Climate change and forestry in Sweden – a literature review

Kungl. Skogs- och
Lantbruksakademiens
Årg. 143 • Nr 18 • År 2004

TIDSKRIFT

Ansvarig utgivare: Akademiens sekreterare och VD: Bruno Nilsson
Redaktör: Gunilla Agerlid

Climate change and forestry in Sweden – a literature review

Report from Climate and the Forest Committee

KUNGL. SKOGS- OCH LANTBRUKSAKADEMIEN
STIFTAD 1811

Rapporten sammanställd under medverkan av
Skog. dr Johan Sonesson

Preface

This is a report from the "Climate and the Forest Committee", appointed by the Royal Swedish Academy of Agriculture and Forestry (KSLA) to promote the interest of climate change issues among scientists and forest managers. The committee identified a need for a comprehensive literature review as a starting point for their work, culminating in this report.

Members of the committee are Kaj Rosén (chairman), Johan Sonesson (secretary), Johan Bergh, Christer Björkman, Kristina Blennow, Hillevi Eriksson, Sune Linder, Markku Rummukainen and Jan Stenlid, all of whom contributed to this report, Johan Sonesson acting as editor.

Summary

The scope of the study was to review the relevant literature regarding the impact of climate change on forestry in Sweden, to synthesise current knowledge, to draw conclusions on likely effects of climate change and to identify areas in which further research and knowledge are required.We have limited the study to the effects over short and medium time spans (20–100 years), focussing on direct climatic effects on the trees, and indirect effects mediated by the climatic impact on soils, herbivores, insects, pests and diseases. We have largely ignored other aspects of forests and climate change.

This literature review has revealed major deficiencies in our knowledge about the effects that expected climate change will have on the forest ecosystems. For instance, the potential effects of climatic changes on the structure and processes of forest ecosystems are even less certain than the likely nature and magnitude of the climatic changes *per se*.

However, the most likely effects of climate change can be predicted. They generally include an increase in potential biomass production, possibilities to grow new species commercially and increased risk of several kinds of damage. Climate change appears to offer new opportunities to forestry, while increasing the risk of calamities. This calls for radical approaches to both forest- and risk-management.

The reviewed literature contains indications that a better understanding of the links between climate, the forest and forestry is required. However, the study also identified three major obstacles that need to be overcome in order to improve our understanding of the issues, risks and possibilities associated with the potential impact of continued climate change on forests and forestry:

- Studies undertaken so far have generally addressed some specific aspect of the overall forestry/forest system, instead of adopting a more integrated approach in which the system as a whole and various feedback mechanisms are considered.
- The studies published so far differ in their choices of climate change scenarios. Thus, the findings refer to different shifts in temperatures, precipitation and other climate variables, making it difficult to collate and integrate the findings.
- The transience of the anticipated climate changes have not been included in the studies, as they typically refer to impacts under a specific, static, new climatic regime. However, instead of switching instantaneously to a new climatic regime sometime in the future, the forest and forestry will

probably face continuous, ongoing changes in climate, implying that conditions will constantly change within a typical tree-crop rotation, and from one rotation to the next.

Future research on the effects of climate change on forestry and forest ecosystems has to take account of a broad spectrum of scientific fields, but a multidisciplinary scientific approach will probably be essential.

Introduction

Interest in the effects of future climate changes is increasing. Climate models, and thus predicted climate scenarios are becoming more regionally detailed, and are also improving in their representation of variability and extremes of different climatic parameters. Studies of the impact of climate change on ecosystems and human society are becoming successively more relevant and interesting.

During the last decade Sweden has experienced somewhat warmer annual mean temperatures in comparison with the rest of the 20:th century. In particular, the winters have been milder, typically with only temporary snow cover in southern Sweden. A number of notably extreme weather events have also occurred, including both occasional drought spells and heavy or persistent rains leading to flooding in various parts of the country. Public opinion and the media often hold these developments to be a sign of climate change. This belief has contributed to increased interest in the future effects of climate change. The question is simply: Will it be worse in the future?A few years ago, the Intergovernmental Panel of Climate Change, IPCC, summarised current knowledge on the future of the world forest ecosystems in terms of continued climate change during the 21:st century (Watson et al. 1997). They predicted that a substantial fraction (a global average of one third) of the existing forested area of the world is likely to undergo major changes in broad vegetation types, with the greatest changes occurring in high latitudes and the least in the tropics. In their regional outlook for Europe they stated that forest ecosystems might expand at northern latitudes into previous tundra and permafrost areas. The effect on wood production in the production forests of Europe is expected to be minor, or at least not threatening. Forests cover more than half the land area of Sweden. Forestry and the forest industry are of crucial importance to the Swedish economy. Forests also supply the Swedes with recreational facilities and commodities, such as game, berries and fuel wood. Trees are long-lived and forestry is a long-term business: rotations in Swedish forestry are normally between 60 and 100 years. Trees that are young today are most likely to live the later part of their lives in a different climate from the present. This makes the assessment of possible impacts of climate change very important, not only for the forestry sector, but also to for Swedish society in general. Furthermore, irrespective of whether or not the climate will in fact change, the current debate on climate change has already affected management of the Swedish forests. Eleven percent of southern Swedish non-industrial private forest owners surveyed in 1999 claimed to have changed their forest management practices because of the possibility of climatic changes (Blennow and Sallnäs, 2002).

To promote the awareness of climate change issues among scientists and forest managers, the Royal Swedish Academy of Agriculture and Forestry (KSLA) has appointed a “Climate and the Forest Committee”. The committee identified a need for a comprehensive literature review as a starting point for their work, culminating in this report, funded by the Royal Swedish Academy of Agriculture and Forestry (KSLA) and the National Board of Forestry (SKS). The Forestry Research Institute of Sweden (Skogforsk), the Swedish University of Agricultural Sciences (SLU) and the Swedish Meteorological and Hydrological Institute (SMHI) have contributed in kind. The scope of the study is to review the relevant literature regarding the impact of climate change on forestry in Sweden, to synthesise current knowledge, to draw conclusions on likely effects of climate change and to identify areas in which further research and knowledge are required.We have limited the study to the effects over short and medium time spans (20-100 years), focussing on the direct effects of climate change on the trees, and indirect effects mediated by their effects on soil, herbivores, insects, pests and diseases. We have largely ignored other aspects of forests and climate change. The effects of forest damages and management on the efficiency of forests as carbon sinks have not been included in the study. Neither have the potential effects of climate change on biodiversity and conservation, the possible effects on logging and transportation operations, or the global effects on forestry and other forms of land use.

We have mainly focused on literature that has reported results and predictions for Scandinavia, but material concerned with other temperate and boreal forest regions has also been considered, where appropriate.

Climate scenarios

Future climate scenarios are based on predictions of how the world will develop in the future. Modelled trends in technology, the economy, population social inequalities and other relevant factors profoundly affects predicted anthropogenic emissions of greenhouse gases and other climate-forcing variables. Where appropriate, especially for carbon dioxide generated by the consumption of fossil fuels, the emission scenarios are entered into biogeochemical models, such as for the carbon cycle. This leads to estimates of changes in atmospheric composition, and radiative forcing driving the enhanced greenhouse effect. The climatic consequences are then studied through simulations with General Circulation Models (GCMs) at the global scale. In order to examine climate change on national and even finer scales, these are nowadays increasingly being followed by regionalisation using different techniques, such as regional climate modelling.In recent years, scenarios of both emissions and their climatic consequences have been steadily refined in attempts to reduce and understand remaining uncertainties (IPCC 2001). Uncertainties still remain, but the basic message that the world is warming is still valid. Indeed, this message has become better founded and more detailed thanks to recent research efforts. Further change appears to be inevitable during the 21st Century, and strategies to cope with it will have to be developed. Over an even longer time scale, the magnitude of climate change may still be limited, depending on what actions are taken and global socio-economic trends. Climate change during the 21st Century is sometimes referred to as global warming. The anticipated rise in global mean temperature is, indeed, a central issue. However, other changes in the climate system, not least those affecting the hydrological cycle and water availability, will also be very important. Climate change is also very likely to have different effects on different regions, and its consequences, on a regional basis, may be quite different than the global mean changes.The Swedish regional climate modelling programme, SWECLIM, (Rummukainen, 2003) developed in 1996–2003, enabled the climate of Northern Europe, and the ways in which it might be affected by global warming during the 21st Century to be adressed. Among other things, SWECLIM calculated a set of four detailed regional climate change scenarios (Räisänen et al. 2003, 2004) using an advanced regional climate modelling system. These calculations were based on two different emission scenarios (dubbed "A2" and "B2" by Nakićeović et al. 2000) and simulations by two different global climate models. In terms of global mean warming, the SWECLIM regional scenarios corresponded to a global mean temperature rise of 2.5–3.5°C.

The SWECLIM scenarios should be understood as plausible descriptions of how the regional climate might have changed by the future period of 2071–2100, compared to the recent period of 1961–90. They are not forecasts, as neither the underlying emission scenarios nor the global simulations include estimates of probabilities. Neither should they be taken as best-case or worst-case alternatives. Rather, they fall well within the range of recent global mean warming calculations derived from several global models and additional emission scenarios. For the period from 1990 to 2100, this range is 1.4–5.8°C (IPCC, 2001).

The regional scale changes are dependent on the global scale, but are more detailed

As is well-known on the global scale, the regional calculations indicate that the magnitude of climate change will depend on the cumulative amount of greenhouse gas emissions. If there are large emissions in the future, major changes can be expected, but if emissions are smaller, the magnitude of climate change will also be smaller. In the SWECLIM-scenarios, the results based on emission scenario A2 correspond to greater anthropogenic climate forcing than results based on emission scenario B2. The sign of the simulated change in most climatic variables is the same, regardless of which of these two emission scenarios is used. Generally, however, the magnitude of the calculated changes increases with the forcing, so the A2-results highlight better the expected nature and direction of the changes than the B2-results.

This is especially true for aspects that naturally tend to be highly variable, such as precipitation, and all kinds of extremes. It should be noted, however, that the A2-results are not more or less likely than the B2-results. Consequently, in assessing the possible consequences of climate change, a range of scenarios should be considered. However, the scenarios should be internally consistent (as the different climate variables are interconnected) and in the interest of combining and comparing impact assessment studies, there should be some common denominator as to the underlying climate change scenarios used.

Compared to global simulations, the regional models address in more detail such small-scale features as topography, land use, snow cover, lake ice and sea ice on the Baltic Sea. These are not well-represented in typical global models. They do, however, have important influences on the regional climate and the way it is projected to change due to global warming. Accounting for these factors requires regional studies. Some aspects of the regional scenarios by SWECLIM relevant to forests and forestry are summarised below. For clarity, only subsets of the available scenarios are mentioned, depending on the particular aspect being considered.

Temperature

In the SWECLIM scenarios, the annual mean temperatures in different parts of the Nordic region are projected to increase from 2 to 5°C, depending not only on the emission scenario, but also on the underlying global simulation. One example is depicted in Figure 1. The spatial pattern of change exhibits slight regional gradients from west to east and from south to north. In our region, temperature zones are predicted to move northwards (upwards) in the order of 150 km (100–150 m) for every 1°C rise in mean temperature. Winter temperatures increase more than summer temperatures in Northern Europe. Thus the winter warming is stronger and the summer

Figure 1. Annual mean temperature corresponding to 1961–90 mean conditions (left), calculated regional changes under the A2 emission scenario by 2071–2100 (middle) and the projected mean conditions in 2071–2100.

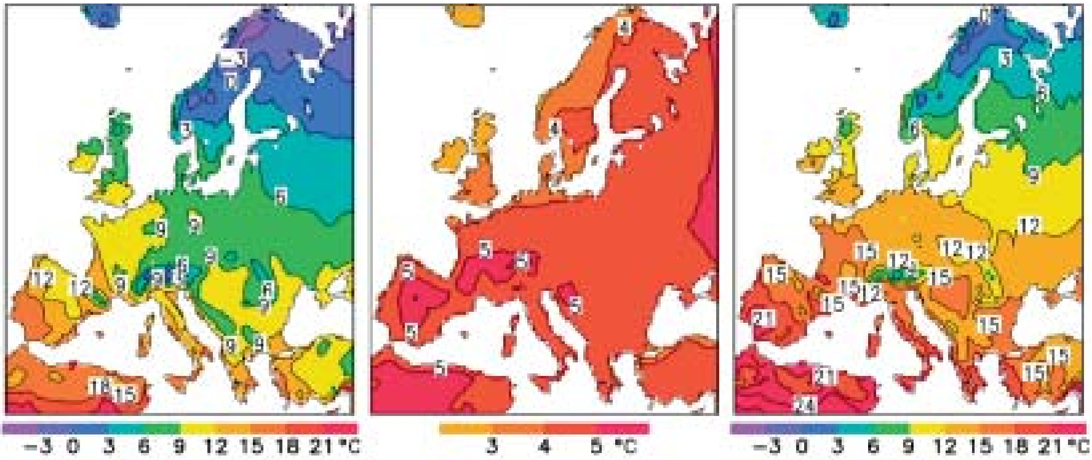
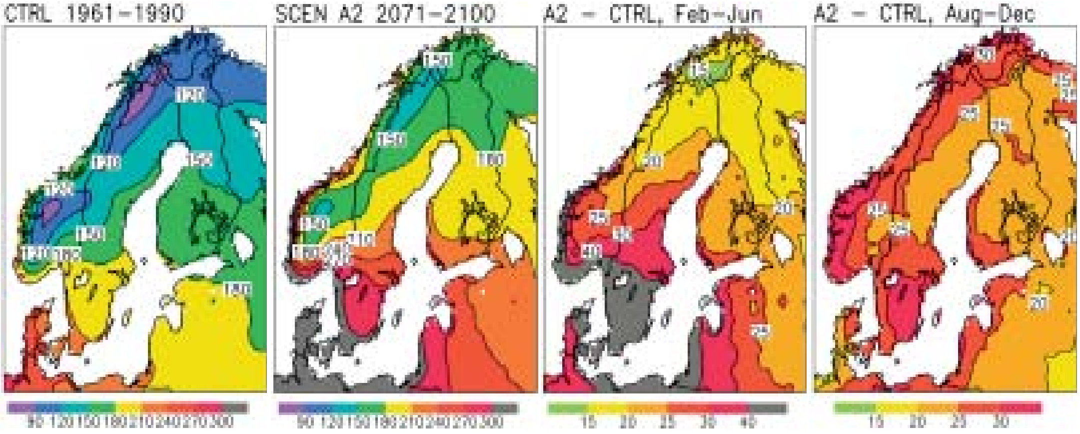


Figure 2. The calculated mean length (in days) of the vegetation period in the control simulation (far left panel; nominally 1961–90 conditions) and in one of the future scenarios (second left panel). The respective contributions of an earlier start and a later termination to the annual change in the length of the vegetation period are illustrated in the two panels to the right.


