Finnish Environment Institute Mimeographs

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Climate change adaptation and biological diversity

Juha Pöyry and Heikki Toivonen

FINADAPT Working Paper 3

FINNISH ENVIRONMENT INSTITUTE

CLIMATE CHANGE ADAPTATION AND BIOLOGICAL DIVERSITY

Juha Pöyry and Heikki Toivonen[1]

FINADAPT WORKING PAPER 3

[1] **Finnish Environment Institute (SYKE), Research Programme for Biodiversity, Box 140, 00251 Helsinki**

This publication should be cited as:

Pöyry, J. and Toivonen, H. 2005. Climate change adaptation and biological diversity. FINADAPT Working Paper 3, *Finnish Environment Institute Mimeographs 333*, Helsinki, 46 pp.

Preface

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"[1]. The IPCC lists two reasons why adaptation is important in the climate change issue. First, an understanding of expected adaptation is fundamental in evaluating the costs or risks of climate change. Second, adaptation is a key response option or strategy, along with mitigation. Even with reductions in greenhouse gas emissions, some climate change is regarded as inevitable, and it will be necessary to develop planned adaptation strategies to deal with the associated risks as a complement to mitigation actions.

In Finland, there has been substantial progress during the past decade in investigating the potential impacts of climate change on natural and human systems. In contrast, there has been much less attention paid to adaptation. This was recognised by the Finnish Parliament as early as 2001, when it recommended that a separate programme for adaptation to climate change be initiated. As a result, a task force co-ordinated by the Ministry of Agriculture and Forestry completed Finland's first National Strategy for Adaptation to Climate Change in 2005.[2]

At about the same time as the Strategy document was being drafted, a research consortium named FINADAPT also began its work. The goal of the consortium, involving 11 partner institutions co-ordinated by the Finnish Environment Institute, was to undertake an in-depth study of the capacity of the Finnish environment and society to adapt to the potential impacts of climate change. FINADAPT was funded for the period 2004-2005 as part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment. It comprised 14 work packages (WP) covering: 1) co-ordination, 2) climate data and scenarios, 3) biodiversity, 4) forests, 5) agriculture, 6) water resources, 7) human health, 8) the built environment, 9) transport, 10) energy infrastructure, 11) tourism and recreation, 12) economic assessment, 13) urban planning, and 14) a stakeholder questionnaire. The primary objective of FINADAPT was to produce a scoping report based on literature reviews, interactions with stakeholders, seminars, and targeted research.

This report considers the implications of climate change for biological diversity and nature conservation in Finland. Projected changes in climate are likely to result in rapid geographical and altitudinal shifts of climatic zones, and it is uncertain how natural species will adapt to such changes. The work package 3 study summarises changes in biota that have already been observed in response to recent warming, describes changes that are anticipated in the future, and discusses how human intervention, through conservation policies, might help to promote biodiversity whilst also facilitating natural adaptation.

Timothy Carter, Consortium Leader
Helsinki, December 2005

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[1] IPCC, 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds)]. Cambridge University Press, Cambridge and New York, p. 982.

[2] MMM, 2005. *Ilmastomuutoksen kansallinen sopeutumisstrategia* (Finland's National Strategy for Adaptation to Climate Change) [Marttila, V., Granholm, H., Laanikari, J., Yrjölä, T., Aalto, A., Heikinheimo, P., Honkatuki, J., Järvinen, H., Liski, J., Merivirta, R. and Paunio, M. (eds)], Ministry of Agriculture and Forestry, Helsinki (available in Finnish, 276 pp., Swedish 212 pp. and English, 280 pp.) http://www.mmm.fi/sopeutumisstrategia/

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CLIMATE CHANGE ADAPTATION AND BIOLOGICAL DIVERSITY

Juha Pöyry* and Heikki Toivonen

Finnish Environment Institute (SYKE), Research Programme for Biodiversity,
Box 140, 00251 Helsinki

*Corresponding author: juha.poyry@ymparisto.fi

Executive Summary

This report examines possible climate change adaptation measures concerning biodiversity and nature conservation in Finland. The study is based on a literature survey and an expert questionnaire. It also draws on feedback from an international expert seminar arranged on 9 May 2005.

Recent climate change has already produced numerous impacts on biodiversity. These include observed effects on physiology, phenology (i.e. timing of biological phenomena), distributional shifts, changes in community structure and (micro)evolutionary changes of living organisms. The examples observed in Finland include advanced spring arrival and breeding of birds, expanding northern range limits of butterflies and moths and increasing multivoltinism of moths. Based on recent climate scenarios (e.g. FINSKEN), increasing impacts on biota, including immigration of new species, disintegration of the current communities and reconstruction of new assemblages of species, can be expected in the future. These changes are expected to be gradual and without critical thresholds at first, but the projected decrease in the cover of spruce-dominated forests by the period 2070-2099 (FINADAPT scenario A2) would particularly have major implications for biodiversity in Finland.

The Finland's National Strategy for Adaptation to Climate Change (FNSACC) made 21 recommendations of possible measures that could help the adaptation of natural biota to climate change. The strategy distinguished between actions that could be applied in public and private sectors. It also suggested that many of the proposed actions should already be put in place during the period 2005-2010.

To evaluate the recommendations presented in the FNSACC, we carried out a literature search and compiled a short review about the various actions and adaptation measures presented in the international scientific literature. Publications were searched from the major reference data bases, e.g. ISI Current Contents and Cambridge Scientific Abstracts, and from a selection of major scientific journals in the field (e.g. Environmental Monitoring and Assessment, Climatic Change and Global Change Biology). Further relevant papers were discovered from the reference lists of published articles. In addition, a number of major international assessments on the subject were consulted.

The main suggestion found in many of the reviewed papers is that it is important to ensure that species are able to move to more suitable regions as the climate changes. The proposed instruments for this include building a spatially and temporarily representative network of protected areas (PA) to aid the existence of viable populations. The latter option could be achieved by placing PAs in areas with strong environmental gradients (e.g. altitudinal change) and by managing PAs to diminish extinction rates of populations for those species that have remained outside their climate optimum. In extreme cases, ex situ conservation and subsequent introductions may be applied with some key species. Further, regional landscape planning, at the scales of regions, nations and continents, is often suggested as a tool to enhance the possibilities of species to migrate to new areas. Ecological corridors and management of areas outside PAs could be potential tools for pursuing this goal.

To assist in the evaluation of the national strategy, a questionnaire was delivered to the participants of the international expert seminar (n = 61). The questionnaire included some background information on

the predicted biodiversity impacts of climate change, and a number of proposed adaptation measures abstracted from the literature. The respondents were asked to evaluate these measures with respect to their general effectiveness and to their realism particularly under the Finnish circumstances. Every fifth participant returned the questionnaire (n = 12).

Nearly all of the expert respondents considered some future adaptation measures necessary in biodiversity conservation. Three of the six evaluated measures (extensive network of PAs, large and environmentally heterogeneous PAs, and ecological corridors) were considered effective or very effective by the experts. The effectiveness of habitat restoration and management was doubted by some respondents. Only translocation of species was generally considered as an ineffective measure. Application of the suggested measures appeared to raise much scepticism among the experts, and variation among the respondents' opinions was revealed to be large. Four of the evaluated measures were considered to show some applicability under the Finnish circumstances (large and environmentally heterogeneous PAs, ecological corridors, habitat restoration and management, and management of the non-conserved matrix), although the possibilities to establish large and environmentally heterogeneous PAs were also doubted by many experts. Implementation of an extensive network of PAs and translocations were generally considered unrealistic in Finland.

The measures proposed for the administration and planning in FNSACC are in principle beneficial to biodiversity. Many of the suggested measures can be considered as 'win-win' or 'no regret' solutions and are therefore widely applicable. However, their ecological implications should be assessed in more detail. Most measures are suggested to be implemented during 2005-2010, which in some cases may be premature because knowledge of their effects is still somewhat insufficient. In the near future, more attention should be paid to increasing the general awareness of climate change adaptation with respect to biodiversity conservation. In the field of research and dissemination the suggested measures are mostly practical and focus on applied solutions. A national monitoring system for biodiversity would be necessary to follow up changes caused by climate change, a measure that would be highly profitable to the whole field of nature conservation. New research and broad assessments on the suggested adaptation measures are also needed. Concerning economic and technical strategies, the formulation of a strategy to control harmful invasive species is considered important. The suggested habitat restoration measures are good, though a more thorough evaluation of the goals of habitat management in the context of changing climate should be conducted.

Practical knowledge on the effectiveness of the adaptation measures regarding biodiversity benefits is still largely missing, and there is urgent need for such research. Most of the research on climate change and biodiversity has hitherto concerned the observed or the predicted impacts, although large gaps exist there too. Themes with the greatest research needs include: regional modelling of relationships between climate change, ecosystem functioning and biodiversity, assessment of species and habitats with high national and international conservation priority for their responses to climate change, assessment of PAs for the likely effect of climate change and, in the light of these assessments, revision of the management methods of PAs, identification of species and habitats at risk being significantly affected by climate change, and measures such as ecological corridors that could aid species movement into new regions when current occurrences become unsuitable. For impact studies, systematic collecting of species-specific baseline data, and further development of the predictive modelling of individual species' responses, and downscaling scenarios to the scale of individual PAs and local models are considered important. Studies conducted at multiple spatial scales should be preferred.

1. Introduction

1.1. Climate change in Finland

1.1.1. Observed changes

The third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) concluded that the global mean temperature increased by 0.6 ± 0.2 ºC during the 20th century (IPCC, 2001). In the northern hemisphere, the 1990s was likely the warmest decade within the last millennium. Simultaneously diurnal temperature ranges have decreased, which is mainly attributed to increased cloudiness (Easterling et al., 2000). In the mid and high latitudes of the northern hemisphere a decadal increase of 0.5-1 % in annual precipitation has occurred mainly during autumn and winter seasons of the last century (IPCC, 2001).

