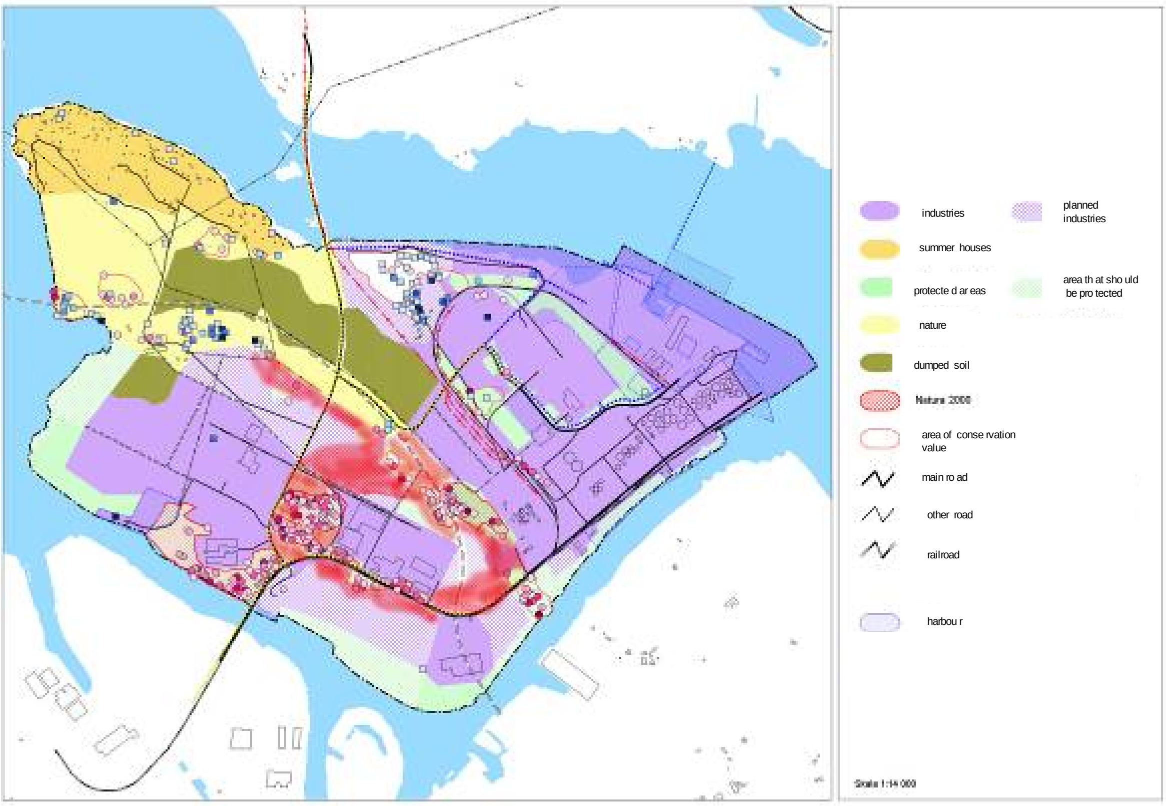


Figure 14. Proposed areas for restoration of oaks (red) for long term survival of the fauna dependent on old oaks. The area is 80 ha in total including the Natura-2000 areas. Pink and red dots=hollow oaks, blue squares=other deciduous trees.

St Anna – conservation at a landscape scale

How to conserve a living oak landscape in the archipelago

As discussed earlier, there is a considerable amount of deciduous forest and open, flower-rich semi-natural grasslands with oak in the inner archipelago on the deeper soils. There are also areas of oak in the central archipelago especially on the larger islands. Together these areas constitute an oak landscape rich in species. The landscape is however, heavily fragmented and there is a need for conservation planning to ensure the survival of the species in the landscape in the long term. In the case study above from Händelö, the focus was on ensuring populations in a single site survive. The focus of this case study is how to conserve a living oak landscape in a broader setting.

Biodiversity of the oak landscape of St Anna archipelago, results of the WKH survey

A total of 882 ha of oak site with high conservation value were identified in surveys between 1995-2002. The areas were separated into four classes:

Class 1) Large areas with large (>1 m diameter) oaks and hollow oaks. Smaller stands of very large oaks and occasionally single giant oaks.

Class 2) Stands with oaks of at least 200 years old, occasionally single very large oaks

Class 3) Single 200 year old oaks or larger stands with oaks up to 150 years

Class 4) Stands dominated by 75-100 years old oaks, which may contain single 150-year-old trees. The stands contain oaks with the typical savannah-shape of open-grown trees.

As described above, the large number of national red-listed lichens and insects recorded show that the St Anna archipelago is a hot-spot for oak and pine species. An insect survey directed at old hollow oaks confirmed that the area has a high biodiversity (Ranius 1998). At least 16 red-listed species were found to be present, including the hermit beetle. Beetle species were surveyed by sieving wood mould from hollow oaks.

Identification of potential functioning systems of oak sites

The WKH survey identified valuable sites and they were classified according to their conservation value. The survey provides an excellent base for further conservation planning in the area. The value however, of a site in a fragmented landscape is not only related to the quality and area of the single site, but also how it is connected to other sites. Local population dynamics are affected by the populations in the neighbourhood through dispersing individuals. Species living in systems of interconnected local populations are referred to as living in metapopulations (Hanski and Gilpin 1991). In a metapopulation the local populations are not viable on their own, but as a whole system. Local extinction in a metapopulation may be "repaired" by immigration from a population nearby. Metapopulations exists in equilibrium between extinction and colonisation of local populations between the sites. If the extinction rate is too high compared to colonisation the whole metapopulation will become extinct. This can happen when areas become smaller and more isolated. Isolated sites have a higher probability of containing no species. The same is true for small sites because they can only support small populations that are more prone to extinction. Generally, large and non-isolated sites are occupied and small and/or isolated sites are unoccupied (Thomas et al. 1992; Bergman and Landin 2001). The definition of which sites in a fragmented landscape are part of a metapopulation must be described with regard to the dispersal ability of the studied species.

Based on the data from one species, the hermit beetle, oak sites less than 200 m apart were classified as parts of a metapopulation system. A total of 105 systems consisting of 1-17 sites were identified (Fig 15, 16). The system on Djursö with 210 ha of high quality oak sites is particularly outstanding. This is the only system larger than the minimum viable area of 57 ha calculated in the Händelö example above. There are four other systems larger than 30 ha and another four larger than 20 ha. Compared with other modern landscapes these figures are impressive, however none of the systems are as large as the minimum area calculated for the most sensitive beetle species, 954 ha.