CTRL 1961–1990

SCEN A2 2071–2100

A2 – CTRL, Feb–Jun

A2 – CTRL, Aug–Dec

warming weaker, than the annual mean change. Extreme conditions will also change. The yearly minimum temperature might increase by 10–15°C, i.e. much more than the mean winter temperature. The yearly maximum temperature is calculated to increase by about as much as the mean summer temperature, i.e. 1–5°C. In Central and Southern Europe there is a similar large warming in minimum temperatures. However, compared to Northern Europe even the maximum temperatures change more than the summer mean temperature. In Central and Southern Europe the summertime warming might exceed the warming during wintertime.

One consequence of the projected changes in temperature is that the vegetation period will be prolonged (see Figure 2), starting a few weeks earlier and terminating a few weeks later compared to present conditions. This implies an increase in the cumulative amount of solar radiation available for photosynthesis during the vegetation period. Changes in cloudiness are significant for the same reason. These are projected to be of the order of a few percent in Sweden, with less cloud in southern Sweden but more in northern Sweden in the summer.

Precipitation

The mean annual precipitation is calculated to increase by 0–40%, with a higher increase in northern than in southern Sweden. Here, seasonal variations in the calculated change are even more striking than for temperature (Figure 3). Precipitation increases in autumn, winter and spring in the whole country. Some of the precipitation increase arises from an increase in the number of days with precipitation, but the amounts involved also increase. In the summer, on the other hand, the main feature is the decrease in precipitation by 0–40% in southern Sweden. There is also an increase in precipitation intensity in the summer, despite the reduction in the summer season total.

Water balance / water resources

Changes in precipitation inevitably affect the amount of water available at the earth's surface. However, temperature also plays a role. It dictates whether precipitation is temporarily stored as snow cover or finds its way directly to the soil and further to ground water and runoff. Temperature also affects the amount of available soil moisture by controlling evaporation, and transpiration, via physical and biological effects. Increasing temperature increases evaporation, even if it has no further effect, and thus the net effect of climatic change on the simulated water balance (Figure 4) is not dictated by precipitation changes alone.

Soil moisture

Annual mean soil moisture is calculated to decrease in most of the country except the northernmost parts, mainly due to reduc-

Figure 3. Regionally simulated seasonal precipitation changes by 2071–2100 in the winter (panels to the left) and summer (panels to the right) based on two different global models and the A2 emission scenario. The changes are in percentages compared to simulated 1961–90 mean conditions. The difference in the predictions for the Norwegian west coast in the winter are to a large part attributable to the very different regional circulation changes described by global simulations. The response of regional circulation systems in the North Atlantic region to global warming is a major area of uncertainty in climate science.

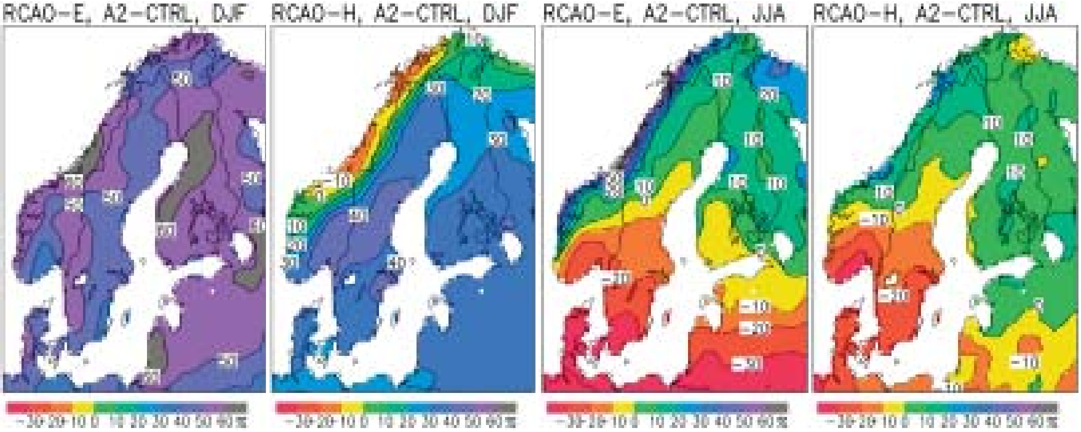
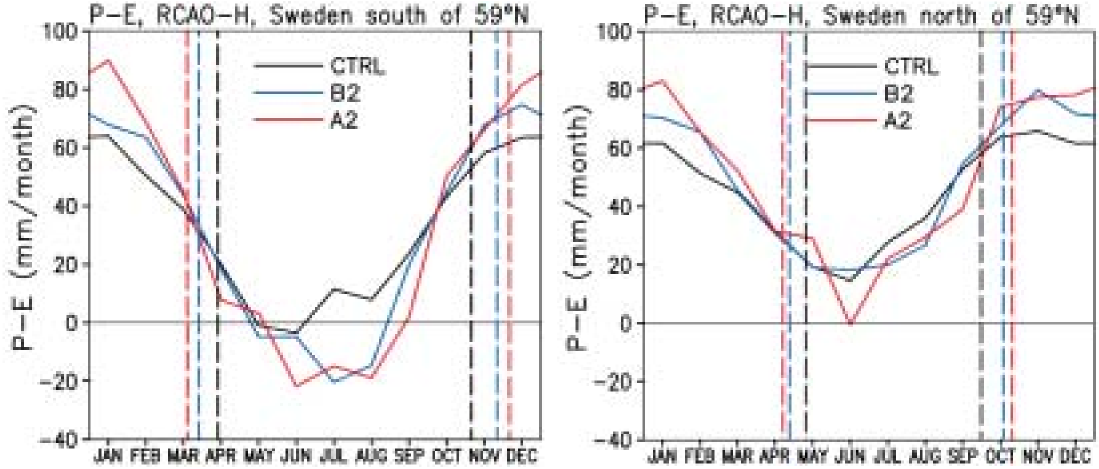


Figure 4. **Calculated water balances (as the net of monthly precipitation minus evaporation) according to some of the SWECLIM simulations. Possible biological changes of water use efficiency by trees and plants are not accounted for. The calculated start and end of the vegetation period (dashed lines) are also shown. Left: Sweden south of 59°N. Right: Sweden north of 59°N. The nominal 1961–90 conditions are from a "control simulation" (CTRL). B2 and A2 are future simulations based on two different emission scenarios, which are predicted to be weaker in the B2 than in the A2 scenario (SWECLIM Årsrapport 2002.).**



tions in soil moisture in late summer in southern Sweden driven by the combination of higher evaporation, lower summer precipitation and earlier snowmelt. Potential changes in vegetation caused by increases in carbon dioxide, the climate changes or adjustments in land use have not been included in the regional simulations so far. The possibility that the water use efficiency of plants could change has been discussed, leading to additional effects on transpiration and soil moisture conditions.

Snow conditions

The typical number of days with snow cover is calculated to decrease across the entire country as a consequence of the warming. Southern Sweden may have snow for only a few days per year during a typical winter in the future. In central Sweden, lasting snow cover may persist for 1–4 months per year and for 3–6 months in northern Sweden. In addition, the maximum snow depth is predicted to decrease, despite higher precipitation. The projected warming leads to more of the precipitation falling as rain rather than as snow.

Wind

The calculated changes in average winds close to the earth's surface (10 m) differ between the simulations, roughly in line with the larger-scale atmospheric circulation responses to global warming. In simulations where the winds do increase, they tend to do so during winter and spring. The mean wintertime changes span from +20% to unchanged conditions. In summer and autumn the simulated changes are small in all cases studied. Changes in extreme winds follow the changes in mean wind speeds.

In the rest of this report, the results discussed on how climate change might impact forests are drawn from published studies. The climate scenarios assumed in many of these studies do not conform to the regional scenarios briefly described above. In a number of cases, rather idealised scenarios have been adopted, and furthermore they only address a few variables. Thus, it is difficult to compare the studies or to combine their results in any quantitative manner.

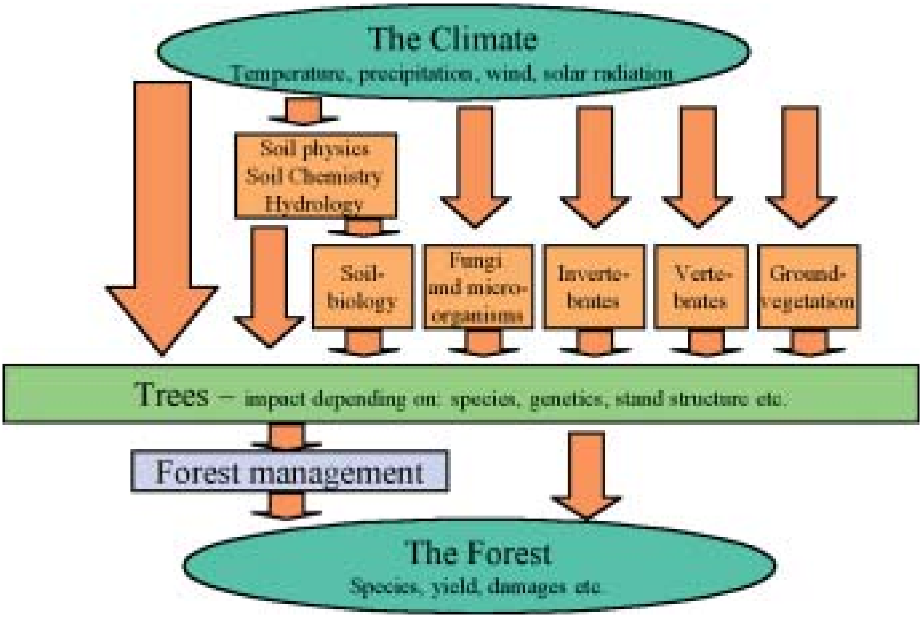
The complexity of the system

Climatic changes will affect forests in many different ways, via both their direct effects on the climate on the trees and their indirect effects on soil, pests and diseases affecting the trees. In the literature many studies reporting results and predictions on the effects of single climate variables and single species have been reported (Harrington et al. 1999). However, the effects of climatic change on ecosystems will be much more complex and difficult to predict than such studies imply, since so many variables, species and their interactions have to be considered. Predictions based on comparisons between climate records and records of damage, species distributions and other relevant factors have also been made in numerous studies. Some scientists interested in changes that are likely to occur in a specific area have examined processes in other geographic areas, where the present climate matches the future climate predicted for it. The best general prediction for the impact of climate change on ecosystems is probably obtained through synthesising results from as many studies as possible, obtained using all of the different approaches mentioned above. A conceptual framework for analysing ecosystem responses to climate change has been suggested by Shaver et al. (2000), who emphasise the complexity of the models needed to predict the impact. In addition to these effects on the forests, the state of the forests is also affected by changes in the way they are managed in response to possible climate changes (Blennow and Sallnäs, 2002), although this aspect is not well covered in the literature.

This review has been essentially based on the conceptual model of the direct and indirect impacts on forests summarised in Figure 5.

- According to international climate research, anthropogenic global warming is already occurring, and it will continue during the 21st Century. The anticipated changes are large compared to natural variability over similar time periods.
- Global scenarios in general, and measures of global mean warming in particular, lack sufficient detail that is relevant to estimates of the impact of expected 21st Century climate changes on forests and forestry in Northern Europe. Better detail can be gained from regional studies.
- A number of climatic aspects relevant to forests and forestry are likely to change due to global warming. These include the length of the vegetation period, water availability, soil temperature and snow conditions. Changes in variability and extremes are relevant as well as changes in mean conditions.
- Due to the uncertainties related to future socio-economic development, future emissions and sensitivity of the climate system, statements about climate change, and consequently its effects, are essentially probabilistic. A range of plausible scenarios should be studied to promote better understanding of the problems and new possibilities that might arise, and to assess the need for action. It also is important to strive for coherency across different studies, so the results can be compared and used to develop an integrated understanding.

Figure 5. Conceptual model underlying this review.



Direct impact of climate on trees

Tree species distributions

Climate is a major factor determining the geographical distribution of tree species. The general effect of a warmer climate will be that the range-limits of individual species will move northwards/upwards. At present the natural southern limit of a number of species including Norway spruce (*Picea abies*) and grey alder (*Alnus incana*) are considered to pass through Sweden. The northern/upper limits of a large group of species also occur in Sweden, in fact the upper (altitudinal) limits of all the tree species in Sweden occur here, since no trees grow above the treeline (by definition) in the Scandes.

Sykes and Prentice (1995) simulated the potential distribution ranges of the most common Swedish tree species in a climate resulting from a doubling of the atmospheric CO_2 –content (2×CO_2-scenario). They used a bioclimatic model (STASH) and predicted major changes in species distributions in response to large climate changes, especially winter warming. Some of the common boreal species (e.g. Norway spruce, Scots pine (*Pinus sylvestris*) and grey alder) are predicted to withdraw to the far north.

A more recent simulation of the future range-limit of Norway spruce has been made by Bradshaw et al. (2000), who also used the STASH-model and a 2×CO_2-scenario. However the climate scenarios have been modified since the study by Sykes and Prentice (1995). The new prediction is that Norway spruce will withdraw from the coastal areas of southern and central Sweden, but remain in the interior parts of southern Scandinavia. Bradshaw et al. (2000) have validated their prediction by simulating historical range-limits of Norway spruce based on historical climate records and compared them to the species distribution as observed in pollen records. They found that the southern range-limit of Norway spruce has been tracking climate change closely during the last 1000 years (Figure 6).