In Finland, an increase of 0.7 ºC in mean annual temperature was documented during the 20th century (Tuomenvirta, 2004). Greatest increase of ca 1.5 ºC in mean temperature occurred during spring season (March-May), whereas changes in other seasons have been more modest. Winter temperatures have increased especially since 1970s in the connection with strengthened westerly winds during a period with high North Atlantic Oscillation (NAO) index values (Tuomenvirta, 2004). Daily minimum temperatures have also in Finland increased more than daily maximum temperatures, apparently due to increased cloudiness and marine humid air masses brought by westerly winds into Fennoscandia.

1.1.2. Predicted changes

The IPCC/TAR also produced scenarios for global climate change during 21st century (IPCC, 2001). It was projected that global mean temperature would increase by 1.4 to 5.8 ºC between 1990 and 2100, a change larger than observed during 20th century and very likely unseen in the last 10 000 years. Winter precipitation is expected to increase in the mid and high latitudes of the northern hemisphere by the second half of 21st century, and more intensive precipitation events are expected in many parts of the world (IPCC, 2001).

In Finland, the FINADAPT project has recently produced new climate scenarios for the 21st century (Carter et al., 2005; Ruosteenoja et al., 2005). By the 2020s, the mean annual temperature is projected to increase by 1 to 3 ºC and the mean annual precipitation by 0 % to 15 % compared with the baseline period 1961-1990 (Ruosteenoja et al., 2005). By the 2050s, the corresponding changes are 2 to 5 ºC and 0 % to 30 %, and by the 2080s, 2 to 7 ºC and 5 % to 40 %, respectively. The presented ranges of climate change projections stem from differences in model assumptions and emission scenarios. The largest changes are predicted to occur during winter seasons, but the projected summer time warming is also statistically significant (Ruosteenoja et al., 2005). The simulations based on the FINADAPT scenario A2 predict that the yearly mean temperature would be 4-5 ºC higher during the period 2070-2099 than currently (Carter et al., 2005; Ruosteenoja et al., 2005), and that the thermal sum of the growing season would increase by ca 500 day degrees by the same period (Kellomäki et al., 2005). Changes of this magnitude would mean shifts of the bioclimatic zones ca 500 km towards north. These predicted changes are markedly stronger than those observed during 20th century.

1.2. Impacts

1.2.1. Observed impacts on biodiversity

Recent climate changes during the last few decades have already produced various impacts on biota. The fields where impacts have been reported include physiology, phenology, distributional shifts of individual species, community structure and (micro)evolutionary changes (Hughes, 2000; McCarty, 2001; Parmesan & Yohe, 2003; Root et al., 2003; Walther et al., 2002).

The most commonly reported physiological impact involves increased primary production of individual plants (Myneni et al., 1997), which has been illustrated by e.g. increased forest growth (Kellomäki et al., 2005; Spiecker et al., 1996). This increase has at least partly been caused by an interaction between warming and rising CO_2 concentrations (Hughes, 2000; Menzel & Fabian, 1999). At the level of ecosystems, a more pronounced variation of the seasonal CO_2 cycle has been attributed to increased biomass production especially in high latitudes of northern hemisphere caused by prolonged growing season (Keeling et al., 1996; Menzel et al., 1999).

Phenological changes are most apparent in spring activities which have occurred progressively earlier in many taxa since 1960s, e.g. leaf unfolding in plants (Menzel et al., 1999), flight period in butterflies and moths (Ellis et al., 1997; Roy & Sparks, 2000; Woiwod, 1997) and spring migration and breeding in birds (Crick & Sparks, 1999; Lehikoinen et al., 2004). Advanced spring arrival and breeding of birds has also been observed in Finland (Ahola et al., 2004; Järvinen, 1994), which has resulted in higher breeding success in at least one bird species (Järvinen, 1994). Multivoltinism has become commoner among Finnish moths since 1980s (Leinonen, 2005). Changes in phenological events have increasingly been reported to cause mismatches in timing between trophic levels (Edwards & Richardson, 2004; Watt & McFarlane, 2002; Voigt et al., 2003). In a recent review, phenological mismatches between species and their food resources were observed in a majority of the studies available (Visser & Both, 2005).

Range shifts have been most pronounced in species that have high dispersal abilities, e.g. birds and butterflies, and consequently they have been able to track climatic changes closely (Parmesan, 1996; Thomas & Lennon, 1999), as has been observed with butterflies in northern Europe (Parmesan et al., 1999). Yet species-specific habitat and resource availability will be decisive whether the predicted range shifts can be realized (Walther et al., 2002), as has been exemplified by the recent responses of butterflies in the UK (Warren et al., 2001) and in Finland (Kuussaari et al., 2005). Species, such as vascular plants, with weaker dispersal abilities will inevitably lag behind the new climate spaces (Grabherr et al., 1994), although a rise of >100 m of tree limit in the southern Scandinavian mountains has been observed over the last century (Kullman, 2001).

Simultaneous shifts in the ranges of many species will inevitably result in changes in the composition of plant and animal communities. Expansions of tree and shrub vegetation have been reported in Alaska due to the recent warming trend (Chapin et al., 2005). These vegetation changes are predicted to cause a positive feedback loop interacting with summer warming that could further enhance the effects of atmospheric heating by two to seven times. In the grasslands of Colorado the recent warming trend, especially of night temperatures, has caused a shift in the abundance of prevailing plant species (Alward et al., 1999). This change will also have economic implications due to the lowered value of grasslands as cattle pastures. Significant recent changes have also been reported from marine communities (Hughes, 2000; McCarty, 2001). The expansion of species towards higher latitudes and altitudes will at least temporarily be reflected in a higher species richness in such transient communities (McCarty, 2001; Walther et al., 2002), though in northern latitudes increasing species richness may become more permanent (see below).

Verified observations evolutionary changes have so far been very few, and most reported impacts in wild populations occur within the limits of phenotypic plasticity by individual organisms. Genetically determined changes are increasingly expected in the future due to e.g. more frequent mismatches in species interactions (see Clarke, 2003). Examples where (micro)evolutionary changes have apparently been involved include increased dispersal propensity among individuals from edge populations of expanding species (Hughes et al., 2003; Simmons & Thomas, 2004; Thomas et al., 2001) and adaptation of photoperiodic preference towards shorter day lengths as growing season has become longer (Bradshaw & Holzapfel, 2001).

1.2.2. Predicted future impacts on biodiversity

Considering the projected changes represented in climate scenarios, much greater changes at the level of species, communities and biomes may be expected during the 21st century than what were observed during the late 20th century. The predictions for living organisms include further changes in the distributions and phenology of individual species, subsequent mismatches in species interactions resulting in reassembly and shifts of communities and whole biomes. Numerous modelling exercises with "bioclimatic envelopes" have recently been conducted to predict future ranges of individual species and larger communities at national (e.g. Berry et al., 2003; Berry et al., 2002; Huntley et al., 1995) and continental scales (Thuiller et al., 2005), and of whole biomes at national (e.g. Scott et al., 2002; Villers-Ruíz & Trejo-Vázquez, 1998) and global scales (Thomas et al., 2004).

Berry at al. (2003; 2002) presented an example of bioclimatic modelling in an assessment of the sensitivity and vulnerability of terrestrial habitats and species to climate change. The future range shifts were modelled for Great Britain and Ireland by training and validating artificial neural networks with the current European distributions, and then building regional predictions for two time periods, 2020 and 2050. Predictions were made for 50 species representing a number of differing taxa, mostly vascular plants but also some species of butterflies and vertebrates. The modelling results indicate that species will respond individualistically to the effects of climate change. Species predicted to receive gains in range shifts are distributed along various habitat types. In contrast, species losing more than 25% of their current climate space in Great Britain appear to consist of species occurring solely in northern or montane habitats. It was therefore concluded that northern and montane habitats will be the most vulnerable ones and with limited adaptation possibilities, and thus some losses due to climate change may be inevitable. This observation indicates that communities in highest altitudes and latitudes may also face the highest risk in Finland.

Major changes can be expected in vegetation pattern and plant species composition in many biotopes of Europe during the 21st century (Araújo et al., 2004; Bakkenes et al., 2002; Thuiller et al., 2005). As an example, one third of the 1400 modelled higher plant species present in a studied grid cell in 1990 would disappear from that cell by 2050 (Bakkenes et al., 2002). Species predicted to experience greatest range losses show northern or eastern distribution patterns (Skov & Svenning, 2004). Shifts in the composition and prevalence of tree species may also be expected at high latitudes (Sykes, Prentice & Cramer, 1996; Thuiller, 2003). In Fennoscandia, an overall increase of 26% in species richness of vascular plants may be expected by model predictions (Sætersdal et al., 1998). The highest increase in plant species richness would occur in the southern part of the area as a result of immigration with the proportion of immigrant species exceeding 50% in a wide belt covering the lowlands around the Baltic Sea including southern Finland and extending into northern and central Russia (Bakkenes et al., 2002; Sætersdal et al., 1998). Further, some species restricted to northernmost Fennoscandia might become regionally extinct in the area (Sætersdal et al., 1998). However, according to the model predictions of Bakkenes et al. (2002), over 70% of the currently occurring higher plants would maintain their distribution in southern Finland and over 90% in northern Finland. In contrast to the predictions presented by Bakkenes et al. (2002), Araújo et al. (2004) estimated that the areas with the highest number of species with diverging distribution areas would be located around the Pannonian plain in east-central Europe, and the lowlands around the Baltic including southern Finland.

A major challenge in bioclimatic modelling has been the combination of land-use data with climate variables to investigate species' propensity for migration from current to future ranges (Hill et al., 1999, 2003). The interaction between climate change and habitat loss is expected to pose a severe constraint especially for the species with weak dispersal abilities and little overlap between current and future distributions (Myers, 1992; Opdam & Wascher, 2004; Travis, 2003). It has been predicted that habitat generalist species will be able to cope better with shifts in their climate envelopes, whereas habitat specialists with already fragmented habitats will show an increasing inability to follow the new climate spaces and these species will face an increasing amount of local and ultimately regional extinctions (e.g. Hill et al., 2003). This phenomenon has already been observed with the divergent recent trends of the generalist and specialist butterflies in Great Britain (Warren et al., 2001) and in Finland (Kuussaari et al., 2005).

