Climate change affects the ecosystem services provided by nature to mankind. For example, diverse ecosystems, pristine, sufficient and good quality water resources or balanced water economy in urban areas are under threat. Changing and degenerating ecosystem services may also violate the nature-based livelihoods as agriculture, forestry, fishery, and nature tourism. Climate is changing, and adaptation is a burning issue already at the moment.

The effects of climate change and the conditions for adaptation of ecosystem services and livelihoods has been estimated by EU LIFE+ funded project VACCIA (Vulnerability Assessment of Ecosystem Services for Climate Change Impacts and Adaptation — VACCIA). The three-year (2009–2011) project was led by the Finnish Environment Institute SYKE and participated by Finnish Meteorological Institute and the universities of Helsinki, Jyväskylä and Oulu. In this Synthesis Report, the main results of the VACCIA project and arising conclusions as well as the central adaptation challenges are presented. The impact mechanisms within the ecosystems are complicated and still largely unknown, and much research and surveying is still needed to successfully adapt to climate change.

Ecosystem services and livelihoods – vulnerability and adaptation to a changing climate

VACCIA Synthesis Report

Bergström Irina, Mattsson Tuija, Niemelä Eerika, Vuorenmaa Jussi, Forsius Martin (eds.)

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Helsinki 2011

Finnish Environment Institute
FOREWORD

Climate change poses a major challenge for mankind. As the climate changes, ecosystem services — that is, the important goods and services provided by nature — come under threat. For example, diversity of ecosystems or availability of sufficient clean and good-quality water resources may be endangered. In addition to the environment, climate change affects livelihoods, such as agriculture, forestry, fishing, and nature tourism, as well as land use in the urban environment. Climate change is here already. Will we be able to mitigate its effects, and how can we adapt to the inevitable changes brought by the future?

The threats and challenges to ecosystem services and for means of livelihood that are caused by climate change, and their capacity to adapt to change in the environment, were evaluated in the EU LIFE+ funded project ‘Vulnerability Assessment of Ecosystem Services for Climate Change Impacts and Adaptation – VACCIA’. Contributors to this extensive project, for 2009–2011, came from the Finnish Environment Institute (project coordination); the Finnish Meteorological Institute; and the universities of Helsinki, Jyväskylä, and Oulu. For a range of periods over its three years, the project employed about 100 experts from these institutions, along with further experts, from MTT Agrifood Research Finland and the Finnish Game and Fisheries Research Institute.

The Synthesis Report presents the main results of the VACCIA project, produced by the 13 subprojects (‘Actions’) of the project. It is our hope that a wide audience gain good insight into the effects of climate change on Finnish nature and on possible means by which nature and nature-based livelihoods can adapt to the change.

We also hope that the results of the VACCIA project can be utilised regionally, nationally, and internationally in work to find ways to face the common climate challenge.

We want to thank all VACCIA researchers and experts who have participated in the writing of the Synthesis Report. We extend many thanks also to Heikki Toivonen, the Finnish Environment Centre, and Susanna Kankaanpää, the Helsinki Region Environmental Services Authority, for their invaluable comments on the manuscript. We are grateful also to Jenni Simkin, for arranging the editing of the English-language version of the report.

Helsinki, 29th November 2011

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EXECUTIVE SUMMARY
Martin Forsius

The vulnerability of ecosystem services provided by nature to climate change and the possibilities for adaptation of different sectors of society to these changes were studied in the Vulnerability Assessment of Ecosystem Services for Climate Change Impacts and Adaptation (VACCIA) project. The project was funded by the LIFE+ instrument of the EU (project LIFE07 ENV/FIN/000141). This extensive project was carried out in 2009–2011. Coordinated by the Finnish Environment Institute (SYKE), it also had participants from the Finnish Meteorological Institute and the universities of Helsinki, Jyväskylä, and Oulu. The project was based on data and infrastructures of intensively studied areas belonging to the Finnish Long-Term Socio-Ecological Research (FinLTSER) network. In the following synthesis report, among the results and conclusions presented in this report; also some publications and other products (see Annex 6) produced in the VACCIA project are notified.

The key aims of the VACCIA project were to:
• Derive realistic environmental change scenarios.
• Demonstrate and develop the use of remote sensing information (GMES) for the assessment of ecosystem services and their changes.
• Develop modelling, geographic information system (GIS), and database tools for ecosystem change assessments.
• Assess how anticipated climate change would change the production of ecosystem services, and identify critical change thresholds.
• Identify options for adaptation to the changing conditions.
• Disseminate information to authorities, decision-makers, and citizens.
• Support local and regional planning and decision-making.
• Provide information for development of national and EU climate change adaptation strategies.

Climate change mitigation and adaptation are complementary strategies. Both the variations in the present climate and increasingly changing conditions require planned adaptation measures. Extreme events and various threshold values of the ecosystems are crucial for the development of feasible adaptation measures. The threshold values depend on the sensitivity of the ecosystems. An ecological threshold can be defined as the point where a small change in the external conditions causes a large and sudden change in the ecosystems. In the VACCIA project, ecosystem changes and their threshold values were assessed from several approaches, including mathematical modelling, analysis of long time series of data, laboratory experiments, and workshops.

Policy processes of relevance for VACCIA
Information on the ecosystem service vulnerability and potential adaptation measures is needed for the development of environmental

policies. For the VACCIA project, key environmental policy processes at the national and international levels are:

- The national climate change adaptation strategy and its update process. The main goals of the strategy have been confirmed in the national climate and energy strategies as well as the climate change and energy foresight study of the government.
- The European Commission White Paper on adaptation, which sets out a framework for reducing the EU’s vulnerability to the impact of climate change. This paper states, for example, that a comprehensive and integrated policy is needed to maintain and improve key ecosystem products and services.
- The Communication from the European Commission – Halting the Loss of Biodiversity by 2010 – and Beyond – Sustaining Ecosystem Services for Human Well-being. This communication identifies key policy areas for action, along with related objectives and supporting measures for meeting the 2010 targets and putting biodiversity on the course to recovery.
- The Communication of the European Commission - Our Life Insurance, Our Natural Capital: An EU Biodiversity Strategy to 2020. This strategy is aimed at reversing biodiversity loss and speeding up the EU’s transition to a resource-efficient and ‘green’ economy.

Development of tools for detection and forecasting of ecosystem changes: climate and air pollution scenarios and remote sensing

The climate change scenarios used in the VACCIA project were based on the results of several general circulation models (GCMs) and three emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) (Special Report on Emission Scenarios, SRES A1B, A2, and B1). The scenarios were used as input data for the ecosystem models used in the project and for the environmental impact assessments. The data were produced as time series and as 30-year means for the periods 2010–2039, 2020–2049, 2040–2069, and 2070–2099. Because the changes are slow and can lie within the bounds of natural variation, the scenarios are uncertain. The main general conclusions based on the scenario data were the following:

- Temperatures increase more in winter than in summer; the number of hot days in summer increases, and hot periods get longer. The thermal (temperature-data-based) winter period grows shorter, and the summer and growth periods get longer.
• The amount of precipitation increases. The increase is greater in the north than in the south. The number of days with heavy rain increases during all seasons. In the south, the number of clear days is likely to increase.
• Snow cover decreases especially in the south, but in Lapland the amount of snow may increase during mid-winter.
• Relative humidity in winter may increase.
• The average wind speed is likely to increase a few per cent in September–April.
• The frost layer will decrease.
• Winters will be cloudier.

The changes in air quality in northern regions were evaluated by means of data from the highly instrumented Pallas station in western Lapland and through the use of integrated air quality modelling systems. A large amount of information has been obtained about the present and future transport patterns of various chemical compounds as well as the temporal trends in air quality. These are the main results and conclusions:
• The copper and nickel industries in Russia cause considerable emissions of sulphur dioxide and heavy metals into the Arctic atmosphere.
• Fairly large improvements in air quality in the Pallas region have occurred in the last 10 to 20 years. Of the trends in concentrations of the 57 compounds evaluated, 24 were of decrease. However, the concentration of DDD (a breakdown product of DDT) was on the rise. No statistically significant trends were observed for 32 compounds.
• Rather small changes in the air mass transport are predicted for northern Finland. The presently dominating north-western winds will become even more dominant, but also southern and western wind patterns will increase. This is likely to cause a further decrease in pollution transport from the industrial sources on the Kola Peninsula.
• Ship emissions are expected to increase in Arctic Sea areas when the ice cover is decreasing. Consequently, the concentrations of several compounds, such as sulphur dioxide (SO2), nitrogen oxides (NOx), black carbon, carbon monoxide (CO), and carbon dioxide (CO2), are expected to increase as a result of these higher emissions. The loads of NOx compounds and black carbon could for this reason even double before 2050 in the Pallas region.
• Increasing concentrations of NOx compounds could increase ozone formation in areas where that formation is currently limited by low NOx concentrations.

Also, several techniques and tools were developed in the project for the assessment of ecosystem changes, including remote sensing, modelling, GIS, and database software:

a) Remote sensing tools

Thanks to their large area of coverage, remote sensing methods allow measurements of changes in entire ecosystems on a large regional scale. Both large-scale spatial and temporal trends can be investigated by means of sequential processed satellite images. One of the main aims of the remote sensing studies in the VACCIA project was to provide spatially extensive information on changes in land use, with particular emphasis on annual changes in snow cover and vegetation patterns in the ecosystems studied.

The primary source of information was daily satellite images of the middle-resolution (250–1000 m) Terra/MODIS, from which time series of snow cover and vegetation indices for 2001–2008 were derived. The time series were calculated...
for five watershed areas and five distinct land-use classes. In addition, time series for water quality in coastal region were assessed, and the area of green space in city watershed areas was quantified. Furthermore, changes in regional-scale water quality and surface water temperatures were assessed for the largest lakes in Finland. New high resolution satellite instruments soon to enter in use will increase the potential of remote sensing further; these instruments will increase the data’s spatial, temporal, and spectral resolution even more.

b) GIS portal of VACCIA (http://maps.tvarminne.helsinki.fi, 15.11.2011)

A GIS portal integrating different kinds of environmental data was developed as part of the project. This portal displays data on both biological parameters (e.g., species distributions) and physical-chemical variables (e.g., salinity, oxygen, and nutrient concentrations) that are known to be sensitive to climate change. The portal offers both scientific and monitoring data. It provides fast access to recently collected relevant information, thus supporting environmental management and decision-making.

c) Mathematical ecosystem models

The use of several mathematical modelling systems for the assessment of ecosystem changes, ecological thresholds, and adaptation measures was demonstrated for different ecosystems:

- Changes in nutrient load and land-use patterns in watersheds: WSFS and INCA-N models.
- Lakes’ thermal properties and fishery information: MyLake model.
- Forestry: LIGNUM, PipeQual, and MicroForest models.
- Agriculture: several models for agricultural production.

Assessment of ecosystem changes: watersheds and surface waters

The impacts and adaptation measures in watersheds and surface waters were assessed in several subprojects of VACCIA. The main results and conclusions were as follows:

- The watersheds and surface water ecosystems of the boreal zone are sensitive to changes in climate. Changes are predicted with respect to both nutrient cycling and leaching of nutrients into the waters.
- The mean annual water flow at Lake Pyhäjärvi (Asikkalanselkä), in southern Finland, is predicted to increase about 10% by 2070–2099 (WSFS model, A1B scenario). The temporal patterns in leaching of phosphorus (P), nitrogen (N), and suspended matter will change: the spring maximum will decrease in spring and summer but increase during winter. If no major changes in land use occur, the changes in annual loads of P and N would be relatively small: from 228 to 230 kg P d⁻¹ and from 9,400 to 9,500 kg N d⁻¹ for 2070–2099 (A1B scenario). The corresponding increase in annual loading of suspended matter would be from 740 to 920 kg d⁻¹.
- Large changes are predicted in the thermal properties and stratification patterns of the lakes. Measurements of the lakes Pääjärvi and Valkea-Kotinen (Häme region, southern Finland) already show a shortened ice-cover period over the last 20 years.
- The results with the MyLake model predict an increase in lake surface temperatures of 2–3°C by 2070–2099. Correspondingly, permanent ice cover would not be formed each year, or ice might form and melt several times during the same winter. Similar results were obtained from lakes Pääjärvi and Valkea-Kotinen with this model system.
- Ecosystem services of small shallow lakes are particularly vulnerable to the effects of advancing climate changes.
The Valkea-Kotinen lake and catchment area is one of the most investigated and monitored sites in Finland, also belonging to the Natura 2000 network. A separate comprehensive report on the main findings for this area was produced as part of the VACCIA project (see www.environment.fi/syke/vaccia and Annex 6).

Changes in ecosystems: coastal areas

The changes in chemical, physical, and biological variables and their interactions in relation to climate change impacts were investigated in coastal areas in southern and western Finland. These results indicate that the environmental conditions have already changed, and further changes are likely to occur. As a result, the distribution, reproduction, and species relations will change or these changes have already occurred.

a) Western Gulf of Finland

Longitudinal scientific data describing changes in the western parts of the Gulf of Finland have been made available via the GIS portal developed and maintained by the Tvärminne Biological Station of the University of Helsinki (see above). The main results and conclusions from these materials are the following:

• Long-term measurements (1939–2007) of water turbidity show a decrease in visibility depth from about 7 m to about 3.5 m, with the greatest changes occurring in the mid-1980s. This points to increasing eutrophication. Increased occurrence of floods and heavy rains is likely to increase the loads of nutrients and suspended matter even further.

• The salinity of the Baltic Sea is showing short-term variation, but in coastal areas of the Gulf of Finland, a slight decreasing trend has been observed. It has been posited that climate change is causing the decreasing frequency of salt-water pulses, but this connection has not been completely verified.

• The combined impact of the various environmental changes of the Baltic has caused clear species changes.

• Climate warming has resulted in earlier spring migration and later autumn migration of water birds. On average, autumn migration is 0.37 days/year later (11 days over 30 years).

b) Bothnian Bay

Seashores in the northernmost Baltic Sea (in the Bothnian Bay) are home to several endangered plant and animal species that occupy a temporally and spatially narrow belt between the sea and dense upper shore vegetation. The main focus in the associated subproject was on assessing impacts on critically endangered species in these sensitive habitats. The main results and conclusions were the following:

• Climate warming is expected to change the hydrological conditions of low elevation meadows in northern parts of the Bothnian Bay. In the more southern parts of Finland, the process is unlikely to be as extensive. Especially in the Bothnian Bay, the rise in sea level will slow the rate of new shore emerging with land uplift and short-term wind raise floods may become more common. These floods would be due to the increase in water level caused by certain directions of wind, leading to seawater being pushed into the Bothnian Bay.

• The habitats of the creeping alkaligrass (Puccinellia phryganodes) are concentrated in those soils that are most strongly eroded by ice in the lowest meadow zone. The two occurrences of creeping alkaligrass in the Bothnian Bay are the only ones within the EU, and the species has recently been classified as critically endangered (CR).
• Both the creeping alkali grass and the endangered (EN) Arctic pendantgrass (*Arctophila fulva var. pendulina*) are locally threatened by overgrowth of meadows and the resulting increase in competition with other grasses.

• Effects of catastrophic flooding on the population viability of endangered species become more likely as the climate changes.

• The critically endangered southern dunlin (*Calidris alpina schinzii*) is the most endangered of the waders in seashore areas. A significant proportion (80%) of the southern dunlins in Finland nest in the grazed shoreline meadows of the Bothnian Bay. Some nests of this small wader are destroyed in wind-raise floods, but predators play a larger role in the reproductive success of the species at the moment.

**Ex situ conservation of biodiversity for protection of ecosystem services**

*Ex situ* conservation is defined as protection of an organism ‘off-site’ – i.e., outside its native habitat. Internationally, *Ex situ* conservation has been applied increasingly in recent decades. According to the most recent decisions for the Convention on Biological Diversity (CBD), in Nagoya, 75% of threatened plant species should be in accessible *Ex situ* collections, preferably in the country of origin, and 20% included in recovery and restoration programmes. In VACCIÁ, the reaching of these targets in Finland was assessed for the first time, and an *Ex situ* action plan for the conservation of threatened native plant taxa in Finland was prepared. The main results and conclusions were as follows:

• The *Ex situ* conservation in Finland is concentrated in botanical gardens of the universities of Oulu, Helsinki, Turku, and Joensuu.

• 18% of the nationally threatened taxa are covered by *Ex situ* conservation measures, while the target is 75%. There are also problems with these measures’ quality with respect to genetic intactness.

• The survey conducted formed a basis for an action plan for the *Ex situ* conservation of threatened native plant taxa in Finland. It includes 11 concrete targets for helping reach *Ex situ* conservation of 40% of threatened species by 2016.

**Changes in ecosystems: urban areas**

The combined impacts of land-use and climate change on ecosystem services in the designated urban areas in the cities of Lahti and Helsinki were studied in another subproject. Particular emphasis was put on studying the importance of the increases foreseen in precipitation levels and compactness of urban structure. The following main results and conclusions emerged from the work:

• A denser urban structure decreases the amount of urban green areas providing local ecosystem services and reduces their quality and that of the urban hydrology.

• In many cases, the decreasing quality of groundwater and various anomalies of the surface waters can be attributed to lack of living ‘freely breathing’ surfaces.

• The transformations have direct effects on the amount of runoff and its quality, especially in areas with a high proportion of impermeable surfaces. The negative effects linked with runoff water are both local, in the flow areas, and regional, contributing to the pollution of surface waters and erosion of riverbeds.