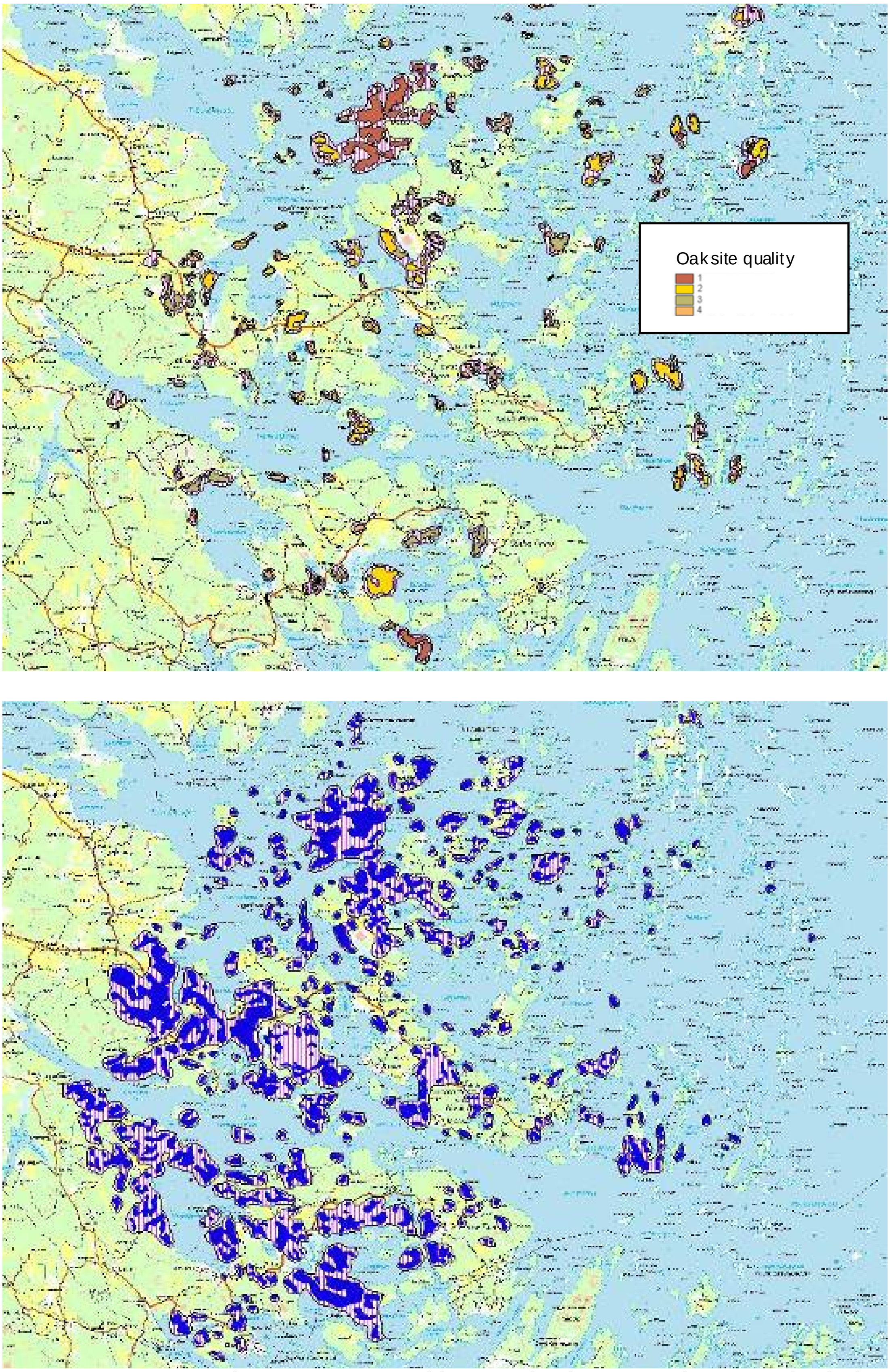


Figure 15. Current oak systems (top) and historical oak systems (bottom). The decline from 19th century to today has been severe.

Different groups of species require different landscape configurations. Insects use the landscape at a small scale and many of the hollow oak specialists are thought to have limited dispersal ability. One oak specialist among the birds is the middle spotted woodpecker (*Dendrocopus medius*). It has a much better dispersal ability (kilometres) than the hermit beetle (max 190 m in studies) but it requires larger areas of habitat. It is has been extinct in Sweden since 1982. Studies of the now extinct population revealed that they needed territories of around 25 ha including at least 10 ha of oak woodland (Pettersson 1984). The distribution was clearly confined to large areas of oak woodland. In a 500 ha site, there needs to be at least 125 ha of oak woodland in order for the middle spotted woodpecker to occur regularly. In the study area there are around 8 potential territories in the current landscape compared with at least 40 territories in the past. The study area is obviously too small for landscape planning with regard to the middle spotted woodpecker.

A comparison between the hermit beetle and the middle spotted woodpecker clearly identifies the differences and the similarities. A population of 250 pairs of the middle spotted woodpecker requires around 6 250 ha with a minimum of 2 500 ha of oak woodland compared with 57 ha of high quality oak woodland with hollow oaks for the hermit beetle. Both species however, are favoured by large reasonably well-connected sites, even if the middle spotted woodpecker requires much larger areas.

Identification of historical potential functional systems of oak sites

Sweden has an almost unique number of old detailed maps. Mapping had begun by the 17th century. In this example, maps from the 19th century were used because they cover the whole study area. The maps show the distribution of deciduous forest with symbols and these have been used in the interpretation of the maps. One weakness with the interpretation is that the symbols do not distinguish between different deciduous trees and oaks cannot be differentiated. Due to the fact that the oak had a special position in the landscape (see “The history of the oak in Sweden”) most of the areas indicated as deciduous woodland probably contained oaks, and likely also old hollow oaks.

The oak sites identified in the WKH survey are not totally comparable with the historical material but the historical maps probably give a rather good picture of the situation. There is data on oaks from 1749 and St Anna together with an adjacent area (Skällsvik) had 11 283 large oaks of which 4 887 were “hollow, top damaged or stem damaged”. This large number highlights that the historical area of deciduous tree cover was large and often contained old oaks. The estimated historical area was 2 534 ha compared to the existing 882 ha. Eight systems of oak were larger than the minimum viable area of 57 ha calculated in the Händelö example compared with only one today. A total of 16 systems (four today) were larger than 30 ha.

The decline of areas with oak has obviously been severe until now. Only 35% remains of the historical area. It is known that a decline in habitat amount and increasing isolation will result in species loss. The response by the species may be delayed however, due to habitat characteristics. This is especially true for areas of oak. Species can live for decades in small sites which contain old oaks but when the trees die all species become extinct. A decline in habitat area may cause an extinction debt, where more species live in a site than the site can sustain in the long term (Tilman et al. 1994; Hanski and Ovaskainen 2002). The extinction debt is paid either by extinction of species or restoration of habitat to increase the habitat area.

Hedin (2003) suggests that the transition time (the time it takes for a metapopulation to reach a new equilibrium after habitat loss) for extinction for the hermit beetle is 50-150 years. The loss in St Anna has occurred some time during the last 130 years. It is therefore of critical importance to increase the number of hollow oaks in the coming years to prevent extinctions.