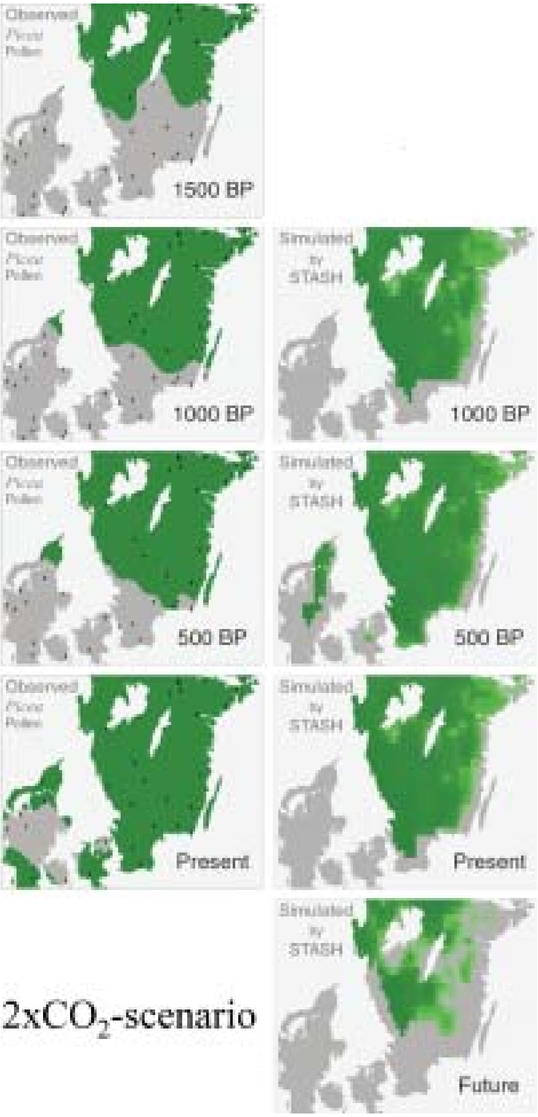


Figure 6. **Observed and simulated Norway spruce distributions during the past 1500 years and a predicted future distribution (after Bradshaw et al. 2000)**

The upper range-limits of tree species in the Scandinavian mountains are likely to rise to higher altitudes. Large areas that are treeless today are likely to be covered with forests in the future. The establishment of new forests in these areas is a slow process, but there are indications that it has already begun. Kullman (2002) has registered newly established seedlings of Norway spruce, Scots pine, hairy birch (*Betula pubescens*), rowan (*Sorbus aucuparia*) and willows (*Salix* spp) at altitudes 100–375 metres higher than the range-margins described in the 1950:s in the studied area (Kilander 1955).

The future distributions of tree species are not only dependent on the natural range-limit set by climate. Bond and Richardson (1990) have studied vegetation changes in the pre-Pleistocene past and invasions of pine-trees in present South Africa, comparing them to climate records. They concluded that vegetation change is most often caused by changes in disturbance regime or in competitive interactions, especially at the seedling stage, and not primarily by direct effects of climate. They also state that climate-induced mortality of *established* plants appears to be rare, especially for longer-lived species.

Human activities like forest management, fire prevention and management of moose and deer populations have powerful effects on the species distribution and composition of forests today, and their influence is likely to have similar strength in the future. Indeed, simulations of the future species composition of forests in north-eastern Germany (Lindner 2000) indicate that forest management will have a greater impact than the climate on species composition, even under future climate change.

The use of tree species outside their natural range is very common in plantation forestry. In Europe Norway spruce is widely used for plantations outside its natural range, mainly successfully. However, the frequency of damages to Norway spruce is commonly considered to be higher outside its natural range than within it. Norway spruce stands outside the species present natural range are likely to be the first to be severely damaged by a warmer climate. Redfern & Hendry (2002) predict that Norway spruce will cease to be a productive tree species over much of England in a future warmer climate.

In conclusion, the most important predicted effect of climate change on species ranges is that the northern range limits of most native broadleaves and many introduced tree species will expand. In the Scandinavian mountains the upper-range limits of tree species will also rise, leading to forests developing on previously treeless areas. The natural range-limit of Norway spruce may withdraw from the south Swedish coasts but the species will most likely continue to be a productive plantation species even in southern Sweden.

Wind and snow damages

The predictions for future average and extreme winds are uncertain. However, in general windiness is expected to increase. In a windier climate, the risk of wind damage to trees is also expected to increase. The frequency and magnitude of extreme winds will important, although other changes in variables such as soil freezing and indirect effects of climate change on the status of the forests are also expected to affect the risk of wind damage. The effects of climate change on the risk of wind damage to forests in Sweden are currently being studied (Blennow in prep.) using a system of models called WINDA (Blennow and Sallnäs, in press) and the latest climate scenarios (Räisänen et al 2003). Preliminary results for Asa Experimental Forest in Småland indicate a slight increase in the probability of wind damage due to changes in the wind regime. However, including changes in the state of the forest in the simulations is expected to further increase the probability of wind damage. Reductions in soil-freezing may also contribute to increasing frequencies of windthrow because of weaker tree anchorage during frost-free soil conditions. Simulations for Scots pine in Finland (Peltola et al. 1999) indicate that the frost-free period will increase in length, and thus increase the likelihood of winds causing damage. In southern Finland the calculated amount of felling winds with non-frozen soil will increase from 55% to 80%, and in northern Finland from 40% to 50%, in a climate with a 4°C higher average annual mean temperature. In Sweden, wind damage is currently a bigger problem in the south of the country than in the north, and windthrow is more common than stem breakage (Persson, 1975). For the southernmost part, where soil freezing is rare or shallow, the effect of reductions in soil freezing will likely be marginal, while further north the effect will likely be more important. On the other hand,

Damage by wind and snow generally varies widely in space and time. Research is needed to characterise the regional distribution of wind and snow damage during the present and future climate. A tool, WINDA, has been developed to help assess the risk of wind damage (Blennow and Sallnäs, in press). Work is underway to use this model together with the SWECLIM scenarios to evaluate effects of climate change on the risk of wind damage. This work should be extended to cover different parts of Sweden, and the combined multiple effects of climate change need to be included in the simulations. Efforts to use WINDA to provide support for decision makers under the current climate have started (Olofsson and Blennow, in press), but additional work is needed where the effects of climate change are included.

snow damage may decrease in large parts of Sweden due to reductions in snow, but the effects of weather extremes make this prediction uncertain.

Frost and winter damages

The phenology of the trees is mainly determined by climatic factors and the photoperiod. Understanding this interaction is of great importance for predicting how trees will respond when climate changes but the photoperiod remains the same. This has profound implications for the effects of climate change on growth, damage and range limits of different species.

The general phenological cycle of temperate and boreal conifers has been reviewed by Hannerz (1998). Budburst cannot occur until the rest phase is terminated, which is accomplished by exposure to low temperatures, below +5°C to +10°C. Once the chilling requirement has been satisfied, budburst is initiated by exposure to high temperatures, providing that the days are not too short to hinder growth. A deficit in chilling will normally increase the temperature required to initiate budburst. Photoperiod is a strong determinant of growth cessation, but temperature and drought may provide additional cues. The hardiness of the plant tissue is highest during winter and dehardening is initiated by temperature, starting several weeks before budburst. The lowest levels of frost hardiness occur in new shoots immediately after budburst. Low hardiness then continues throughout the growing season. After budset, hardiness steadily develops during the autumn and is promoted by low night temperatures.

There is a great variation between species in the chilling requirements, temperature sums and night hours required to initiate the different phenological events during the year (Hannerz 1998). Even within species the required amounts of initiating cues vary widely, and these traits are often highly heritable (Hannerz 1998).

The phenology of young Norway spruce seedlings has been demonstrated to be dependent on the temperature during pollination (Johnsen et al. 1995). The growth of seedlings grown from seeds produced in a warmer temperature cease later than seedlings from the same families produced in a cooler temperature, and thus they are more susceptible to autumn frosts. This effect could be beneficial for the adaptation of Norway spruce to a warmer climate.

The natural southern range limit of Norway spruce is considered to pass through southernmost Sweden, and the critical factor determining this limit is believed to be the species chilling requirement. However, Norway spruce is successfully used in plantation forestry outside its natural range. Skre & Nes (1996) have grown Norway spruce seedlings for three years in normal (for Norway) and elevated (+4°C) winter temperatures, and concluded that warmer winters could lead to increased needle losses and reduced growth the following season, especially in northern provenances. Top-dying sometimes occurs in young Norway spruce trees planted in the British Isles. The factors causing top-dying are not fully understood, but climate is appears to play a role in its initiation, and Redfern & Hendry (2002) predict an increase in top-dying as a response to climate change.

Redfern & Hendry (2002) have also predicted the effects of climate change on frost damage to trees in the UK. They conclude that injuries due to winter cold are likely to decrease, and spring budflush will advance. Thus, the risk of spring frost is unlikely to change, but autumn frosts may become more damaging due to later hardening. The frequency and amplitude of future weather extremes is very important for the occurrence of frost damage, and must be accounted for.

In Scandinavia, ground frosts during clear nights in late spring or early summer frequently damage newly emerged Norway spruce shoots. The risk of this type of frost damage occurring in a warmer climate will be determined by a fine balance between rising temperatures reducing the risk of frost damage, and the earlier start of dehardening increasing the risk (Jönsson et al. 2004).

Decreased vitality due to frost injuries is often considered to be a decline-initiating factor in several tree species. Auclair et al. (1996) have studied the dieback of birch and maple species in eastern Canada and found a strong correlation between dieback periods and an index that is a function of winter frost, root damage due to lack of snow cover, summer drought and heat stress. Dieback was found to occur mainly in old trees, while younger trees remained vital. They concluded that a warmer climate is likely to increase the incidence of dieback in northern hardwoods in Canada. Barklund (2002) identifies frost injuries, often combined with drought spells, as the initiating factor for the decline of European oaks. Frost and drought makes the trees more susceptible to secondary pathogens, and this leads to periods of tree decline over several years. Reductions in snow cover and more frequent drought spells in the future could initiate tree decline, but on the other hand periods of extremely cold winter temperatures are predicted to decrease, especially in southern Sweden, and this could help reduce the risk of tree decline.

Forest fires

An increase in summer temperature combined with lower precipitation and, perhaps, increased winds are likely to increase the risk of forest fires. Bergeron and Flannigan (1995) studied the effect of climate change (2×CO_2-scenario) on the Canadian forest fire weather index (FWI), which is a function of temperature, relative humidity, 24 h precipitation and wind speed. They predicted 1.5–5 fold increases in FWI for large regions, mainly in western Canada. Predictions for some regions in eastern Canada indicated that FWI would be unaffected or decline. Thompson et al. (1998) predicted a 1.5–2 fold increase in FWI for Ontario in a 2×CO_2-scenario.

Suffling (1992) has studied records of forest fires in Sweden, Finland, Norway and Canada and compared them to annual July and August temperatures. He found significantly higher numbers of forest fires and areas affected by fire during years with higher late summer temperatures. Examination of Swedish datasets from 1946–64 indicated that a 2°C increase in July–August temperature may increase the annual area affected by forest fire in Sweden fivefold.

Large regional differences in summer humidity are predicted for the future within Sweden. This has strong implications for the frequency of forest fires, which may decrease

The magnitude of the risk of damage due to late spring ground frosts might well be similar in the future to the magnitude today, but predictions are complicated by a lack of relevant knowledge. There is an obvious need for more knowledge about the combined effects of elevated mean temperatures and earlier dehardening and budburst for different species and sites. The risk of autumn frosts is likely to decrease. The risk of winter damage to Norway spruce due to unfulfilled chilling requirements may increase in southernmost Sweden, but is unlikely to pose critical threat. Periods of hardwood decline may increase due to the risk of frost events combined with drought. There is a need for better understanding of the factors that initiate and promote decline and dieback periods of different tree species.

in some regions and increase in others. Changes in forest fire patterns may occur if clusters of dead wood in the forest increase due to wind damage, pest outbreaks or periods of decline.

Soil properties

Carbon balance

Climate change can be expected to have a fundamental effect on soil properties and processes, and a direct impact on water resources. This will have major implications for the carbon fluxes between forest ecosystems and the atmosphere, and thus influence the rate of CO_2 increase in the atmosphere. Forest ecosystems have the capacity to store large amounts of carbon, and appropriate management practices can mitigate increases of CO_2 in the atmosphere, at least temporarily. However, the focus of this literature study is on climatic effects on damage to the trees and their productivity, so we will not consider carbon balance issues any further.

Soil water and frosts

The warmer climate will probably decrease the length of the soil frost period. This has been predicted for the whole of Finland by Venäläinen et al. (2001). They also predicted an increase in the probability of soil frost in the middle of the winter in southern Finland due to the expected decrease in snow cover. These predictions are also likely to be valid for northern and central Sweden. In southern Sweden soil frosts are likely to occur only occasionally in a warmer future. The occurrence of soil frost has implications for soil structure, soil biology, weathering, flow of precipitation water and the windthrow risk for trees.

Increased precipitation during winters, combined with less soil frost in some areas, is likely to increase soil water during the autumn, winter and spring. Nisbeth (2002) has concluded that soil wetness, waterlogging and flooding are likely to increase in winter throughout the UK in a future climate. This also seems to be a likely development for southern and central Sweden. The risks of erosion will then increase and root development and tree stability may be negatively affected by rise in the water table and increased incidence of waterlogging. In northern Sweden, where summer precipitation is also predicted to increase somewhat, this may lead to areas of productive forestland turning into wetlands that are not suitable for forest production. The areas of wet forest sites may also increase.