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• In the city of Lahti, the average amount of cumulative runoff per month in dense urban areas was more than tenfold that in low-density areas. In Helsinki, the corresponding difference was sevenfold. Also the turbidity and conductivity of the runoff water were much lower in the low-density areas.
• Analyses of soil samples indicated less production of many essential ecosystem services from soils in dense urban areas.
• Even if dense urban structure may be an effective means of decreasing the local carbon footprint, there are other serious environmental challenges in the cities that are readily sidelined when public debate concentrates on one issue at a time. Adaptation to climate change therefore demands a comprehensive vision and understanding that emphasising only certain aspects of the phenomena can make the situation simultaneously worse in other respects. Continued study is needed if we are to establish the necessary basis for decision-making in this field.

Adaptation of livelihoods: agricultural production
In the agriculture subproject, detailed analysis was carried out for climate change impacts and adaptation options related to agricultural production in the watershed area of Lepsämänjoki. The Lepsämänjoki area is part of the larger Vantaanjoki river basin, in southern Finland. The aim was to provide local-scale information on the effects of climate change on cultivars, fertilisation schemes, leaching of nutrients and erosion, biodiversity, and ecosystem services in agricultural systems. Adaptation options and possibilities were also assessed. These were the main results and conclusions:
• The growth period of cultivars has been prolonged as a consequence of increasing mean temperatures. From present-day sowing temperatures, it is predicted that sowing will, on average, start one week earlier in 2011–2040, two weeks earlier by 2041–2070, and three weeks earlier by 2071–2100.
• Increases in the warmth and length of the growing season will improve yield potential and enable the introduction of a wider selection of crops. However, this requires adaptation of cultivation to the new growing conditions: crops need to be bred and farming systems developed.
• Weather extremes that reduce or damage crops are expected to increase because of climate change (heavy rainfalls, long periods of rain, floods, storms, and droughts, as well as exceptionally high summer and winter temperatures).
• The warming climate provides favourable conditions for the spreading and overwintering of pests, pathogens, and weeds.
• Four scenarios describing possible future situations of arable land use in two northern sub-areas of the Lepsämänjoki watershed were produced, each for two points in time: 2025 and 2055. The allocation of land to the various crop species was done in view of the opportunities brought by climate change (according to SRES scenario A2 of the IPCC) for growing of new crop species and for introduction of winter-sown cultivars, as well as the possibility of extending the areas of current crops. The scenarios produced were 1) enhanced protein self-sufficiency, 2) greater winter crop cover, 3) greater crop diversity, 4) cereal monoculture.
• Climate change will bring new challenges for water protection efforts in the farming environment. Even in present conditions, water protection measures have not been effective enough to reduce nutrient loading from fields into waterways to target levels. According to the results from the INCA-N model, climate change will increase the suspended sediment load by about 15% and inorganic nitrogen load by more than five per cent in the erosion-prone Lepsämänjoki area.
Adaptation of livelihoods: forestry
The main focus in the forestry subproject was on assessing how climate change will affect forest biomass production and growth conditions, and when adaptation measures would be feasible. Data from intensively studied areas were used for the assessments. In addition, methods for making growth predictions under climate change conditions were developed, and the possibilities for using indicator species for change assessments were explored. The main results and conclusions were the following:

- It is difficult to separate the direct impact of climate change from other factors in the observed increases in forest growth and resources.
- In Finland, forest growth is mainly controlled by temperature and nitrogen availability, with availability of water being less important. The rising temperature is increasing the decomposition of organic matter in the soil and releases nitrogen that can be used by the vegetation. This increases the growth rate of trees and stemwood production.
- The results from modelling show that climate change in line with the low-change IPCC scenario (B2) would see pine growth in southern Finland increase by 16% and in Lapland by 31%. The corresponding change in the high-change scenario (A2) is 40% in southern Finland and 80% in Lapland. In the latter scenario, temperatures in northern Finland reach the levels of southern Finland by the end of the century; however, the growth rates of forests would still be lower than in the southern areas, because the amount of organic matter and also, therefore, nitrogen pools would be lower than the present levels in the south.
- The growth of deciduous trees responds more rapidly to climate change and consequent changes in soil fertility. If the release of nitrogen increases as predicted, the growth response of birch will be stronger than that of pine.
- Resident birds are ideal study organisms to test for relationships between landscape fragmentation, climate change, and vital rates, because, on account of high site fidelity, they are affected by the same habitat and climatic regimes throughout their annual cycles. With higher spring temperatures, the willow tit (*Poecile montanus*) has significantly advanced its breeding schedule in northern Finland in the last 35 years. The benefits that may result from climate warming are unlikely to compensate for the damage caused by habitat loss and deterioration in quality.
- The biggest challenges facing silviculture with the changing climate are linked to tree species and provenance selection, regeneration methods, stocking densities, and timing of harvesting operations, and to disturbances caused by drought, storms, and fungal and insect attacks.

Adaptation of livelihoods: fisheries
The aim of the fisheries subproject was to study the impacts of climate change on the fish communities and fisheries of a large lake, as well as to assess potential adaptation options. Lake Päijänne is the deepest lake in Finland and has more than 300,000 people living on its shores. The ecosystem services provided by the lake are of key importance for these inhabitants. The catchment and lake model systems described above were used in the assessment of changes, along with laboratory experiments. The following main results and conclusions emerged:

- The predicted changes in lake temperatures and lake ice influence fish behaviour and fisheries. Also the eutrophication of the lake and the associated changes in water quality affect the fish community and the whole fisheries sector. For some fish species, the growing season will increase by as much as a month.
• The impact of the changing climate on the reproduction of vendace and whitefish was studied through laboratory experiments and modelling. These results point to both positive and negative effects.

• The most important fish species for recreational fishing are perch, pike, pike-perch, and brown trout in Lake Päijänne. Trout may in future suffer from high temperatures during summer. The simulated water temperatures might exceed the temperature tolerances of brown trout, so growth could be prevented and mortality increased in the future.

• Pike-perch and perch favour warm water and are predicted to benefit from the increasing temperatures. The results from the models indicate that both the growth rate and food consumption will almost double, which also will affect prey populations.

• The fish communities of the future are likely to be dominated by percids and cyprinids instead of salmonids. At present, professional fishing is based on vendace and whitefish, so the economic value of the available resources will decrease. The by-catch with low marketing value causes extra costs and decreases the profitability of fishing. Also, the predicted changes in the stratification and ice conditions of the lake will affect professional fishing.

Adaptation of livelihoods: nature-based tourism
In the tourism subproject, the critical factors affecting nature-based tourism were assessed with respect to both the local ecosystems and the communities. Future adaptation options were assessed in collaboration with local tourism enterprises and stakeholders. The work was carried out in two northern towns: Kuusamo, with the ski resort Ruka, and the municipality of Sotkamo, home to the ski resort Vuokatti. The following main results and conclusions emerged:

• Changes in precipitation, shorter and warmer winters, and substantial decreases in snow and ice cover could dramatically change the conditions for nature-based tourism in northern Finland.

• A large data-gathering effort comprising collection of statistical data, interviews, workshops, climate data, and scenario assessment was conducted. On its basis, vulnerability thresholds for tourism activities for both summer and winter conditions were identified.

• The results highlighted local perceptions and worries concerning the growing uncertainty of the freezing of water bodies and wetlands and the increasing security risks brought about by the increased variation in weather conditions, particularly for winter tourism and for marketing and transport.

• The increase in risks is related to the generally increasing unpredictability of local weather conditions. These risks will increase in the context of the climate change scenarios assessed.

• The primary challenge for local adaptation to climatic factors is created by the close connection of tourism to other societal practices, processes, and economics.

Summary of adaptation challenges, adaptation options, and suggested priorities for future work
The main challenges and adaptation options for each sector are summarised in Annex 3. A list of suggested priorities for additional work in this field is presented in Annex 4.
Reporting of the results and products of VACCIA (by 15.11.2011)
In line with the priorities of the EU LIFE+ programme, dissemination of the project results was given great attention at local, national, and international scale.

Reports and publications:
- Synthesis report
- 20th anniversary report on the Valkea-Kotinen region
- Layman’s report
- Subproject reports, studies, and research papers (deliverables of the project) (61 pcs)
- Brochure at the beginning and end of the project

Seminars and workshops:
- National final seminar for stakeholders
- Subprojects’ seminars and workshops (13 pcs)

Lectures and presentations at national and international seminars and conferences (10 pcs)

Presentation of results in media:
- Articles in national and regional newspapers (27 pcs)
- Articles in local newspapers (17 pcs)
- Radio presentations (4 pcs)
- Television presentation
- Fairs and other public events (6 pcs)
- Press and news releases on the Internet (7 pcs)

Web sites and portals (all 15.11.2011):
- www.ymparisto.fi/syke/vaccia Homepage of the project, in Finnish
- www.miljo.fi/syke/vaccia Homepage of the project, in Swedish
- www.environment.fi/syke/vaccia Homepage of the project, in English
- http://maps.tvarminne.helsinki.fi VACCIA GIS portal for recognition of changes in coastal ecosystems
- http://vaccia7.maat.helsinki.fi/ Lepsämänjoki Long-Term Socio-Ecological Research (LTSER) network
- http://thule.oulu.fi/vaccia/ VACCIA Web site at the University of Oulu
- http://litdb.fmi.fi/vaccia/database/ VACCIA air quality portal, Finnish Meteorological Institute, Pallas-Sodankylä GAW station

Other products:
1 Introduction

1.1 Ecosystem services and the changing climate

Martin Forsius

Ecosystems generate a range of goods and services that are important for human well-being, collectively called ecosystem services. The production of food and raw materials, clean air and water, flood regulation, and recreation and ecotourism are all dependent on ecosystem services provided by soil, waters, and forests. The production of ecosystem services is based on ecological processes and biodiversity; therefore, it is crucial to understand how the state of ecosystems and the utilisation of natural capital are linked. The concept of ecosystem services was established relatively recently, in the last few decades, but the roots of the related scientific understanding go back to the 1950s. Sustainable management of ecosystem services requires understanding of the functions and key change processes of ecosystems, as well as of the frameworks in which various stakeholders of society operate. In an extensive international ecosystem service assessment\(^{11}\), it was concluded that 15 of the 24 main ecosystem services assessed showed significant decline in different regions of the world. The situation had improved for only four services over the last 50 years. The commonly used system of the Millennium Ecosystem Assessment classifies the ecosystem services into provisioning, regulating, cultural, and supporting services (see Table 1).

Table 1. Ecosystem services according to the classification of the Millennium Ecosystem Assessment

<table>
<thead>
<tr>
<th>SUPPORTING SERVICES</th>
<th>PROVISIONING SERVICES</th>
<th>REGULATING SERVICES</th>
<th>CULTURAL SERVICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil formation</td>
<td>Food</td>
<td>Air quality regulation</td>
<td>Aesthetic values</td>
</tr>
<tr>
<td>Nutrient cycling</td>
<td>Food from nature (game, fish, berries, mushrooms)</td>
<td>Clean air</td>
<td>Spiritual, religious and historical values and information</td>
</tr>
<tr>
<td>Carbon sequestration</td>
<td>Food from agricultural production (cereals, meat, fruit, vegetables)</td>
<td>Climate regulation</td>
<td>Culture and arts</td>
</tr>
<tr>
<td>Primary production</td>
<td>Raw material</td>
<td>Suitable climate for humans</td>
<td>Science and education</td>
</tr>
<tr>
<td></td>
<td>Fiber</td>
<td>Water regulation (including purification and storage)</td>
<td>Recreation and ecotourism</td>
</tr>
<tr>
<td></td>
<td>Bioenergy</td>
<td>Irrigation, industrial and household use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td>Purification of nutrients and waste</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Genetic resources</td>
<td>Pollination of plants</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resistance of crops against pathogens</td>
<td>Biological control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biochemicals</td>
<td>Pest and disease control</td>
<td></td>
</tr>
</tbody>
</table>

Climate change is a major threat to the sustainable production and management of ecosystem services. Increases in temperatures are predicted particularly for land areas in the world’s – and Finland’s – northern regions. In addition to increases in mean temperatures, changes are predicted for minimum and maximum daily temperatures, precipitation, snow cover, the thermal growth period, and other variables characterising our climate (see Section 2.1). Controlled adaptation to these changing conditions is needed if we are to minimise the harm and maximise the benefits to society. All major sectors are affected, including agriculture, forestry, fisheries, ecotourism, and land use in urban environments. Already in present conditions, it is sensible to prepare for climatic variations and extreme events, because this expands the possibilities for adapting to increasing future changes and variability, with greater chances of success.

Assessment of ecosystem changes and potential adaptation options requires information on the following:

- The probability of the change.
- The vulnerability of the various ecosystem services.
- Adaptation options in the individual geographical regions.

The central aim of the Finnish climate change adaptation strategy12 of 2005 is the inclusion of climate change adaptation in the routine planning, development, and implementation measures of the various sectors. The main goals of the strategy have been confirmed in the national climate and energy strategies of 2005 and 200813, 14 as well as the government’s climate change and energy foresight study (2009)15. The need for climate change adaptation has received increasing attention also in the policy development of the European Union. The European Commission White Paper on adaptation16 sets out a framework for reducing the EU’s vulnerability to the impact of climate change. The document states, for example, that comprehensive and integrated policy is needed for maintaining and improving key ecosystem products and services. A Communication from the European Commission on halting the loss of biodiversity and sustaining ecosystem services17 identifies key policy areas for action, along with related objectives and supporting measures for reaching the 2010 targets and putting biodiversity on the course to recovery.

The importance of ecosystem services and biodiversity for climate change mitigation and adaptation is emphasised also in the recently issued EU biodiversity strategy to 202018. This strategy is aimed at reversing biodiversity loss and speeding up the EU’s transition toward a resource-efficient and green economy.

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1.2

The VACCIA project

Martin Forsius

The Vulnerability Assessment of Ecosystem Services for Climate Change Impacts and Adaptation – VACCIA project studied the vulnerability of ecosystem services to climate change and the possibilities for the individual sectors of society to adapt to these changes. As mentioned above, this large three-year (2009–2011) project, funded by the EU LIFE+ programme, was coordinated by the Finnish Environment Institute, with participants also from the Finnish Meteorological Institute and the universities of Helsinki, Jyväskylä, and Oulu.

The connections between ecosystem services and environmental pressures are highly complex, so prediction of changes affecting these domains requires detailed and comprehensive datasets and tools. For this reason, the VACCIA project based its work on data and infrastructures of nine intensively studied areas belonging to the FinLTSER network19 (see Annex 1). This network was established in 2006, and detailed information and data were already available from its well-instrumented, well-studied monitoring and research areas. In the FinLTSER network, groups from universities and research institutes perform multidisciplinary studies of terrestrial, freshwater, and marine ecosystems, as well as agricultural and urban areas. In addition to more conventional ecological and natural-science-based studies, socio-economic evaluations are carried out in the larger study areas. The latter involve also participation from communities, institutions, and private companies. National co-ordination of the network is handled by the Finnish Environment Institute SYKE.

Both the FinLTSER network and the closely related international LifeWatch project20 have been accepted as key national ‘research infrastructures’ (defined as facilities and services essential for conducting research work) and included in the national roadmap for research infrastructures published in 2008. These roadmap projects are considered to be particularly important for national and international research work.

The impacts of climate change on key ecosystem services and several production sectors were assessed in the VACCIA project. Also methods and tools for analysing changes to land use and the air brought about by air pollutants were developed, as were methods for assessing the full impact of several environment change scenarios (see Figure 1). Both sector-specific and general information on the impacts and adaptation options in the individual environmental change scenarios were produced.

The key aims of the VACCIA project were to:

- Devise realistic environmental change scenarios.
- Demonstrate and develop the use of remote sensing information (GMES) for the assessment of ecosystem services and their changes.
- Develop modelling, GIS, and database tools for ecosystem change assessments.
- Assess how the anticipated climate change would change the production of ecosystem services, and identify critical change thresholds.
- Identify options for adaptation to the changing conditions.
- Disseminate information to authorities, decision-makers, and citizens.
- Support local and regional planning and decision-making.
- Provide information for development of national and EU climate change adaptation strategies.

Climate change mitigation and adaptation are complementary strategies. Both variations in the present climate and the increasingly changing conditions require planned adaptation measures. Extreme events and various threshold values of the ecosystems are crucial elements in the development of feasible adaptation measures. The threshold values depend on the ecosystems’ sensitivity. An ecological threshold can be defined as the point at which a small change in external conditions causes a large and sudden change in the ecosystems. In the VACCIA project, ecosystem changes and their threshold values were assessed with several types of approaches, including mathematical modelling, analysis of long time series of data, laboratory experiments, and workshops.

Information on the ecosystem services’ vulnerability and on feasible adaptation measures is needed for the development of environmental policies. Key policy processes of relevance for the VACCIA project have been listed in the summary. The results of the VACCIA project have already been put to use in the current process of updating the national climate change adaptation strategy, and they are also useful
for the national implementation of several EU strategies (see above). The project’s
evaluation of the ex situ conservation goals related to biological diversity (see Section
3.5) has contributed to the implementation of the national obligations of the Convention
on Biological Diversity (CBD)\textsuperscript{21}. Local- and regional-scale development processes
have been supported, for example, by assessment of the vulnerability of nature-based
tourism in the Sotkamo and Kuusamo areas, in north-east Finland (see Section 4.4).
The modelling, remote sensing, and database tools developed and documented in
the project (see Chapter 2) can be used for performing similar assessments in other
regions. The work in this field will be continued after the end of the project.