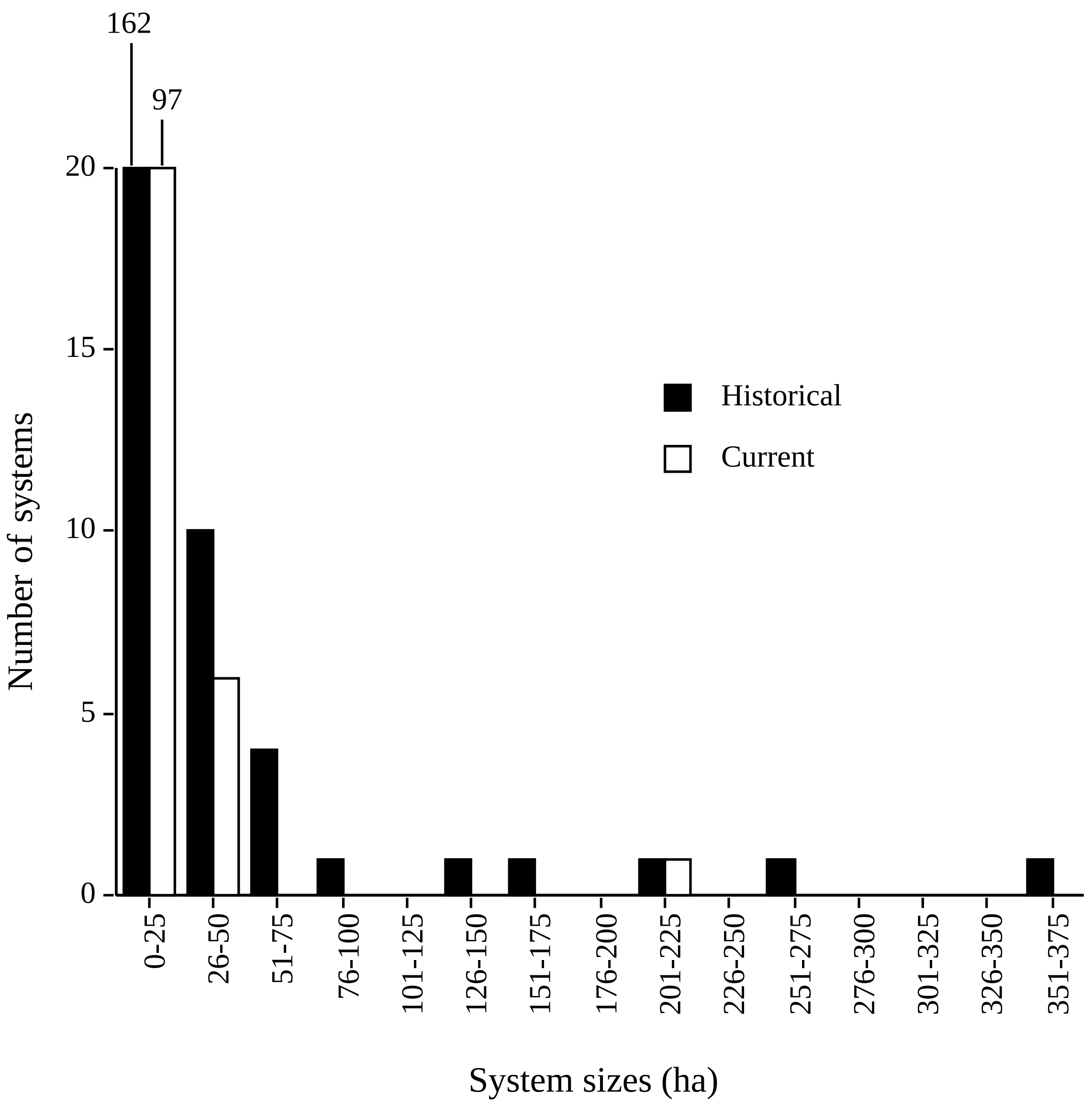


Figure 16. Size distribution of functional oak woodland systems (areas <200 m from each other) today and in the past.

A re-classification of the value of oak sites

The classification during the WKH survey classified the value of single sites. The value of a site is however, also related to its position in the landscape and to its position in the historical landscape. A simple equation was used to give each site a new value according to its landscape position and its quality. The equation is:

$$\log(K \cdot A_b) + \log A_n + \frac{\log A_h}{2}$$

The quality (K) was given a three-graded scale, class 3-4=1, class 2=2, class 1=3. The logarithmic site area A_b, and logarithmic total system area A_n were used, because the species richness in a site is generally related to logarithmic area (MacArthur and Wilson 1967). The historical total system area A_h was given half the importance of the area of the current system.

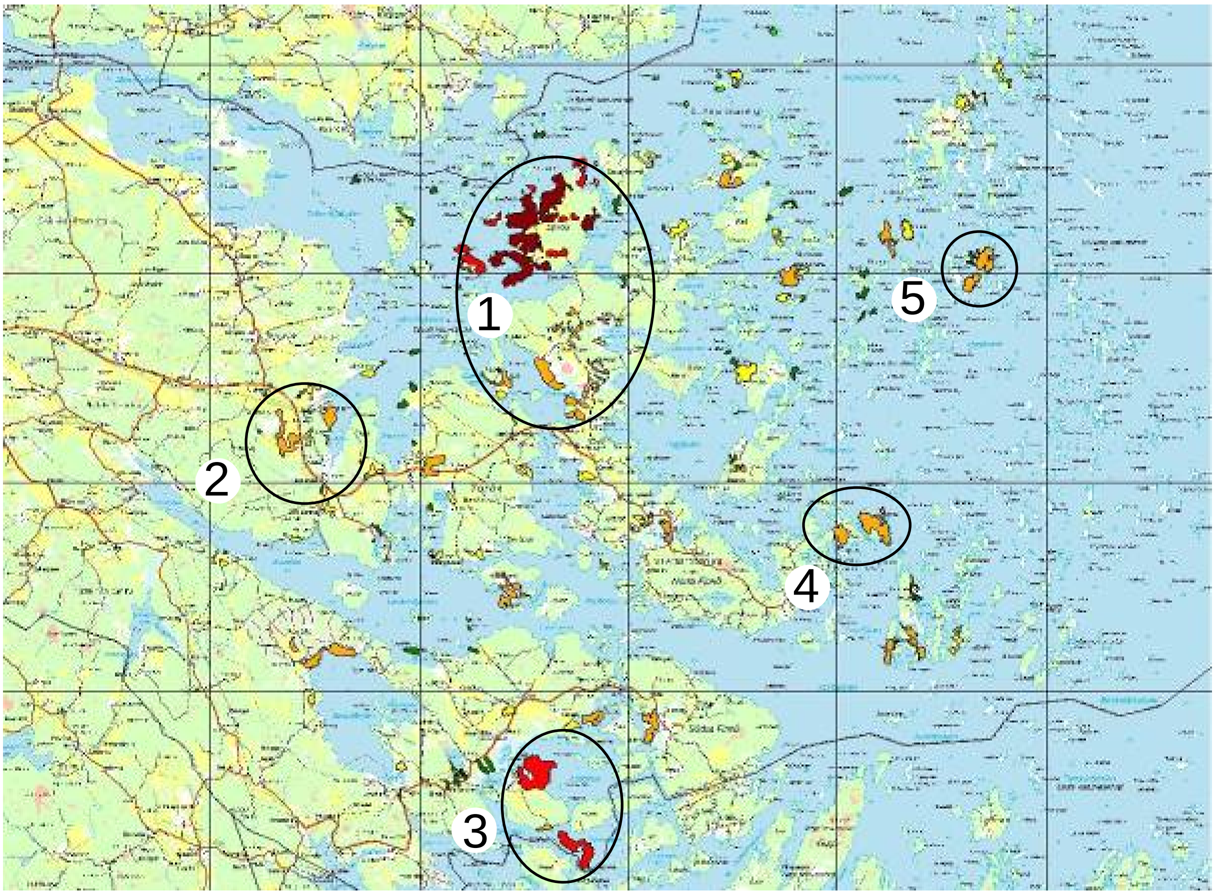
Identification of areas of high priority for conservation and restoration

The results of the re-classification and the other data regarding location (current and historical) and the quality of the oak sites, provides a good base for landscape conservation planning. These combined data clearly point out important areas for management and restoration. The first priority is to graze the ungrazed areas among the oak sites and then try to restore areas in between to connect up systems or sites.