Consequently, Thomas et al. (2004) presented an assessment of species-level extinction risks based on predicted range shifts due to climate change. Their evaluation covered ca 20 % of the Earth's terrestrial surface and a sample of 1 103 species. It was estimated that for maximum climate change projections, the species-level extinction rates would be 21-32 % under universal dispersal assumption (no constraints for dispersal) and 38-52 % with no dispersal assumption. Extinction rates for minimum climate change projections would be 9-13 % under universal dispersal and 22-31 % without dispersal. The largest difference in the predictions was observed to be due to different climate scenarios. Thomas et al. (2004) concluded, contrary to previous assessments (e.g. Sala et al., 2000), that in most regions predicted climate change will be the most important threat to the maintenance of biodiversity during the 21st century. Recently, Thuiller et al. (2005) modelled current and late 21st century distributions of 1 350 European plant species under different climate scenarios, and estimated somewhat lower loss rates. Yet more than half of all plant species would become threatened in Europe by the end of this century. Mountain species were suggested to be the most sensitive to climate change with ~60 % species loss. According to Thuiller et al. (2005), greatest changes in species composition were expected in the transition between the Mediterranean and the Euro-Siberian regions, whereas the boreal region would face few losses but numerous new colonizing species.

1.2.3. Predicted impacts in the Baltic Sea

As a shallow, largely enclosed brackish water body the Baltic Sea is sensitive to many natural and anthropogenic stresses (Silander et al., 2005). These include high nutrient loads, many pollutants, like dioxin, PCBs, and heavy metals, over-exploitation, habitat degradation, and invasive species. Oil and other transportation by ships has greatly increased in the last decade. The period from the early 1990s onwards has been among the warmest recorded, and this combined with reduced intrusions of oxygen rich salty water from the North Sea into the Baltic have caused increased frequencies of oxygen depletion at numerous localities, e.g. in 2002. These stresses can detrimentally impact marine life and fisheries in the Baltic Sea, as well as reducing the sea's ability to remove greenhouse gases from the atmosphere. All the scenarios for climate change project an increase in the inflow from rivers in the northern part of the Baltic Sea, and a reduction in the south (see Graham, 2004).

Continued global warming will probably have serious consequences on biodiversity and living resources in the Baltic Sea. According to Hopkins (2005) the likely impacts on further climate change on Baltic ecosystems are substantial, and may include:

- longer ice-free periods leading to increased areas of open water, resulting in intensified wind mixing, upwelling and winter convection, leading to increased availability of nutrients for phytoplankton production
- changes in sea water temperatures and currents that can affect fish migration, behavior and distributions, with impacts on the associated food webs
- seals, associated with ice-filled environments, will be severely affected by loss of habitat (also Meier et al., 2004)
- increased precipitation, anticipated from global warming, will increase input of terrestrial material to coastal areas
- rising sea levels (Johansson et al., 2004) and elevated temperature will accelerate coastal erosion, reducing light penetration in coastal waters, and alter coastal habitats, e.g. Baltic sea shore meadows
- more storms, especially in autumns, will lead to greater mixing in the water column, greater supply of nutrients, enhanced sediment transport and more rapid coastal erosion
- increase in UV-B radiation levels, due to reduction in the thickness of the ozone layer, causing damaging effects on biota and humans
- wider establishment of more cosmopolitan alien species.

1.2.4. Impacts according to FNSACC

The Ministry of Agriculture and Forestry recently published Finland's National Strategy for Adaptation to Climate Change (FNSACC), which lists a number of possible impacts on biodiversity in the course of climate change (Ministry of Agriculture and Forestry, 2005). These are divided into impacts that are predicted to be advantageous or disadvantageous and into those impacts the direction of which remains still unclear (Table 1). These suggested impacts are discussed briefly below with comments on the emerging future research needs.

Table 1 Predicted impacts on biodiversity by climate change with their possible directions according to the Finland's National Strategy for Adaptation to Climate Change (FNSACC) (Ministry of Agriculture and Forestry, 2005). The impacts are divided into those predicted to be advantageous or disadvantageous and into those the direction of which remains still unclear.

Disadvantages	Direction of the impact unclear or a simultaneous disadvantage and advantage	Advantages
Species characteristic to Southern Finland will have to give way to more southern species. Some of the species adapted to cold conditions may become more threatened.	Many southern species living in forests may migrate several hundreds of kilometres further north.	The amount of dead wood in forests will increase.
The present species of Northern Finland will suffer.	Distribution of many species of the boreal forest zone will change.	The living conditions of some wintering bird species will improve and some herbivorous mammals will benefit.
Pest insects and weeds arriving from the south may cause harm to agriculture and forests.	(Arctic) timberline may shift upward.	Spring migration of birds wintering in the neighbouring areas will occur earlier, which will improve their nesting possibilities.
	The tree species composition in forests will change and deciduous trees will become more common.	
	The melting of palsa mires will change the structure of biotic communities.	
	The biological productivity of water systems will increase and the occurrence and number of algal blooms will change.	
	The number of species in Finland will increase.	
	The risk of pests and diseases and the probability of storm damage will increase.	

<u>Impact disadvantages</u>

- Species characteristic to Southern Finland will have to give way to more southern species. Some of the species adapted to cold conditions may become more threatened.

This suggestion may not entirely come true. Although some boreal species may have to withdraw from the southern parts of their ranges, the general expectation may be an enrichment of the current natural communities (e.g. Bakkenes et al., 2002; Sætersdal et al., 1998). For example, results from the Finnish Moth Monitoring Scheme indicate that the species diversity of moth communities in southern Finland has been steadily increasing since the early 1990s (Leinonen & Söderman, unpublished data).

- The present species of Northern Finland will suffer

This impact seems realistic at the present level of knowledge. When current vegetation zones move north, populations of arctic-alpine species in particular can be expected to become isolated in ever-diminishing patches of suitable habitats. This development leads to smaller population sizes, larger yearly fluctuations in population numbers and higher level of inbreeding, which all cause an elevated risk of local extinctions of populations and eventually regional extinctions of species (e.g. Hanski, 2005).

- Pest insects and weeds arriving from the south may cause harm to agriculture and forests

This impact seems realistic at the present level of knowledge. Taking into account the good dispersal ability of many insects, currently unknown new diseases and pests may also be able to colonize Finland in the future.

<u>Direction of the impact unclear or simultaneously disadvantages and advantages</u>

- Many southern species living in forests may migrate several hundreds of kilometres further north

This impact seems realistic at the present level of knowledge, but the outcome depends largely on the group of organisms in question. For species with good dispersal abilities, e.g. butterflies and other insects, recent expansions of breeding ranges of even some hundreds of kilometres have already been recorded (Kuussaari et al., 2005). For many southern plant species, including woody plants, this prediction may be an exaggeration due to dispersal limitations of the species (Skov & Svenning, 2004).

- Distribution of many species of the boreal forest zone will change

This impact seems realistic at the present level of knowledge, assuming that enough of the suitable habitat exist within the species-specific dispersal range.

- (Arctic) timberline may shift upward

This impact has already been recorded in the Scandinavian mountains where the timberline has risen significantly during the last century (Kullman, 2001). Similarly, observations of a long-term northward expansion of the pine timber-line over the last two centuries in Finnish Lapland has been reported (Juntunen et al., 2005). An upward shift of the timberline is predicted to occur over wide areas of northern ecosystems (e.g. Krankina et al., 1997). Regional modelling on the possible outcomes for different tree species are still needed. In certain mountain birch forest regions, reindeer overgrazing may pose a counteracting force, possible leading to the shrinkage of the total area of mountain birch forest ecosystems.

- The tree species composition in forests will change and deciduous trees will become more common

This impact seems realistic at the present level of knowledge, and the issue is important not only with respect to biodiversity conservation, but has practical implications also for forestry. Recent modelling studies indicate that especially birch species and Scots pine would become more abundant under changing climate (Kellomäki et al., 2005). Further modelling studies are needed to predict 1) impacts of management practices to this succession, and 2) impacts to biodiversity. The latter should become subject of a long-term research.

- The melting of palsa mires will change the structure of biotic communities

This impact has already been recorded in northern Fennoscandia where the coverage of palsas has decreased over the last few decades (Luoto et al., 2004). Major changes can be expected also in many other mire types, including hydrological changes and probable changes in the surface pattern of aapa mires and accelerating overgrowth in raised bogs. It has been predicted that the accumulation of peat will decrease if climate becomes warmer and drier in boreal regions, and eventually the decay of peat will outpace accumulation resulting in the release extra CO_2 in the atmosphere (Hartig et al., 1997). More research on the subject is still urgently needed.

- The biological productivity of water systems will increase and the occurrence and number of algal blooms will change

This impact seems realistic at the present level of knowledge, and consequently tightened measures of water protection are needed to control enrichment. Many species preferring oligotrophic as well as cold waters will probably decline. These include e.g. salmonid and cottid fishes (e.g. Jansen & Hesslein, 2004), stoneflies (Plecoptera) and many freshwater bryophytes (R. Paavola, oral communication). In addition, warm water species such as cyprinid fishes may decrease indirectly due to elevated predator pressure by expanding species as exemplified by a Canadian study (Jackson & Mandrak, 2002). More research is urgently needed with respect to the predicted changes both in the Baltic Sea and inland waters (see Silander et al., 2005).

- The number of species in Finland will increase

This impact seems realistic at the present level of knowledge, but a more detailed analysis is missing. This prediction has been made for plant communities (e.g. Bakkenes et al., 2002; Sætersdal et al., 1998), and observations of an increasing number of new species spreading from the south to Finland have been made for butterflies and moths (Lehto, 2003).

- The risk of pests and diseases and the probability of storm damage will increase

These impacts seem realistic at the present level of knowledge (see Kellomäki et al., 2005). An analysis of the effects of increasing disturbances to biodiversity is needed.

Impact advantages

- The amount of dead wood in forests will increase

This impact seems at least partly realistic at the present level of knowledge, but future forest management will be decisive whether the projected cumulative trend of dead wood will be realized. Further modelling studies are needed to predict more specifically what will be the rate of decomposition.