2 Predicting and detecting change
Climate scenarios and trends in air pollution, remote sensing, and monitoring of land cover

2.1
Climate scenarios
Kirsti Jylhä, Mikko Laapas, Kimmo Ruosteenoja

2.1.1
Studying the climate system

Global climate change, as a result of a strengthened greenhouse effect, is anticipated to alter the climate in Finland. Increased atmospheric concentrations of greenhouse gases (GHGs), such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), reduce the thermal radiation emitted by Earth into space, so the climate is warming up. The global concentration of carbon dioxide has increased since the pre-industrial era by about 40%, with the recent annual growth rate averaging 0.5%. On the other hand, aerosol emissions caused by human activity reduce the intensity of solar radiation into Earth’s surface, and this effect of dimming tends to cool the air close to the ground. Changes in land use, such as urbanisation, deforestation, and drainage of wetland soils, locally affect the climate in Finland as well.

In our assessment of the changes and variations in the climate that have already occurred, we examine long time series of homogenised data from past observations of weather. Nonetheless, possible trends in these time series cannot be extrapolated for climate predictions. Instead, the projections are based on alternative scenarios of future concentrations of GHGs and aerosols and on climate models; these models represent the climate system by numerical methods.

Future climate change cannot be predicted accurately. This is because several sources of uncertainty exert an effect. First, emissions of GHGs and aerosols depend on human actions. Second, there are uncertainties in modelling of the climate system; i.e., how do concentrations of GHGs and aerosols depend on their emissions, and how does the climate system respond to changes in the concentrations? Third, in addition to anthropogenic forcings, the climate system evolves on all spatial and temporal scales in response to natural causes, such as solar variations, volcanic eruptions, and system-internal processes. The smaller the spatial and temporal scales considered, the more important is the role of natural variation.

An important objective of climate system modelling is to support climate change adaptation action plans by developing climate scenarios. For Finland, such estimates of the future climate have been constructed in the ACCLIM research project within the national Climate Change Adaptation Research Programme (ISTO; 2006–2010). The ACCLIM climate change scenarios for Finland are based on output from, in most cases, roughly 20 climate models. The use of such an extended set of climate model data enables us to assess uncertainty ranges attached to climate change scenarios more comprehensively way than before.
2.1.2

Projected changes

The ecosystem services discussed in this report are affected by several climatic variables. From the model projections, the following changes in these variables can be anticipated in Finland:

- The climate is going to see quite clear warming already in the next few decades in comparison to natural temperature variability. The temperature increase is likely to be greater in winter than in summer, but the strong natural variability in winter temperatures also makes the uncertainty range of the projection wider in winter. Wintertime changes in the north will exceed those in the south, whereas summertime changes are expected to be fairly uniform throughout the country.

- Hot summer days will become increasingly common, and heat waves will get longer. In winter, the number of days with subzero temperatures will decrease, and record-breaking cold events are gradually becoming less likely. Almost all climate models predict that the variability of winter temperatures will decrease in consequence of greater warming in the cold part rather than in the mild tail of the temperature probability distribution.

- Thermal winter (daily mean temperature below 0°C) will get shorter, with the opposite projected for thermal summer (warmer than 10°C) and the thermal growing season (above 5°C). In the south-west, the growing season will lengthen more than in other parts of the country. In particular, the thermal autumn will become much longer.

- The longest dry period of the year will remain virtually unchanged. When one considers the four seasons separately, however, periods of no precipitation will become shorter in winter and spring, and in northern Finland also in autumn. In the south in summer, the frequency of wet days may decrease and the maximum length of dry spells might even increase.

- The wintertime soil frost layer will become thinner. By the end of the century, the soil frost depth in snow-free areas will decrease by two thirds in southern and central parts of the country and by a third in the north.

- Alongside temperature, precipitation will increase. Changes in the north will exceed those in the south. Nonetheless, the changes in precipitation are expected to occur rather slowly. It is likely that, over the next few decades, precipitation will be affected more strongly by natural variability than by increasing greenhouse gas concentrations.

- Increases in total precipitation percentages are larger in winter than in summer; nevertheless, summer precipitation will remain more abundant than winter precipitation. Regardless of the slight increases in summer rainfall, water resources may not increase, since evaporation will also intensify in a warmer climate. This would increase the risk of forest fires.

- Days with abundant precipitation will increase in number in all seasons, most distinctly in winter and less so in summer. Events of heavy precipitation will become both more extreme and more commonplace. In summer, the percentage increase in the maximum one-day precipitation amount will exceed those in the season’s total precipitation.

- Climate change gradually increases the likelihood of record amounts of precipitation. However, as to the frequency of periods with exceptional heavy-precipitation events in the present and near-future climate, the statistical uncertainty arising from the small number of such events may still constitute a greater source of uncertainty than the overall effects of climate change.

- Snow cover will decrease, especially in the early and late winter. In relative terms, the changes are greatest in southern Finland. In the north, the changes
are smaller and likely to emerge less clearly from the background of natural variation. Snowfall is decreasing in autumn and spring, in the south also in mid-winter in parallel with the greater frequency of rainfall events there. In Lapland in mid-winter, by contrast, snowfall will probably not decrease but slightly increase. Thaws causing snow-melt will occur more often during the winter season, and winters with abundant snow cover will become gradually less common though not completely disappearing by the end of the century.

- Finnish winters are already quite humid. Most of the models’ simulations show the relative humidity of the air rising a few percentage points by the end of the century. Relative humidity is likely to stay almost unchanged in summer and early autumn. This conclusion is, however, quite uncertain, as different models’ results diverge considerably.

- The average wind speed during the windy season (September–April) appears to be increasing by a few per cent. Maximum wind speeds too are likely to rise slightly. Southerly and westerly winds are projected to see a slight increase in frequency at the expense of winds from the north, east, and south-east. For summer, no significant changes in wind speeds and directions are projected.

- Winter weather will become cloudier, with less incident solar radiation. No major changes in cloudiness and radiation in summer are expected. Spring’s solar radiation is likely to decrease slightly, while the models’ projections for autumn are quite uncertain.

2.1.3

Uncertainty in the predictions in decision-making

Predictions concerning climate change and its impacts inevitably involve a degree of uncertainty. If vulnerability assessment for ecosystem services were based on a single climate model experiment, the outcomes might even be misleading. Efforts can be made to take uncertainty ranges into account in decision-making by means of risk management and other tools. However, the extent to which the changes in the climate perceived in Finland influence, for example, agriculture and forestry or food production also depends on climatic changes outside our national borders. While precipitation is increasing in Finland, Southern and in the summer also Central Europe will get drier. This may have a larger impact on the preconditions for agriculture than the projected greater precipitation and longer growing season in our own country.

2.1.4

Necessary additional research

Research is needed in several areas:

- Besides those of monthly mean temperature and precipitation, uncertainty ranges and probability distributions of further climate variables, such as wind speed and daily precipitation, need to be defined, for better support of the design of means of adaptation.

- Tailored climate change information, often required for vulnerability assessment of ecosystem services, should be offered in a form that affords smooth use. More development is needed for reaching that goal.

- Small-scale climate phenomena and regional variations in climate are worth further study and are particularly relevant for local and regional planning and decision-making.

- Climate change scenarios for Finland need to be updated regularly such that they are increasingly detailed and based on the most recent scientific findings.
2.2 Pollution transport

Pia Anttila, Hannele Hakola, Aki Virkkula, Timo Ryyppö

2.2.1 Air pollution trends

Air pollutants may be transported far from their source areas, hence affecting distant areas also. The VACCIA project examined trends and source areas for atmospheric pollutants and the effect of climate changes on pollution transport to northern regions. Climate change is expected to be strongest in Arctic areas, where ecosystems are already vulnerable. Major pollutants’ trends and source areas were measured at the Finnish Meteorological Institute’s Pallas GAW (Global Atmosphere Watch) station in Lapland (see Figure 2).

The Russian copper and nickel industry on the Kola Peninsula was found to be an important anthropogenic source of sulphur dioxide (SO₂) and heavy metal emissions to the atmosphere within the Arctic and still has an influence on the ambient concentrations in the Pallas area too. However, these results suggest that the sulphur and trace-element load from the Kola Peninsula to the Pallas area has been decreasing slightly for the past 14 years (1996–2009). Also, the long-range-transported sulphate (SO₄²⁻) decreased during the study period. For nitrogen compounds, the situation is not as good: no trends were detected for nitrogen dioxide (NO₂), nitrate (NO₃⁻), and ammonium (NH₄⁺). For nitrogen dioxide, the densely populated continental Europe was identified as the main source area.

Figure 2. The Global Atmosphere Watch (GAW) network’s Pallas station. Photo by Pia Anttila.
Ozone (O₃) is an example of regional, or, rather, global, pollution. It is formed in the atmosphere in chemical reactions between volatile organic compounds (VOCs) and nitrogen oxides with the effect of sunlight. Ozone can be transported long distances, from one continent to another, and cause elevation in concentrations also at distant locations. Ozone concentrations detected at the Pallas station have remained high because of the global emissions. In spite of effective reduction in ozone precursor emissions in Europe, only the concentrations of the more rapidly reacting compounds have decreased at Pallas. Concentrations of polycyclic aromatic compounds (PAHs) have been stable or weakly decreasing since the mid-1990s at Pallas. Some of the heavier PAHs were partly associated with the Kola peninsula industrial sources; these were also the ones with significant decreasing trends. However, the majority of the PAHs arrived at Pallas with southern or western air masses associated with nitrogen dioxide and nitrate, suggesting that traffic exhaust is the predominant source.

As for other persistent organic pollutant (POP) compounds, the global trend has been to reduce production and use of these harmful compounds. This has resulted in significant development in the concentrations detected at Pallas; the majority of POP concentrations were decreasing. However, there was one exception to this positive development: concentrations of DDT (dichlorodiphenyltrichloroethylene) and its breakdown products DDD (dichlorodiphenyldichloroethane) and DDE (dichlorodiphenyldichloroethylene) behaved differently from the rest of the POPs; their concentrations showed an increase.

However, POP compounds are stored in the ecosystem and in a built environment, because of the decadal usage and transport of these compounds, and their evaporation may be greater in warmer temperatures. Also, global usage of insecticides may increase as temperatures rise. It has been estimated that changes in POP emissions may slow down the decrease in concentrations or the concentrations of some of the POP compounds may start increasing again.

2.2.2
Present and future sources of pollution

The main source areas for airborne pollutants are Central Europe and Russia. Currently, the prevailing direction from which air masses arrive in Finland is the south-west. Climate models predict only modest changes in prevailing wind directions toward cleaner marine areas. This would mean less pollution transport to Finland as polluted easterly winds decrease.

On the other hand, the predicted rise in precipitation in this area²² may increase the deposition of, for example, heavy metals, and the expected temperature increase may contribute to the formation of photochemically active pollutants such as ozone.

Climate change may also result in altered distribution of emissions. For example, shipping emissions in the Arctic marine areas are expected to increase with declining sea-ice coverage. Emissions of sulphur dioxide, nitrogen oxides, black carbon, organic carbon, carbon monoxide (CO), and carbon dioxide are expected to increase²³. Increasing nitrogen oxides concentrations could increase ozone formation in remote areas, where ozone formation is nitrogen-oxide-restricted.

Climate change is expected to affect also the geographic distribution of wildfires. In areas where climate change will cause reduction in precipitation (for example,
Southern Europe), earlier snow-melt, higher summer temperatures, and a longer fire season will tend to increase wildfire activity. Increased forest fire activity in boreal regions could have a huge impact on the Northern Hemisphere’s atmospheric trace-gas and aerosol loading. In particular, black carbon, produced in fires, has a positive climate forcing effect, since it adsorsbs incident sunlight and sunlight reflected from snow- and ice-covered surfaces and decreases albedo. Another positive climate forcing effect could come from ozone formation.

### 2.2.3 Necessary additional research

- The effect of changes in rain amounts on air quality.
- The effect of climate change on ozone formation, especially at northern latitudes.
- The indirect effects of climate change on air quality – for example, large-scale forest fires.
- The effect of increasing use of biofuels and warming climate on the air quality (for example, PAHs).

### 2.3 Remote sensing and monitoring of changes in land cover

*Saku Anttila, Pekka Härmä*

Remote sensing allows continuous observation of the environment over extensive areas. This enables the monitoring and comparison of different ecosystems that are geographically distant from each other. A temporal dimension can be gained by contemplating series of interpreted remote sensing images. Furthermore, this kind of seasonal monitoring can be extended to different land-use classes by means of auxiliary data sources. Thus remote sensing can be used to study how climate-driven changes take place within and between ecosystems located in different parts of Finland.

One of the main objectives in the remote sensing work of the VACCIA project was to deliver spatially extensive information on the temporal changes occurring in land cover. Specifically, we concentrated on annual and interannual changes in the snow and green vegetation coverage in ecosystems delimited by drainage basin boundaries and different land cover classes. The primary data source was a set of daily Terra/MODIS satellite images from the years 2001 to 2008. This instrument of the US National Aeronautics and Space Administration (NASA) has a medium spatial resolution (250–1,000 m). The satellite images were interpreted for deriving snow-covered-area and green-vegetation-index (NDVI) estimates. Then, using said data, we extracted, filtered, and modelled time series from each drainage basin and land cover class. The required information was the duration of the brown period – i.e., the time after the snow-melt and before the green vegetation growth. At this time, soil is especially vulnerable to erosion and leaching of its nutrients into water systems; therefore, the information is valuable in the catchment and leaching modelling. A general process description for deriving the duration of the brown period is described in Figure 3.

In the VACCIA project, we also wanted to improve the utility of remote sensing data in climate change and ecosystem services research (see Figure 4). This was promoted through production of several remote-sensing-based products, including water quality time series for coastal areas, estimates of green vegetation percentages...
in small urban watersheds, spatial water quality estimates for lakes, and remote-sensing-based water surface temperature time series for the largest lakes in Finland. In addition, several remote sensing datasets were collected from external data sources and further processed to aid in research into ecosystems’ adaptation to climate change.

Remote sensing, a relatively new method of environmental monitoring and for obtaining measurements, differs from traditional methods in, for example, its spatial dimension. There are, however, several issues that need to be taken into account in the use of such data. Among these are the confounding effect of the atmosphere on the

Figure 3. General process flow description for deriving the duration of the time period after the snow-melt and before green vegetation growth from remote sensing data.
measurements and issues of how spatial resolution affects the information’s accuracy. Nonetheless, the use of remote sensing in ecosystem research can be expected to increase, since it allows simultaneous monitoring of ecosystems on the local but also the global scale. The approach is further supported by new satellite instruments that can provide temporally, spatially, and spectrally more accurate information. Data from the new European SENTINELS satellite series, for instance, will be freely available in the near future for use in environmental research.

Figure 4. Examples of remote sensing datasets produced in VACCIA project. Spatial water quality estimates for lakes (pane a), water surface temperature time series for lakes (pane b), and shares of green vegetation in small urban watersheds (pane c).
3 Ecosystem services’ change and vulnerability amid climate change

3.1 Ecosystem services and their threshold values

Martin Forsius

Climate change mitigation and adaptation are complementary strategies. Both the variability of today’s climate and the increasing future changes predicted require planned adaptation measures (see Figure 5). Vulnerability is defined as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. Measures of vulnerability typically include three components: exposure to climate change, sensitivity to its effects, and adaptive capacity for coping with the effects. Adaptive capacity is a measure of society’s resources and capabilities to offset the adverse effects of climate change or exploit possible benefits. Accordingly, vulnerability can vary greatly between geographical areas, ecosystem services, or sectors.

Extreme events in terms of impacts or with reference to the threshold values of the various systems and processes concerned are of central importance for planning and implementation of adaptation measures. Climate change may lead to greater likelihood of extreme events occurring (e.g., increasing risk of floods), and this has to be considered in, for example, the design and construction of long-term technical infrastructure, such as dams, bridges, and harbours. The threshold values depend on the sensitivity of the systems, and an ecological threshold can be defined as the point where a small change in the external conditions causes a large and sudden change in ecosystems. When the threshold value is exceeded, the system does not necessarily return to its original state anymore, even if the external conditions return to normal.

Figure 5. Framework for climate change mitigation and adaptation. Society and ecosystems can to some extent adapt spontaneously to effects of climate change. In some cases, however, policy decisions are needed for ensuring successful and effective adaptation. Policy actions are needed also for the implementation of feasible mitigation measures.
Ecological threshold values can be identified in accordance with different methodologies, of which statistical analysis and mathematical modelling are the main approaches. In the VACCIA project, since the long-term and comprehensive monitoring and research data from the FinLTSER areas (see Annex 1) were available, both methodologies could be applied. Conditions in which sudden changes occur can be identified via statistical time-series analysis of the long-term data. The threshold values can be identified also through scenario and sensitivity analysis with the calibrated mathematical simulation models. In addition, laboratory experiments and expert judgement techniques were used efficiently in the VACCIA project in this context.

3.2 Catchment areas and water bodies

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3.2.1 Ecosystem services provided by catchment areas and their vulnerability

Terrestrial and aquatic ecosystems in the boreal zone are sensitive to changes in climatic conditions. According to predictions, air temperatures and precipitation in wintertime will reach higher levels (see Section 2.1). As a consequence, nutrients’ turnover times and leaching into water bodies might change. Also, summer surface temperatures in the water bodies are predicted to rise. The temperature stratification is going to last longer and the thermocline sink deeper in stratifying lakes (the thermocline is the permanent layer of water in a thermally stratified body of water that displays a rapid decline in temperature and which separates an upper, warmer layer (the epilimnion) and a lower, colder layer (the hypolimnion)). Changes in catchment areas and water bodies due to global warming also affect the ecosystem services these provide (see Figure 6).