In southern and central Sweden, where summers are predicted to be drier, the risks of permanent changes in site conditions are lower. However, more frequent and severe summer droughts may threaten seedling survival on dry sites and contribute to tree decline. Similar developments have also been predicted for the UK (Nisbet 2002). The greater winter rainfall will, however, decrease the risk of carry-over of soil moisture deficits from one year to the next and thus help counteract damage caused by summer drought spells. Wetter winters and drier summers may lead to greater fluctuations of the ground water table at some sites, and this may also contribute to drought stress and reduced tree vigour.

Nutrient availability

Growth in Swedish forests is primarily limited by nitrogen on most sites. Increases in temperature will also increase the rate of nutrient mineralisation in the soil (Rustad et al. 2001). Therefore, temperature increases due to climate change may stimulate biomass production. To study the effects of increased temperature on forest productivity, a factorial soil warming × fertilisation experiment was established in a 40-year-old Norway spruce stand in northern Sweden (Strömgren & Linder 2002). A 5°C increase in soil temperature

For Nordic conditions, two of the most important growth factors related to soil properties are nitrogen availability and soil moisture. In order to predict future tree growth, more knowledge is needed concerning likely changes in soil moisture conditions under different climate change scenarios. Soil moisture, the C/N-ratio and temperature are important variables for nitrogen mineralization. Climate change will affect these variables, but we need to increase our knowledge of the interactions involved, especially on quantitative and temporal effects over the growing and dormant seasons.

Effects of climate change on decomposition and weathering need to be better understood.

The length and pattern of the growing season as well as the length and conditions during the non-growing season (with respect to snow and soil frost) will seriously affect processes like mineralization, weathering and thus nutrient leaching. Increased leaching of nutrients and other elements may have important effects on the biota and surrounding environments, e.g. groundwater, lake and marine ecosystems.

during the summer resulted in increases in stemwood production of 115% on unfertilised plots and 57% on fertilised plots. These results indicate that in a future warmer climate increased availability of nitrogen, combined with a longer growing season, may increase biomass production substantially. How prolonged these dramatic increases may be is not clear, a major part of the observed increases in growth may be transient.

Biomass production

The impact of climate change on tree growth is dependent on several factors. The most obvious effect of a warmer climate is a prolongation of the growth season, enabling the trees to increase their annual growth rates. The most important effect is the earlier start to the growing season, enabling an early and rapid change from loss of CO_2 to gain (Jarvis & Linder 2000). Bergh (1997) has predicted the net primary production (NPP) in a Norway spruce stand to increase with about 20%, mainly due to the earlier start of the growing season, with earlier and more rapid recovery of the winter-damaged photosynthetic apparatus. Predictions on the effects of longer growth seasons in the Swedish forests indicate that NPP are likely to increase by 9–12% in southern Sweden and by 15–18% in northern Sweden (Bergh et al. 2000). NPP has also been predicted to increase for a number of other tree species in Sweden (Bergh et al. manuscript).

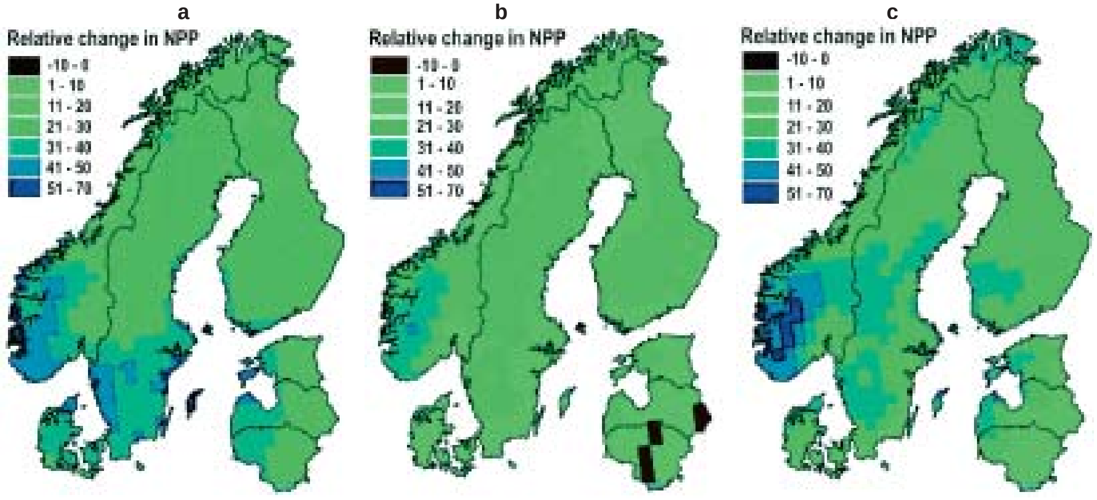
The growth of trees and forests is also predicted to increase in other countries. In Finland the growth of both Norway spruce and Scots pine is predicted to increase, especially in the northern part of the country (Väisänen et al. 1994, Beuker et al. 1996). Simulations for a Norway spruce stand in Norway predict an increase in NPP of 49% with climate change (Zheng et al. 2002). Yield of Sitka spruce (*Picea sitchensis*) is predicted to increase in Scotland (Proe et al. 1996) and forest growth in Oregon is predicted to increase by about 50% (Coops & Waring 2001).

Water has been identified as a limiting factor for tree growth in southern Sweden, especially for Norway spruce (Alavi 1996, Bergh et al. 1999), but also for Scots pine in some years (Cienciala et al. 1998). Water does not seem to be an important growth-limiting factor for Norway spruce in northern Sweden (Bergh et al. 1999). A temperature increase that is not accompanied by an increase in precipitation will increase the frequency of periods of drought stress (Gärdenäs & Jansson 1995). The drier summers predicted for southern Sweden in the most recent climate scenarios (Räisinen et al. 2003) may counteract the higher growth rates predicted in previous studies based on earlier climate scenarios that forecast more summer precipitation in southern Sweden. Simulations of forest productivity in Brandenburg, Germany, under climate change predict a decrease in growth of Scots pine and deciduous tree species due to drought stress (Lasch et al. 2002). In some cases growth may initially increase when the climate starts changing, but decrease as the climate becomes even warmer. This has been predicted for Norway spruce in parts of Germany by Pretzsch & Dursky (2002) in simulated scenarios with +1°C and +3°C temperature increases.

It has been shown that elevated CO_2 concentrations can increase water use efficiency in plants, largely through changes in stomatal conductivity (Eamus & Jarvis 1989). This could to some extent counteract the negative effects of drought stress if summer precipitation decreases in the future. For conifers, however, the stomatal conductance seems to be less affected by increased CO_2 concentrations (Medlyn et al. 2001). Elevated CO_2 concentrations may also increase tree growth due to a carbon “fertilization” effect (Eamus & Jarvis 1989). Simulations for Scots pine forests in southern Finland (Väisänen et al 1994) indicate that an increase in temperature of +5°C will reduce the soil water. At the same time photosynthesis will be enhanced by up to 6–8% under current CO_2 concentrations and up to 8–10% under doubled CO_2 concentrations. Total stem wood production increased up to 6% when all the effects were included in these simulations. The water-use efficiency of the Scots pine ecosystems was predicted to increase by up to 3%. Simulations on a Norway spruce stand in Norway predicted an increase in NPP of 7% with a temperature increase of +4°C and of 36% with a doubled CO_2 concentration (Zheng et al. 2002). When both temperature and CO_2 were increased the NPP increase was predicted to be 49%.

Recent simulations of the possible effects of SweClim’s B2- and A2-scenarios on the production of Scots pine and Norway spruce in northern Europe have been made within the Heureka programme using the process-based growth model BIOMASS. Simulations have been generated for three different age classes: young, middle-aged and old stands. Results for the A2-scenario indicate an increase in NPP of 30–50% in southern Sweden for young stands of Norway spruce and Scots pine and 20–30% in central and northern Sweden (figure 7 a–c). The water availability in the soil in young stands is sufficient and not limiting for photosynthesis and growth, according to the model. However, for middle-aged stands of Norway spruce the increase in NPP is only 0–20% southern Sweden, mainly due to increased water limitations, since the demand from a middle-aged stand is considerably greater than that of young stands. The effect of water in middle-aged stands is weaker for Scots pine than for Norway spruce. The increase in NPP in middle-aged stands for the rest of Sweden is approximately 20–30%. Old stands of Norway spruce also show a large increase in NPP in southern Sweden but less than young stands. Water also limits the growth in old stands, but to a lesser extent compared with middle-aged stands. Old stands of Scots pine have no water limitations and the increase in NPP is 30–50% for most of Sweden. The increase in NPP for the A2- scenario is approximately 10% higher for the whole of Sweden, compared with the B2-scenario. The BIOMASS model is adapted to a boreal climate, but includes no feedback

Figure 7. **Relative change in NPP Norway spruce for the A2-scenario, compared with simulations of the present climate: (a) young stands, (b) middle-aged stands, (c) old stands.**



Regional simulations of net primary production (NPP) in Scandinavia and the Baltic countries have been conducted previously for both Norway spruce and Scots pine, using two of SweClim's recent regional climate scenarios. Results from these simulations are preliminary and the parameterisation of models can be developed further. Results from the simulations are only valid for a mesic sandy-silty moraine, and they cannot therefore be generally applied to dry or moist soil conditions. Furthermore, the model used in these earlier simulations includes no feed-back mechanisms to soil processes, such as mineralization and nutrient availability, which might introduce biased estimates of NPP. However, several models are now available that include such feed-back mechanisms. Sensitivity analysis for different climatic and other variables (e.g. precipitation, temperature and leaf area) would also be valuable for interpreting the results. Furthermore, the long-term effects on production of adverse events, such as severe outbreaks of harmful invertebrates, micro organisms and fungi or windthrows, extreme drought and frost damage in plantations can be incorporated in process-based models by integration with other studies in the abovementioned research areas. Future research needs:

- Further development of the parameterisation and validation of the model
- Inclusion of different soil moisture conditions (dry, moist and wet)
- Inclusion of feed-back mechanisms to soil nutrient dynamics in the models
- Sensitivity analysis for important climatic variables and parameters
- Incorporation and evaluation of long-term effects on calamities and production.

mechanisms, linking climatic variables to soil processes. This might have led to biased estimates of NPP.

A higher temperature sum generally has a positive effect on wood density of Norway spruce and Scots pine in Sweden (Wilhelmsson et al. 2002). Wood density is also known to be relatively high in south-eastern Sweden where summers are dry. This implies that climate change could lead to higher average wood densities in our two major conifers, especially in southern and central Sweden where drier summers are predicted for the future.

In conclusion, the net primary production for Norway spruce and Scots pine is predicted to increase by 0–50%, depending on site and stand age, as a response to climate change. Other tree species will most likely react in a similar way. The importance of water as a growth-limiting factor may increase in middle-aged stands in southern Sweden.

Impact on other organisms of importance to the trees

Invertebrates

Most of the invertebrate species that are serious pests to trees are insects. Evans et al. (2002) have reviewed the effects of climate change on forest insect pests in the UK and found that several different effects are likely to interact. Thus, making accurate predictions is not straightforward because of the complexity of the system. The diversity in life-history strategies among insect herbivores suggests that they will be affected in different ways by global change (Bale et al. 2002). Climate changes are likely to affect in diverse ways the survival and reproduction of the insects, the natural enemies of the insect pests, the nutrient content of the host trees, the vigour and defence capabilities of the hosts and the phenological synchrony of the pest and host (Evans et al. 2002).

The complexity of the effects of climate change on the interactions between insect pests and trees has been illustrated by studies on the spruce budworm (*Choristoneura fumiferana*) published by Fleming and Volney (1995). They have found, for instance, that a higher CO_2 concentration will reduce the nitrogen concentration in the needles of the host and thus the food quality for the insect will deteriorate, while more drought stress will increase the sugar concentration in the needles and improve the food-quality.

Volney and Fleming (2000) have reviewed the impact of climate change on three defoliating insect species that are major forest pests in North American boreal forests: spruce budworm, jack pine budworm (*Choristoneura pinus*) and forest tent caterpillar (*Malacosoma disstria*). They concluded that outbreaks of these species are likely to increase in frequency and intensity under climate change, particularly in the margins of the host tree ranges.

The autumnal moth (*Epirrita autumnata*) has been subjected to several studies that are relevant to insect herbivore's responses to climate change. The autumnal moth recurrently defoliates vast areas of mountain birch forests in the Scandes and Northern Fennoscandia, where it has been suggested that winter temperatures will be raised the most by the anticipated climate warming. The species is also found outside the mountain birch forest but no outbreaks (defoliations) have been recorded in other habitats. The dynamics of northern populations of the autumnal moth are heavily influenced by larval parasitoids, which cause oscillations in the moth's populations that are more or less synchronised at a landscape or regional scale (Bylund 1997). Defoliating outbreaks of the moth, together with climate, have been suggested to be the major driving forces of the dynamics of the mountain birch forest (Tenow et al 2001). It is well established that the winter minimum temperature is a crucial factor delimiting the moth's distribution in the north. Incidences of low winter temperatures and other types of unusual weather patterns also affect the temporal population dynamics of the moth. It has been suggested that a warmer climate may both increase the distribution of outbreaks into new areas and affect the frequency of population peaks (Tenow 1996, Virtanen et al 1998, Bylund 1999). Some studies suggest counteracting effects may occur, e.g. higher winter survival rates of eggs combined with lower survival rates of larvae due to higher mortality rates caused by parasitoids and other natural enemies in the summer (Niemelä et al 2001, Virtanen & Neuvonen 1999).

The importance of green spruce aphid (*Elatobium abietinum*) as a major pest to Sitka spruce is predicted to increase in Scotland if the climate becomes warmer (Straw 1995). If the climate becomes more humid, however, fungal diseases and pathogens attacking the aphid may have a controlling effect, counteracting the possibility of damage increasing. Green spruce aphid is present in southern Sweden, but the damage it does to Norway spruce and Sitka spruce are very limited today. However, its seriousness could increase for these reasons in a warmer climate.

Low winter temperatures limit the northern range of some insect pests. For instance, the critical winter temperature for egg mortality of the European pine sawfly (*Neodiprion sertifer*) is -36°C (Austarå 1971). Virtanen et al. (1996) have predicted increases in the frequency of outbreaks in eastern and northern Finland as a response to warmer winters due to climate change.