- The living conditions of some wintering bird species will improve and some herbivorous mammals will benefit

This impact seems realistic at the present level of knowledge, but impacts at the ecosystem level are also expected due to increased herbivory

- Spring migration of birds wintering in neighbouring areas will occur earlier, which will improve their nesting possibilities

This impact has already been observed with certain bird species (Järvinen, 1994), but in the future ecological mismatches may also emerge causing possible deleterious impacts in food webs.

1.3. Adaptation measures and policy

The predicted impacts of climate change are expected to be of such large magnitude that some adaptation measures will apparently be unavoidable (Parry et al., 1998). Adaptation to climate change may be divided into two types: autonomous or spontaneous adaptation and planned adaptation (Carter & Kankaanpää, 2003). Autonomous adaptation is characteristically reactive, i.e. adaptations take place only after climate change impacts have become evident. Adaptation by natural systems including plant and animal species and communities is typically autonomous and reactive (Carter & Kankaanpää, 2003). Quaternary responses of individual species indicate that most species may be expected to possess range shifts able to track climate change instead of adapting phenotypically or genetically *in situ* (Coope, 1995; Graham, 1990; Noss, 2001). This prehistoric reference underlines the importance of planned adaptation to aid biodiversity conservation under changing climate, with a special focus on large-scale habitat management and planning to make dispersal possible for species that have tight habitat requirements or that are weak dispersers (Hannah et al., 2002a; Hill et al., 2002; Warren et al., 2001). Planned adaptations can be either reactive or pro-active, which means that they take place before impacts are evident, and therefore the pro-active planned adaptation can be considered typical of human societies (Carter et al., 2003; MacIver & Dallmeier, 2000a). With these definitions, it may be generalized that in human societies autonomous adaptation corresponds to private actions and planned adaptation corresponds to actions by public sector or government organizations (Carter et al., 2003; Pittock & Jones, 2000).

The FNSACC lists a number of possible actions to enhance survival of biodiversity in the course of climate change (Ministry of Agriculture and Forestry, 2005). A number of actions are suggested to be implemented during the period 2005-2010 (marked by asterisk * below). These and other actions with longer time frames are divided between public and private sectors as following:

1.3.1. Public sector

Administration and planning

- Reducing human-induced stress on nature by controlling land use (*)
- Evaluation, development and monitoring of the extent of the network of protected areas (*)
- Maintaining original habitats (*)

- Changes in policy regarding the management and use of protected areas when necessary (*)
- Taking valuable habitats into consideration in the management and use of forests (*)
- Conservation of valuable traditional farmland biotopes with the help of the agri-environmental support scheme (*)
- Including an evaluation of the impacts of climate change in the ongoing planning and development projects for the promotion of biodiversity (*)
- Introduction of an information system for protected areas (*)

Research and dissemination

- Increasing cooperation, information and consultation between the different administrative sectors (*)
- Imformation to forest owners and training of forest professionals (*)
- Improving the monitoring, planning and information systems for biodiversity (*)
- Evaluation of the possibilities of *ex situ* protection with regard to climate change (*)
- Studies of threatening factors caused by climate change at the of ecosystem and species level
- Carrying out general habitat-level follow-ups and supplementary species-level follow-ups

Economic and technical strategies

- Control and prevention of the spread of invasive alien species (*)
- Restoration and management of valuable habitats (*)
- Prevention of the extinction of species with the help of zoos and planting (*)
- Reconstructing and restoring wetlands and mires (*)

1.3.2. Private sector

- Reducing the environmental pollution load on the environment and the atmosphere
- Conservation of valuable traditional farmland biotopes (*)
- Taking valuable habitats into consideration in the management and use of forests (*)

In the following chapters we review these proposed adaptation measures in the light of recent scientific literature and make an attempt towards a synthesis to guide future adaptation actions in biodiversity conservation in Finland.

2. Material and methods

2.1. Literature survey

As the first method applied in the literature survey, two major databases of scientific literature were searched through for articles on climate change adaptation with respect to biodiversity and nature conservation. These databases were ISI Current Contents (the library agriculture, biology and environmental sciences that covers the period from 1997 to current) and Cambridge Scientific Abstracts (CSA; the library environmental management and pollution that covers the period from 1967 to current). The key words used in the search included climate change, adaptation and biodiversity.

The hits produced by the key word search were then checked through manually to find out whether the citations showed actual relevance for the subject. Also a selection of major scientific journals in the field (e.g. Environmental Monitoring and Assessment, Climatic Change and Global Change Biology) were searched for appropriate papers with the same methods. All the searches were conducted on 10 March, 2005.

The second method applied in the literature survey involved an opportunistic search of previous publications on climate change adaptation and collection of relevant citations.

2.2. Expert questionnaire

To assist in the evaluation of the national strategy, a questionnaire was delivered to the participants of an international expert seminar (*n = 61*). The questionnaire first included some background information on the predicted biodiversity impacts of climate change, followed by seven general questions which covered the following issues: the expected biodiversity impacts by climate change, the need for adaptation measures, the possible management actions inside and outside PAs and in aquatic ecosystems, the main research needs and the monitoring of climate change impacts (see Appendix for the Questionnaire).

Following the IPCC definition of the climate change adaptation, seven proposed adaptation measures abstracted from the literature were listed. The expert participants were asked to evaluate these measures with respect to their general effectiveness and to their realism particularly under the Finnish circumstances. Effectiveness was evaluated using the following scale: 1 – very effective, 2 – effective, 3 – ineffective, 4 – very ineffective and 5 – no opinion. Similarly, realism was evaluated according to the following categories: 1 – wide applicability, 2 – local applicability, 3 – unrealistic, 4 – very unrealistic and 5 – no opinion. The participants were also asked to comment on their evaluations. Finally, respondents were invited to present potentially important adaptation measures that were not listed under the specific questions.

3. Results

3.1. Review of the scientific literature

A search of the library "Environmental management and pollution" of the CSA produced 238 hits with the key words climate change and adaptation. After checking through titles and abstracts for the actual topic, 12 of these papers were selected for a more detailed analysis (Berry et al., 2003; Clarke, 2003; Deshingkar, 1998; Droogers, 2004; Hartig et al., 1997; MacIver, 1998; Meynecke, 2004; Pittock, 1999; Ramakrishnan, 1998; Ravindranath & Sukumar, 1998; Smith & Lazo, 2001; Williams, 2000). Similarly, a search of the library "Agriculture, biology and environmental sciences" of the ISI Current Contents produced 299 hits with the same key words, and nine of these papers were selected for a more detailed analysis (MacIver, 1998; MacIver & Urquizo, 2000; Meynecke, 2004; Noss, 2001; Ramakrishnan, 1998; Ravindranath & Sukumar, 1998; Usher, 2000; Williams, 2000). Further searches were made on the periodicals "Climatic Change" and "Environmental Monitoring and Assessment" by using the key word Adaptation. The search of the former periodical produced 51 hits, and five of these papers were selected for a further analysis (Hartig et al., 1997; Krankina et al., 1997; Ramakrishnan, 1998; Ravindranath & Sukumar, 1998; Smith et al., 2001). The search of the latter periodical produced 15 hits, and seven of these papers were selected for a further analysis (Bwango et al., 2000; Lister, 1998; MacIver, 1998; MacIver & Dallmeier, 2000; Pittock & Jones, 2000; Usher, 2000; Williams, 2000). Similar searches of the journals "Global Change Biology" and "Global Environmental Change A" yielded 27 and 26 hits, respectively. Based on the abstracts, none of these was selected for a further analysis.

While conducting the literature survey, it soon became obvious that papers that were handling biodiversity conservation in the context of climate change were usually not using the word *adaptation*. Instead, a more general terminology was often employed indicating that the study was concerned with e.g. modelling future ranges and survival of species within a given network of PAs. This semantic difference between climate change adaptation studies in biodiversity conservation and other fields probably stems from the use of the term adaptation in evolutionary biology. In the evolutionary context this word is assigned to an autonomous inherited response within a population to a change in the environment. Therefore, using the word adaptation in the context of planned actions for adapting to climate change may be avoided by many ecologists and conservation biologists.

Due to the above limitation in search criteria, further papers had to be searched for as references in other publications (see Material and methods). This opportunistic search approach eventually produced more papers with actual relevance on the subject. The main themes emerging from the analysed papers are presented below with comments and main conclusions from the articles.

3.1.1. Performance of protected areas (PAs) under changing climate

Projected climate change is expected to produce major challenges to nature conservation and PA management. The current PAs have been evaluated in several studies in terms of their ability to maintain the current species pools (Burns et al., 2003; Coulston & Riitters, 2005; Hannah et al., 2005) and biotopes (Scott et al., 2002; Villers-Ruíz & Trejo-Vázquez, 1998), and to support the future maintenance of biodiversity (Coulston & Riitters, 2005; Hannah et al., 2002a; Pyke & Fischer, 2005). Bioclimatic envelope models with current distributional data, a few different climate scenarios and simple assumptions of species' dispersal abilities (universal migration and no migration) are usually applied in the modelling to achieve a measure of the sensitivity of model performance. Development of methods to aid selecting PAs has also begun in order to assist protecting both the current and the future ranges of species (Araújo et al., 2004; Pyke & Fischer, 2005).

In Mexico, Villers-Ruíz & Trejo-Vázquez (1998) modelled the future representation of vegetation zones in 33 PAs. They concluded that only nine of these parks would maintain their current vegetation. These changes would be caused by decreasing precipitation and by increasing temperature and potential evapotranspiration. Similarly, Scott et al. (2002) modelled the future biome representation in the 39 Canadian national parks with the global vegetation models (GVM) under doubled-CO_2 climate change scenarios. Major changes in biome representation were predicted so that in 5 of 6 vegetation scenarios a novel biome appeared in over half of the parks. The proportional occurrences of northern biomes declined, whereas southern biomes increased in the national park system. Scott et al. (2002) concluded that the predicted climate change will pose an unprecedented challenge to the present mandate and management of national parks in Canada. Burns et al. (2003) assessed the ability of eight selected US national parks to maintain their current mammal communities. Species losses up to 20% were predicted for individual parks, and this in combination with the influx of new species would result in strongly converted mammal communities. The authors suggested that their evaluation was conservative, because changes in species composition may cause further unpredictable indirect impacts on communities (Burns et al., 2003). Coulston & Riitters (2005) presented a gap analysis of the current PA system in the Douglas fir (*Pseudotsuga menziesii*) forest type in the Western United States. It was suggested that by conserving a plant community or vegetation type, other components of biodiversity that are associated with that type are conserved simultaneously. The conclusion was that the present PAs occurred in cooler and more arid parts of both current and predicted envelopes.