Figure 6. Mechanisms of impact of climate change on ecosystem services provided by catchment areas and water bodies.
The ecosystem services provided by catchment areas are formation of groundwater, regulation of hydrology, and nutrient retention capability of catchment areas. In future, groundwater formation will be less than at present if hot and dry summers become more common. Also, groundwater quality can decline. If, as predicted, extreme weather conditions (e.g., rainstorms) become common, the regulation of hydrology will be affected. As a consequence, floods and drought periods will grow more common. Also the nutrient retention capability of vegetation and soil in catchment areas can change in response to severe summer floods, as happened in summer 2004. A rise in winter temperatures shortens the snow-cover period that protects soil from erosion, and it accelerates the activity of the microbes in the soil. The predicted increase in precipitation in winter will add to the water runoff. Increasing nutrient loads will arise as a consequence, which intensify the eutrophication of waters. On the other hand, predicted acceleration in the growth of forests (see Section 4.2) will intensify nutrient uptake from the soil, which can help to reduce leaching of nutrients from forest areas.

Many of the crucial ‘pain points’ of the ecosystem services provided by catchment areas are related to changes in precipitation, evaporation, and land use. From the groundwater formation standpoint, the amount and timing of precipitation have a crucial role. Among other things, the concentration of iron in groundwater can increase if water tables fall dramatically because of drought. For the regulation of hydrology, also water level regulation and passage decisions have an effect. From the perspective of the nutrient retention capacity of vegetation and soil in the catchment areas, the crucial role belongs to the time outside the growing season, when plants’ nutrient uptake is minor and, in the absence of soil-protecting vegetation or snow cover, erosion is high. Also certain changes in land use, such as drainage, are reducing the nutrient retention capability of the catchment areas.

3.2.2
Eutrophication as a threat to the ecosystem services provided by water bodies

Ecosystem services provided by water bodies include clear water, fish stocks, and recreational accessibility. As climate change advances, the greatest threat to the ecosystem services provided by water bodies is eutrophication of those water bodies. If the annual cycle of hydrology changes, with spring arriving earlier and autumn being delayed, the nutrient retention capacity of water bodies may decline. This intensifies eutrophication of water bodies. With eutrophication and overgrowth of vegetation, the water quality, recreational accessibility, and aesthetic values of aquatic nature in water bodies decline. With global warming, the ice-cover period in lakes shortens. According to the simulations, the average freeze-over will shift from December to January and melting from May to March in Asikkalanselkä, a southern basin of Lake Päijänne, by the end of this century. In some winters, solid ice cover will no longer form: several freeze–thaw cycles in the same winter will become common. Shortening of the ice-cover period and lengthening of the frost-heave period are already creating difficulties for wintertime recreational accessibility – e.g., for winter fishing and movement on ice, such as skiing, snowmobiling, and skating. Changes accompanying global warming are predicted also for fish and crayfish stocks (see Section 4.3). Stocks of cold-water species, such as salmonids, are suffering a setback while warm-water species (e.g., cyprinids) are becoming more abundant.

Amid climate change, the ecosystem services provided by water bodies are especially vulnerable in shallow lakes with a small surface area. From the perspective of the nutrient retention capacity of water bodies, water quality, recreational accessibility, and the aesthetic values of aquatic nature, most of the crucial pain points are related
to excessive nutrient loading and harmful effects of eutrophication (blue-green algae blooms and overgrowth by vegetation). From the angle of fish stocks, the crucial pain point is the excessive increase of summer temperatures in water bodies to a point where species adapted to cold water may disappear, especially from shallow lakes and streams.

The most important adaptation challenges in terms of ecosystem services provided by catchment areas and water bodies are related to increased runoff, erosion, and nutrient loads, and their temporal changes. In addition to climate change, these are affected by changes in land use. Especially challenging is to distinguish the effects of climate change and land use from each other. Considering land-use changes is especially challenging, because land use is controlled by policy and economy, factors with poor long-term predictability.

3.2.3

Targeted water protection actions

To protect ecosystem services provided by catchment areas and water bodies, water protection actions should be intensified, to respond fully to the conditions resulting from climate change. The future will see the majority of the nutrient loading into water bodies take place in the winter, as it does now. Present water protection methods, such as wetlands and buffer zones, do not function efficiently enough outside the growing season. Also, the peaks in loading due to extreme weather conditions such as rainstorms should be accounted for in the dimensioning of water protection actions. One clear challenge is to survey the sites that are truly problematic in water protection terms and implement sufficient and efficient water protection actions on those sites. However, the effects of water protection actions for the sites appear slowly in water bodies, and climate-change-caused impacts on water bodies may mask the effects of water protection actions. This poses challenges to the monitoring of the measures’ effects.

3.2.4

Necessary additional research

The following measures are required:

- Researching the means to reduce nutrient loads outside the growing season, including the cost-efficiency and implementation of various means.
- Researching the effects of collection of wood for energy production in water bodies on different catchment areas and watersheds, taking into account climate change impacts on hydrology and erosion.
- Researching the role of nitrogen and phosphorus in eutrophication of water bodies from the standpoint of protection of ecosystem services.
- Researching the implications of bacterial activity in removing nitrogen from freshwaters.
- Researching the implications of increased temperatures for the decomposition of organic matter in freshwater bodies and increased nitrogen loading from land sources.
- Researching the effects of increasing leaching of organic matter into freshwaters, from the water service angle, and studying means to moderate loading as climate change progresses.
- Evaluating the basis for selection and assignment of water protection actions, and their ecologically, politically, and economically efficient and sustainable implementation.
3.3 Coastal areas

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3.3.1 Changes in the western Gulf of Finland that are already reflected in the biota

Long-term data on environmental change in the western Gulf of Finland have been gathered in VACCIA’s GIS portal at Tvärminne Zoological Station, University of Helsinki (http://maps.tvarminne.helsinki.fi/). The portal gives open access to a large number of scientific publications, monitoring results, and their visualisations.

The effects of climate change are diverse in coastal marine ecosystems. These changes are both biotic and abiotic and interact with other processes affecting the ecosystem. The research area of climate change effects deals with changes in a multiplicity of factors as well as with interactions between such changes, and, further, with the responses of the ecosystem to these changes and interactions.

The salinity in the Baltic Sea overall is showing considerable short-term fluctuations, but in the coastal waters of the Gulf of Finland, the long-term trend is of slight decrease. The salinity in the Baltic Sea is regulated by inflows of Atlantic saltwater through the Danish straits as well as by freshwater runoff and precipitation. Variations in air pressure and the sea level explain the probability of the saltwater inflows. Climate change has been suggested as the cause for the saltwater inflows getting rarer, but the causal connection is still somewhat unclear.

Another considerable change is the increased turbidity of the water. Water’s turbidity is dependent on eutrophication – i.e., increased amounts of nutrients in the sea – as well as on the dissolved and particulate runoff matter from the drainage area. The nutrient discharges are primarily caused by human activities and would have increased even in the absence of the mechanisms of climate change. Floods and rain may further increase the leaching of nutrients and levels of turbidity-enhancing matter. The temporal distribution of dry and rainy periods is also relevant; for instance, more nutrients are retained in the soil during a dry summer and are then flushed into the sea in autumn and spring. Other observed changes are advanced sea-ice break-up in the spring and shifting of the annual phytoplankton maximum from spring towards late summer.

The combined effects of the changes in the Baltic Sea have become clearly visible in the biota in recent decades. The most noteworthy changes are:

- Decreased charophyte vegetation.
- Increased reed (*Phragmites australis*) coverage and distribution.
- A shift in benthos dominance from the amphipod *Monoporeia affinis* to the bivalve *Macoma baltica*.
- Increase and successful spreading by the polychaete *Marenzelleria viridis*.
- Decline in blue mussel (*Mytilus edulis*) populations.
- Strong increase for the roach (*Rutilus rutilus*) and other cyprinids.
- Decrease of pike (*Esox lucius*) in the outer archipelago areas (see Figure 7)\(^{24}\).
- Rapid decline in common eider (*Somateria mollissima*) populations.
- Strong increase in the great cormorant (*Phalacrocorax carbo*) population.
- Advanced spring migration of bird species.

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The changes have decreased habitat diversity, which leads to a need for management and preventive measures. Changes in the food-web structure (e.g., decline in blue-mussel numbers, habitat loss of valuable fish species, and prevalence of cyprinids and great cormorants) are directly reflected in recreational and professional fishing, and in the public debate surrounding these issues.

3.3.1.1 Precipitation changes as increased pressure for controlling eutrophication
The core environmental problem in the Baltic Sea – its eutrophication – may become even worse with environmental change. The greatest challenge related to eutrophication is that of agricultural discharges. This challenge will only become emphasised under the pressure of climate change. Hence, in planned measures associated with agriculture, such as buffer zones, fertiliser usage, and use of field areas, the primary adaptation means should be to prepare for the effects of the runoff caused by rainfall and floods.

3.3.1.2 Biomanipulation in order to prevent changes
Changes at the species level are a consequence of several simultaneously occurring processes; in addition to climate change, eutrophication plays a key role. Such changes can locally be prevented via biomanipulation. For instance, areas colonised by reed vegetation can be mechanically restored. Similarly, cyprinid fish stocks may be decreased through reduction fishing. Concurrently, nutrients are removed from the sea while other species’ competitive conditions may improve. It is, however, worth noting that such means neither eliminate nor prevent the original changes’ causes.

It is of great importance to understand the mechanisms behind the changes when one is planning manipulation. For example, regulation of the great cormorant population has often been suggested as a ‘trick’ for reviving fish communities. Long-term datasets, however, show strong fluctuations in the fish community long before the increase in cormorant populations. Therefore, adjustment by means of manipulation is challenging and requires extensive understanding of the food web’s functioning.

3.3.1.3 Necessary additional research
- Increased understanding of the correlation between nutrient runoff and meteorological data.
- Research on the behaviour of nutrients in different precipitation scenarios (e.g., dry summers and rainy autumns).
- Research into species interactions in marine ecosystems.
- Clarification of the true impact of cyprinid reduction at the ecosystem level.
- Effect of biomanipulation on other than its target species.
3.3.2

Less seashore meadowland and more wind-raise floods in the Bothnian Bay

Climate warming is expected to increase precipitation and wind-raise sea floods, which may change the hydrological conditions of low-elevation meadows in the northern parts of the Bothnian Bay. In more southern parts of Finland, this process is unlikely to be as extensive. Especially in the Bothnian Bay, the rise in sea level will slow the rate of new shore emerging with land uplift and short-term wind-raise floods may become more commonplace (as mentioned above, wind-raise floods are the increase in water level caused by certain directions of wind, leading to sea water being pushed to the end of the Bothnian Bay).

The decreasing rate of emergence of new shore area will make the low-growth vegetation meadow zone narrower, diminishing and deteriorating the habitat for the species requiring it. Even in its present state, the succession of the land uplift shores of the Bothnian Bay is rapid. From a five-year survey, the low-growth meadow species can already be seen to be declining in abundance. As the rate of new shore emergence declines, the low-growth meadow zone becomes narrower. The associated species experience this as a decrease in the amount and quality of the habitat they require. An increase in wind-raise floods in late spring will affect the reproductive output of ducks and shore waders in particular.

The number of habitats for birds nesting on low-elevation seashores will decrease, and, in addition, the birds’ reproductive success may decrease. Flood damage affects reproductive success directly through damage to nests but also by delaying the time of nesting by increasing the proportion of re-nesting in the population. The recruitment value of late nesting is lower for many species. The effects of wind-raise floods on vegetation may be both negative and positive.

The 2010 Red List of Finnish Species reports shores to be the prime habitat for a significant proportion (12.9%) of endangered species. The report states overgrowth to be the most important threat. Overgrowth results from several processes and attempts have been made to slow it via active management. Climate change and its consequences, in all their complexity, have not been taken into account, and the Red List does not yet consider them a significant threat. The material below presents the effect of climate change on habitats, with examples of endangered species studied in the Bothnian Bay.

3.3.2.1 Overgrowth of seashore meadows as a threat to endangered grasses

The endangered (EN) Arctic pendantgrass (Arctophila fulva var. pendulina) (see Figure 8) grows in the wettest parts of the seashore.

Figure 8. Arctic pendantgrass (Arctophila fulva var. pendulina). Photo by Marko Hyvärinen.

meadows of the Bothnian Bay, often at the water line or on bare mud. We can conclude that the species is dependent on vegetative reproduction, as viable seeds have not been detected in the Bothnian Bay population. The ecological requirements for creeping alkaligrass (Puccinellia phryganodes) and the threats to it are in many respects similar to those in the case of the Arctic pendantgrass, but its habitats are concentrated in those soils that are most strongly eroded by ice in the lowest meadow zone. The two occurrences of creeping alkaligrass in the Bothnian Bay are the only ones in the European Union, and the status of the species has recently been changed to ‘critically endangered’ (CR).

Both the Arctic pendantgrass and the creeping alkaligrass are locally threatened by the overgrowth of meadows and the resultant increase in competition with other grasses, such as the common reed (Phragmites australis) and the creeping bentgrass (Agrostis stolonifera). In order to succeed, the species require disturbances, such as scouring of vegetation by changes in sea level (see Figure 9) and movement of ice, which keep the shore habitat open. These disturbances also break loose fragments of vegetation and spread them locally. The success of the creeping alkaligrass is further affected by the grazing of geese in the low-elevation shoreline meadows. Soft and palatable, creeping alkaligrass is the preferred food of a nesting/moulting greylag goose (Anser anser). However, creeping alkaligrass tolerates grazing well, especially as grazing reduces the density of its competitor grass species. The performance of this species can further be improved through transplantation of plant fragments to new areas.

3.3.2.2 Floods and predators as threats to the southern dunlin’s reproductive success

The effect of catastrophic floods on the population viability of endangered species will increase as the climate changes. The critically endangered southern dunlin (Calidris alpina schinzii) (see Figure 10) is the most endangered of the waders at seashores. Some nests of this small wader are always destroyed in wind-raise floods, but predators play a larger role in its reproductive success at the moment.

A significant proportion (80%) of the southern dunlins in Finland nest in the grazed seashore meadows of the Bothnian Bay. In these environments, also trampling by cattle destroys nests (see Figure 11). The nests are also vulnerable to damage from predators. Predator damage can be reduced by covering the nests with steel netting that is sufficiently dense to prevent attacks by larger, predatory birds but loose enough not...
to prevent the dunlin female reaching the nest. Our studies showed that the most important factor for nesting success among southern dunlins is reduced grazing by cattle and delayed onset of grazing in the nesting area. The effect of wind-raise floods may increase, but active prevention of damage at the time of the flooding is difficult. Preventing damage would require fast reaction to the rise in sea level, availability of a large number of personnel, and knowledge of the location of individual nests in the meadows. In the long run, it would be more efficient to concentrate on protection of the meadows that southern dunlins use for nesting from floods and to give preference to grazing practices that reduce nesting damage.

3.3.2.3 Targeted restoration, for improved adaptation

Fluctuations in water level and the changes therein have a different effect on the endangered grasses and southern dunlins. The success of the seashore grasses requires disturbances wrought by changes in water level, while floods during the nesting time are detrimental to the production of southern dunlin offspring. Arctic pendantgrass and southern dunlins do not occupy the same meadows, which makes it easier to choose restoration and management practices that take the differing requirements of these species into account. The natural disturbance regime of Arctic pendantgrass and creeping alkegrass habitats should be preserved by avoidance of land-use practices and structures that change the movement of currents and ice in the critical areas. The changes in water level in the nesting habitats of southern dunlins, in contrast, should be minimised by, for example, choosing management sites that are not susceptible to wind-raise floods.

3.3.2.4 Grazing in the revival of seashore meadows

Many overgrown seashore habitats have been brought under management with the European Union’s special support for agricultural environments. For example, over 2,500 ha of traditional biotopes receive special support in the Bothnian Bay. About 90% of this area is managed by grazing and the rest by mowing. The grazing is done mainly by cattle, with less than 15% grazed by sheep, or the areas may be grazed by horses or mixed livestock. Of the area grazed by cattle, about 90% is used for beef cattle (mostly cows) and the rest for dairy-breeds heifers. Seashore management practices have changed greatly since the early 20th century, when mowing was the other central management practice and nearly all grazing cattle were of dairy breeds.

Grazing by cattle has led to the desired outcome for seashore meadows: the vegetation is significantly lower, and low-growing species (such as halophytes) are more common than in unmanaged meadows. The shoreline meadows grazed by beef cattle are often more completely eaten and have less detritus, making the vegetation more open than in meadows grazed by dairy-breeds cattle. Mid-sized beef cattle thrive better with the sparse fodder of natural meadows than larger beef cattle do. The animal type (breed and physiological state) and their numbers could be matched more carefully with the availability of food in the seashore meadows. Lighter cattle could be more suitable grazers in nature management if the soil of seashore meadows becomes more frequently inundated and softened by wind-raise floods. The management of upper shores will grow more important in the preservation of sufficiently large open meadows. This may require creation of new meadow environments above the actual seashore zone.

The value of environmental management, especially habitats restored and maintained by grazing, will change, which will also change the compensation for special agricultural environments. The goals of nature management will receive more weight than economic goals in decisions on where the special environment support in agriculture is to be targeted. The profitability of the management should be ensured so that this practice can continue far into the future. If drier management sites are
sought, further from the shore, questions of land ownership, especially the scarcity of the commons, may make the planning of management projects more difficult. Because of the effects on birds, the grazing season should be shortened in the late spring, which may increase the costs of supplementary feeding.