One of the major insect pests in Swedish forests is the spruce bark beetle (*Ips typographus*), outbreaks of which occurred in the Nordic countries after warm summers in the beginning of the 1970:s (Löyttyniemi et al. 1979) and in 1976 (Bakke 1983), but after cooler summers in the late 1970:s the populations decreased (Bakke 1983). This implies that climate change with predicted warmer and drier summers in southern Sweden could increase the frequency and severity of outbreaks of the spruce bark beetle. A decrease in the vigour of Norway spruce subjected to stress due to warm winters at its southern range limit could further exacerbate the situation. More frequent damage by the spruce bark beetle due to climate change has also been predicted for the UK (Anderbrant 1986, Evans et al 2002).

The most serious insect pest in Sweden is the large pine weevil (*Hylobius abietis*), due to the mortality it causes to planted seedlings. No predictions have been published about the possible impact of climatic changes on the large pine weevil as a pest in forest plantations. However, the large pine weevil is more common in areas with warmer and drier summers. Bejer-Petersen et al. (1962) have studied this issue, and comment that it is difficult to draw general conclusions about the climatic preferences of the species. The larval period varies between one and three years in Sweden, and since developmental time in insects is directly affected by temperature, a change in climate could alter the length of the larval period. Possible consequences are difficult to predict.

Other invertebrates may also occur as forest pests. The pinewood nematode (*Bursaphelenchus xylophilus*) is native to North America and has caused pine wilt disease with severe tree mortality since it was introduced to Japan. The pinewood nematode has recently established populations in Portugal and it has the potential to spread over most of Europe, but wilt disease on living trees are only expected to occur in areas where the mean July or August isotherm is >20°C and epidemic wilt is only likely at temperatures >24°C (Evans et al. 1996). If climate change results in a temperature increase of the magnitude predicted by the most extreme recent scenarios (Räisänen et al. 2003) pine wilt disease could occur in southern Sweden. However, this is also dependent on the pinewood nematode spreading to Sweden and the future occurrence of beetles of the genus *Monochamus,* the vector that carries the nematode from tree to tree (Linit 1988).

Most insect species have good dispersal ability and their range-limits can be predicted to change simultaneously with climatic changes. Changes have already been observed in the distribution of native European butterfly populations, with northern ranges extending and southern ranges contracting (Virtanen & Neuvonen 1999). The same effects are likely to be apply to forest insect pests (Evans et al. 2002). The range limits of the tree species hosting the insect pests will move much more slowly, and these differences in migration rates may cause directional changes with time in damage pattern. The short-term response to a warmer climate may be that the ranges of the pest and host partly separate, with a consequent reduction in pest damage, while in the long term, as the host tree species migrate into the new range of the insect pests, the damage may increase again. The importance of this type of interaction due to different parts of the ecosystem responding at different speeds to climate change has been emphasised by Shaver et al. (2000).

Insect species, especially those occurring in periodic outbreaks, have a large potential for genetic adaptation to new environments due to the huge numbers of individuals involved and their short generation times (Fleming and Volney 1995). Natural selection is therefore likely to play a major role in adaptation of insect species to climate change, for instance in maintaining the phenological synchrony between insect pest and tree hosts.

As mentioned above, the complexity of the insect pest systems makes it difficult to make accurate predictions or generalisations about

The main reason for the uncertainties about the effects of climate change on insect damage is that the host plant and the pest insect's natural enemies will be affected by global change as well as the insect itself (Bale et al. 2002). It is essential, therefore, to understand how important interactions – those determining density and population trends – will be affected. Moreover, different types of pest insects are likely to differ in their responses. To account for these differences we need to identify and pick out suitable model systems, representing different categories of insects.

To improve predictions about possible future insect pest problems there is a need to concentrate research efforts. We suggest that future research should be focused on a set of selected insect species. Each selected species should represent a larger group of known or potential pest species, and a substantial body of basic biological knowledge should be available about it. In addition, the species selected should preferably represent a wider range of taxonomic and ecological groups.

Regarding the types of studies that should be undertaken, we believe that the best strategy is to include a combination of long- and short-term studies complemented by modelling efforts. Further studies should include, for instance, investigations of long-term changes in population densities and their correlations to climatic data, replicated at several sites, and short-term experiments focussing on important mechanisms and interactions identified in empirical studies, are needed. The results from these experiments and observations should be used to continuously develop and evaluate population models. A valuable use for such models is to study changes in the risks associated with insect pests.

the impact of climate change on insects. Harrington et al. (2001) reviewed this matter and found that studies focusing on insect pest species often predict increases in the populations, their range-limits and the damage they cause, while studies focusing on rare and endangered species often predict decline and increased threats to the studied insect populations. Harrington et al. (2001) also suggest that studies reporting catastrophic scenarios are over-represented in the scientific literature because studies reporting little or no change receive less attention and they are more difficult to get published. This calls for caution when discussing the effects of insect pests on forests in a changing climate.

In conclusion, damage due to insect pests may increase somewhat in a warmer climate. The range limits of some insects may also expand. However, it is difficult to make accurate predictions because of the complexity of the system, involving climate, host-trees, insect pests and their natural enemies.

Vertebrates

The tree species composition of young forest stands in Sweden today is mainly dependent on two factors. First, forestry, which favours certain species like Norway spruce and Scots pine in regeneration and early thinning. Second, the interaction between browsing pressure of moose and deer and the palatability of the different tree species. High browsing pressure during the last 20 years has promoted the planting of low palatability species like Norway spruce and lodgepole pine (*P. contorta*) on large areas that would otherwise be regenerated with Scots pine or broadleaved species. Browsing by moose in young Scots pine stands is considered to be the largest silvicultural problem in Sweden today (Friberg pers. com.). Climate determines the ranges of tree species, but plays a minor role in determining the species composition of the forests established today. Continuing large populations of large herbivores are likely to have a similar impact on species composition in the future, so the impact of climate on the herbivores will be important.

Moose (*Alces alces*) has a circumpolar distribution, and its southern range-limit is mainly determined by temperature. In winter coats moose become stressed by temperatures higher than 5°C, while in summer coats they experience stress at temperatures of 14°C or higher (Karns 1997). During warm weather they normally seek shade and water. The southern range-limit of moose in Europe today is mainly influenced by human intervention, but the climatic limit is considered to be at approximately latitude 50°N. In a future warmer climate, moose may very well suffer severe temperature stress in southern Sweden and gradually disappear from these areas. The decline of moose populations in Ontario due to climate change has been predicted by Thompson et al. (1998).

Roe deer (*Capreolus capreolus*) is distributed over the whole of Sweden, but populations in northern Sweden have a low density and in many areas they are highly dependent on winter feed supplied by humans. A warmer climate with shorter winters and thinner snow cover will most likely increase the population densities in central and northern Sweden. Red deer (*Cervus elaphus*) and fallow deer (*Dama dama*) have scattered distributions in southern and central Sweden, but are slowly increasing and may in the future have a continuous distributions over large parts of Sweden. The effects of a warmer climate on these species can be expected to be similar to those for roe deer. However, roe deer have higher dispersal abilities and may respond more rapidly to the changing climate.

The future population densities of large herbivores will also be strongly affected by population management measures taken by humans, and changes in the populations of large carnivores. The amount of damage by large herbivores on trees may also change if climate change affects the quantity and quality of alternative forage species like herbs and dwarf-shrubs. The browsing by moose and roe deer on trees is partly determined by the length and depth of the snow cover. With less snow the animals feed more on field-layer vegetation and less on trees (Cederlund et al.1980). Snow cover is also the critical factor initiating winter migration of moose in northern Sweden, and reductions in the duration of snow cover could make browsing damage in the winter ranges less severe (Ball et al. 1999).

In conclusion, the ranges of roe, red and fallow deer are likely to expand northwards while moose populations may decline in southernmost Sweden if the climate becomes warmer. The impact of populations of large herbivores is likely to be at least as important for the regeneration success of trees in the future as it is today. Population patterns of large carnivores and management by hunting are the two main factors influencing deer and moose populations besides the climate.

Micro-organisms and Fungi

Fungi comprise the major group of microorganisms that cause severe disease to forest trees. In addition, certain bacteria and, to a lesser extent, viruses and mycoplasma-like organisms are known to be disease agents. There are also a number of complex diseases or decline syndromes of trees where the causal factors include several interacting disease agents, both biotic and abiotic. The nutritional mode of the microorganisms is of importance when considering their impact in forests and the potential influence of climatic change on disease development. Biotrophic pathogens, such as rusts and mildews, rely on living host cells for their nutrition, and thus may frequently be favoured by environmental conditions promoting vigorous growth of the host. Necrotrophic pathogens, on the other hand, kill host tissues before feeding on dead cells. These pathogens are often favoured in their development by conditions that stress the host organism. This is especially important when considering opportunistic, relatively weak pathogens that can cause major disease symptoms when developing on hosts stressed by environmental conditions, while perhaps only causing negligible effects to a vigorously growing host.

In the context of forestry and potential damage to the trees, the most important effects of climate change on herbivores are likely to be changes to the populations and environments of cervids, wild boar and (possibly) hares. From the present climatic scenarios, several aspects of the tree-large herbivore system can be identified that deserve special attention:

- The impact of expanding or shrinking tree species ranges (with accompanying vegetation changes) and the implications for the distribution of herbivores and population densities.
- The impact of summer weather on forest rotation time, food quantity, food quality and the implications for herbivore population dynamics and damage patterns.
- The impact of winter weather on migration, habitat use and foraging patterns, together with the implications for animal distributions at regional and landscape scale, the relative amount of foraging in different vegetation layers and the impact of large herbivores on the migration rate of woody species.

Man and other predators are confounding factors.

The principal assumptions about the complexity of the pest-host-environment interactions discussed above are also valid for microbial and fungal pathogens. Most pathogens with that disperse via spores will rapidly respond to climate change via adjustment of their range limits and frequency of outbreaks.

The fungus *Heterobasidion annosum* (root and butt rot) is the most economically serious disease in Swedish forests. Its spore production and dispersal are generally promoted by increased temperatures. Dry weather also favours dispersal. Low winter temperatures and snow decrease spore production and dispersal (Redfern & Stenlid 1998). This implies that the spread of *H. annosum* after thinning will be favoured by climate change, especially in southern Sweden. It is possible that severe damage, which is currently restricted to the coasts of southern Sweden, may start to affect larger areas of southern and central Sweden (Stenlid pers. com.).

A number of different inter-sterility groups of *H. annosum* are known to occur, with differing host and regional ranges. The S-group, which mainly attacks Norway spruce, is distributed over the whole of Sweden. In southern Sweden, the P-group attacks Norway spruce, Scots pine and other tree species (Korhonen et al 1998). The absence of the P-group in northern Sweden and the northern parts of neighbouring countries implies that the range limit may be set mainly by climatic factors. A warmer climate could thus imply a northward spread of the P-group with Scots pine being attacked, especially on sandy soils with relatively high alkalinity (Stenlid pers. com.).

Root disease cause by *Armillaria spp.* occurs across the entire country on several tree species, including the economically important conifers. This pathogen mainly infects trees that have a reduced vitality due to some kind of stress. Drought stress is reported to make trees more susceptible to *Armillaria* infection (Wargo & Harrington 1991). A future climate with warmer and drier summers is likely to promote *Armillaria* and cause increased damage by this pathogen.

Outbreaks of *Gremmeniella abietina* have occurred regularly in Sweden. Two different types of disease can be distinguished. In southern Sweden attacks are mainly confined to middle-aged stands of Scots pine, while in northern Sweden it occurs in young stands of Scots pine and lodgepole pine, mainly attacking the lower parts of the tree that are covered by snow during winter. There are also indications of corresponding ecotypic differentiation within *G. abietina* (Hellgren 1995).

The main factor promoting outbreaks of *G. abietina* is rainy, cool and cloudy weather during the growing season, which increases spore dispersal and survival rates of the pathogen. The opposite conditions, warm and sunny summers, are not conducive for infection and promote canker healing (Hellgren 1995). This implies that outbreaks of *G. abietina* will be less frequent in the future warmer and drier climate predicted by the current scenarios. The northern disease type is dependent on deep and long-lasting snow cover (Hellgren 1995), and a warmer climate is likely to contribute to a reduction in damage caused by *G abietina* in large areas of central and northern Sweden.

Phacidium infestans cause damage to needles and mortality, mainly to Scots pine, but also to lodgepole pine. The pathogen is common in northern Sweden. Deep and soft snow is a prerequisite for this pathogen, and with warmer winters and less snow the damage it causes is likely to decrease in Sweden and totally disappear from some areas.

Some pathogens exploit frost damage to infect trees. *Lachnellula willkommii* is known to attack larch (*Larix spp.*) trees in this way. If the frequency of frost damage changes in a future climate scenario, the damage caused by this type of pathogen will probably decline.

Pathogen species that are not currently present in Sweden may be able to invade southern Sweden in a future climate. Several important species that cause severe damage are present in southern and central Europe, like some oomycete species of the genus *Phytophthora,* and have the potential to cause diseases in a future, warmer Sweden.

The following general effects of changed climatic conditions on the flora of microorganisms affecting forests in Sweden can be predicted.

1. Organisms for which dispersal is favoured by mild whether can be predicted to increase in importance. For example, the window for spore dispersal of *Hetereobasidion annosum* is expected to expand into the winter period under milder climatic conditions.
2. Organisms that are disfavoured by the warmer conditions are likely to decline in importance, e.g. the snow mould *Phacidium infestans,* which requires snow cover in order to infect conifer seedlings efficiently.
3. Organisms (e.g. *Armillaria* spp) that are favoured by the stress conditions created by extreme weather conditions, such as drought will tend to increase in importance.
4. The distribution ranges of some organisms that require warmer conditions than are currently found in Sweden may expand from continental Europe into Scandinavia. This group includes organisms like *Spharopsis sapinea,* which causes shoot blight, and *Phytophthora* spp which causes root rot.