Hannah et al (2005) modelled the future occurrence of over 300 species in the plant family Proteaceae within the current PA network in the Cape floristic region in South Africa. It was predicted that a substantial number of species will lose their climatic envelope and consequently all occurrences in PAs by the year 2050. A much larger number of species were predicted to experience a major loss in the extent of their range that is protected, though for some species this gap could be partly filled by founding new PAs. A major obstacle for the Proteaceae species may be caused by changes in human actions, which themselves may also be shifted towards higher elevations due to climatic forcing (Hannah et al., 2005). The combined effects of habitat loss and alteration and climate change were predicted to add a further 30 to 37 species to the current list of 126 threatened Proteaceae species in the Cape region.

In Europe, Araújo et al (2004) assessed the potential of the existing reserve selection methods to select PAs that would maintain their present species pool in the course of scenarios of projected climate change. Data on the current distributions of 1 200 species of vascular plants were included in the modelling. An estimated 6-11 % of the current species pool in the selected hypothetical reserve network would be lost during a 50-year period with the predicted changes. It was calculated that 93 % of species would maintain various levels of overlapping populations, whereas 2 % would have non-overlapping distributions and 5 % would completely lose their current climate space. It was concluded that it would be possible to mitigate species extinctions within reserves, but new, more comprehensive means are needed to support especially those species that will have temporarily non-overlapping populations.

The performance of the global reserve network in protecting future patterns of biodiversity is further complicated by the observation that many species and biotopes are currently only weakly represented within PAs. For example, Rodrigues et al. (2004) showed that 12 % of the >11 600 analysed terrestrial vertebrate species are not represented in the current PAs. The proportion of unrepresented threatened species was observed to be even higher (20 %). It may be assumed that inadequately studied taxa (e.g. insects) or taxa with high level of endemism (e.g. plants) are less well represented (Rodrigues et al., 2004).

In accordance with the above observation, Hannah & Salm (2003) pointed out that a systematic reserve network design with revised goals due to climate change is needed to take into account the predicted range shifts in species distributions. Many current reserves have been founded on an *ad hoc* basis, without preset rules and systematic planning. The importance of selecting reserves that cover both the current and predicted ranges of a focal species is emphasized. This could be possible to achieve in situations when there is large altitudinal variation in terrain. When this is not possible, connectivity is required to aid species to spread into new reserves.

3.1.2. Habitat management within PAs

Habitat management within PAs to maintain a healthy status of habitats and ecosystems, and viable populations of focal species has been suggested to be perhaps the least controversial of the adaptation measures suggested in the context of biodiversity conservation (Halpin, 1997). With a closer look, however, different approaches to management can be distinguished based on its goals and possible outcome.

Suffling & Scott (2002) discussed the current national park management in Canada in the light of projected climate change, and they proposed four different policy options for park management: 1) static management, 2) passive management, 3) adaptive management, and 4) hybrid management, the last being a combination of the above (see question 11 in Appendix). *Static* management was defined as the continuing protection and management of current ecological communities within current reserve boundaries using current goals. *Passive* management was defined as the acceptance of ecological responses to climate change which means that evolutionary processes will be allowed to take place unhindered. This approach may also be called a *"laissez-faire"* strategy. Adaptive management is aimed at maximising the capacities of species and current ecological communities to adapt to climate change with the aid of active management (e.g. fire prevention, invasive species suppression, species translocations). Suffling & Scott (2002) suggested that something akin to adaptive management would be the course that PA agencies should adopt as a general management strategy. This opinion was justified by the observation that projected changes extend beyond the tolerance and dispersal abilities of many species. However, it was noted that adaptive management will also raise ethical and scientific questions concerning, for example, the allocation of the limited resources available in park management.

Hannah & Salm (2003) suggested that a mix of incremental improvement, limited surrogacy (e.g. use of a umbrella taxonomic group) and general rules for reserve selection may be the most effective strategy for the future, assuming that it will be possible to establish new PAs. According to Hannah & Salm (2003), intensified management for present goals is the first step towards a future management strategy. The next step involves assessment of current management activities against those anticipated with climate change, and subsequent update of the management goals and practises. Competing management approaches may be expected to emerge, and in such situations cooperation between national agencies and governments is required.

Hossell et al. (2003) stated that nature conservation has traditionally focused on maintaining the existing situation or *status quo* in PAs. Climate change raises new demands for upgrading management practices within PAs. Three types of management policies were discussed. *Preservative management* was suggested to remain as the most important management policy in the near future, although its importance is expected to become increasingly untenable with increasing climate change effects. It may also be needed e.g. in keeping invading unwanted species in check. *Dynamic solutions* to manage habitats and species include all measures that actively work in concert with the direction of the effects caused by climate change. Species translocations, habitat creation and temporary PAs founded to serve e.g. as stepping stones are examples of such measures. In some situations climate change is expected to overwhelm all effort to preserve current communities and habitats, and in such situations a *"laissez-faire"* strategy may be inevitable. In such situations *ex situ* conservation might still be possible.

3.1.3. Landscape planning and management outside PAs

An important measure, already proposed in several early papers on the subject, is to establish corridors as part of regional land use planning that would aid the movement of species into new areas that become suitable when climate changes (e.g. Halpin, 1997; Peters, 1992; Peters & Darling, 1985). In Finland, a similar approach for conserving forest biodiversity has been presented by Lindén et al (2000). They suggested that two wide "mega-corridors" of forested land should be established to connect the currently biodiversity-rich forest in Russian Carelia ("the Green Belt of Fennoscandia") with the forested regions along the Suomenselkä watershed area in central Finland and with the forested regions in northern Sweden.

Corridors, however, carry with them uncertainties, because it is unclear whether species will be able to disperse fast enough to track climate changes projected for the 21st century (Hannah et al., 2005). Further, different species have different habitat requirements, and although many empirical examples have shown that corridors assist the movement of species between habitat patches (e.g. Beier & Noss, 1998), the general benefits of corridors mainly comprising one habitat type for a larger number of species have been questioned (Halpin, 1997; Hulme, 2005). It could still be possible to identify, through modelling studies, chains or tracks of possible migration routes (Skov & Svenning, 2004; Williams et al., 2003), and areas where these tracks overlap might be managed or protected as corridors for multispecies migration (Hannah et al., 2005; Skov & Svenning, 2004; Williams et al., 2003).

Berry at al. (2003) concluded that in cases lacking an overlap between the current and predicted distributions, the characteristics of the intervening habitat were estimated to be crucial. Therefore, conservation and management of habitats outside PAs will be essential to aid dispersal of species. A similar conclusion was presented by Hannah & Salm (2003). Araújo et al (see above 2004) calculated that in Europe 2 % of plant species would have nonoverlapping distributions in the period 2021-2050 compared with the current distribution, and 5 % of species would completely lose their current climate envelope. The authors estimated that it would be possible by management to reduce species extinctions within the existing reserves, but species with diverging future distributions and limited dispersal abilities would anyway face a considerable risk of extinction. Consequently, Araújo et al (2004) concluded that more comprehensive means are needed to support especially those species that will have temporarily non-overlapping populations.

3.1.4. Monitoring

MacIver & Dallmeier (2000a) suggested that monitoring and the development of early-sign indicators for biodiversity changes should become a cross-cutting theme in all biodiversity adaptation research and policy. Similarly, Hannah et al. (2002a; 2002b), Suffling & Scott (2002) and Hannah & Salm (2003) all considered monitoring essential for the management of reserves. A monitoring program with a representative sample of all taxa should be based on the scenarios developed in both regional and site planning. The site plan then specifies how management actions should be reformulated with evolving conditions. Monitoring should continuously produce material for the updates of management practises.

Hossell et al. (2003) further suggested that because species respond individualistically to the effects of climate change, habitat-level changes should be monitored by using "umbrella" or "key-stone" species as reference taxa. Changes observed in these could be used to reformulate conservation objectives. According to Hossell et al. (2003) monitoring should be concentrated in areas or habitats with greatest expected changes.

3.1.5. Policy instruments

Hannah et al. (2002a) argued that more emphasis should be put on the issue of biodiversity conservation and adaptation to the impacts of changing climate. Two points were expressed: 1) the position of biodiversity conservation should be strengthened in climate change adaptation discussions, and 2) conservation strategies should be developed to help the survival of biodiversity under climate change. A schedule with five key elements for a climate change –integrated conservation strategy (CCS) was presented.

A CCS is suggested to begin with regional (subcontinental) modelling to assess the possible climate change effects on biodiversity (Hannah et al., 2002b). Regional modelling, which is considered more cost-effective than similar analysis at the single park level, is concluded by sensitivity analysis based on local circumstances. Three specific activities would be designed based on the analysis: expansion of PAs due to temporarily nonoverlapping populations, managing the matrix land use outside PAs and regional coordination of management actions. Finally, implementation of these elements requires world-wide transfer of financial and technical resources.

Hannah et al. (2002b) emphasized the urgent need to integrate the current tools created separately in the fields of biogeography, conservation biology and practical management to tackle the deleterious effects of climate change. Synthesis is needed not only across these disciplines but also across theory and practise. Strengthening of co-networking on different disciplines and authorities that work with the issues of biodiversity adaptation under changing climate was also emphasized by Ravindranath & Sukumar (1998) and MacIver & Urquizo (2000). Hannah et al. (2002b) also suggested that sound conservation plans should be prepared not only for climate warming but for sudden cooling due to uncertainties caused by possible abrupt changes in world's thermohaline circulation system (see Bryden et al., 2005; Carter et al., 2005). A further problem for conservation planning is posed by species assemblages for which there are no current analogues. These may be created due to species' individual responses to climate change. Therefore, community representation in reserve system may be an impractical and misleading target. Instead, surrogates such as climate variables should be used alongside biological variables. Conservation responses to extreme or periodic events will require monitoring and adaptive management to the observed changes.