### 3.3.2.5 Necessary additional research

The following research work related to the Bothnian Bay should be carried out:

- Continued monitoring of endangered plants on low-growth seashores, to 1) give a reliable picture of the balance between the population growth and disturbance amid climate change and 2) improve the evaluation of the frequency and intensity of disturbance factors in climate change.
- Investigation of the invertebrate fauna on the seashore, which may have an impact on the availability of resources for birds, with consequences for their reproductive success.
- Description of the organisms inhabiting the shorezone area, to allow observing and monitoring changes in their populations.
- Investigation of the effects of different methods of restoration and management beyond monitoring studies – an impact analysis should be done for the most central endangered species such that their complete life cycle is considered.
- Evaluation of the effects of a switch in the most important grazers used in seashore management – beef cattle have largely replaced traditional dairy cattle in the management of seashore meadows, and better knowledge of the effect on vegetation is needed.
- Evaluation of the environmental effects of grazing and animal well-being considerations as well as the profitability of different management practices.

### 3.4 Urban environments

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#### 3.4.1 Transformations in the ecosystem services of urban environments

The goal of the multidisciplinary VACCIA subproject titled ‘Assessment of Climate Change and Land Use Impacts in Urban Environments’ has been to study the combined effects of the land-use and climate change for the ecosystem services in the designated urban areas in the cities of Lahti and Helsinki.

Ecosystem services have a particularly important role in the cities. Green areas such as parks provide the majority of the ecosystem services in urban areas, cleansing the air, filtering the water, removing urban pollution, binding carbon dioxide into the soil, reducing the risks of flooding, and addressing other storm-water-related issues. Urban green areas, in a wider sense, also present aesthetic value and serve as an asset by being an important part of the local cultural heritage in the form of the historical built environment.

One of the focal changes foreseen in the future of urban ecosystem services is the increasing precipitation level and the ‘urban heat island’ phenomenon accompanying rapidly advancing urbanisation all over the world. Prior research has demonstrated that a denser urban structure decreases the quantity of urban green areas providing local ecosystem services and weakens their quality as well as the urban hydrology. In many cases, the decreasing quality of groundwater, as well as various anomalies of the surface waters, can be attributed to the lack of living ‘freely breathing’ surfaces.
These transformations have direct effects in the increasing amount of runoff and its declining quality, especially in areas in which the proportion of impervious surfaces is high. Negative effects linked with the runoff water are both local, in the form of the flow areas, and regional, contributing to the pollution of surface waters and the erosion of riverbeds.

The role of ecosystem services, especially in northern climes, raises many essential questions, such as:

- Which urban ecosystem services are the most important?
- What is the real capacity and capability of cities to provide ecosystem services for their inhabitants?
- How can ecosystem services be incorporated into urban planning processes and as tools for the planners?

3.4.2

Denser urban structure as a future challenge

Dense urban structure presents a serious challenge of adaptation for ecosystem services as well as for urban green areas in a broader sense. As urbanisation advances rapidly all over the world, climate change forces metropolitan areas and large cities to consolidate their urban structures. New developments such as residential neighbourhoods are often planned to be denser than previously, and older neighbourhoods too are being made more compact, through filling in of previously unused lots.

The most common argument for a denser urban structure is that a more compact city is a more ecological one, decreasing the need for longer commutes by car, enabling development of the public transport networks, and providing services closer to the people and more economically, all of which help to reduce the local carbon footprint. Although new and more environment-friendly technical solutions in urban planning and in construction engineering are constantly emerging, more compact urban areas inevitably have less green space, which amounts to reduction in urban ecosystem services.

With the annual rainfall predicted to increase 15–20% in consequence of climate change, the growing area covered by impermeable surfaces inevitably increases the risk of flooding in urban areas. Yet different approaches to planning could enable increasing the proportion of permeable surfaces in areas with a large population and construction density. Allowing storm waters to soak in by increasing the amount of permeable surfaces offers a solution to the runoff problem in urban environments (see Figure 12).

![Figure 12. The amount of storm waters against the area of impermeable surfaces at the measurement points in Lahti and Helsinki. The fewer permeable surfaces there are, the less precipitation will soak in, with more running off as storm water.](image-url)
As an example of a different solution, making urban structure more compact does not necessarily mean that all non-built lots and other areas will be built up and ultimately covered with sealed surfaces. The question is also one of how much the city can be consolidated both upward and downward. Numerous examples, from all over the world, show that new types of innovative solutions in planning, architecture, and construction technology enable building of a vertically denser city.

Even if dense urban structure can be an effective means of decreasing the local carbon footprint, there are other serious environmental challenges in the cities, which are easily pushed aside when public debate concentrates on one issue at a time. Adaptation to climate change demands a holistic view and understanding that emphasis on certain aspects of the phenomena can make the situation simultaneously worse elsewhere.

Since not all ecosystem services can be replaced with technical solutions, we should consider whether the direct advantages and benefits that a denser urban structure offers are greater than the long-term harm that denser cities cause in the end. This issue is challenging, as it involves political values and the necessity of making ‘hard decisions’. Does the worry about carbon end up undermining other measures aimed at sustainable long-term development of the urban environment? As the argument is now framed, consolidation of urban structure leads increasingly often to a trade-off between cities’ basic infrastructure and green areas.

A slightly different, yet equally important, potentially negative development trajectory is that of diminishing urban green space eventually reducing the general well-being and happiness of the residents. Parks and other recreational green areas in cities offer not only benefits to citizens’ health but important aesthetic and cultural values.

One major challenge is related to the difficulty of assessing ecosystem services in monetary terms. This problem is especially topical in growing metropolitan areas and cities such as Helsinki, where the local geography and history make buildable zoned land a relatively scarce resource today and the demand for housing is constantly high. Such situations force many cities to prioritise maximal efficiency of land use in planning, often at the cost of green areas.

On the other hand, cities’ planning departments are aware of the threats posed to ecosystem services and green areas in general. Urban planning in Finland is highly regulated by international standards, and, in the case of Helsinki, the city itself is a powerful landowner within its own borders. From this perspective, the public sector has all the necessary tools and means to react.

3.4.3 Necessary additional research

- Addressing whether cities and urban environment in general can serve as real laboratories for the research of consequences of climate change.
- Examination of whether ecosystem services are sensitive in different ways to climate and temperature changes, construction work, the changing socio-economic structure of neighbourhoods, or other such phenomena.
- Consideration of how ecosystem services could be evaluated and assessed with indicators compatible with the economic indicators used in urban planning.
3.5

Ex situ conservation of plant biodiversity

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Ex situ conservation is defined as protection of an organism ‘off-site’ – i.e., outside its native habitat. Internationally, ex situ conservation has been increasingly applied in recent decades as part of the toolbox of the conservation biologist. In Europe, the conservation status of more than half of the habitats and species listed in the annexes of the EU Habitats Directive is classified as unfavourable, and the target of halting biodiversity loss by 2010 was not reached. Under these circumstances, plants protected ex situ (for instance, in botanical garden collections) are increasingly important as a supplement to in situ conservation (on-site conservation or the conservation of genetic resources in natural populations of plant or animal species). From ex situ collections, preserved in the form of living plants, stored seeds, and tissue cultures, plants can be reintroduced to their original habitat or, where necessary, an ecologically restored habitat. Alternatively, new areas, considered to provide more favourable living conditions as climate change proceeds, can be targeted.

The Global Strategy for Plant Conservation (GSPC), which sets several outcome-oriented global targets for 2010, was approved in Decision VI/9 of the Conference of the Parties (COP) to the Convention on Biological Diversity in 2002. Target 8 includes the following commitment to ex situ conservation of threatened species: ‘60 per cent of threatened plant species in accessible ex situ collections, preferably in the country of origin, and 10 per cent of them included in recovery and restoration programmes’. Moreover, a new strategy for plant conservation was adopted at the COP in Nagoya in 2010, with revised targets of 75 and 20 per cent, respectively.

Finland has adopted the GSPC but has neither implemented its ex situ recommendations nor officially planned out their implementation yet. Hence, there is an urgent need to fulfil this obligation in the face of the rapid changes in the environment brought about by climate change. Internationally, botanical gardens and their international collaboration organisation Botanic Gardens Conservation International (BGCI) have actively promoted the CBD-based Global Strategy for Plant Conservation by, for example, publishing a specific agenda for conservation of biodiversity. In VACCIA, Finnish botanical garden collections were investigated, for finding nationally threatened vascular plant species of known wild origin. To assess the accessions’ potential in future reintroduction programmes thoroughly, the quality of origin data and genetic intactness were ranked. In total, 77 accessions, in 56 vascular plant target taxa, were cultivated as living plants, representing 18% of all nationally threatened taxa. The results of the survey are consistent with results from similar studies carried out at botanical gardens in other countries, showing deficiencies in intra-species and within-population diversity, but the accuracy of origin data and genetic intactness of the accessions were found to be good.

3.5.1

*Ex situ* conservation action plan

The survey formed a basis for an *ex situ* action plan for the conservation of threatened native plant taxa in Finland (Action 11, Annex 6). It includes 11 concrete targets for helping to reach the target of 40% of threatened species being subject to *ex situ* conservation by 2016. This would mean that 50 new taxa (at species, subspecies, or variety level) were collected in addition to the 22 already *ex situ* conserved. Moreover, the material would be maintained in conditions where there is no danger of cross-breeding with closely related taxa. For a genetically representative sample, seeds from as many populations as possible, and from 50–200 genetic individual in the ideal case, should be collected.

For meeting the national targets, a workable infrastructure, including a national seed bank, should be established. Moreover, for those native plants that do not set seed, *ex situ* conservation can be developed on the basis of vegetative propagation, micropropagation, and cryogenic conservation of plant tissues. In cryogenic storage, totipotent plant material is stored for long periods in liquid nitrogen (e.g., at –196°C) or in its gaseous phase (approx. –150– –160°C). Together with these two *ex situ* methods, living outdoor collections in botanical gardens, which form the basis for current *ex situ* collections, should be maintained and developed. Also, the conservation of some special organisms, such as cryptogams (ferns, mosses, fungi, and lichens), needs a great deal of attention, including basic research, if it is to be successfully incorporated into *ex situ* conservation schemes.

3.5.2

Necessary additional research

- Evaluation of the conservation status of cryptogamic taxa and assessment of feasible *ex situ* methods for them.
- Development of scientific criteria for the selection of plant taxa to be conserved *ex situ*.
- Implementation of the Finnish *ex situ* action plan and its integration into international programmes.
4 Adaptation is necessary for livelihoods

4.1

Agriculture

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4.1.1

Longer growing seasons and earlier sowing

The thermal growing season has become several days longer in Finland over the last hundred years. Farmers have adjusted via earlier sowings in the past few decades. The future will see spring advance further, and sowings will start earlier. For example, sowings are expected to advance by a week between 2011 and 2040. In autumn, however, given the low light intensity and short days, the growing season will not be prolonged. Higher temperatures during spring and summer will increase the effective temperature sum. Increases in the warmth and length of the growing season improve the yield potential and enable the introduction of a wider selection of crops. However, this requires adaptation of cultivation to the new growing conditions: suitable crops need to be bred and farming systems developed.

Climate change is not the only process affecting the socio-ecological production environment. Adaptation to climate change has taken place and will continue along with the ongoing structural changes in Finnish agriculture (sharp decline in the number of farms, specialisation by region and of individual farms, and increasing farm size), changes in the global market, and the never-ending change of the Common Agricultural Policy of the European Union.

4.1.2

Weather variability and the vulnerability of agriculture

Weather extremes that reduce or damage crops, such as heavy rainfall, long periods of rain, floods, storms, and droughts, as well as exceptionally high summer and winter temperatures, are expected to increase with climate change. Snow will more often fall on unfrozen ground, cycles of freezing and thawing will increase, and the average snow cover will be thinner. Even if winters are getting milder on average, there will still be early springtime frosts that can reduce yields. Increasing erosion and risk of soil compacting (brought about by rainy winters with thin snow cover), heavy rainfall, and floods threaten to reduce the fertility of the soil. A warming climate also favours the spreading and overwintering of pests, pathogens, and weeds.

Farms have always had to adapt to constantly changing weather conditions, but increasing weather extremes and variability between growing seasons will require even more adaptation capacity, especially in economic terms. The increase in extreme weather threatens to weaken yields in many agricultural production areas around the globe, and is likely to bring about shifts in the global market. Therefore, northern agriculture may play an increasingly important role in ensuring food security.
4.1.3

Changing conditions and viability issues, posing challenges to adaptation

The effects of warming on Finnish agricultural production are expected to be positive in part but also partly negative. For example, milder winters enable more winter-sown crops to be cultivated, but at the same time the overwintering risks will increase because of fluctuating winter conditions. Warming will increase the yield potential, but yields are likely to be lower for many of the recently cultivated crops not adapted to higher temperatures. Early-summer drought may start to restrict yields – rainfall is expected to increase only at the end of the growing season. Regardless of rising mean temperatures, winter and cold periods during the growing season are not disappearing. Therefore, more resources are needed for breeding cultivars that are adapted to the new growing conditions in Finland.

Climate change brings new challenges to water protection efforts in the farming environment. Today’s water protection measures have not been effective in reducing nutrient loads from fields to waterways to target levels, and conditions will not improve. Erosion and leaching of nutrients from the fields will increase with higher rainfall and thinner snow cover during winter, as well as with increased floods and periods of heavy rains. The decay of organic matter in the soil will increase in a warmer climate, releasing more nitrogen from the soil. The VACCIA project produced local climate change knowledge with the Lepsämänjoki agricultural watershed (a sub-basin of southern Finland’s Vantaanjoki river basin) as a case-study area. According to water quality modelling, climate change will increase the suspended sediment load by about 15% and inorganic nitrogen load by over five per cent in this erosion-prone area.

Farmers are concerned about the profitability of production and with debts from big investments, as well as the uncertainty brought by the frequent changes in agricultural policy and support systems. Possible future responsibilities for reducing emissions of greenhouse gases at the farm level and the cost of these measures bring new concerns. The measures required because of climate change should be viable at the farm level both economically and technically, whether they have to do with more efficient water protection or climate change mitigation. Adaptation to climate change at the farm level demands long-term political and economic incentives. Agricultural policy should support farmers in such a way that investment in the best possible practices is profitable.

4.1.4

Plant breeding and diversification as adaptation measures

A warmer climate and a prolonged growing season will enable the introduction of cultivars with higher yield potential. However, Finland’s long day conditions will not change, and cultivars adapted to more southern light conditions will not be successful here. Cultivars that can make use of the longer growing season and higher temperatures but are still adapted to long days must be bred. In addition, breeding is needed for greater efficiency in nutrient and water use, disease-resistance, and overwintering capacity. Plant breeding can also advance the introduction of novel overwintering cultivars. These are attractive because of their higher yield potential and ability both to avoid early-summer drought and to make use of the prolonged growing season right from the start in the spring, as well as for providing protective soil cover in winter.

Water protection must be improved through work toward closed nutrient cycles and by intensified measures targeting those fields that have the highest risk of nutrient leaching and erosion. Targeted basin-specific measures need to be developed, with attention to the farmers’ knowledge of local conditions. The drainage system should be able to cope with exceptionally high rainfall. In addition, vegetation cover in
erosion-prone areas should be as wide as possible in winter, to reduce erosion and nutrient leaching.

The uncertainty that is predicted to increase with climate change, weather variation and extremes, outbreaks of pests and diseases, and shifts in global markets can be alleviated via diversified production. A longer growing season enables selection of diverse crop species for cultivation. For example, oilseed rape, the fava bean, and the field pea may become major crops. Increasing cultivation of these crops would enhance Finland’s self-sufficiency in protein crop production, which at the moment is only around 20%. Furthermore, legumes reduce the need for nitrogen fertilisers by fixing nitrogen from the air.

VACCIA has produced four scenarios of possible arable land use in two northern sub-areas of the Lepsämänjoki watershed for each of two points in time: 2025 and 2055. Land was allocated for the various crop species in view of the opportunities brought by climate change (according to the IPCC’s SRES scenario A2) for growth of new crop species and for introduction of winter-sown cultivars, as well as the possibility to extend areas of current crops. The scenarios produced are 1) greater protein self-sufficiency 2) greater winter crop cover, 3) more crop diversity, and 4) cereal monoculture. Figure 13 shows the crop combinations of scenarios 3 and 4 in one of the northern sub-areas of the watershed in 2025. In 2009, 49% of the region’s field area was cultivated with barley and 15% with spring wheat. Also some autumn wheat, rye, oilseed rape, and turnip rape were cultivated. Approximately a quarter of the area was used for other plants.

4.1.5 Necessary additional research

- Development of methods for water protection that are adapted to local conditions, in co-operation with farmers, and research concerning the efficiency of new methods.
- Development of methods for risk management related to pests, plant diseases, and weeds.
- Development of improved water management (including irrigation systems), and research on closing the nutrient cycles in farming.
- System research on the joint impacts of major socio-economic changes that affect agricultural production alongside climate change.
- Examination of the nutrient loading of waterways and the profitability of different local crop combinations in conditions of climate change.
4.2

Forestry

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4.2.1

Changes experienced and expected in forestry

The increase in carbon dioxide (CO\textsubscript{2}) of about one third from the pre-industrial era and simultaneous slight temperature increase have not yet produced a clearly distinguishable growth response in Finnish forests, according to tree ring time series. In parallel with climate change, there has been an increase in nitrogen deposition and a dramatic change in the forest structure due to a shift in silvicultural practices since 1950s, both of which drive forest productivity in the same direction as climate change (see Figure 14).