Ground vegetation

Ground vegetation of herbs, grasses, ferns and shrubs is an important factor determining the regeneration success of tree species, for natural regeneration as well as for planting or seeding in silvicultural systems. Competition between ground vegetation and tree seedlings is generally more severe on fertile sites than on poorer ones. There is also a north-south gradient, where the heaviest competition from ground vegetation occurs in southern Sweden and declines to the north. In a warmer climate, both the climate itself as well as possible increases in nutrient availability may increase the competitive pressure on tree seedlings. Intensified competition may be due to increased pressure from present ground vegetation species, as well as the invasion of new species promoted by the warmer climate.

Research should be directed towards understanding how trees react to milder winter conditions. Several shoot- and needle- infecting fungi developing during the period when the trees are dormant. This is likely to be affected under the currently considered climatic scenarios. The interplay between dormancy of the tissues and fungal development is thus of great interest for predicting future disease outbreaks.

Another area for future research is the interplay between stress episodes and the development of decline symptoms on trees. It is of crucial importance to understanding how pathogenic fungi are triggered under these conditions.

Tree and stand factors of importance to the impact of climate change

Tree species

The range limits of tree species will change as climate changes, as discussed above. In plantation forestry, tree species are often used outside their natural range and this will probably also be the case in the future. The effects of climate change on the suitability of four plantation tree species in the UK have been reviewed by Ray et al. (2002). They conclude that the suitability for plantation forestry of Sitka spruce,

Corsican pine (*Pinus nigra)*, Douglas fir (*Pseudotsuga menzieesii*), and beech (*Fagus sylvatica*) will all increase in Scotland. In large parts of England, in contrast, Sitka spruce probably will cease to be suitable, while Douglas fir will remain suitable and the suitability of Corsican pine will increase. They also predict that beech may not be suitable as a timber crop in parts of southern England. Norway spruce is predicted to be more prone to "top-dying" damage in Scotland and to cease being a productive species in England (Redfern & Hendry 2002). Thompson (1998) predicts that the effects of climate change on the suitability of Sitka spruce as a plantation species in Ireland will be minimal. Other species, like Norway spruce and Scots pine, will probably be adversely affected.

Norway spruce is currently the main plantation species in southern Sweden. The range limit of Norway spruce is predicted to move northwards in response to climate change (Bradshaw et al. 2000). Whether Norway spruce will continue to be a suitable plantation species in the southernmost parts of Sweden and in coastal areas cannot be predicted with confidence, but it is likely to continue to be suitable somewhat outside its natural range. Other species may very well prove to be more suitable than Norway spruce in some parts of southern Sweden in the future.

The number of species both native and introduced that are suitable for plantation forestry is highest today in southern Sweden, while there are fewer species to choose from in northern Sweden. A warmer climate is likely to make a number of species, like native hardwoods and exotic conifers, more suitable and potentially interesting as forestry species in a larger part of Sweden. This may increase the species diversity in managed forests, at least at the landscape scale.

In both naturally regenerated forests and planted forests the competition between different tree species may be affected by climate change. The relative competitiveness of some species will change, and this has implications for future species composition and stand structure of mixed forest stands. Kellomäki & Kolström (1992) have predicted that the early height growth of silver birch (*B. pendula*) will increase more than that of Scots pine in southern Finland as a response to climate change. This implies that early management with pre-commercial thinning will be more important in the future to promote the development of stands.

There is a need for more knowledge about biomass production and management of a number of species of potential interest for forestry in a warmer climate. Knowledge about altered competition patterns between species are also of great importance. A better understanding of the physiological and ecological factors determining the southern range limit of Norway spruce as well as range limits for other species would also be desirable.

Genetic variation

Most of the studies reviewed above make predictions about the effects of climate changes on different species. However, not only are responses of different species likely to differ, the responses of different populations and genotypes within species will also differ, although these differences are likely to be generally smaller than between species. Large genetic variations between populations (provenances) of forest trees clearly occur for many traits of adaptive significance. Within populations, large genetic variations in growth and biomass traits in response to different temperatures and water availability have been reported for young seedlings of Scots pine (Sonesson & Eriksson 2000) and Norway spruce (Sonesson et al. 2002).

The genetic variation within species will allow seedling material to e selected for reforestation in the future that is better adapted to the future climates (Thompson 1998). However, trees that have already been planted today will probably be growing in climates that they are less well adapted to in the later part of their rotation than the earlier stages. Studies on provenance trials indicate that the growth reduction, compared to the optimal provenance, in a future warmer climate will be in the range of 5–10% for Norway spruce (Schmidtling 1994) and Scots pine (Persson 1998). The non-optimal adaptation of old trees in the future may also cause a loss of vigour, resulting in increased susceptibility to pests and diseases. The magnitude of this risk cannot be easily predicted, but it will increase if the climate changes are rapid.

Evolution based on natural selection in response to environmental changes tends to be slow because of the long generation time of trees. Trees therefore have to rely on their phenotypic plasticity to withstand variations in weather, which can be considerable between years. Wind-pollinated tree species with a large distribution range, like Norway spruce and Scots pine are considered to have high phenotypic plasticity for many adaptive traits (Eriksson & Ekberg 2001). The large phenotypic plasticity will be beneficial for the capacity of trees to survive and thrive in a changed future climate, within certain limits.

Management strategies

Risk management

An analytical framework for risk management in relation to climate change is needed to help decision makers attain their goals in accordance with their values and to help the research community provide useful decision support. Some components of such an analytical framework will be described below, but a more detailed description requires additional research. For example, it is important to understand how different groups of decision makers perceive uncertainties and risks related to climate change. At least two levels of uncertainty can be identified. First there is uncertainty about whether or not the climate is changing and what the climate will be like in the future. Secondly, there are uncertainties about how climate changes will affect the forest and what forestry measures will be

Research should focus on identifying adaptive traits of importance in a changing climate, and the genetic variation and phenotypic plasticity associated with these traits. Studies are needed on the most important forestry species today and on new species of potential interest for the future climate. The genetic control of pest resistance also needs to be urgently researched, both for the common conifers as well as a broader range of potential forestry species.

useful. Decision makers' perceptions of these uncertainties affect their forestry decisions and, consequently, the state of the forests. Thus, it is important to distinguish between direct effects of the climate and indirect effects of forest management in order to understand the effects of a changing climate and, not least, to allow the decisions to be improved.

The analytical framework is intended to assist decision makers in their risk analysis and to help them choose the appropriate strategy to attain their goals, in accordance with their values. For this, the risk factors perceived as being most important by either decision makers or the research community need to be identified. Research is needed to help identify such risk factors and the questions that most need to be answered. The risks may be due to deficiencies in the knowledge base or to uncertain events. For each of the identified risk factors the research community can help answer questions. To maximise their utility, the answers should be presented in a format that facilitates decision making. The Nature of such decision support will depend on the risk factor under consideration. Research is needed to assist the communication of risk between the research community and the decision makers, as well as between groups of researchers and between groups of decision makers.

Genetic material

The period that is most important for tree seedlings is in the first years during and immediately after establishment. Therefore, the general recommendation for selecting genetic material for regeneration purposes is to use material that is well adapted to the climate it will experience during the first years (Sonesson 2001). Planting seedlings that are adapted to the predicted warmer climate may lead to high rates of mortality and few seedlings living to experience the anticipated future climate.

In order to provide forestry with well-adapted material for future regeneration in the rapidly changing climate, it is of crucial importance to have a well-designed breeding programme. The Swedish breeding programme is integrated with a dynamic gene conservation programme and provides scope to maintain and develop the amount and structure of genetic variation needed for future selections (Danell 1993). The Swedish breeding programme is focused on Norway spruce, Scots pine, lodgepole pine and silver birch. Other species are subjected to minor intermittent breeding efforts.

Besides managing genetic variation and structure, the breeding programme has other features that enhance the scope for developing and selecting well adapted genetic material for the future.

- The generation time in tree breeding is generally 20–30 years, which is less than half the generation time in nature, so the adaptation process is faster in the breeding population than in nature.
- Nature always selects for the current climate. In breeding programmes we can

In conclusion, the principal motive for conducting research related to risk management in the context of climate change is to help make better forestry decisions. For this we need to better understand both the direct effects of climate change on the bio-physical system and its indirect effects mediated via the social system. A set of key terms summarising the issues involved would include: analytical framework for risk management, risk perception, understanding effects of climate change, risk factors, decision support, risk communication and decision strategy.

select for a future predicted climate by testing in artificial or natural conditions that resemble the predicted climate.
- In the breeding programme each genotype is tested in the field at several sites with different climates. This provides knowledge that can be used for future recommendations on the transfer of genetic material.

Species selection

If drastic climatic changes occur in the future it may be impossible to find well adapted material of our main forestry species. Switching to species better adapted to the new climate would probably be the best option under such circumstances. Southernmost Sweden is the area where this development would be most likely to occur, and Norway spruce the most likely species to be affected. To supply the spruce-based industry in the region with similar raw material, plantations of Sitka spruce could be appropriate options. Other alternative tree species could be found among native hardwoods.

Another relevant reason for switching the species used is that climate change may alter the relative competitiveness among species. This could help make species other than those used today commercially attractive. Changes in soil moisture due to changes in precipitation and evaporation could change the choice of species on certain sites. Less precipitation in the summer in southern Sweden could, for instance, make Scots pine more suitable on some sites that at present would be best suited for Norway spruce.

Regeneration practices

The likelihood that summer droughts will become more frequent has implications for regeneration practices. Site preparation measures involving the creation of patches or mounds of mineral soil are commonly used

Our most economically important tree species are managed in the breeding programme. Therefore, they offer the best opportunities for rapid adaptation and knowledge-based material transfer. Tree species of minor economic importance receive less attention from forestry and may have greater difficulties in adapting to a rapidly changing climate. Since climate change will probably make forestry with some alternative species a viable option, at least in southern Sweden, it could be appropriate to allocate more of the breeding efforts to these species.

Breeding-related research should focus on.
- A wider range of species than today
- Methods for genetic testing for future climate scenarios
- Studies of transfer effects and G×E interactions
- Methods and scope for resistance breeding

The use of a broader range of species could offer a means for forest landowners to spread the risks of an uncertain future. A warmer climate will likely increase the number of species that are suitable for forest production in most of Sweden. Trees can be mixed within stands or as a mosaic of monocultures of different species. Research should consequently allocate more resources to forestry species that may be interesting in the future.

today. One of the beneficial effects of this practice is that it improves water availability for the seedlings. In a future, drier summer climate thorough site preparation would become even more important than today. More intensive site preparation may also be needed to control ground vegetation since it may otherwise compete increasingly intensely with the seedlings for water, nutrients and light. Chemical control of competing vegetation is commonly used in plantation forestry in warmer countries and this could be necessary in Sweden as well, if alternative methods are not developed.

Direct seeding is used in some areas today. The germination of the seeds are very poor during droughts and the method is currently not recommended on dry sites in south-eastern Sweden. If future summers will become drier, this could lead to a decrease in the area that is suitable for direct seeding.

The future need to establish forests with species and genetic materials that are adapted to the new climate will probably lead to an increased use of artificial regeneration, mainly planting. Natural regeneration with the old maladapted seeds from the old stands will probably not be a viable alternative. However, natural regeneration will probably be possible with several species in areas where climate currently limits seed production, e.g. Scots pine in high altitudes in northern Sweden and beech in southern and central Sweden.

Stand management

Climate change will change the site conditions on forestland over the whole of Sweden. This will change the relative competitiveness of the tree species. For southern Finland, Kellomäki & Kolström (1992) have predicted that silver birch will become more competitive relative to Scots pine in a future climate and they conclude that more intense cleaning of broadleaves will be necessary if Scots pine is to be used as a production species in the future. Changes in competitiveness among species would likely have effects on stand management in most mixed species stands.

The most significant change in stand management is likely to be towards shorter rotations, for several reasons. First, the increased productivity of the forest stands will make the optimal rotation time shorter. Second, the genetic material planted today will not be optimally adapted to the future climate and it could be desirable to replace it with better adapted material to exploit the productivity of the site. Third, the non-optimal adaptation of the trees in the later part of the rotation may lead to damage that necessitates an earlier final harvest than planned. Shorter rotations due to increased productivity can increase the economic return of investments in silviculture. This may result in more intensive stand establishment and management methods being deployed in some regions and by some landowners.

Stand management may also be affected by calamities like windthrow and attacks by bark beetles or root rot becoming more frequent, as expected in some areas. Management measures to foster forest health may include early and hard thinning to promote stability and vigour in the trees, stump treatments against rots, and restrictions on the amount of wood left in the forest after harvest.

Research should focus on regeneration methods adapted to dry summers and drought spells. This includes development of site preparation methods, seedling material and after-planting treatments. Methods should also be adapted to the possibilities of increased competition from ground vegetation.

More research in this area is needed on:
- The impact on tree health of different management methods and logging operations.
- Methods promoting intensive management and shorter rotations.
- Forest management in stands of alternative species and mixtures of species.

Health monitoring

In a rapidly changing climate, monitoring the health of the forest is very important in order to take necessary actions to prevent adverse effects. The health of the Swedish forests is continuously monitored by the Swedish National Forest Inventory. A system of sample plots is assessed at regular intervals and data about the sites and trees are recorded. Health is also monitored by the National Board of Forestry through surveys among their local forestry districts. The monitoring system is probably satisfactory, but there may be a need to monitor additional traits and to follow up carefully the results of the inventories in the future.

Quarantine

To prevent new pests and pathogens entering the country that could establish in Sweden if the climate becomes warmer, quarantine regulations can be used. Quarantine regulations are more likely to be effective in Sweden, which has a fortunate geographical location in this respect, with a sea border separating it from neighbouring countries to the south, than they would probably be in many other countries.

Conclusions

The most likely effects of climate change on trees and forests are summarised in Table 1. The general prediction is that potential biomass production, the opportunities to grow new species commercially and the risks of several kinds of damages will all increase. It seems that climate change will offer new opportunities to forestry, while increasing the risks of calamities occurring (and/or making them more difficult to anticipate and thus handle) demanding new approaches to forest- as well as risk-management.