A high priority area is Djursö (210 ha system today), with an even larger historical area (360 ha). Historically, several existing systems (Djursö, Yxnö) were connected and by restoring areas in between it may be possible to re-connect them (Fig 17). Other important areas include the system of sites around Herrborum, consisting of several historically connected systems. In the south it may be possible to re-connect the top quality areas of Ängelholm and Vrångö, which were historically connected to one other.

Interestingly, there are also several valuable oak systems in the central archipelago where it is important to maintain the grazing animals (for example Inre and Yttre Olsön and Skogsböte).

In restoring these areas back to oak pastures, larger and therefore more viable systems can be created. A survey of younger oaks is in progress that will give a good base for the restoration work in the landscape (Fig 18). If it is not possible to create oak pastures, it may be possible to link oak sites through the managed timber forests. Oaks may be actively favoured during forest practices (Fig 19). In many cases single large oaks exist inside timber forests as a remnant of the past. In some areas, oak timber production should be encouraged. There are also often oaks along the edges of open fields that may be “released” from coniferous trees. Together, these activities can create large, viable oak ecosystems in the long term.



.

Figure 17. Classification of oak areas based on both site quality and the surrounding landscape. Both current and historical distributions are considered in the classification. Examples of systems of sites with high conservation value: 1 = Djursö-Yxnö, 2 = Herrborum, 3 = Ängelholm-Vrångö, 4 = Inre and Yttre Olsön, 5 = Skogsböte.

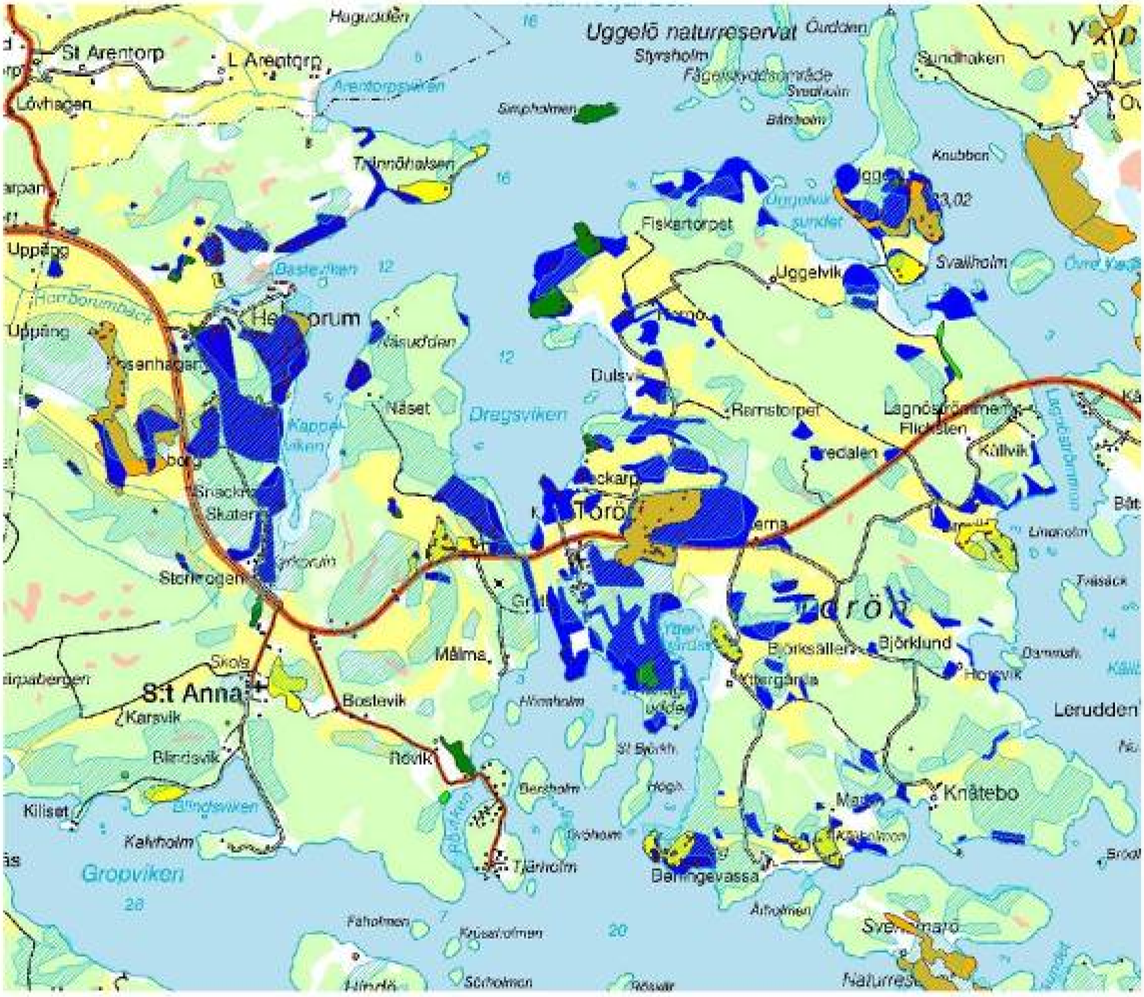


Figure 18. A combination of historical and current knowledge of the distribution of areas of oak is an excellent base for conservation measures. The blue areas show areas containing young oaks and the other colours, areas with old oaks of high but different quality. The shaded blue areas show historical deciduous forests. Together these data can be used to identify high priority areas.

Figure 19. An old oak in a coniferous plantation that has been saved for the future by cutting the Norway spruce growing around it. Oaks may be actively favoured like this during forestry practices. Photo: Jens Johannesson.

Grazing in semi-natural grasslands with oak, a prerequisite for a living oak landscape
The majority of the species in the oak sites and the oak itself is favoured by grazing (Fig 20, 21). When the grazing ceases and the woodlands become closed forest, the oak has problems regenerating (Bakker et al. 2004).

Today, only 38% of the oak sites are grazed. Since the 1950s the traditional management has decreased in this area as well as the in the rest of Sweden. The number of available grazing animals is limited and therefore careful planning is required and new ideas about how to ensure the majority of the oak sites are managed. Many of the oak sites in the archipelago are on dry soils that may only need grazing every second year, but this would require adjustments to the rules for payment to farmers from the EU that currently relate to annual grazing.

A complementary approach would be a central administration for the mediation of grazing animals so that they are directed to the right areas of high nature conservation value. This kind of activity already exists at the County Administration Board in Östergötland.

Figure 20. Grazing in the archipelago is a prerequisite for a living and rich oak landscape. Photo: Karl-Olof Bergman.

Figure 21. Argynnis paphia, a butterfly that is rare in many other countries but thriving in oak woodlands in the archipelago. Photo: Karl-Olof Bergman.