The predicted CO\textsubscript{2} increase and the climatic feedback mechanisms will lead to a rise in temperature of about 2–5°C by the end of the 21st century. We estimate that by 2100, the CO\textsubscript{2}- and temperature-induced increase in leaf-specific gross primary production (GPP) for pine will be 16%, 31%, or 41%, depending on the IPCC scenario (B1, A1B, and A2, respectively). A significant amount of the increase is attributable to the longer growing season, as 2085’s maximum increase in instantaneous photosynthetic rates in mid-summer caused by elevated CO\textsubscript{2} is only 10–15% higher than current rates. The increase in production will be greater for birch, which has a steeper instantaneous temperature response and higher temperature optimum for photosynthesis than pine does. Our analysis predicts that elevated CO\textsubscript{2} will decrease instantaneous transpiration rates in both pine and birch. With the future’s longer growing season, however, annual cumulative leaf-specific transpiration will remain at roughly the present level while the leaf area increase may elevate annual transpiration at the forest level.

4.2.2

Accelerated tree growth

Increased GPP alone results in a smaller growth increase than that of GPP because soil nutrients are simultaneously depleted. However, temperature-driven acceleration in nitrogen cycling and change in within-tree biomass distribution along with productivity changes caused growth of roughly eight per cent per degree Celsius in pine stemwood production with mature stands. This resulted largely from lower relative growth below ground. The observed temperature response of soil CO\textsubscript{2} efflux and increase in active growth and decomposition period (temperature >5°C) length point to an increase of six per cent in the rate of decomposition per 1°C temperature increase. The average growth increment in closed-canopy stands with CO\textsubscript{2} scenario B1 and a mean annual temperature rise of 2°C was 16% for southern Finland and 31% for Lapland. The extreme CO\textsubscript{2} scenario, A2 (see Figure 15), with a temperature rise of 5°C resulted in growth enhancement of 40% in southern Finland and 80% in the north. In this scenario, Lapland’s climate eventually becomes warmer than the current climate in southern Finland, but wood production will remain slightly lower in the north, as the initial pools of organic matter in the soil and, correspondingly, organic nitrogen are smaller in the north. The experimental results from the large-scale CO\textsubscript{2} increase experiments show similar patterns in terms of elevated CO\textsubscript{2} and soil warming experiments had a similar outcome in terms of nitrogen availability.
4.2.3 Extreme events and competition, downscaling acceleration of tree growth

The average number of drought days will not increase significantly with climate change, but more severe drought periods may be seen more frequently, which could seriously affect growth and increase leaf turnover and mortality. The number of drought days will be about double that of 2006, with a similar rainfall pattern, in the new climate with elevated temperature. Overall, increase of drought days was not predicted to cause significant reduction in plant productivity, but it may directly influence growth, which is more sensitive to drought than GPP is. The long-term historical growth data showed a slight decrease in both pine and spruce growth in dry years, with the impact lasting longer for spruce.

Elevated temperature, greater CO₂ concentrations, and more rapid turnover of organic matter in the soil (releasing more nitrogen to plant use) will lead to sites’ eutrophication. This favours more rapid post-disturbance development of grasses and herbs. Also comparable-size seedlings of broad-leaved species such as birches are better competitors for resources in conditions of high resource availability during early development than are conifers. For southern Finland, we may assume that in 2100 the peak biomass of herbs and grasses on a fertile MT (Myrtillus type) site will be double that for rich OMT (Oxalis-Myrtillus type) sites currently and will be about the level now seen on a rich OMT site or poor CT (Calluna type) site.

4.2.4 Sedentary birds documenting changes

Human-induced habitat destruction/fragmentation and climate change are two major threats to global biodiversity. Climate change has already caused changes in physiology, phenology, reproductive success, and survival for various species, including birds. In the last 20 years, average populations of common forest birds declined by nine per cent in Europe, decreasing most in northern and southern regions. Intensive exploitation of forest resources is considered the main reason for the decline in Northern Europe. For species to survive, it is crucial to maintain their environments as global change progresses and to complement the species’ capacity to change their distribution ranges. Resident birds are ideal study organisms to test for relationships...
between landscape fragmentation, climate change, and vital rates, since high site fidelity means that they are affected by the same habitat and climatic regimes throughout their annual cycles.

In Finland, the composition and age structure of forests have changed, although the forest cover has stayed the same. In addition, modern forestry practices have decreased the number of dead trees in forests, with the concurrent population decline of many species dependent on decaying snags. Forestry has decreased the quality of habitats for the case species examined, the willow tit (*Poecile montanus*) (see Figure 16), by reducing the suitable breeding and wintering area, with associated reduction in the carrying capacity of forests (carrying capacity refers to the maximum number of individuals of the species a given environment can sustain).

The most important factor in willow tit nest site selection seems to be the presence of standing decayed deciduous trees. Willow tits are highly site-tenacious. As long as a suitable decaying tree remains for excavation of a nest hole, a pair may stay breeding in the same territory even when logging or thinning has drastically altered the territory. Many secondary hole-nesting passerines benefit from the presence of willow tits by using their old nest cavities. Availability of suitable nesting holes can limit the population sizes of hole-nesters. Because of intense competition for nest sites, some individuals have to settle for lower-quality sites, with poor reproductive success.

With higher spring temperatures, the willow tit has significantly advanced its breeding schedule in northern Finland over the past 35 years. Also, the timing of the availability of primary food items used by parids for nestling provisioning, caterpillars feeding on birch foliage, has advanced. Therefore, warm springs allow willow tits to time their breeding in better synchrony with the availability of food, which changes the nourishment supply of their young. This has modest positive effects on the breeding success of this species. With climate warming, warm springs will be seen more often, which, on average, will lead to better synchrony of food availability and food demand. Nonetheless, the possible benefits of climate warming are unlikely to compensate for the damage caused by habitat loss and deterioration in habitat quality.

Figure 16. Willow tit (*Poecile montanus*). Photo by Antti Below.
4.2.5
Climate change as a factor increasing profitability but also risks in forestry

Overall, silviculture will become more profitable with changing climate, as forest productivity increases. The net present value of the final harvest could more than double in southern Finland and triple in the north. At the same time, more vigorous growth of ground vegetation makes forest regeneration more difficult and costly. In the current, transition phase, the increased growth is partially decoupled from the need for increased effort in stand establishment, as the forests have been regenerated in the current climate while their growth benefits from the improving growth conditions.

The warmer climate will expose forests to new, harmful insects and pathogens, and even some currently harmless ones may become problematic. Although, on average, drought will not be a major factor decreasing growth, it may have an important role in triggering mortality in combination with various biotic vectors. Also climatic change will expose the forests more to storms, as the soil becomes gradually less frozen during the high-wind periods in autumn and winter. Non-frozen soils will also make harvesting operations more difficult, particularly in wet areas.

The need to consider the requirements of other ecosystem services, such as carbon sequestration, water production, and biodiversity, will increase as the climate changes, as will the trend toward use of forests for recreation. The impact on forest management could be considerable, depending on whether these can be assigned a clear economic value or are included in the norms guiding forestry. The demand for renewable fuels is already starting to influence silviculture. If harvesting of wood for biofuels is badly organised, a significant long-term impact on forest fertility may result; on the other hand, it provides new possibilities for alternative silvicultural practices that are based on coppicing in the new climate. The situation in Lapland is particularly interesting, as silviculture plays a smaller role than other land uses in those northern forests. With climate change, silviculture will become more profitable and conflicts between land uses will increase, particularly since protected areas account for a large proportion of the total land area.

4.2.6
Challenges for silviculture

The greatest challenges faced by silviculture in the changing climate are linked to tree species and provenance selection, regeneration methods, stocking densities, and timing of harvesting operations and to disturbances caused by drought, storms, and fungal and insect attacks. The non-frozen soil will impose large practical challenges on harvesting operations, particularly on wet soils. These will influence both management of individual stands and planning of regional forest management – even the selection of the silvicultural chain to be used.

Higher site fertility and more frequent disturbances improve the profitability of broadleaf trees’ management relative to that of conifers. Also, species that are now of only marginal economic value, such as oak, elm, and ash, will become more widely available with climate change. However, the risk entailed by the large interannual variation in weather will still limit the usability of more southern species / provenance for many years to come.

More intense competition from ground vegetation and competing tree species implies that the window of opportunity for stand regeneration will become much narrower and increase both scarification and herb-layer treatment needs, also making their correct timing more acute. Avoidance of large-scale natural disturbances caused by drought or wind-throws needs to be considered in the planning of stocking densities.
and timing of harvesting. Of the current species, spruce is the most vulnerable to both of these disturbances. These factors influence the relative advantages of different silvicultural chains and must be considered in choices from among clear-cutting-based silviculture (currently dominant), continuous-cover silviculture, and fast-rotations silviculture.

Increased precipitation outside the growing season, more intensive rainfall periods, and more rapid decomposition of organic matter may increase runoff from forested areas and increase erosion and nutrient leaching immediately after clear-cutting. On the other hand, the more rapid development of ground vegetation and greater total biomass in forests will have an opposing effect. On average, runoff during the growing season will not change much, but greater precipitation outside the growing season may increase nutrient leaching if no means are applied to prevent it. This additional load may have a harmful influence on small-scale headwater bodies whose water quality is weakened by the warming climate.

Utilisation of forest bioenergy, carbon sequestration, and other climate influences and guaranteeing of the other ecosystem services that forests provide may imply new, conflicting requirements for the use of forests. The positive climate impacts of forest-based bioenergy need to be compared against their influence on the carbon store in the forests. Highly intensive use of bioenergy may not be compatible with the maintenance of biodiversity, as present practices have already led to a large decrease in dead wood material in the forests and a consequent decline in species diversity. Climate change also imposes a challenge for regional planning of the forest mosaic, as it should support the opportunity for species migration in the south–north direction.

4.2.7 Scheduling of new modifications in silviculture as the key for successful adaptation

Adaptation of silviculture is problematic, as there is still considerable uncertainty of the climate expected by 2100, by which time the forests now being established will reach their maturity. The optimal tree species breakdown might be very different then from what is ideal now. Use of pine on present dry growing sites is well justified, as regeneration is easy in the current climate and growth will accelerate. Also, there is currently no good alternative, but the further into the future we move, the more alternative tree species will become viable on these sites. On fertile sites, it is rational to establish mixed spruce–hardwood stands. Spruce–birch mixture is already a competitive combination in comparison to pure spruce stands. If climatic changes create problems for spruce, the hardwoods can be grown and harvested as planned. In southern Finland, one could try more valuable hardwoods, such as oak, in the mixture – types whose use is, on account of temperature-based limitations, only marginal at present.

Climate change facilitates the use of more varied silvicultural chains. These should be considered already in today’s species selections. For example, one could anticipate the regeneration problems of the future by selecting species that can be regenerated through coppicing on fertile sites. Hybrid aspen is a viable option already, and the possibility of regeneration through coppicing makes it an interesting alternative if competition from ground vegetation increases. Increasing fertility favours continuous-cover forestry, and higher temperatures will allow use of other shade-tolerant species, such as beech, in the future. The greater probability of wind-throws with such alternatives must be considered.

In a clear-cutting regeneration scheme, correct timing of sapling stand tending and thinnings becomes more critical. More rapid tree development increases competition and creates risks for the trees that are targeted in silviculture. Increasing fertility
requires denser stands for wood quality control, particularly for pine. In forest-based bioenergy production, the depletion of soil-based nutrients become more critical, as the growth is increasingly nutrient-limited.

Safeguarding forest biodiversity requires more attention to maintenance of different types of forest environments and their south–north continuum. Forestry operations need to consider watershed-level entities in the protection of watercourses and bodies that are also threatened by eutrophication. These requirements impose new demands on regional planning of forest management. The new situation also adds new demands for the training and education of forest-owners and practitioners.

4.2.8 Necessary additional research

- Studies of interannual variation of forest growth and its links to weather and the immediate and delayed impacts of extreme events on tree growth and survival.
- Studies of the various tree species’ characteristics and responses to changes.
- Studies of the characteristics and reactions to changes of different species of ground vegetation in forests.
- Studies of the dynamics of nitrogen circulation under climate change conditions and their feedback to tree growth, particularly in connection with bioenergy harvesting.
- Recognition of the key characteristics of habitats required for species’ existence, and study of the effects of habitat destruction and climate change (e.g., responses of boreal forest birds).
- Research into the responses to climate change made by different species and populations in various environments.
- Research on the impact of climate change on population dynamics and viability.
- Research into the effects of climatic change on phenological events at different trophic levels (plants, invertebrates, and vertebrates) in boreal habitats.

4.3 Fisheries

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4.3.1 Changes for the fisheries in the Lake Päijänne area

There will be large changes in temperatures of lakes at the end of this century, according to simulations based on scenarios of climate change. In the deepest part of Lake Päijänne (Ristinselkä), temperature stratification during summer will last longer and the metalimnion will be deeper (see Figure 17). Temperature in the epilimnion will be 2–3°C higher than at present, and the growing season for some fish species could increase by as much as two months. In winter, there will not be permanent ice cover every year, and lakes are expected to freeze and melt several times in the course of the same winter. The changes in temperature and ice cover will affect the behaviour of fish and also the fisheries. In addition, eutrophication and changes in water quality (see Section 3.2) affect the fish community and therefore the entire fisheries.

In Lake Päijänne, the most important fish species in economic terms are vendace and whitefish. For example, the 1996 catches were 150 and 114 tons, respectively. The effect of climate change on reproduction of these species was studied via laboratory
experiments and modelling. Eggs were incubated at temperatures representing the average temperatures yielded by simulations for the future. The earlier spring did not affect the survival of eggs. The hatching proportion was at the same level as in eggs incubated at natural temperatures. The average spawning date of vendace will be about three weeks later by the end of this century, if the simulations of future water temperatures are accurate. Hatching, however, will occur about two weeks earlier than at present, because of the warmer autumn and earlier spring. Compared to the present situation, the water temperature at hatching time will be, on average, 2–3°C higher, according to water temperature simulations. This may have both positive and negative effects on the survival of vendace larvae. Larvae eat zooplankton, whose amount in warm water can be higher; therefore, also the larvae’s growth rate may be higher. On the other hand, also the activity levels and food consumption of predators, especially perch, will be higher.

During summer, adult vendace migrate to the epilimnion to eat at dusk and dawn, spending the rest of the time in deeper and colder water layers. If the temperature in the epilimnion grows too high and the metalimnion sinks deeper, this vertical migration might be disturbed. This could have effects on the feeding, growth, and reproduction ability of vendace. At the same time, the habitat available for vendace in summer could decrease. In some shallower areas, the shrinking of the cold hypolimnion could be harmful to smelt stocks, especially if the oxygen content in deep areas decreases because of eutrophication. Smelt prefer cold water and are important prey for many predatory fish species in boreal lakes.

4.3.2
The effect of climate change on fish stocks

The most important fish species for recreational fishing are perch, pike, pike-perch, and brown trout in Lake Päijänne. Trout may suffer in the future because of high temperatures in summer. Brooks and rivers are spawning habitats of brown trout, and trout spend the first years of their life in these running waters. The simulated water temperatures could be above the temperature tolerances of brown trout; therefore, growth might be prevented and mortality increased in the future. Summer 2010 was extremely warm, and after that the brown trout densities observed were consequently low in central Finland. Also, the drying of small creeks during summer and increasing runoff of suspended solids to spawning sites are harmful to reproduction of brown trout.
Pike-perch and perch favour warm water and are expected to benefit from increasing temperatures. At present, in northern Lake Päijänne, a six-year-old pike-perch weighs about 1 kg, but the estimated weight for the same age is 1.8 kg (see Figure 18) when the simulated temperatures of the end of this century are used. Also, food consumption will almost double (see Figure 19), which affects prey populations too. At the same time, however, the longer growing season in the first year of life can improve survival through the first winter.

### 4.3.3 The vulnerability of fisheries

In general, the fish communities of the future will be dominated by percids and cyprinids instead of salmonids. At present, professional fishing is based on vendace and whitefish, so the economic value of the available resource by today’s standards will fall. The by-catch with low marketing value causes extra costs and decreases the profitability of fishing.

If in warm summers the metalimnion is deeper than in today’s climate, vendace and whitefish will live deeper in the water column so be more difficult to catch by trawling. High temperature also increases the cost of chilling. Because the open-water period will be longer, the trawling season will be longer, however, which could make it more profitable in some respects. As for traditional winter seining, operations will become more difficult. The effects of mild winters on fisheries and fish stocks have been observed, for example, in Pyhäjärvi, in south-west Finland.

### 4.3.4 Adaptation — challenges and recommendations

Fishing as a livelihood has to adapt to changes in both environment and fish stocks. Professional fishing has already adapted to large interannual variation; for example, large fluctuations are typical of vendace stocks. The adaptation has consisted of changes in target species or fishing areas. There are also projects focusing on exporting coarse fish. These too aid in adaptation. If the proportion of percids rises and that of coregonids falls in the professional catch, the total catch weight decreases. Yet economic value need not be lower, on account of higher producer prices. The expected changes will be slow enough that a livelihood already adapted to change in short periods can adapt to these changes.

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**Figure 18.** The observed (1971–2000) average mass of pike-perch of a given age, with predictions for the same for 2070–2099 via the simulated temperatures and bioenergetics models for Lake Päijänne.