Hannah et al. (2002a) suggested that conservation planning should take into account future patterns of biodiversity along with current ones, eventually requiring an increase in the number of PAs. This goal might be achievable with planning of regional reserve networks, and managing (with international co-operation) the matrix between the reserves to provide landscape connectivity for the different species. Finally, Hannah et al. (2002a) concluded that *no* reserve network could buffer against large-scale extinctions if the scenario of an unlimited change with no mitigation actions will come true.

Scott et al. (2002) discovered several potential vulnerabilities in the current national park administration of Canada, including the national park system plan, individual park objectives, and fire and exotic species management plans. The state authority responsible for park management, Parks Canada, has traditionally concentrated on the protection of the current ecosystems, whereas more emphasis should be paid on assisting ecosystems to adapt to climate change. It was concluded that the predicted climate change will pose a unprecedented challenge to the national park management in Canada.

After discussing the current national park management in Canada in the light of the projected climate change, Suffling & Scott (2002) proposed six steps aimed at updating PA management to combine biodiversity conservation with climate change adaptation. The first step would be a thorough assessment of the Canadian national parks system plan. This would include e.g. a review of lands reserved for future PAs and suggestions to enhance connectivity of the PA network (see above). The second step would consist of vulnerability analyses of individual parks that should focus on management objectives in relation to the risk of climate change. The third step covers monitoring of species and nature type composition occurring in PAs. Monitoring and updates to park management plans should be interconnected. The fourth step considers the effects of tourism on PAs under changing climate. The fifth step of improved emergency planning and infrastructure is based on the prediction that costs associated with forest fires, flood and avalanche management are likely to increase during climate change. Some park infrastructures may have to be replanned to standards appropriate to a changed climate and in some cases to tolerate greater extremes. In the final sixth step, Suffling & Scott (2002) call for an increasing level of co-operation between researchers and agencies responsible for PA management to strengthen monitoring, impact research and implementation of adaptation strategies. Further, the authors advocate international co-operation with other northern nations, including Finland.

Hossell et al. (2003) presented an assessment of nature conservation policies and practices based on the results of the MONARCH project in the United Kingdom. Current targets of nature conservation are based upon national, European and international legislation, agreements and policies. It was suggested that the outcome of such an assessment will be largely dependent on the spatial scale used. Because species respond individualistically to the effects of climate change, it was also suggested that habitat-level changes should be monitored by using "umbrella" or "key-stone" species as reference taxa. Changes observed in these could be used to reformulate conservation objectives. Three types of management strategies within PAs were discussed (see above).

3.2. A review of international assessments

IPCC's Technical Paper V (Gitay et al., 2002) and CBD Technical paper nr. 10 prepared by the *Ad Hoc* Technical Expert Group (AHTEG) on Biodiversity and Climate Change have considered the interlinkages between biological diversity and climate change. They discussed in detail the effects of climate change on biodiversity (Korn et al., 2003). Further, these documents identified several potential adaptation options to reduce negative impacts on climate change on biodiversity. Adaptation options include activities aimed at conserving and restoring native ecosystems, managing habitats for rare, threatened, and endangered species, and protecting and enhancing ecosystem services. Recommendations on general adaptation options include:

- Reduction of other pressures on biodiversity arising from habitat conversion, over-harvesting, pollution, and alien species invasions.
- A major adaptation measure is to counter habitat fragmentation, through the establishment of biological corridors between PAs, particularly in forests.
- Multiple-used PAs designed to take into account projected change in climate, can be beneficial to biodiversity
- Creation of networks of reserves with connecting corridors to provide dispersal and migration routes for plants and animals

- Conservation of biodiversity and maintenance of ecosystem structure and function are important climate change adaptation strategies because genetically-diverse populations and species-rich ecosystems have a greater potential to adapt to climate change
- Other design opportunities such as including gradients of latitude, altitude and soil moisture within PAs, providing buffer zones surrounding PAs, minimizing habitat fragmentation and additional conservation of biodiversity in "hot-spot" areas
- Protecting climatic refugia at all spatial scales, therefore allowing persisting populations of plants and animals to recolonize surrounding landscape when conditions favourable for their survival and reproduction return
- Captive breeding for animals, *ex situ* conservation for plants and subsequent translocation programs can be used to augment or re-establish some threatened or sensitive species.

Korn et al. (2003) also gave a set of more specific adaptation options for various ecosystems. Resilient ecosystems maintain biodiversity and continue to deliver ecosystem goods and services under climate change. More recently, a new AHTEG expert group on Biodiversity and Adaptation to Climate Change identified biological factors that confer resilience (AHTEG 2005). Key biological factors for successful directed adaptation are:

- Maintaining genetic heterogeneity is both a goal and a tool of directed adaptation. Replicate, viable and heterogeneous populations minimize their shared risk and maximise their opportunities for successful adaptation
- Regenerative populations are essential for the sustainability of species populations and community structure. The maintenance of climatic conditions necessary for all life cycle phases is crucial for the long-term viability of populations. The management of habitats to ensure suitable micro-climates for key phases is an essential component
- Maintaining multiple successional states can confer contrasting resource and habitat types under which selected species are able to persist and reproduce throughout the landscape
- Climate change will cause species with limited tolerance to relocate to more suitable locales requiring habitat connectivity across environmental gradients. Directed adaptation needs to provide access to these new locations often across fragmented or disturbed landscapes or seascapes. These new habitat needs cannot necessarily be predicted. As a result it may be prudent to ensure a range of habitat options along environmental gradients.

3.3. Expert opinions

Every fifth participant of the international expert seminar returned the questionnaire (*n = 12*). Respondents' answers to the questions are covered below in more detail. First, the respondents were asked to answer seven general questions concerning the effects of climate change on biodiversity.

1) What do you regard as the main threats of climate change to the native biodiversity?

The general notion of most respondents was that major range shifts will occur due to climate change. This will cause declines in many species presently occurring in Finland, and this would concern especially species of northern habitats. Simultaneously new species will be able to colonize Finland, and these may accelerate by competition the declines of species currently occurring here. Finally, there was concern that the lack of basic knowledge may result in unwise adaptation measures.

2) Are adaptation measures needed at all in nature conservation and for maintaining biodiversity? Please give reasons for your answer.

A clear majority (10 out of 12) of the respondents supported the application of adaptation measures to aid biodiversity conservation under changing climate. This opinion was usually justified by the observation that the current human-influenced landscapes are often too fragmented for species to be able to migrate to new areas if the current ranges become unsuitable. However, it was also pointed out that many of the predicted changes need not to be counteracted at all.

3) What approaches are required to maintain high genetic diversity in protected areas (PA) and managed ecosystems?

The main approach here was to maintain large and well-connected viable populations of species. This could be possible with the aid of a dense network of large and heterogeneous PAs and landscape ecological planning to enhance connectivity between core areas, by e.g. dispersal corridors.

4) How should forests outside PAs be managed to enhance their adaptive capacity to climate change?

It was commonly suggested that heterogeneity, e.g. concerning the age structure of stands, of forests should be enhanced to improve the adaptation capability of forests. Forest management should preserve a number of undisturbed (unlogged) patches in each region. Generally, the conservation and maintenance of biodiversity should be incorporated into the forest management recommendations.

5) How should aquatic ecosystems be managed to enhance their adaptive capacity to climate change?

The commonest suggestion here was to constrict the projected increasing productivity by cutting nutrient leaching and the subsequent enrichment of water systems. It was also suggested that exceptional flood and drought regimes should be controlled to prevent decimation of whole communities of aquatic organisms. The lack of knowledge among the experts appeared to be larger compared with terrestrial systems because many respondents left this question unanswered.

6) What kind of research on climate change impacts and adaptation is needed? Some possible examples are given below:
   A) modelling relationships between climate change, ecosystem function, and biodiversity
   B) modelling relative responses of individual species to climate change and predicting community structures under climate change scenarios
   C) Estimation of the potential of *ex situ* and *in situ* conservation under climate change
   D) Evaluation of threats connected with climate change at the levels of ecosystems and individual species

The above examples received quite balanced support among the experts. Choices A and D were supported by five respondents whereas choices B and C were supported by four and three respondents, respectively. In accordance with this, many detailed suggestions on the research topics were also presented. These included e.g. methods of reserve selection, modelling using a bottom-up approach, more comparative knowledge on endangered and other species, knowledge on ecosystem functioning and interactions, studies conducted at multiple scales and methods to suppress invasive species.

7) What kinds of monitoring activities should be developed to assess the impact of climate change on biodiversity and what are the indicators that should be monitored?

It was generally noted that the current monitoring schemes should be enhanced to receive more baseline data and to cover large geographical and habitat variability. Monitoring should include species with different life-histories and contrasting population trends, and population dynamic data, e.g. on reproductive success, besides the commonly monitored yearly abundances should also be collected. Current data should be used more efficiently.

In the following, the respondents were asked to evaluate a number of specific measures that have been proposed to facilitate the survival of biodiversity under climate change.

8) An extensive / representative protected area (PA) network:
   - a network that is spatially even in all parts of the country

A clear majority (10/12) of the respondents considered the suggestion of an extensive/representative protected area (PA) network as an effective or very effective measure of climate change adaptation with respect to biodiversity conservation (Figure 1). However, a majority (8/12) of the respondents considered this measure unrealistic under the Finnish circumstances. It was commented that a spatially even network probably might not be effective, but that a temporarily representative network would work better under changing climate. Building a representative PA network was considered unrealistic, especially in southern Finland for political reasons and because such a network would consist of small isolated areas.