St Anna – conservation at a landscape scale
How to conserve a living pine forest in the archipelago

One of the most important trees in the Swedish coastal zones is scots pine, *Pinus sylvestris*. Over large parts of Sweden, very little of the pine forest is unaffected by forestry. The special conditions in the Swedish archipelago however, have resulted in more pine forest in a natural state (Fig 22, 23). An average of 10% of the forests in the archipelago was WKH and some islands had as much as 50 % (Regional Forestry Board, Östra Götaland 2003). The intensive forest management in most other pine forests (average 1% WKHs) has resulted in a reduced amount of coarse woody debris (CWD). This reduction has been documented as having a considerable impact on species diversity in the forests. Beetles, which are one of the largest groups of saproxylic insects in Sweden, are to a great extent affected by a decreasing amount of CWD. Pine forest is an important habitat because of the large number of saproxylic species that depend on *Pinus sylvestris*.

In order to understand the patterns of biodiversity, a study of saproxylic beetles was carried out in the archipelago. It is important to understand these patterns for effective conservation. Ten high quality study sites (Fig 24) were chosen with data from the Natura 2000 and the Woodland Key Habitat surveys. Eight window traps were placed on logs of *Pinus sylvestris* at each research site. The survey period stretched from the 23rd of April to the 5th of September and the traps were emptied four times during this period, once a month. All beetle species were identified to species level and the naming followed Catalogus Coleopterorum Sueciae (Lundberg 1995).

The aim of the study was to investigate the patterns of species richness of saproxylic beetles in the archipelago. Important issues to address were:
Is it better to concentrate on the protected areas or is it better to distribute the areas over the whole archipelago? How important are Woodland Key Habitats for diversity? How does the individual quality of logs and density of logs at the sites affect the diversity of beetles?

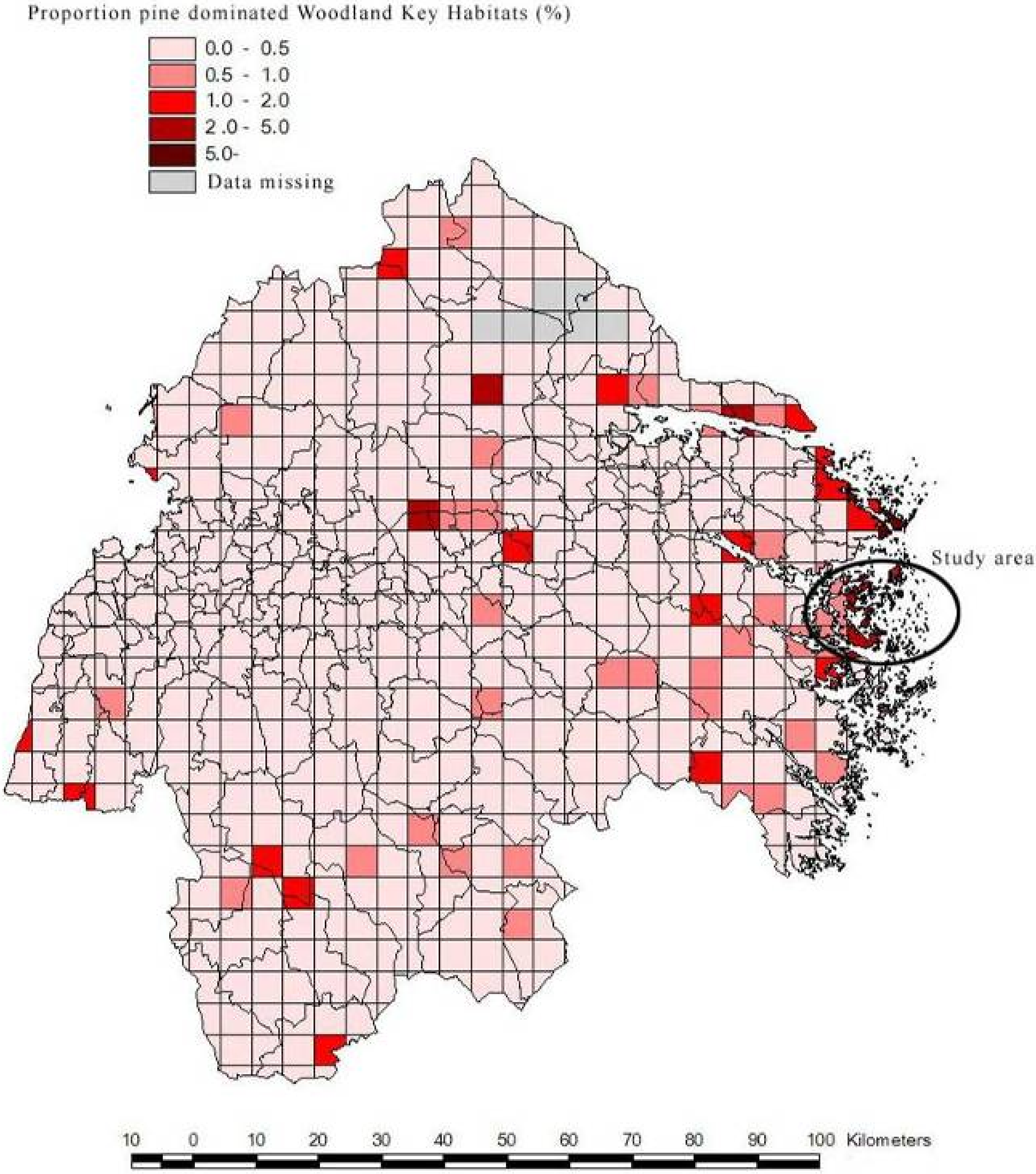


Figure 22. The proportion of pine dominated Woodland Key Habitats in relation to the total amount of forest in the county of Östergötland (5x5 km squares). The study area, the archipelago of St Anna is indicated on the map.