**Figure 19.** The annual food consumption of pike-perch in 1971–2000 and predictions made for the same for 2070–2099 with the bioenergetics model. The estimates are based on the speed of growth presented in Figure 18.
4.3.5 Necessary additional research

- Changes in temperature stratification in different types of lakes.
- The response of different fish species to changing water temperatures.
- The interactions within the fish community.
- Analysis of the existing biological database in the context of weather data.
- Development of models for fisheries management applications.

4.4 Tourism

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The critical change thresholds for nature-based tourism (see Table 2) and the outlines for local adaptation measures in the context of locally scaled climate change scenarios were defined via a purpose-built vulnerability assessment model. The assessment, realised by the University of Oulu, focused on the ecological, social, and health impacts of climate change and potential adaptation measures in two towns in north Finland: the town of Kuusamo, with the Ruka ski resort, and the municipality of Sotkamo, home to the ski resort Vuokatti.

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<th>Table 2: Local vulnerability thresholds of current tourism</th>
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<td><strong>Town of Kuusamo</strong></td>
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<td><strong>Winter</strong></td>
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<td>• Daily averages below 0°C for artificial snow production in October for Autumn break high season in ski resort</td>
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4.4.1 Examination of vulnerability thresholds

Changes in precipitation, shorter and warmer winters, and substantial decreases in snow and ice cover can dramatically change conditions for nature-based tourism in northern Finland. The assessment focused on tourism and related communities and on formulating suitable adaptation measures with collaborative planning in future workshops involving local tourism stakeholders.

The assessment began with basic research into local tourism, its local and regional importance, and contextual everyday practices. This made it possible to position the role of climate change among the variety of environmental and societal factors with a local effect. The policy relevance of the study was heightened via reciprocal co-operation in regional climate change strategy work by the Council of Oulu Region and the Regional Council of Kainuu. The results were presented also to the municipal councils of Kuusamo and Sotkamo. Decision-makers’ feedback emphasised the need for information on changes already perceived in long-term local weather patterns and the perspectives of the regions of origin of tourism. The assessment was accomplished by interviewing local tourism stakeholders, reviewing local economic statistics, and analysing local daily weather statistics in combination with locally scaled climate change scenarios produced by the Finnish Meteorological Institute. Information was collected also from local health-care and security services personnel, and from international tourism operators.

4.4.2 Increased risks in winter tourism that stem from changing weather conditions

The research results emphasised local perceptions and worries related to growing uncertainty of the freezing of water bodies and wetlands and increasing security risks brought on by the increased variations in weather conditions and, particularly, for winter tourism and for marketing and traffic. The increase in risks is related to the overall increase in the unpredictability of local weather conditions (see figures 20–22). These risks will increase in the context of the climate change scenarios provided.

4.4.3 The most important adaptation challenges

In the context of increasing climatic uncertainty, local development relying on certain types of tourism, such as winter tourism, is a choice with high and multidimensional risk. If the winter tourism season were to shorten and snow cover decrease permanently (see figures 21 and 22), it might increase customer peaks, increase strain on local services (including the health-care and security sectors), and lower the use rates and efficiency of the tourism infrastructure. On the other hand, the effects of warming are not without flip sides: warming of surface waters can extend the water activity season, but if water quality suffers on account of increasing algae or microbe activity, swimming and potable water restrictions could result. These kinds of changes can reduce the attractiveness of local nature for tourists.

As an example of the increasing climatic uncertainties, we can see in Figure 22 the decreasing of snow depths and shortening snow seasons in the Kajaani region, particularly over the last decade. The changes are not so obvious in Kuusamo, although 30-year average air temperatures show a sharper upward trend in Kuusamo than in Kajaani. The formation of snow cover and, for example, the resultant changes in the freezing conditions of water bodies are connected to several climatic factors so are hard to predict.
Figure 20. Absolute deviation of the average for extreme cold days (daily minimum temperatures below –20°C) for winters 1960–2010. Minimum temperatures are considered from 6 am to 6 pm. Winter 1960 means winter period from 1st of November 1959 to 30th of April 1960. Concretisation of tourism stakeholders’ expression of their worries regarding perceived changes in local weather patterns. From daily weather data from the nearby Kajaani airport, a decrease in the number of extreme cold days in comparison to the 50-year average can be observed (weather data from the Finnish Meteorological Institute).

Figure 21. Variations in the longest duration of permanent snow cover of over 20 cm, which is needed for many winter tourism activities, such as snowmobiling, in Kuusamo and Kajaani 1960–2010 (weather data from the Finnish Meteorological Institute). Winter 1960 means winter period from 1st of November 1959 to 30th of April 1960. Before the year 2000 locations for snow measurements were at Kajaani and Kuusamo airports and after the year 2000 at Kajaani Paltaniemi and Kuusamo Toranginaho.

Figure 22. The averages of daily snow depth maxima by decade at the Kajaani and Kuusamo airports, 1960–2010 (weather data from the Finnish Meteorological Institute).
4.4.4

Development of tourism services as an adaptation measure

The major proactive and obvious adaptation measures are to expand year-round local tourism and develop new tourism activities based on the changing weather conditions. The primary challenge for local adaptation to climatic factors results from the close connection of tourism to other societal practices, processes, and economics. For example, holiday seasons are defined on the basis of other societal factors than the availability of recreation services alone, and the transport options available are dependent on state interventions as well as energy taxation and general regulation of technology. Furthermore, societal and environmental processes might be different in the regions of origin of the tourism. This might have more crucial effects on tourism than do the direct environmental changes in local tourism destinations.

For short-term adaptation, safe crossings should be built over the bodies of water, more road sand and other salt should be used, and alternative tourism activities for varying weather conditions should be developed.

As for long-term adaptation, tourism routes should be built on dry land. Routes should be planned also for year-round use and to be exploitable in conditions of limited snow cover. Planning that depends on risky areas should be avoided (steering clear of, for example, risky shore plans), and year-round tourism activities and attractions should be supported.

In addition, for mitigation of the impacts caused by tourism on the climate, usage rates of the tourism infrastructure should be increased, public transportation developed, and production of local renewable energy supported.

4.4.5

Necessary additional research

- Studies of the impacts of climate change should consider both regions of destination and regions of origin.
- Study of climate variations and scenarios at the local level should be increased.
- Multidisciplinary methods for studying the nexus between climate change and various health and security issues should be developed.
5 Reporting of the results and products of VACCIA

According to the objectives of EU LIFE+ programme, a special attention was paid on the dissemination of the results of the project. Besides the deliverables and the milestone products of the project, the VACCIA experts have visited in numerous international scientific conferences and workshops, presented their results in international and national public seminars, disseminated information via local, regional and national newspapers and journals as well as via internet portals and special Web sites of the VACCIA subprojects. By far, VACCIA has attracted interest more than 70 times via public media and seminars in addition to publish and disseminate information in more than 80 project deliverables and stakeholder seminars. Moreover, 7 internet portals and Web sites have been produced within the project, and project material has been disseminated for the national climate change portal ‘Ilmasto-opas’ (‘Climate Guide’) for citizens (http://www.ilmasto-opas.fi/). VACCIA has also contributed Synthesis Report of Finland’s Climate Change Adaptation Research Programme (ISTO; 2006–2010), launched as part of the implementation of the National Strategy for Adaptation to Climate Change. The ISTO Synthesis Report will appear in 2012.

Reports and publications:
- VACCIA Synthesis Report
- 20th-anniversary report on the Valkea-Kotinen region
- Layman’s report
- Subproject reports, studies, and research papers (deliverables of the project) (61 pcs)
- Brochure at the beginning and end of the project

Seminars and workshops:
- National final seminar for stakeholders
- Subprojects’ seminars and workshops (13 pcs)

Lectures and presentations at national and international seminars and conferences (10 pcs)

Presentation of results in media:
- Articles in national and regional newspapers (27 pcs)
- Articles in local newspapers (17 pcs)
- Radio presentations (4 pcs)
- Television presentation
- Fairs and other public events (6 pcs)
- Press and news releases on the Internet (7 pcs)

Web sites and portals (all 15.11.2011):
- www.ymparisto.fi/syke/vaccia Homepage of the project, in Finnish
- www.miljo.fi/syke/vaccia Homepage of the project, in Swedish
- www.environment.fi/syke/vaccia Homepage of the project, in English
- http://maps.tvarminne.helsinki.fi VACCIA GIS portal for recognition of changes in coastal ecosystems
- http://vaccia7.maat.helsinki.fi/ Lepsämänjoki Long-Term Socio-Ecological Research (LTSER) network
- http://thule.oulu.fi/vaccia/ VACCIA Web site at the University of Oulu
- http://litdb.fmi.fi/vaccia/database/ VACCIA air quality portal, Finnish Meteorological Institute, Pallas-Sodankylä GAW station
The key components of the VACCIA project are nine geographical areas, which together form the Finnish Long-Term Socio-Ecological Research network (FinLTSER), part of the Finnish national-level research infrastructure. Ecological and environmental research is the main focus in the LTER areas, while socio-economic research is strongly represented in the LTSER areas.
ANNEX 2. VACCIA – The main results and conclusions

Climate scenarios
- The temperature increase is likely to be larger in winter than in summer. Hot summer days will become increasingly common and heat waves get longer. The thermal winter season, as judged by daily mean temperature, will get shorter, while the opposite is projected for thermal summer and spring, as well as, particularly in south-west Finland, for thermal autumn.
- Precipitation amounts will increase. The changes in the north will exceed those in the south. Days with abundant precipitation will become more common in all seasons. Concurrently, periods of no precipitation might even become longer in the south in summer.
- Snow cover will be reduced, especially in southern Finland. In Lapland in mid-winter, however, snowfall may see a slight increase.
- In winter, the relative humidity of the air may increase slightly.
- The wintertime soil frost layer will become thinner.
- Wintertime weather will become cloudier.

Pollution transport
- The Russian copper–nickel industry on the Kola Peninsula is an important anthropogenic source of sulphur dioxide (SO₂) and heavy metal emissions to the atmosphere within the Arctic. In 1996–2009, the sulphur and trace-element load from the Kola peninsula to the Pallas area decreased slightly, along with sulphate (SO₄²⁻) concentrations.
- No trends were detected for nitrogen compounds, and Central Europe was found to be the predominant source area for nitrogen.
- Over the past 10–20 years, the air quality in the Pallas area has been rather favourable. The concentrations of polycyclic aromatic hydrocarbons (PAHs) and other persistent organic pollutants (POPs) have been decreasing – with one exception: the concentration of DDD (dichlorodiphenyldichloroethane, a breakdown product of DDT (dichlorodiphenyltrichloroethane)) has been increasing.
- In the changing climate, south-westerly winds will become more frequent; however, the projected change is reasonably small. As easterly winds grow more infrequent, Kola Peninsula emissions will be transported to Pallas in decreasing amounts.
- Significant growth of international shipping in the Arctic Ocean is expected as a result of decreasing ice cover. Several atmospheric pollutants, such as sulphur dioxide (SO₂), nitrogen oxides (NOₓ), black carbon, organic carbon, carbon monoxide (CO), and carbon dioxide (CO₂), are expected to increase as a result of increased shipping emissions.
- Increasing nitrogen dioxide (NO₂) concentrations may increase ozone (O₃) formation in the areas where nitrogen dioxide limits ozone formation.

Catchment areas and water bodies
- Terrestrial and aquatic ecosystems in the boreal zone are sensitive to changes in climatic conditions. The nutrients’ turnover times and leaching into water bodies are predicted to change. Increase in wintertime temperatures will shorten the snow-cover period that protects soil from erosion and accelerates the activity of the microbes in the soil. The predicted increase of precipitation in winter would add to water runoff. As a result of the above-mentioned factors, increasing nutrient loads will arise, intensifying the eutrophication of waters.
- Thermal conditions and stratification of lakes are predicted to change. On account of global warming, the period of ice cover on lakes will shorten. In some winters, no solid ice cover will be formed anymore, with several melt–freeze cycles in the course of the same winter becoming commonplace. Summer surface temperatures of water bodies are predicted to rise. The temperature stratification is going to last longer and the thermocline sink deeper in stratifying lakes.
- As climate change advances, the ecosystem services provided by water bodies will be especially vulnerable in shallow lakes that have a small surface area.

Coastal areas
- Western Gulf of Finland
  - Large short-term dynamics will be seen in the salinity of the Baltic Sea, but in the coastal area of the Gulf of Finland, a weak long-term trend of decline can be observed. Climate change has been suggested as the reason for the lower frequency of salt-water pulses, but the causality has not been fully clarified.
  - Water turbidity has increased as a consequence of eutrophication, increased nutrient load, and other dissolved and particulate matter from the catchment area. Floods and precipitation may further increase the runoff of nutrients and turbid substances.
  - Interactions among Baltic Sea changes are clearly visible in the biota. Structural food-web changes are reflected in the fish stocks and hence in leisure-time and professional fishing.
  - Among waterfowl, spring migration will be earlier and autumn migration later.
### b) Bothnian Bay

- Climate warming is expected to change the hydrological conditions in low-elevation meadows in the northern parts of the Gulf of Bothnia. Especially in the Bothnian Bay, the rise in sea level will slow the rate of new shore emerging with land uplift and short-term wind-raise floods may become more common in spring to summer.
- Shores are the primary habitat for an important proportion (12.5%) of Finland’s endangered species.
- Habitats of the critically endangered (CR) creeping alkaligrass (*Puccinella phryganodes*) are concentrated on the land uplift shores that are most strongly eroded by ice in the lowest meadow zone. The two occurrences of creeping alkaligrass in the Bothnian Bay are the only ones in the EU.
- Both the creeping alkaligrass and the endangered (EN) Arctic pendantgrass (*Arctophila fulva var. pendulina*) are locally threatened by the overgrowth of meadows and the resulting increase in competition with other grasses.
- The effect of catastrophic floods on the population viability of endangered species will increase as the climate changes.
- The critically endangered southern dunlin (*Calidris alpina schinzii*) is the most endangered of the waders on seashores. Around 80% of southern dunlins breed in grazed seashore meadows of the Bothnian Bay. Some nests of the species are destroyed in wind-raise floods and also through trampling by grazing cattle during the breeding season.

### Urban environments

- Increasing levels of rainfall caused by climate change and rapidly advancing urbanisation will lead to an increased amount of storm water and that water’s deteriorating quality, especially in areas with significant amounts of impermeable surfaces. Changes in rainfall patterns and increased amounts of built impermeable surfaces in urban areas mean increased risk of urban flooding.
- In many places, a variety of surface water problems can be attributed to diminishment in living ‘free breathing’ soil on account of lower water tables and deterioration in quality.
- Adapting to climate change requires a holistic view. It should be understood that excessive emphasis on certain issues in climate change mitigation may make the situation worse in other areas. Scientific research is the key to understanding the consequences of these phenomena.

### Ex situ conservation of plant biodiversity

- The largest ex situ collections are found in Oulu and Helsinki universities’ botanical gardens.
- Ex situ conservation is underdeveloped in Finland, with only 18% of threatened species ex situ conserved (the internationally agreed target is 75%).
- A Finnish ex situ conservation strategy and action plan for higher plants have been published. The latter includes 11 concrete aims for improving the situation. The general aim is to reach 40% by 2016 and 75% by 2020.

### Agriculture

- Four illustrations of possible future arable-land use circumstances in two northern sub-areas of the Lepsämänjoki watershed for two points in time (2025 and 2055) were produced in the project. Land was allocated to the various crops in view of the opportunities brought by climate change (according to SRES scenario A2 of the IPCC) for introducing new crop species and winter-sown cultivars, as well as for extending areas of present crops. The next few decades there should see different options arise for crop production in Finland, depending on agricultural policy and other factors. The scenarios produced are of 1) increased protein self-sufficiency, 2) greater winter crop cover, 3) greater crop diversity, and 4) a cereal monoculture.
- Climate change brings new challenges for water protection efforts in a farming environment. Today’s water protection measures have not been efficient enough to reduce nutrient loads from fields to waterways to the targeted level even in present-day conditions. According to water quality modelling, climate change will increase the suspended sediment load by about 15% and the inorganic nitrogen load by over five per cent in erosion-prone areas.
### Forestry
- It is difficult to distinguish explicitly the past climate change effect from the observed acceleration of forest growth in Finland.
- Tree ring series do not indicate accelerating tree growth, but analysis has revealed their weaker correlation to temperature variation in recent decades in comparison with earlier records. The earlier springs are reflected in earlier leaf flushing in the phonological time series, though.
- Temperature and nitrogen availability restrict forest growth in Finland and not so much drought. Elevated temperatures will accelerate soil decomposition processes that release nitrogen to plant use. This will accelerate tree-growth and stemwood production.
- Simulation-based analysis indicates that the mildest climate change scenario of the IPCC (B1) would accelerate pine stand growth by 16% in southern Finland and 31% in Lapland. The corresponding numbers for the scenario of greatest change (A2) are 40% and 80%. The temperature in Lapland will reach the current temperature in southern Finland in this scenario by the end of the century, but forest growth will remain behind that of southern Finland, because the accumulated organic matter and resulting nitrogen stores are lower in Lapland than they are already in southern Finland.
- The growth response of current broadleaf trees to climate change is more sensitive to soil fertility than that of conifers. If nitrogen turnover accelerates in the predicted fashion, the growth response of birch will be stronger than that of pine.
- Resident birds are ideal study organisms for exploring the relationships between landscape + climate changes and vital rates since they are affected by the same habitat and climatic mechanisms throughout their annual cycles. With warming springs, the willow tit (*Poecile montanus*) has advanced its breeding in northern Finland over the past 35 years. Possible benefits gained through climate warming are unlikely to compensate for the harm caused by habitat loss and deterioration.