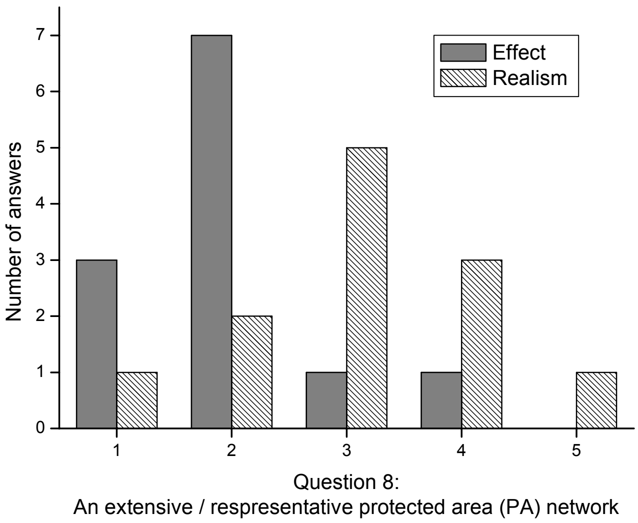

Figure 1 Results of an expert evaluation for the suggested measure "An extensive/representative protected area (PA) network". Effectiveness of the measures was evaluated by using the following scale: 1 – very effective, 2 – effective, 3 – ineffective, 4 – very ineffective and 5 – no opinion, and the realism of these measures was evaluated by using the following scale: 1 – wide applicability, 2 – local applicability, 3 – unrealistic, 4 – very unrealistic and 5 – no opinion.

9) Large and heterogeneous PAs
   - climatic refugia that exhibit high habitat diversity and, where relevant, great topographic variation. These are predicted to better maintain populations of plants and animals in the course of expected climate change

All respondents considered the suggestion of large and heterogeneous PAs as an effective or very effective measure in climate change adaptation (Figure 2). Also a majority of the respondents (7/12) considered this measure widely or locally applicable in Finland. However, it was pointed out by some respondents that it may not be possible to build large and environmentally heterogeneous PAs in southern Finland due to the lack of potential areas.

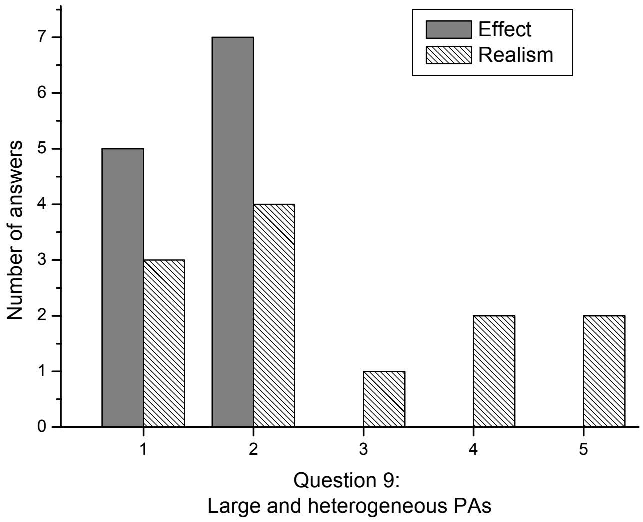

Figure 2 Results of an expert evaluation for the suggested measure "Large and heterogeneous PAs". Scales for effectiveness and realism are as for Figure 1.

10) Extensive corridors connecting the existing nature conservation areas:
   - requiring landscape-ecological planning to set up the corridor network, buffers and stepping stones

All respondents considered the suggestion of extensive corridors connecting the existing PAs as an effective or very effective measure in climate change adaptation (Figure 3). A majority of the respondents (8/12) also considered this measure widely or locally applicable in Finland, though some scepticism also occurred mainly due to political reasons. It was emphasized that the corridors should be geographically wide to work in practise, but that these corridors would not need to be fully protected.

11) Management of PAs. Please circle the management alternative you prefer:
   - Static: continuation of management and protection of current habitats and species within current PA boundaries, using current goals
   - Passive: acceptance of ecological responses to climate change and allowing evolutionary processes to take place unhindered
   - Adaptive: maximization of the capacity of habitats and species to adapt to climate change through active management (e.g. species translocation or suppression of invasive species), either to slow the pace of ecological change or to facilitate ecological change towards a new climate-adapted state
   - Hybrid: some combination of two or more of the management types above (if selected, please specify)

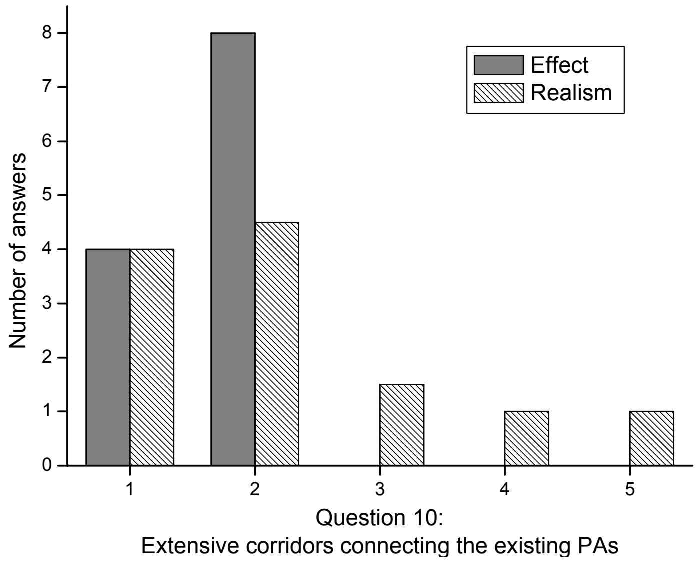

Figure 3 Results of an expert evaluation for the suggested measure "Extensive corridors connecting the existing nature conservation areas". Scales for effectiveness and realism are as for Figure 1.

None of the respondents considered the static management strategy as an option under climate change. Instead, half of the respondents considered some type of hybrid management as the main strategy for PA management during climate change. Another two respondents suggested that hybrid strategy for PA management would be preferable under some situations, because at least some adaptive measures were considered unnecessary or even questionable and because adaptive measures may not always be possible to apply. Adaptive and passive management of PAs were considered as the primary strategies by three and one respondents, respectively.

12) Restoration and management of valuable habitats, e.g. wetlands and different kinds of peatlands

A clear majority (9/12) of the respondents considered the suggestion of restoration and management of valuable habitats as an effective or very effective measure (Figure 4). Also a majority of the respondents (9/12) considered this measure widely or locally applicable in Finland. Restoration was considered to be effective for some habitat types, e.g. mires, but not for all. Restoration was also thought to be a costly measure for a wide application.

13) Biodiversity-oriented management of landscapes outside the PAs (the non-conserved matrix) incorporated into agricultural and forestry practises:
- to support populations of plants and animals outside the focal nature conservation area
- to provide further connectivity along the corridors
- to maintain key biotopes

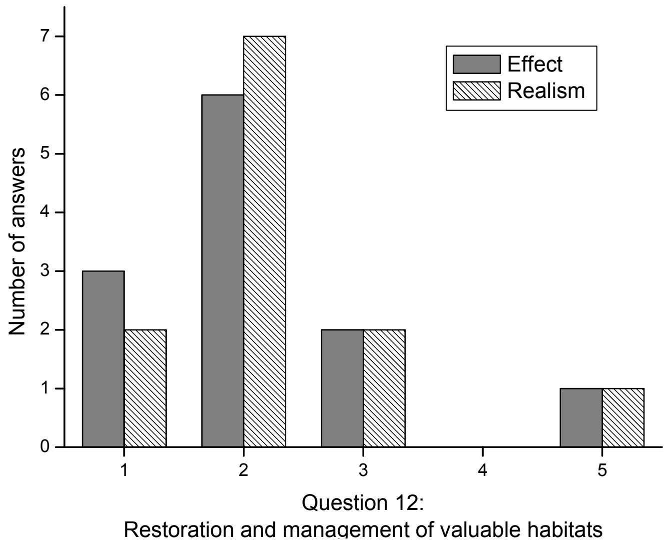

Figure 4 Results of an expert evaluation for the suggested measure "Restoration and management of valuable habitats". Scales for effectiveness and realism are as for Figure 1.

Nearly all (11/12) of the respondents considered the suggestion of biodiversity-oriented management of landscapes outside the PAs as an effective or very effective measure (Figure 5). This measure was also considered as widely or locally applicable by most respondents (9/12). However, some respondents pointed out that forests and agricultural habitats are currently so effectively utilized that only small fragments may be accounted for in biodiversity-oriented management (e.g. the key habitats in forestry).

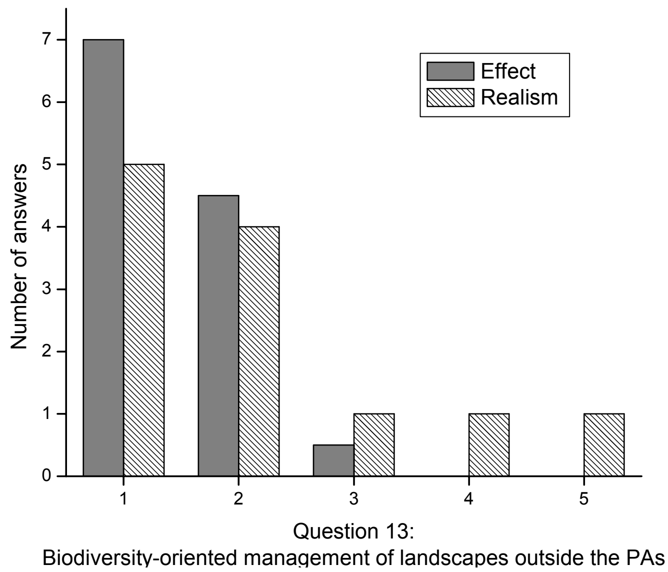

Figure 5 Results of an expert evaluation for the suggested measure "Biodiversity-oriented management of landscapes outside the PAs". Scales for effectiveness and realism are as for Figure 1. Note that one effectiveness response was shared between categories 2 and 3.

14) Translocation of plant and animal populations to more suitable areas:
    - including captive breeding of the vulnerable species

A majority (8/12) of the respondents considered the suggestion of translocation of plant and animal populations as an ineffective or very ineffective measure (Fig. 6). Half of the respondents (6/12) also considered translocations as an unrealistic measure that may be applied only in a very restricted number of situations when no other measures are any longer available.

15) Please suggest other important adaptation measures within or outside Pas

Other adaptation measures proposed by the expert respondents included development of conservation methods and scenarios, use of temporary protection areas, formulating an eradication program for invasive species, restrictions for the use of ornamental plants and developing methods to stop nutrient enrichment in natural communities.