It should be considered that most of the studies referred to in this report are based on rather old climate scenarios and, furthermore, the scenarios used vary considerably from one study to another. The studies often consider only one factor, often temperature. In rare cases a few factors and their interactions have been considered, but virtually all of the studies published so far have failed (or been unable) to consider all of the climatic factors expected to change with increased CO_2 concentrations in the atmosphere. Some

Table 1. Likely effects of climate change on forest productivity and health in Sweden in a short to medium time span (20–100 years). + = increase, - = decrease.

Changes in:	Southern Sweden	Central Sweden	Northern Sweden
Tree species diversity	++	+++	+
Wood production	+++	+++	+++
Damages caused by:			
Windthrow	+	+	+
Snow breakage	-	-	-
Forest fires	+	+	±
Spring frost	±	±	±
Autumn frost	-	-	-
Winter damage	+	±	±
Hardwood decline	+	+	±
Drought	++	+	±
Waterlogging	+	+	++
Invertebrates	+	+	+
Vertebrates	±	+	+
Microorganisms and fungi	±	±	±
Ground vegetation	+	+	+

of the more recent studies that have focused specifically on Swedish forests have started using the more consistent set of regional climate scenarios provided by SWECLIM. There have also been very few attempts to model the effects of transient climate change scenarios, despite the fact that in practice the climate will change gradually.

Research needs

This literature review has revealed major shortcomings in our knowledge about impacts that an expected climate change will have on the forest ecosystems. Its potential effects on the structure and processes of the forest ecosystems are even more uncertain than the nature and magnitude of the climate change *per se*.

The reviewed literature contains indications of the relevance and importance of a better understanding of the climate-forest/forestry linkages. However, the study also identifies three major obstacles that need to be overcome in order to improve our understanding of the issues, risks and possibilities related to the potential impact of continued climate change on forests and forestry:

1) Studies so far have generally addressed specific aspect of the overall forestry/forest system, instead of exploring aspects of the system as a whole and feedback mechanisms (cf. Figure 5).
2) Studies published to date have differed in their choice of climate change scenario. Thus, they refer to different changes in temperature, precipitation etc. making it difficult to collate the findings and to synthesis a coherent body of knowledge.
3) The transience of the anticipated climate change has not been included in the studies, as they typically refer to the effects of a specified new climate regime. However, rather than switching instantaneously to a new static climate sometime in the future, the forest and forestry will be experiencing continuous, ongoing changes in climate, implying that conditions will be constantly changing within a typical rotation period, and from one rotation to the next.

Swedish forests are the prime raw material for the forest-based industry that is very important nationally. The need for management and the long rotation period for this renewable raw material makes its increasingly important to improve our knowledge base about effects of climate change, our scope to take measures early enough to counteract negative effects and to take advantage of opportunities for improved growth.

In parallel with the concern related to the raw material base, various human activities, such as land-use (including forestry) and air pollution have profound effects on the forest ecosystems, severely impacting the structure and function of the forest ecosystems. The impact of climate change on factors such as biodiversity and biogeochemical processes has to be included in the future research.

Future research into the effects of climate change on forest ecosystems has to take account of a broad spectrum of scientific fields, but a multidisciplinary scientific approach is probably essential. Obvious areas which have to be interactively considered include:

- The development of climate scenarios, including climate-forest interactions
- The effect of climate change on soil physical, chemical and biological processes, including their relationships to tree growth
- Biomass production and forest management strategies, including development and selection of genetic material.
- The effect of climate change on vertebrates, invertebrates, microorganisms (including fungi) and ground vegetation
- Risk and risk management

References

Alavi, G. 1996. Radial stem growth of Picea abies in relation to spatial variation in soil moisture conditions. Scand. J. For. Res. 11: 209–219.

Anderbrant, O. 1986. A model for the temperature and density dependent re-emergence of the bark beetle *Ips typographus*. Entomologia Experimentalis et Applicata 40: 81–88.

Auclair, A.N.D., Lill, J.T. & Revenga, C. 1996. The role of climate variability and global warming in the dieback of northern hardwoods. Water, Air and Soil Pollution 91: 163–186.

Austarå, Ö. 1971. Cold hardiness in eggs of *Neodiprion sertifer* (Geoffroy)(Hym., Diprionidae) under natural conditions. Norsk Entomologisk Tidskrift 18: 45–48.

Bakke, A. 1983. Host tree and bark beetle interaction during a mass outbreak of *Ips typographus*. Z. Angew. Entompl. 99:118–125.

Bale, J.S. et al. 2002. Herbivory in global change research: direct effects of rising temperature on insect herbivores. Global Change Biology 8: 1–16.

Ball, J.P., Ericsson, G. & Wallin, K. Climate change, moose and their human predators. In: Animal responses to global change in the north. Hofgaard, A., Ball, J.P., Danell, K. & Callaghan, T. (eds.). Ecological Bulletins 47. Lund. Sweden.

Barklund P. 2002 Ekskador I Europa. Skogsstyrelsen, Jönköping. Rapport No 1. In Swedish.

Bejer-Petersen, B., Juutinen, P., Kangas, E., Bakke, A., Butovitsch, V. Eidmann, H. Hedqvist, K.J. & Lekander, B. 1962. Studies on *Hylobius abietis* L. I. Development and life cycle in the Nordic countries. Acta Entomologica Fennica 17: 1–106.

Bergeron, Y. & Flannigan, M.D. 1995. Predicting the effect of climate change on fire frequency in the southeastern Canadian boreal forest. Water, Air and Soil Pollution 82: 437–444.

Bergh, J., Freeman, M. & Räisänen, J. Effects of global change on net primary production in northern Europe – a model based analysis with a regional resolution. Manuscript.

Bergh, J., Linder, S., Lundmark, T. & Elfving, B. 1999. The effect of water and nutrient availability on the productivity of Norway spruce in northern and southern Sweden. For. Ecol. Manage. 119: 51–62.

Bergh, J. 1997. Climatic and nutritional constraints to productivity of Norway spruce. Acta Universitatis Agriculturae Suecica. Silvestria 37. PhD-thesis. 34 pp.

Bergh, J., Flemberg, S., Kindberg, J., Linder, S., Räisänen, J., Strömgren, M. & Wallin, J. 2000. Framtida klimatförändringar – tänkbara effekter på den svenska skogen. Fakta Skog, SLU, Uppsala. Nr 13. 4 pp. In Swedish.

Bergh, J., Freeman, M., Sigurdsson, B., Kellomäki, S., Laitinen, K., Niinistö, S., Peltola, H. & Linder, S. Modelling the short-term effects of climate change on the productivity of selected tree species in Nordic countries. Manuscript.

Beuker, E., Kolström, M. & Kellomäki, S. 1996. Changes in wood production of *Picea abies* and *Pinus sylvestris* under a warmer climate: Comparison of field measurements and results of a mathematical model. Silva Fennica 20(2–3): 239–246.

Blennow, K., & Sallnäs, O. WINDA – A system of models for assessing the probability of wind damage to forest stands within a landscape. Ecological Modelling. In press.

Blennow, K., & Sallnäs, O., 2002. Risk perception among non-industrial private forest owners. Scandinavian Journal of Forest Research 17: 472–479.

Bond, W.J. & Richardson, D.M. 1990. What can we learn from extinctions and invasions about the effects of climate change? South African Journal of Science: 86: 429–433.

Bradshaw, H.W., Holmqvist, B.H., Cowling, S.A. & Sykes, M.T. 2000. The effect of climate change on the distribution and management of *Picea abies* in southern

Scandinavia. Can. J. For. Res. 30: 1992–1998.

Bylund, H. 1997. Stand age-structure influence in a low population peak of Epirrita *autumnata* in a mountain birch forest. – Ecography 20:319–326.

Bylund, H. 1999. Climate and the population dynamics of two insect outbreak species in the north. – Ecol. Bull. 47:54–62.

Cederlund. G., Ljungqvist, H., Markgen, G. & Stålfelt, F. 1980. Foods of moose and roe deer at Grimsö in central Sweden, results of rumen content analysis. Swedish Wildlife Research. 11(4): 169–247.

Ciencialia, E., Kucera, J., Ryan, M.G & Lindroth, A. 1998. Water flux in boreal forest during two hydrologically contrasting years; species specific regulation of canopy conductance and transpiration. Ann. Sci. For. 55: 47–61.

Coops, N.C. & Waring, R.H. 2001. Assessing forest growth across south-western Oregon under a range of current and future global change scenarios using a process model, 3-PG. Global Change Biology. 7: 15–29.

Danell, Ö. 1993. Breeding programs in Sweden, general approach. *In* Progeny testing and breeding strategies. Proceedings of the Nordic group of forest tree breeding. Lee S.J. (ed). Forestry Commission. Edinburgh, U.K. 184 p.

Eamus, D & Jarvis, P.G. 1989. The direct effects of increase in the global atmospheric CO_2 concentration on natural and commercial temperate trees and forests. Advances in Ecological Research 19: 1–53.

Eriksson, G. & Ekberg, I. 2001 An introduction to forest genetics. Swedish Univeristy of Agricultural Scienses. Uppsala. pp 165.

Evans, H.F., McNamara, D.G., Braasch, H., Chadoeuf, J. & Magnusson, C. 1996. Pest risk analysis (PRA) for the territories of the European Union (as PRA area) on *Bursaphelenchus xylophilus* and its vectors in the genus *Monochamus*. EPPO Bulletin 26. 199–249.

Evans, H., Straw, N. & Watt, A. 2002. Climate change: implications for insect pests. Forestry Commission Bulletin, Forestry Commission, Edinburgh, UK. No 125. 99–118.

Fleming, R.A. & Volney, W.J.A. 1995. Effects of climate change on insect defoliator population processes in Canada's boreal forest: some plausible scenarios. Water, Air and Soil Pollution. 82: 445–454.

Gärdenäs, A. & Jansson, P-E. 1995. Simulated water balance of Scots pine stands in Sweden for different climate change scenarios. J. Hydrol. 166: 107–125.

Hannerz 1998. Genetic and seasonal variation in hardiness and growth rhythm in boreal and temperate conifers – a review and annotated bibliography. The Forestry Research Institute of Sweden. Report No. 2: pp.140.

Harrington, R, Fleming, R.A. & Woivod, I.P. 2001. Climate change impacts on insect management and conservation in temperate regions: can they be predicted? Agricultural and Forest Entomology 3: 233-240.

Harrington, R., Woiwod, I. & Sparks, T. 1999. Climate change and trophic interactions. TREE 14(4): 146-150.

Hellgren, M. 1995. *Gremmeniella abietina* – disease biology and genetic variation within Fennoscandia. Swedish University of Agricultural Sciences. Dissertation.

IPCC 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., and Johnson, C. A. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 p.

Jarvis, P. & Linder, S. 2000. Constraints to growth in boreal forests. Nature. 405: 904–905.

Johnsen, Ø., Skrøppa, T., Haug, G., Apeland, I. & Østreng, G. 1995. Sexual reproduction in a greenhouse and reduced autumn frost hardiness of *Picea abies* progenies. Tree Physiology 15:551–555.

Jönsson, A.M., Linderon, M-L., Stjernquist, I. And Schlyter, P. 2004. Climate change and the effect of temperature backlashes causing frost damage in *Picea abies*. Submitted manuscript.

Karns, P.D. 1997. Population distribution, density and trends. In: Ecology and management of the north America moose. Franzmann, A.W. & Schwartz, C. (eds.). Smithsonian Institution Press. Washington and London. 125–127.

Kellomäki, S. & Kolström, M. 1992. Computations on the management of seedling stands of Scots pine under the influence of changing climate in southern Finland. Silva Fennica 26(2): 97–110.

Kilander, S. 1955. Kärlväxternas övre gränser på fjäll i sydvästra Jämtland samt angränsande delar av Härjedalen. Acta Phytogeographica Suecica 35: 1–98. In Swedish.

Korhonen, K. Stenlid, J. Capretti, P. & Karjalainen, R. 1998. Distribution of *Heterobasidion annosum* intersterility groups in Europe. In: Woodward, S., Stenlid, J., Karjalainen, R. & Hüttermann, A. A. *Heteribasidion annosum* biology, ecology, impact and control. CAB International, Wallingford, UK pp. 93–104.

Kullman, L. 2002. Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. J. Ecol. 2002. 90: 68–77.

Lasch, P., Lindner, M., Erhard, M., Suckow, F. & Wenzel, A. 2002. Regional impact assessment on forest structure and functions under climate change – the Brandenburg case study. For. Ecol. Manage. 162: 73–86.

Lindner, M. 2000. Developing adaptive forest management strategies to cope with climate change. Tree Physiology 20: 299–307.

Linit, M.J. 1988. Nematode-vector relationships in the pine wilt disease system. Journal of Nematology 20: 227–235.

Löyttyniemi, K. et al. 1979. Insect pests in forests of the Nordic countries 1972–1976. Folia Forest. 395:1–13.

Medlyn, B.E., Barton, C.V.M., Broadmeadow, M. Ceulemans, R., de Angelis, P., Forstreuter, M., Freeman, M., Jackson, S.B., Kellomäki, S., Laitat, E., Rey, A., Roberntz, P., Sigurdsson, B., Strassenmeyer, J., Wang, K., Curtis, P.S. & Jarvis, P.G. 2001. Elevated CO_2 effects on stomatal conductance in European forest species: a synthesis of experimental data. New Phytologist 149: 247–264.

Nakićović N, Alcamo J, Davis G, de Vries B, Fenhann J, Gaffin S, Gregory K, Grübler A, Jung TY, Kram T, La Rovere EL, Michaelis L, Mori S, Morita T, Pepper W, Pitcher H, Price L, Raihi K, Roehrl A, Rogner H-H, Sankovski A, Schlesinger M, Shukla P, Smith S, Swart R, van Rooijen S, Victor N, Dadi Z (2000) Emission Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, 599 pp.

Niemelä, P., Chapin III, F.S., Danell, K. and Bryant, J.P. 2001. Herbivory-mediated responses of selected boreal forests to climatic change. – Climatic Change 48:427–440.