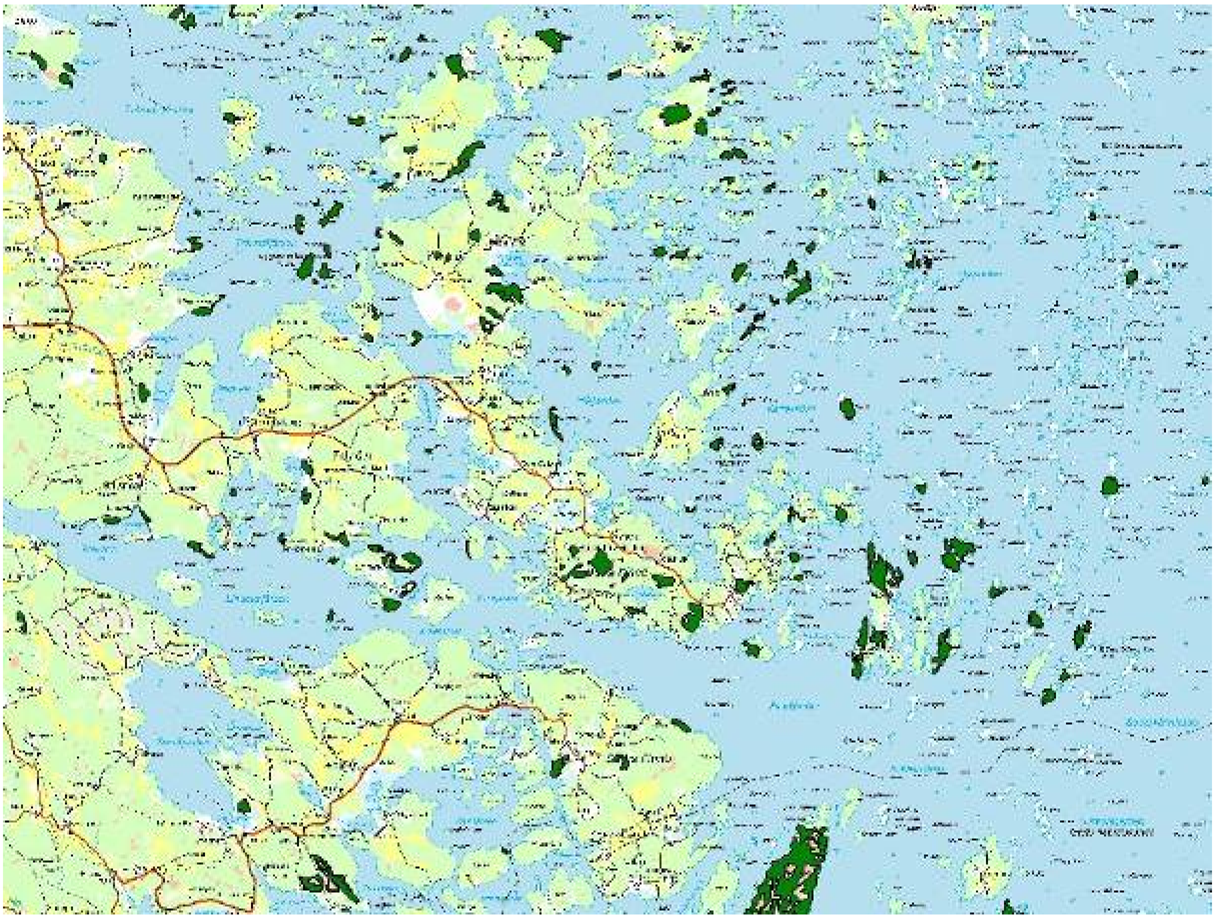


Figure 23. Distribution of valuable pine forests in the study area. The special conditions in the Swedish archipelago have resulted in more of the pine forest being in a natural state than in many other forests in Sweden. An average of 10% of the forests in the archipelago are Woodland Key Habitats, on some islands there was as much as 50 %.

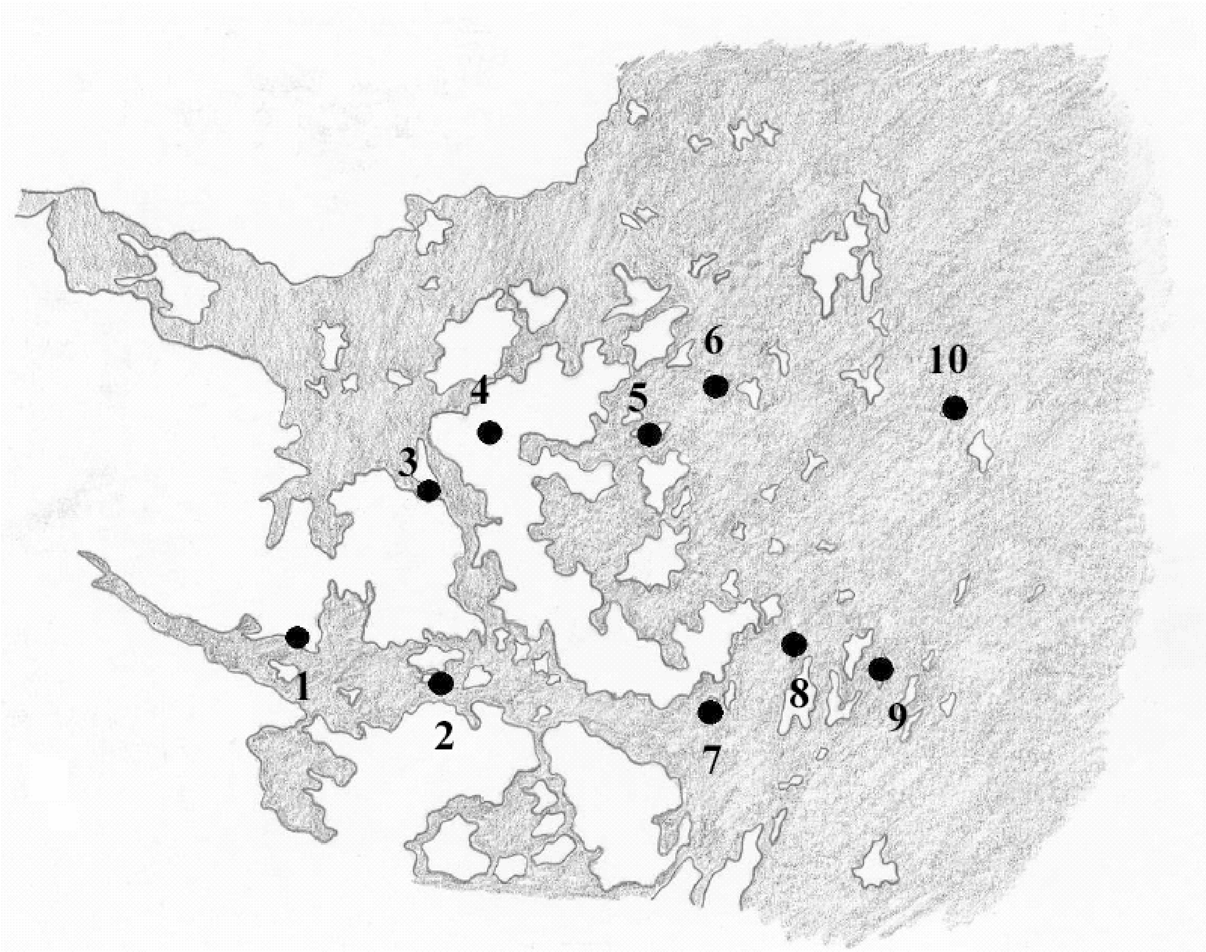


Figure 24. Map of the ten research sites in the archipelago of St Anna, Östergötland, Sweden. Illustration Emma Larsson.

Ecology of scots pine

The scots pine is a tree which occurs widely all over Sweden. Due to the fact that the species is tolerant of extreme conditions like dry well-drained infertile soils or wet peat soils most pine forest occur in these habitats. The thin soils on the rocky islands in the archipelago create forests dominated by scots pine. The scots pine is fire-adapted and historically, dry pine forests burnt regularly, with intervals of as much as 20 years (Niklasson and Nilsson 2005). The situation is totally different today when forest fires are extinguished as soon as they occur. In many reserves norway spruce has become the dominant tree as a result of the lack of fires instead of the original scots pine.

The scots pine may live as to be as much as 700 years old, but in contrast to the oak, most of the species living on it are is dependent on the pine once it has died. After death there is a succession of invertebrate species and processes that occur (Siitonen 2001). The first stage occurs only one to two years after the death of the tree. The tree is then colonised by phloem-feeders. The second stage lasts 5-10 years when the remainder of the phloem and mycelium growing under the bark is consumed. The third stage begins when the bark has fallen off and most of the species then eat polypore fruiting bodies or fungoid wood. This stage lasts for several decades. Many threatened species occur during this stage (Ehnström and Waldén 1986). The fourth stage begins when the whole tree starts to fall apart. Only a few wood-feeding insects occur due to the low nutrient content in the wood. Later in this stage litter-dwelling invertebrates use the log until it disappears.