### Fisheries
- The predicted changes in temperature and ice-cover duration will affect fish behaviour and fishing. Also, eutrophication and changes in water quality have an effect on the fish community and therefore fisheries – extensively so. The growing season may lengthen by even a month for certain species.
- The effect of changing climate on the reproduction of vendace and whitefish was studied through laboratory experiments and modelling. The results indicate that there can be both positive and negative consequences for pre-recruit survival.
- The most important target species in recreational fishing are the perch, pike, pike-perch and brown trout. In the future, brown trout may suffer from high summer temperatures. The predicted temperature increase may be so great that in warm years the water temperature exceeds the upper temperature tolerance for brown trout and therefore decreases its growth rate and increases mortality.
- Pike-perch and perch are warm-water species that would benefit from a temperature rise. Modelling results point to a significant increase in the growth rate and food consumption of pike-perch.
- Fish communities will shift toward a system dominated by percids and cyprinids. This means that the economic value of the resources exploited will probably decrease. Also, the changes in temperature stratification and ice-cover duration will affect commercial fishing.

### Tourism
- Changing precipitation, shortening and warming winter, the decreased number of days with snow, and diminution of snow depth and cover can have a crucial influence on the preconditions for nature-based tourism in northern Finland.
- The results emphasized the local-level perceptions and concerns surrounding increasing uncertainty of the freezing of waters and wetlands and the increasing risks of weather variation – in particular, for winter tourism, traffic, and marketing.
- Increasing risks will arise in relation to the decline in the weather’s predictability. These risks will increase if the most likely climate change scenarios are realised.
### ANNEX 3. VACCIA – The main challenges and adaptation options

- **Catchment areas and water bodies**
  - Attention to the predicted increase of runoff, erosion, and nutrient loads, and to their temporal element.
  - Distinguishing of the effects of climate change and land use from each other.
  - Intensification and dimensioning of water protection actions.
  - Considering the difficulties posed by shortening of the ice-cover period and lengthening of the frost-heave period for wintertime recreational accessibility.

- **Coastal areas**
  1. **Western Gulf of Finland**
     - Reduction of load from agriculture.
     - Countermeasures to increased runoff due to precipitation and floods.
     - Measures: buffer zones, fertiliser amounts, and use of crop land.
     - Means: biomanipulation and reduction in cyprinid numbers (effect mechanisms need to be understood).
  2. **Bothnian Bay**
     - Land-use planning.
     - Selection of management and grazing practices so as to minimise loss of nests of meadow breeding birds via wind-raise floods.
     - Development of management practices for shoreline meadows.
     - Targeting and optimisation of the special support for agricultural environments provided by the European Union.

- **Urban environments**
  - From the perspective of ecosystem services and urban green areas, condensing urban structures (one of the main future challenges) – innovative and new types of infrastructure designs and technical solutions are needed to optimise ecosystem services in the urban environment.
  - Artificial recharge of storm waters via use of more permeable surfaces, a viable solution to the challenge in the urban environment.

- **Ex situ conservation of plant biodiversity**
  - For meeting the national targets, a workable infrastructure needs to be developed (a national seed bank, micropropagation, cryogenic storage, living outdoor collections in botanical gardens).
  - Conservation of some special organisms, such as cryptogams (ferns, mosses, fungi, and lichens), needs a great deal of attention, including basic research.

- **Agriculture**
  - Breeding of cultivars that can make use of the prolonged growing season and higher temperatures but are still adapted to long day conditions (in addition, plant breeding is needed for improved nutrient and water-use efficiency, disease-resistance, and overwintering capacity).
  - Enhanced water protection, with the aim of closed nutrient cycles and targeting of intensified measures to those fields that have the highest risk of nutrient leaching and erosion.
  - More diversified crop rotations, to alleviate the risks and disadvantages of monocultures, for example, in respect of soil fertility and plant diseases.
  - Ensuring that the measures required at the farm level are made viable both economically and technically – adaptation to climate change requires long-term political and economic incentives.

- **Forestry**
  - Addressing of the central adaptation challenges in forestry, in species selection, stand regeneration, optimal stand densities, and timing of intermediate cuttings, as well as consideration of the impacts of drought, fungal diseases and insect outbreaks, and wind throws.
  - Awareness that utilisation of renewable bioenergy from forests, forest carbon sequestration, other climate effects, and safeguarding of other ecosystem services impose conflicting demands for forest utilisation – the positive climatic influences of bioenergy use need to be compared with changes in the carbon storage of the forests.
  - Examination of greater variation in the tree species breakdown and forest management objectives.
  - As a required response to accelerating vegetation development and increased competition, greater attention to the timing of sapling stand tending and intermediate cuttings in the palette of silvicultural practices.
  - Maintaining of the migration possibilities of forest species in the management of forest landscapes.
  - For conservation and maintenance of saproxylic organisms, ascertaining the level of continuous availability of decaying wood, an essential element that should be better considered in forest planning.
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<th>Fisheries</th>
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<td>• The required adaptation of commercial fishing to changes in fish stocks and the operation environment.</td>
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<td>• Addressing the fact that the ice-cover period will shorten so the trawling season will be longer, while, on the other hand, the traditional winter seining will be impossible in mild winters.</td>
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<td>• Awareness that commercial fishing has already adapted to large interannual variations, wherein the means for adaptation have been switching among different target fish species or fishing areas.</td>
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<td>• Utilisation of the projects targeting enhanced export of less economically valuable fish as an aid to adaptation.</td>
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<td>• Consideration of the predicted uncertainty of weather conditions due to climate change as a risk for those choosing dependence on winter tourism at the local level.</td>
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<td>• Awareness that impacts of climate warming can also be contradictory – for example, warming surface waters can lengthen the water activity season, but if water quality declines because of the increase in algae and microbes, this can result in, among other things, prohibitions of swimming and use as potable water.</td>
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<td>• Use of the most apparent and proactive adaptation measures: the development of year-round tourism and of tourism services that can cope with the changing climatic conditions.</td>
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<td>• Awareness that adaptation measures are needed as both short-term solutions (e.g., building of safe crossings over bodies of water) and long-term solutions (e.g., not building in risky areas in the first place).</td>
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<td>• Mitigation of the impacts of tourism on climate change by such means as improved public transport and intensified local renewable energy production.</td>
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### ANNEX 4. VACCIA – Suggested priorities for additional work

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<th>Topic</th>
<th>Suggested Priorities</th>
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| **Climate scenarios**                      | • Besides those of monthly mean temperature and precipitation, uncertainty ranges and probability distributions of further climate variables, such as wind speed and daily precipitation, need to be defined, for better support of the design of means of adaptation.  
• Tailored climate change information, often required for vulnerability assessment of ecosystem services, should be offered in a form that affords smooth use. More development is needed for reaching of that goal.  
• Small-scale climate phenomena and regional variations in climate are worth further study and are particularly relevant for local and regional planning and decision-making.  
• Climate change scenarios for Finland need to be updated regularly such that they are increasingly detailed and based on the most recent scientific findings. |
| **Pollution transport**                    | • The effect of changes in rain amounts on air quality.  
• The effect of climate change on ozone formation, especially at northern latitudes.  
• The indirect effects of climate change on air quality – for example, large-scale forest fires.  
• The effect of increasing use of biofuels and warming climate on the air quality (e.g., polycyclic aromatic hydrocarbons (PAHs)). |
| **Catchment areas and water bodies**       | • Researching the means to reduce nutrient loads outside the growing season, including the cost-efficiency and implementation of various means.  
• Researching the effects of collection of wood for energy production in water bodies on different catchment areas and watersheds, taking into account climate change impacts on hydrology and erosion.  
• Researching the role of nitrogen and phosphorus in eutrophication of water bodies from the standpoint of protection of ecosystem services.  
• Researching the implications of bacterial activity in removing nitrogen from freshwaters.  
• Researching the implications of increased temperatures for the decomposition of organic matter in freshwater bodies and increased nitrogen loading from land sources.  
• Researching the effects of increasing leaching of organic matter into freshwaters, from the water service angle, and studying means to moderate loading as climate change progresses.  
• Evaluating the basis for selection and assignment of water protection actions, and their ecologically, politically, and economically efficient and sustainable implementation. |
| **Coastal areas**                          | a) Western Gulf of Finland  
• Increased understanding of the correlation between nutrient runoff and meteorological data.  
• Research on the behaviour of nutrients in different precipitation scenarios (e.g., dry summers and rainy autumns).  
• Research into species interactions in marine ecosystems.  
• Clarification of the true impact of cyprinid reduction at the ecosystem level.  
• Effect of biomanipulation on other than its target species.  

b) Bothnian Bay  
• Continued monitoring of endangered plants on low-growth seashores, to 1) give a reliable picture of the balance between the population growth and disturbance amid climate change and 2) improve the evaluation of the frequency and intensity of disturbance factors in climate change.  
• Investigation of the invertebrate fauna on the seashore, which may have an impact on the availability of resources for birds, with consequences for their reproductive success.  
• Description of the organisms inhabiting the shorezone area, to allow observing and monitoring changes in their populations.  
• Investigation of the effects of different methods of restoration and management beyond monitoring studies – an impact analysis should be done for the most central endangered species such that their complete life cycle is considered. |
| Urban environments                                                                 | Evaluation of the effects of a switch in the most important grazers used in seashore management – beef cattle have largely replaced traditional dairy cattle in the management of seashore meadows, and better knowledge of the effect on vegetation is needed.  
Evaluation of the environmental effects of grazing and animal well-being considerations as well as the profitability of different management practices.  
Addressing whether cities and urban environment in general can serve as real laboratories for the research of consequences of climate change.  
Examination of whether ecosystem services are sensitive in different ways to climate and temperature changes, construction work, the changing socio-economic structure of neighbourhoods, or other such phenomena.  
Consideration of how ecosystem services could be evaluated and assessed with indicators compatible with the economic indicators used in urban planning. |
| Ex situ conservation of endangered native plants                                    | Evaluation of the conservation status of cryptogamic taxa and assessment of feasible ex situ methods for them.  
Development of scientific criteria for the selection of plant taxa to be conserved ex situ.  
Implementation of the Finnish ex situ action plan and its integration into international programmes. |
| Agriculture                                                                        | Development of methods for water protection that are adapted to local conditions, in co operation with farmers, and research concerning the efficiency of new methods.  
Development of methods for risk management related to pests, plant diseases, and weeds.  
Development of improved water management (including irrigation systems), and research on closing the nutrient cycles in farming.  
System research on the joint impacts of major socio-economic changes that affect agricultural production alongside climate change.  
Examination of the nutrient loading of waterways and the profitability of different local crop combinations in conditions of climate change. |
| Forestry                                                                           | Studies of interannual variation of forest growth and its links to weather and the immediate and delayed impacts of extreme events on tree growth and survival.  
Studies of the various tree species’ characteristics and responses to changes.  
Studies of the characteristics and reactions to changes of different species of ground vegetation in forests.  
Studies of the dynamics of nitrogen circulation under climate change conditions and their feedback to tree growth, particularly in connection with bioenergy harvesting.  
Recognition of the key characteristics of habitats required for species’ existence, and study of the effects of habitat destruction and climate change (e.g., responses of boreal forest birds).  
Research into the responses to climate change made by different species and populations in various environments.  
Research on the impact of climate change on population dynamics and viability.  
Research into the effects of climatic change on phenological events at different trophic levels (plants, invertebrates, and vertebrates) in boreal habitats. |
| Fisheries                                                                          | Changes in temperature stratification in different types of lakes.  
The response of different fish species to changing water temperatures.  
The interactions within the fish community.  
Analysis of the existing biological database in the context of weather data.  
Development of models for fisheries management applications. |
| Tourism                                                                            | Studies of the impacts of climate change should consider both regions of destination and regions of origin.  
Study of climate variations and scenarios at the local level should be increased.  
Multidisciplinary methods for studying the nexus between climate change and various health and security issues should be developed. |
ANNEX 5. Organisation of VACCIA

Project leadership:

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ANNEX 6. VACCIA – products and other publications by subject

Products and other publications can also be found from VACCIA home page: www.environment.fi/syke/vaccia.

Derivation of land-use data using GMES-based products (Action 2)

Derivation of climate change and pollution transport scenarios (Action 3)

Synthesis and dissemination (Action 4)

Development of a GIS-platform for identification of changes in management criteria of coastal ecosystems (Action 5)

Assessment of climate change and land use impacts in urban environments (Action 6)
5th stakeholder meeting and 2nd stakeholder seminar, presentation of main findings, publication incl. recommendations. VACCIA Deliverable 8 (manuscript).
VACCIA Action 6: Muistiinpanot sidosryhmäkokouksesta, Minutes of the stakeholder meeting 240809. 2009. VACCIA Deliverable 2. 5 pp.
VACCIA Action 6: Third stakeholder meeting and first stakeholder seminar. 2010. VACCIA Deliverable 5. 7 pp.

Assessment of impacts and adaptation measures for agricultural production (Action 7)
Technical report on the approach, process and results. VACCIA Deliverable 7 (manuscript).

The Finnish Environment 26en | 2011


Vulnerability and adaptation of catchment areas and lakes for climate change impacts (Action 8)

Document of 5th stakeholder meeting and 2nd stakeholder workshop. VACCIA Deliverable 9 (manuscript).


Assessment of impacts and adaptation measures for forest production; Case study at Northern Härme and Lapland (Action 9)
Regional predictions of forest structure. VACCIA Deliverable 5 (manuscript). Stakeholder seminar 3 documented. VACCIA Deliverable 6 (manuscript). Technical report on results. VACCIA Deliverable 7 (manuscript).


Assessment of impacts and adaptation of fisheries production and wash off effects in Lake Päijänne (Action 10)

Assessment of impacts of climate change on biodiversity in coastal ecosystems and implementation of new policies and conservation strategies (Action 11)
Orell, M. 2009. Outline of research methodologies, conservation stage and management of boreal forest species. VACCIA Milestone 2. 3 pp.
Strategy and action plan for ex situ conservation of threatened forest species in Finland. VACCIA Deliverable 3 (manuscript).

Assessment of climate change impacts and adaptation measures for tourism related communities in two northern towns: ecological, social and health impacts of climate change (Action 12)


Assessment of the impacts of climate change on pollution transport to the Arctic region (Action 13)


http://litdb.fmi.fi/apache2-default/mysql_testi/metalli_alku.php,
http://litdb.fmi.fi/apache2-default/mysql_testi/paaioni_alku.php,

This report is a summary of results from the project Vulnerability Assessment of Ecosystem Services for Climate Change Impacts and Adaptation (VACCIA), funded by the European Union’s LIFE+ programme. Partners in the extensive three-year (2009–2011) project, coordinated by the Finnish Environment Institute (SYKE), included the Finnish Meteorological Institute, the University of Helsinki, the University of Jyväskylä and the University of Oulu. Key results from the 13 VACCIA Actions are compiled in the summary. The Actions assessed the threats and challenges posed by climate change to ecosystem services and livelihoods, and suggested methods for adapting to changing conditions. The report also highlights further research needs.

The publication’s introduction describes the ecosystem service concept and provides an insight into policy processes for handling ecosystem services and their adaptation to a changing climate. Results of the Actions are assembled in the following three chapters, the first presenting key methods used in the project for monitoring changes and predicting future changes, the second describing the change in ecosystem services, and the third reviewing vulnerability and adaptation. An extensive summary section is also included. Annexed tables present the project’s key results and conclusions compactly, alongside the resulting adaptation challenges and needs for further research.

Monitoring and prediction of changes is based, e.g. on climate and air quality scenarios produced by the project, and remote sensing and geographic information materials. Of ecosystem services, those produced by catchments and water bodies are examined, alongside changes in the biodiversity of coastal, water and forest environments, studied with the help of sample species. Ecosystem services needed by urban areas are examined from the viewpoint of climate change and changes in land use. Among livelihoods, agriculture, forestry, fisheries and tourism are studied.
Ecosystem services and livelihoods – vulnerability and adaptation to a changing climate.

VACCIA Synthesis Report.

(Ecosystem services and livelihoods – vulnerability and adaptation to a changing climate. VACCIA-hankkeen yhteenvetoraportti.)
PRESENTATIONSBLAD

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| Nyckelord | klimatförändringar, ekosystemtjänster, effekter, anpassning, lantbruk, skogsbruk, fiskeri, turism, Finland | | |

| Finansiär/ upphagsgivare | Europeiska unionens program LIFE+ | | |

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Climate change affects the ecosystem services provided by nature to mankind. For example, diverse ecosystems, pristine, sufficient and good quality water resources or balanced water economy in urban areas are under threat. Changing and degenerating ecosystem services may also violate the nature-based livelihoods as agriculture, forestry, fishery, and nature tourism. Climate is changing, and adaptation is a burning issue already at the moment.

The effects of climate change and the conditions for adaptation of ecosystem services and livelihoods has been estimated by EU LIFE+ funded project VACCIA (Vulnerability Assessment of Ecosystem Services for Climate Change Impacts and Adaptation — VACCIA). The three-year (2009–2011) project was led by the Finnish Environment Institute SYKE and participated by Finnish Meteorological Institute and the universities of Helsinki, Jyväskylä and Oulu. In this Synthesis Report, the main results of the VACCIA project and arising conclusions as well as the central adaptation challenges are presented. The impact mechanisms within the ecosystems are complicated and still largely unknown, and much research and surveying is still needed to successfully adapt to climate change.