Olofsson, E. and Blennow, K. Decision support for identifying spruce stand edges with high probability of wind damage. Forest Ecology and Management, In press.

Peltola, H., Kellomäki, S. & Väisänen. H. 1999. Model computations of the impact of climatic change on the windthrow risk of trees. Climatic Change 41: 17–36.

Persson, P., 1975. Stormskador på skog – Uppkomstbetingelser och inverkan på skogliga åtgärder. (Windthrow in forests – It's causes and the effect of forestry measures). Department of Forest Yield Research, Royal College of Forestry, Stockholm. Research Notes 36. In Swedish with English summary.

Persson, B. 1998. Will climate change affect the optimal choice of *Pinus sylvestris* provenances? Silva Fennica 32: 121–128.

Pretzsch, H. & Dursky, J. 2002. Growth reaction of Norway spruce (*Picea abies* (L.)

Karst.) and European beech (*Fagus sylvatica* L.) to possible climatic changes in Germany. A sensitivity study. Forstw. Cbl. 121(1): 145–154.

Ray, D., Pyatt, G. & Broadmeadow, M. 2002. Modelling the future suitability of plantation forest tree species. Forestry Commission Bulletin, Forestry Commission, Edinburgh, UK. No 125. 151–167.

Redfern, D. & Hendry, S. 2002. Climate change and damage to trees caused by extremes of temperature. Forestry Commission Bulletin, Forestry Commission, Edinburgh, UK. No 125. 29–39.

Redfern, D.B. & Stenlid, J. 1998. Spore dispersal and infection. In: Woodward, S., Stenlid, J., Karjalainen, R. & Hüttermann, A. A. *Heteribasidion annosum* biology, ecology, impact and control. CAB International, Wallingford, UK pp. 105–124.

Rummukainen, M. 2003. The Swedish regional climate modeling program, SWECLIM, 1996–2003. Final report. *Reports Meteorology and Climatology 104,* SMHI, Norrköping, Sweden, 47 pp.

Rustad, L.E., Campbell, J.L., Marion, G.M. et al. 2001. A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia 126: 543–562.

Räisänen, J., Hansson, U., Ullerstig, A., Döshser, R., Graham, L.P., Jones,C., Meier, M., Samuelsson, P. & Willén, U. 2003. GCM driven simulations of recent and future climate with the Rossby centre coupled atmosphere – Baltic Sea regional climate model RCAO. SMHI, Reports Meteorology and Climatology. No 101. 61 p

Räisänen, J., Hansson, U., Ullerstig, A., Döshser, R., Graham, L.P., Jones,C., Meier, M., Samuelsson, P. & Willén, U. 2004. European climate in the late 21st century: regional simulations with two driving global models and two forcing scenarios. Climate Dynamics 22: 13–31.

Schmidtling, R.C. 1994. Use of provenance tests to predict response to climate change: Loblolly pine and Norway spruce. Tree Physiol. 14: 805–817.

Shaver, G.R., Canadell, J., Chapin III, F.S. Gurevitch, J., Harte, J., Henry, G., Ineson, P., Jonasson, S., Mellilo, J., Pitelka, L. & Rustad, L. 2000. Global warming and terrestrial ecosystems: a conceptual framework for analysis. Bioscience 50(10) 871–882.

Skre, O. & Nes, K. 1996. Combined effects of elevated winter temperatures and CO_2 on Norway spruce seedlings. Silva Fennica 30(2–3): 135–143.

Sonesson, J. 2001. Skogsodlingsmaterial för framtidens klimat. Skogforsk. Resultat No 6. 4 p, In Swedish with English summary

Sonesson, J. & Eriksson, G. 2000. Genotypic stability and genetic parameters for growth and biomass traits in a water?temperature factorial experiment with *Pinus sylvestris* L. seedlings. For. Sci. 46(4): 487–495.

Sonesson, J., Jansson, G. & Eriksson, G. 2002. Retrospective genetic testing of *Picea abies* under controlled temperature and moisture regimes. Can. J. For. Res. 32(1) 81–91.

Straw, N.A. 1995. Climate change and the impact of green spruce aphid, *Elatobium abietinum* (Walker), in the UK. Scottish Forestry. 49(3): 134–145.

Strömgren, M & Linder, S. 2002. Effects of nutrition and soil warming on stemwood production in a boreal Norway spruce stand. Global Change Biology 8: 1195–1204.

Suffling, R. 1992. Climate change and boreal forest fires in Fennoscandia and central Canada. In: Boer, M. & Koster, E. (eds.). Greenhouse impact on cold-climate ecosystems and landscapes. Catena Supplement No 22: 111–132.

Sykes, M.T. & Prentice, I.C. 1995. Boreal forest futures: modelling the control on species range limits and transient response to climate change. In: Apps, M.J., Price, D.T. & Wisniewski, J. (eds.). Boreal forests and global change: peer-reviewed manuscripts selected from the International Boreal Forest Research Association conference, held in Saskatoon, Saskatchewan, Canada, September 25–30 1994. Water, Air and Soil Pollution 82(1–2). 415–428.

Tenow, O. 1996. Hazards to a mountain birch forest-Abisko in a perspective. – Ecol. Bull. 45:104–114.

Tenow, O. 1975. Topographical dependence of an outbreak of *Oporinia autumnata* Bkh. (*Lep., Geometridae*) in a mountain birch forest in northern Sweden. – ZOON 3:85–110.

Tenow, O., Bylund, H. and Holmgren, B. 2001. Impact on mountain birch forests in the past and the future of outbreaks of two geometrid insects. – In F.E. Wielgolaski (ed.), Nordic mountain birch ecosystems. Man and Biosphere series vol. 27., Parthenon Publishing group, New York, pp. 223–239.

Thompson, D.G. 1998. Getting the species and provenances right for climate change. Irish Forestry. 55(2): 114–121.

Thompson, I.D., Flannigan, M.D., Wotton, B.M. & Suffling, R. 1998. The effect of climate change on landscape diversity: an example in Ontario forests. Environmental Monitoring and Assessment 49: 213–233.

Venäläinen, A., Tuomenvirta, H., Heikinheimo, M., Kellomäki, S., Peltola, H., Strandman, H, & Väisänen, Hannu. 2001. Impact of climate change on soil frost under snow cover in a forested landscape. Climate Research. 17: 63–72.

Virtanen, T., Neuvonen, S., Nikula, A., Varama, M. & Niemelä, P. 1996. Climate change and the risks of *Neodiprion sertifer* outbreaks on Scots pine. Silva Fennica 30(2–3): 169–177.

Virtanen, T., Neuvonen, S. and Nikula, A. 1998. Modelling topoclimatic patterns of egg mortality of *Epirrita autumnata* (*Lepidoptera: Geometridae*) with Geographical Information System: predictions for current and warmer climate scenarios. – Journal of Appl. Ecology 35:311–322.

Virtanen, T. & Neuvonen, S. 1999. Climate change and macrolepidopteran biodiversity in Finland: Global Change Science 1: 439–448.

Virtanen, T. and Neuvonen, S. 1999. Performance of moth larvae on birch in relation to altitude, climate, host quality and parasitoids. – Oecologia 120:92–101.

Volney, W.J.A. & Fleming, R.A. 2000. Climate change and impacts of boreal forest insects. Agriculture, Ecosystems and Environment 82: 283–294.

Väisänen, H., Strandman, H. & Kellomäki, S. 1994. A model for simulating the effects of changing climate on the functioning and structure of the boreal forest ecosystem: an approach based on object-oriented design. Tree Physiology. 14: 1081–1095.

Watson, R.T., Zinyowera, M.C., Moss, R.H. & Dokken, D.J. 1997. The Regional Impacts of Climate Change: An Assessment of Vulnerability. Special Report of IPCC Working group II. Cambridge University Press, UK. pp 517.

Wargo, P.M. & Harrington, T.C. 1991. Host stress and susceptibility . I: *Armillaria* root disease. CG Shaw III and G.A Kile (eds.) USDA forest service agricultural handbook No 691. Washington DC pp 88–101.

Wilhelmsson, L., Arlinger, J., Spångberg, K., Lundqvist, S-O., Grahn, T., Hedenberg, Ö. & Olsson, L. 2002. Models for predicting wood properties in stems of *Picea abies* and *Pinus sylvestris* in Sweden. Scand. J. For. Res. 17: 330–350.

Zheng, D., Freeman, M., Bergh, J., Rösberg, I. & Nilsen, P. 2002. Production of *Picea abies* is south-east Norway in response to climate change: A case study using process-based model simulation with field validation. Scand. J. For. Res. 17: 35–46.

Personal communications

Ragnar Friberg
Göran Örlander

Förteckning över tidigare utgivna nummer

År 2003; Årgång 142

Nr 1 Det sydsvenska landskapet, framtidsvisioner och framtidssatsningar SAMT Idéer för framtidens skogslandskap
Nr 2 Viltets positiva värden
Nr 3 Inför toppmötet i Johannesburg
Nr 4 Kapital för landsbygdsföretagare
Nr 5 Kompetensförsörjningen i svenskt jordbruk
Nr 6 Fiskets miljöeffekter – kan vi nå miljömålen?
Nr 7 Verksamhetsberättelse 2002
Nr 8 De glesa strukturerna i den globala ekonomin – kunskapsläge och forskningsbehov
Nr 9 Tro och vetande om husdjurens välfärd (Enbart publicerad på www.ksla.se)
Nr 10 Svenska satsningar på ökad träanvändning (Enbart publicerad på www.ksla.se)
Nr 11 Kapital för landsbygdsföretagare (Enbart publicerad på www.ksla.se)
Nr 12 Feminisering av Moder natur? Östrogener i naturen och i livsmedel
Nr 13 Crop and Forest Biotechnology for the Future
Nr 14 Landskap och vindkraft – i medvind eller motvind (Enbart publicerad på www.ksla.se)
Nr 15 Lantbrukskooperationen – Hållbar företagsidé eller historisk parentes
Nr 16 Utvecklingen i Polen
Nr 17 Mid Term Review Vad händer i Sverige när EU ändrar jordbrukspolitik?
Nr 18 Soil and surface water acidification in theory and practice
Nr 19 Skogsindustrinsråvaruförsörjningskedja – pågående utveckling och utblickar mot andra branscher
Nr 20 CAP och folkhälsan
Nr 21 Vilda djur i stadsmiljö – Tillgång eller problem? –
Nr 22 Översvämningar och deras orsaker
Nr 23 Sötvattenfisk – Framtidens resurs (Enbart publicerad på www.ksla.se)
Nr 24 Mat med mervärden – Goda affärer (Enbart publicerad på www.ksla.se)
Nr 25 Hur planeras boendet på landsbygden? OCH Trädgården som rekreation och terapi (Enbart publicerad på www.ksla.se)
Nr 26 Det nya uppdraget – högre utbildning för landsbygd och landskap (Enbart publicerad på www.ksla.se)
Nr 27 Hör göken han gal – Hur kan ekologiskt lantbruk och samhället gynna den biologiska mångfalden? (Enbart publicerad på www.ksla.se)
Nr 28 Den svenska modellen för husdjursavel och dataregistrering samt datautnyttjande inom husdjurs- och växtodlingsområdet (Enbart publicerad på www.ksla.se)

År 2004; Årgång 143

Nr 1 Ecosystem services in European agriculture – theory and practice
Nr 2 Vad gör vi när vi inte vet? (Enbart publicerad på www.ksla.se)
Nr 3 Ekologiskt Forum mönstrar köttet och marknaden (Enbart publicerad på www.ksla.se)
Nr 4 Jordbruk – ekologi – samhälle (Enbart publicerad på www.ksla.se)
Nr 5 LBU-programmet, skogen och landsbygden – till vilken nytta? (Enbart publicerad på www.ksla.se)
Nr 6 Framtida forskning inom den gröna sektorn (Enbart publicerad på www.ksla.se)
Nr 7 Ekologisk produktion med miljönytta (Enbart publicerad på www.ksla.se)
Nr 8 Har jord- och skogsbruk en roll i framtidens kultur? (Enbart publicerad på www.ksla.se)
Nr 9 Aktuella trämekaniska alternativ (Enbart publicerad på www.ksla.se)
Nr 10 Mat för livet eller dödlig diet? (Enbart publicerad på www.ksla.se)
Nr 11 Verksamhetsberättelse 2003
Nr 12 Kvävehushållning och kväveförluster – förbättringsmöjligheter i praktiskt jordbruk
Nr 13 Sigvard Andersson – En nyskapande forskar- och lärargärning i markfysik
Nr 14 Vem köper biologisk mångfald? (Enbart publicerad på www.ksla.se)
Nr 15 Svenskt jordbruk i EU-25 – Östutvidgningens betydelse för jordbruks- och livsmedelsnäringen i Sverige (Enbart publicerad på www.ksla.se)
Nr 16 Vad är tvivelaktigt med vattenorganisationens direktiv? What's fishy about the Water Framwork Directive? (Enbart publicerad på www.ksla.se)
Nr 17 Behövs en tredje aktionsplan för ekologisk produktion? (Enbart publicerad på www.ksla.se)
Nr 18 Climate change and forestry in Sweden – a literature review

Kungl. Skogs- och Lantbruksakademiens Tidskrift (KSLAT) har, under olika namn, utkommit sedan 1813, då akademien grundades. Från och med 1994 utges KSLAT som en numrerad serie av skrifter (15–20 häften/år) med egna titlar. Innehållet består huvudsakligen av dokumentering från akademiens sammankomster och seminarier – även debattnummer förekommer – och speglar akademiens verksamhetsområde; de areella näringarna och till dessa knutna verksamheter.

Prenumerationspris 350 kr/år.

Kungl. Skogs- och Lantbruksakademien
Drottninggatan 95 B, Box 6806, 113 86 Stockholm
Tel 08-54 54 77 00, Fax 08-54 54 77 10, Postgiro 18 32 80 - 7

ISSN 0023–5350 ISBN 91–89379-94-2

Pris 75:-

Eskilstuna Offset AB, Eskilstuna 2004