Even although the pine ecology is different from the oak ecology, the general conservation thinking for long term survival of saproxylic beetles is the same:

- there are successional changes in substrate
- there is a need for a continuous supply of substrate
- the substrate has to be produced within reasonable distances from similar substrates
- the substrates need to exist in a certain density

Patterns of diversity

The study resulted in an impressive number of individuals and species. In total, 11840 individuals of 520 beetle species were caught in the study. Of these 196 (38%) species were saproxylic and associated with coniferous trees and 13 of those species (153 individuals) were red-listed in Sweden (Fig 25).

There was a clear pattern in species richness among the ten islands. The number of species increased with increasing amount of coniferous forest in the area (radius 1000 m from the site). The pattern was most pronounced for red-listed species (Fig 26.). The most isolated islands located far away from other coniferous forests and from the mainland had the lowest number of species. Somewhat surprisingly, the quality in terms of density of coarse woody debris increased closer to the mainland and correlated with the amount of coniferous forests in the area (Table 4.). You would expect that forestry management would be more intensive close to the mainland for logistical reasons. Fortunately, many of the pine forests close to the mainland are still of good quality. It may also be that the islands closer to the mainland are somewhat more productive which results in a greater production of logs. Another surprising result was that the species richness of beetles was not correlated with how well connected the site was to high quality Woodland Key Habitats in the surroundings but better correlated with the amount of coniferous forest in the surroundings regardless of quality. The interpretation of this result is that most of the forests in the archipelago are generally of high quality, almost reaching the level of Woodland Key Habitat and therefore contributing to the overall species richness.

The importance for beetle species of the quality of single logs was also studied. The amount of sun exposure was the environmental variable that was most important to the community of beetle species. The results showed that there was one group of species positively correlated with sun exposure and another large group correlated with shade. In addition, a large log diameter was important for several of the red-listed beetle species.

Figure 25. Buprestis octoguttata, *one of the threatened beetles dependent on dead wood found in the study. Photo: Karl-Olof Bergman.*

Implications for conservation
These results have important implications for the conservation of coastal pine woodlands. Firstly, this study indicates that the priority in protecting pine forest should be concentrated on the islands close to other areas with coniferous forest and close to the mainland and that large areas should be protected and created rather than small scattered sites. The results also showed that all of the coniferous forests contributed to the species richness, not just the top quality sites, implying that management of all of the forests is important for the biodiversity in the area.

Forest management practices that maintain biodiversity should be encouraged over the whole area, which may also decrease the need for strictly protected areas. It is important to leave large pines and logs regularly distributed over the area that are allowed to develop naturally when logging.

At the tree level, the results indicate that it is important to have sites with a varied amount of sun exposure when conserving a rich beetle fauna and to conserve sites with a high density of large logs.

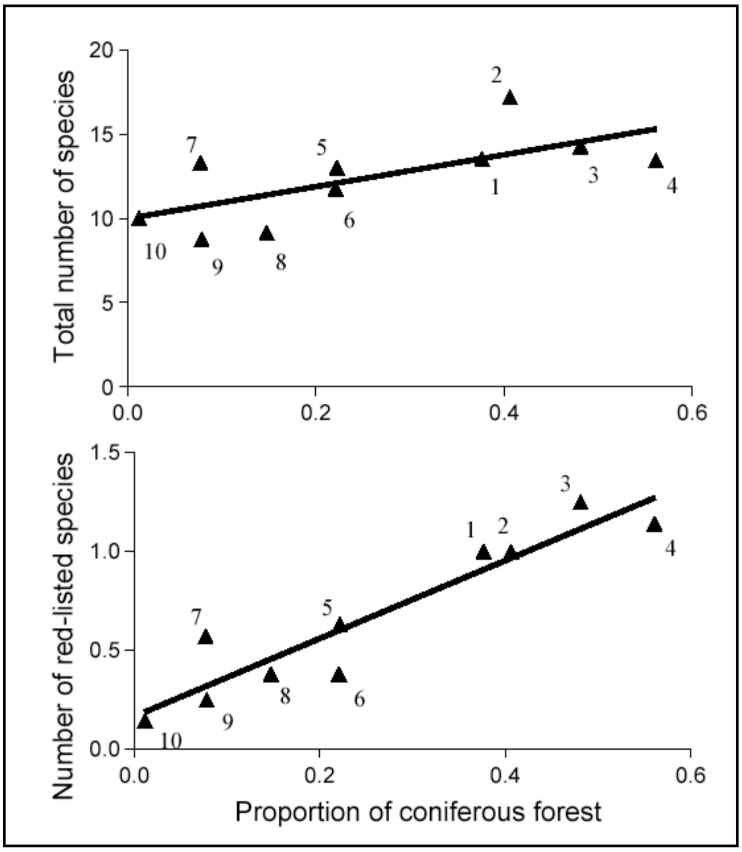


Figure 26. The relationship between the proportion of coniferous forest in the surrounding area and the number of saproxylic beetles species, depending on logs of Pinus sylvestris in the archipelago of St Anna. From Eklund and Larsson, 2004.

Table 4. The correlation matrix shows the relationship between environmental variables. Numbers in bold show relationships with significant correlation (p<0.05). The abbreviations in the matrix are;1) Number of species, 2) Number of red-listed species, 3) Number of logs, 4) Density of logs, 5) Number of snags, 6) Density of snags, 7) Connectivity, 8) Site area, 9) Proportion of coniferous forest (radius 1000 m) and 10) Proportion of land (radius 1000 m). The correlation matrix has not been compensated for multiple tests. From Eklund and Larsson, 2004

	# spec	Red-list	# logs	D logs	# snags	D snags	Con	Area	Prop. forest	Prop. land
# spec	1									
Red-list	**0.796**	1								
# logs	0.086	0.486	1							
D logs	0.267	**0.699**	**0.826**	1						
# snags	0.107	0.354	**0.633**	**0.644**	1					
D snags	0.303	0.524	**0.336**	**0.681**	**0.834**	1				
Con	-0.161	-0.021	-0.016	-0.004	-0.034	-0.022	1			
Area	-0.168	-0.136	0.287	-0.207	-0.021	-0.440	0.011	1		
Prop. forest	**0.690**	**0.936**	0.528	**0.745**	0.285	0.445	0.134	-0.264	1	
Prop. land	0.575	**0.887**	0.543	**0.707**	0.157	0.292	0.155	-0.195	**0.964**	1

Acknowledgements
I wish to thank Kenneth Claesson, Jens Johannesson, Hans Liman, Eddie Sturesson and Bo Thor for their valuable help during the work with this report.

References

Bakker, E. S., Olff, H., Vandenberghe, C., de Maeyer, K., Smit, R., Gleichman, J. M. & Vera, F. M. V. 2004. Ecological anachronisms in the recruitment of temperate light-demanding tree species in wooded pastures. - Journal of Applied Ecology 41: 571-582.

Bergman, K.-O. & Landin, J. 2001. Distribution of occupied and vacant sites and migration of *Lopinga achine* (Nymphalidae: Satyrinae) in a fragmented landscape. - Biological Conservation 102: 183-190.

European Communities. 2002. The path to sustainability. Luxenbourg, Environmental research in the European area. Report EUR 19441.

Ehnström, B. & Waldén, H. W. 1986. Faunavård i skogsbruket. Den lägre faunan. - Skogsstyrelsen.
Forman, R. T. T. & Alexander, L. E. 1998. Roads and their major ecological effect. - Annual Review of Ecology and Systematics 29: 207-231.
Gustafsson, L.-Å. (1983). Botanisk inventering av Östergötlands skärgård, Länsstyrelsen i Östergötlands län.
Gärdenfors, U. & Baranowski, R. 1992. Skalbaggar anpassade till öppna respektive slutna ädellövskogar föredrar olika trädslag. - Entomologisk Tidskrift 113: 1-11.
Hannah, L., Carr, J. L. & Lankerani, A. 1995. Human disturbance and natural habitat: a biome level analysis of a global dataset. - Biodiversity & Conservation 4: 128-155.
Hanski, I. & Gilpin, M. 1991. Metapopulation dynamics: brief history and conceptual domain. - Biological Journal of Linnean Society 42: 3-16.
Hanski, I. & Ovaskainen, O. 2002. Extinction debt at extinction threshold. - Conservation Biology 16: 666-673.
Hedin, J. 2003. Metapopulation ecology of Osmoderma eremita - dispersal, habitat quality and habitat history. Department of Ecology. Lund, Lund University: 138.
Hultengren, S., Pleijel, H. & Holmer, M. 1997. Ekjättar - historia, naturvärden och vård. - Naturcentrum AB.
Jansson, N. 1996. Vedskalbaggsfaunan i tre ek-områden i Norrköping. Norrköping, Norrköpings kommun.
Jansson, N. 1998. Miljöövervakning av biotoper med gamla ekar i Östergötland, Länsstyrelsen i Östergötland.
Jansson, N. & Claesson, K. (2001). Grova och ihåliga ekar i Eklandskapet söder om Linköping i Östergötland, Länsstyrelsen i Östergötland.
Jones, W. 2002. EC habitats directive: favorable conservation status, Joint nature conservation committee.
Karlsson, J. (2003). Effects of isolation, matrix, area and tree qualities on beetles, Coleoptera, associated with hollow oaks, Linköping university. Department of biology.
Kuitunen, M., Viljanen, J., Rossi, E. & Stenroos, A. 2003. Impact of busy roads on breeding success in pied flycatcher *Ficedula hypoleuca*. - Environmental Management 31: 79-85.
Lindqvist, M. & Nyberg, H. 1989. Lavarna och luftmiljön. - Fältbiologerna.
Lindborg, R. and eriksson O. 2004. Historical landscape connectivity affects present plant species diversity. - Ecology 85: 1840-1845.
Lundberg, S. 1995. Catalogus coleopterorum Sueciae. - Naturhistoriska riksmuseet.
MacArthur, R. H. & Wilson, E. O. 1967. The theory of island biogeography. - Princeton University Press.
Mader, H. J. 1984. Animal habitat isolation by roads and agricultural fields. - Biological Conservation 29: 81-96.
McLean, I. F. G. & Speight, M. C. D. 1993. Saproxylic invertebrates - the European context. - In: Kirby, K. J. and Drake, C. M. (ed.), Dead wood matters: the ecology and conservation of saproxylic invertebrates in Britain. English Nature Science No. 7. English Nature, pp. 21-32.
Niklasson, M. & Nilsson, S. G. 2005. Skogsdynamik och arters bevarande. - Studentlitteratur.
Pettersson, B. 1984. Ecology of an isolated population of the middle spotted woodpecker, Dendrocopos medius (L.), in the extinction phase. Uppsala, Sveriges lantbruksuniversitet.
Ranius, T. (1998). Hålträdslevande skalbaggar på öar i S:t Anna, Östergötland. Lund.
Ranius, T. 2001. Constancy and asynchrony of *Osmoderma eremita* populations in tree hollows. - Oecologia 126: 208-215.
Ranius, T. 2002. Population ecology and conservation of beetles and pseudoscorpions living in hollow oaks in Sweden. - Animal Biodiversity and Conservation 25.1: 53-68.

Ranius, T., Antonsson, K., Jansson, J. & Johannesson, J. 2001. Inventering och skötsel av gamla ekar i Eklandskapet söder om Linköping. - Fauna och Flora 96: 97-107.

Ranius, T. & Hedin, J. 2001. Oecologia. - The dispersal rate of a beetle, *Osmoderma eremita*, living in tree hollows 126: 363-370.

Ranius, T. & Hedin, J. 2004. Hermit beetle (*Osmoderma eremita*) in a fragmented landscape. - In: Akcakaya, R. H., Burgman, M. A., Kindvall, O.et al (ed.), Species conservation and management. Oxford University Press, pp. 162-170.

Ranius, T. & Jansson, N. 2000. The influence of forest regrowth, original canopy cover and tree size on saproxylic beetles associated with old oaks. - Biological Conservation 95: 85-94.

Ranius, T. & Jansson, N. 2002. A comparison of three methods to survey saproxylic beetles in hollow oaks. - Biodiversity and Conservation 11: 1759-1771.

Ranius, T. & Nilsson, S. G. 1997. Habitat of *Osmoderma eremita* Scop. (Coleoptera: Scarabaediae), a beetle living in hollow trees. - Journal of Insect Conservation 1: 193-204.

Ranius, T. & Wilander, P. 2000. Occurrence of *Larca lata* H.J. Hansen (Pseudoscorpionida: Garypidae) and *Allochernes wideri* C. L. Koch (Pseudoscorpionida: Chernetidae) in tree hollows in relation to habitat quality and density. - Journal of Insect Conservation 4: 23-31.

Reijnen, R., Foppen, R., Ter Braak, C. & Thissen, J. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. - Journal of Applied Ecology 32: 187-202.

Saccheri, I., Kuussaari, M., Kankare, M., Vikman, P., Fortelius, W. & Hanski, I. 1998. Inbreeding and extinction in a butterfly metapopulation. - Nature 392: 491-494.

Sarlöv Herlin, I. L. & Fry, G. L. A. 2000. Dispersal of woody plants n forest edges and hedgerows in a Southern Swedish agricultural area: the role of site and landscape structure. - Landscape Ecology 15: 229-242.

Siitonen, J. 2001. Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forests as an example. - Ecological Bulletins 49: 11-41.

Speight, M. C. D. 1989. Saproxylic invertebrates and their conservation. - Council of Europe.

Thomas, C. D. & Hanski, I. 1997. Butterfly metapopulations. - In: Hanski, I. and Gilpin, M. E. (ed.), Metapopulation biology: ecology, genetics and evolution. Academic Press, pp. 359-386.

Thomas, C. D., Thomas, J. A. & Warren, M. S. 1992. Distribution of occupied and vacant butterfly habitats in fragmented landscapes. - Oecologia 92: 563-567.

Thor, B. & Gad Burgman, N., Eds. 2004. Integrated Coastal Zone Management in Forests by the Baltic Sea. Managing the Baltic Sea, Coastline Reports 2.

Tilman, D., May, R. M., Lehman, C. L. & Nowak, M. A. 1994. Habitat destruction and the extinction debt. - Nature 371: 65-66.

Turin, H. & den Boer, P. J. 1988. Change in the distribution of carabid beetles in the Netherlands since 1880. - In: den Boer, P. J. (ed.), Carabid beetles: their adaptations and dynamics. Kluwer, pp. 489-495.

Zhang, Q.-H. (2001). Olfactory recognition and behavioural avoidance of angiosperm non-host volatiles by conifer bark beetles. Swedish university of agricultural sciences. Alnarp, Swedish university of agricultural sciences.