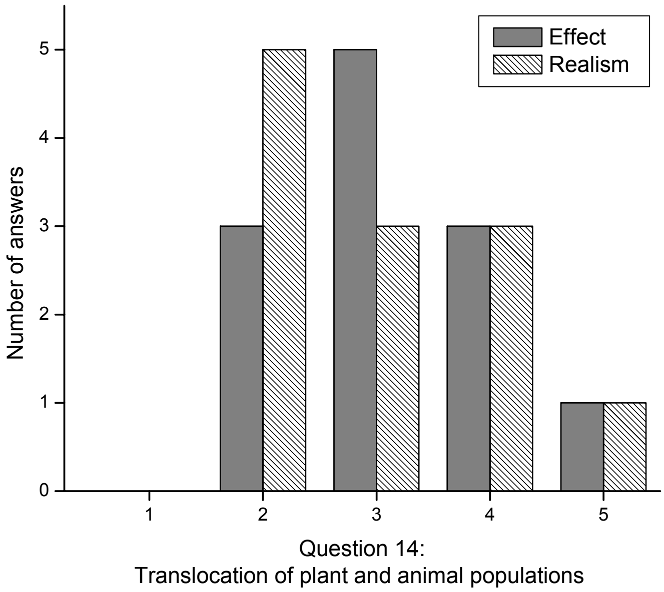

Figure 6 Results of an expert evaluation for the suggested measure "Translocation of plant and animal populations to more suitable areas". Scales for effectiveness and realism are as for Figure 1.

4. Discussion

4.1. Adaptation measures

The main suggestion for conserving biodiversity found in many of the reviewed papers is that it is important to ensure that species are able to move to more suitable regions as the climate changes. The most important proposed instruments for this include building a spatially and temporarily representative network of protected areas (PA) to aid the existence of viable populations of species vulnerable to climate change, and to use regional land-use planning to build corridors that would provide connectivity and dispersal routes for species moving between the core natural areas. The goal of temporarily representative PA network might be achieved by placing PAs to areas with strongest environmental gradients (e.g. high altitudinal change) and by managing PAs to diminish extinction rates of populations for those species that have remained outside their climate optima. Maintaining temporarily representative occurrences of vulnerable species may appear difficult in PAs, especially in southern Finland where environmental gradients are only gentle. This view was also shared by many of the expert respondents to our questionnaire.

The current Finnish network of PAs is very unevenly distributed. Taking forests as an example, in southern Finland less than 1% of the forested land is included in protected areas whereas in northern Finland more than 10% of the forested land is allocated to conservation at some level (see Virkkala et al., 2000). The present level of knowledge suggests that the current PAs will be unlikely to maintain viable populations of climatically vulnerable species under changing climate due to their small areas. In addition, a large number of key habitats are left unmanaged under the current forest practices in Finland, and these could also aid the conservation of climatically vulnerable species. These areas are nonetheless susceptible to environmental changes due to their small sizes and highly fragmented spatial configuration, and populations of vulnerable species living in these habitats are prone to local extinctions (Hanski, 2000, 2005; Pykälä, 2004). Therefore it remains unlikely that the key forest habitats would significantly contribute to the conservation of climatically vulnerable species. In northern Finland, however, the spatially more dense network allows better options for the maintenance of populations within PAs, and due to the landscape ecological planning in forest management within the state-owned areas there might be realistic possibilities for creating corridors that would provide connectivity between PAs. As altitudinal variation is generally higher in northern Finland, maintaining temporarily overlapping occurrences of species may also prove out easier there.

It was suggested in an Indian study that due to uncertainties concerning climate prediction models as well as models of vegetation change, currently only "no regret" approaches to adaptation with respect to forest biodiversity conservation are acceptable by forest planners (Ravindranath & Sukumar, 1998). Although located in a different climatic zone where the climatic projections are less robust than in northern Europe, and under greatly different societal circumstances, a similar situation may generally still be the case in Finland. The Finland's National Adaptation Strategy for Climate Change proposed several adaptation measures in forestry (Ministry of Agriculture and Forestry, 2005), but these are mainly concerned with challenges caused by climate change to timber production. The major model predictions here with relevance to biodiversity are generally connected with shortened growth cycles of trees, changes in tree species composition and dominance, and increasing amount of decaying wood in forest stands (see Kellomäki et al., 2005). In this context, the projected decrease in the cover of spruce-dominated forests due to elevated summertime water stress would particularly have major implications for biodiversity.

Predictions of major changes in habitat and species composition in the northern latitude PAs (Scott et al., 2002) suggest that new goals for management measures in PAs have to be implemented during the forthcoming decades (Suffling & Scott, 2002). There is currently a basic conceptual division between static/preservative management solutions and adaptive/dynamic management solutions in the context of habitat management within PAs. To achieve a compromise over this gap, hybrid management approaches with characteristics of both static and adaptive management (Suffling & Scott, 2002) have been proposed. However, there is currently a lack of applied examples of such measures. As a first step towards this direction, the current management measures could be make to work more efficiently (Hannah et al., 2003). Monitoring in the PAs is needed to follow up changes in populations and in species composition, but also to adapt management measures to the new goals of conservation. In Finland, the Natural Heritage Services of Metsähallitus would probably be the authority responsible for arranging monitoring in PAs. However, the outcomes of most management measures under changing climate may be very unpredictable and new research on their effects on biodiversity is urgently needed also in Finland.

In extreme cases, *ex situ* conservation and subsequent translocations may be applied with some key species. The weight given to this measure in the recent scientific literature varies widely between important (e.g. Hulme, 2005) and marginal (e.g. Hannah et al., 2002a). The answers by the expert respondents suggest that application of this measure in Finland might be suitable only occasionally, e.g. with key stone species which by definition are essential for the functioning of biological processes within an ecosystem. A perhaps less strongly justified group for *ex situ* conservation consists of threatened and conspicuous "flag ship" species which, however, often are targets of specific conservation programmes. In either case, the prerequisite for successful *ex situ* conservation is that the species in concern can breed in captivity (e.g. zoos) and are suitable for translocations.

4.2. Expert questionnaire

Due to the limited age and size of the field of climate change and biodiversity conservation studies, we consider that we were able to screen through a representative set of researchers and administrative experts on the subject in Finland. Nearly all of the respondents considered some future adaptation measures necessary in biodiversity conservation. Three of the six evaluated measures (extensive network of PAs, large and environmentally heterogeneous PAs and ecological corridors) were considered effective or very effective by the experts. This is in line with suggestions found in the recent scientific literature (see above). The effectiveness of habitat restoration and management was doubted by some respondents, because these measures can only be applied at a limited scale. Only translocation was generally considered as an ineffective measure by most respondents.

Practical implementation of the suggested measures appeared, however, to raise much scepticism among the experts, and variation among the respondents' opinions was revealed to be large. Four of the evaluated measures were considered to show some applicability under the Finnish circumstances (large and environmentally heterogeneous PAs, ecological corridors, habitat restoration and management and management of the non-conserved matrix), although the possibilities to establish large and environmentally heterogeneous PAs, particularly in southern Finland, were also questioned by many experts. Implementation of an extensive network of PAs and species translocations were generally considered unrealistic in Finland.

4.3. Evaluation of the National Strategy for Adaptation

Finland's National Strategy for Adaptation to Climate Change listed a number of possible actions to enhance survival of biodiversity in the course of climate change (Ministry of Agriculture and Forestry, 2005). These are presented in detail in section 1.3. The suggested actions are evaluated and discussed briefly below in the light of the international scientific literature and assessments.

The measures proposed for the <u>administration and planning</u> in the FNSACC are in principle beneficial to biodiversity. Many of the suggested measures can be considered as 'win-win' or 'no regret' solutions and are therefore widely applicable. Their biodiversity considerations should, however, be assessed in more detail, particularly those concerning forest management, maintenance of traditional rural biotopes and land-use in general. Land use planning with the goal of stopping habitat loss and fragmentation, excessive nutrient loads or further drying of natural ecosystems should be encouraged. Measures suggested for PAs are useful in building capacity for their management and monitoring.

Most measures are suggested to be implemented during 2005-2010, which in some cases may be premature because knowledge of their effects is still somewhat insufficient.. In particular, sensitivity and vulnerability analysis for targeted species and habitats, as well as more detailed scenarios describing pressures on biodiversity would be useful for the suggested monitoring and assessment of the coverage of the PA network. In the near future, more attention should also be paid to increasing general awareness of climate change adaptation with respect to biodiversity conservation. This is important in order to gain better acceptance for the adaptation options needed and, for example, for changing management objectives of the PAs.

In the field of research and dissemination the suggested measures are mostly practical in their scope and focus on applied solutions. A national monitoring system for biodiversity, a measure that would be highly profitable to the whole field of nature conservation, would be useful to follow up changes caused by climate change, as well as for analysing the pressures on species and state and trends of biodiversity in general. However, indicators for species sensitive to climate change have also been suggested in some European countries (e.g. the Netherlands) and should be an essential set among those used in monitoring biodiversity. New research and broad assessments on the suggested adaptation measures are also needed. *Ex situ* conservation methods should be assessed and experiences collected. In the Finnish case, the National Heritage Services of Metsähallitus might under the Finnish circumstances be the authority which could implement experiments on the subject.

Concerning economic and technical strategies, the formulation of a strategy to control harmful invasive species is considered very important. The invasive species, e.g. new pests and pathogens are considered as one of the main threats to biodiversity therefore their successful prevention is very important for the maintenance of the ecological integrity of ecosystems. The suggested habitat restoration measures are good, though a more thorough evaluation of the goals of habitat management in the context of changing climate should be conducted. Potentials of *ex situ* conservation measures are also important to support *in situ* conservation.

The actions suggested for the private sector are strongly connected with the regulatory actions taken by administration and planning of the public sector. Maintenance of the traditional semi-natural biotopes is currently functioning as a part of the national agri-environment support scheme in Finland. Valuable "key" biotopes are taken into account as a part of the currently applied forest practises e.g. through the forest certificate system. Reduction of atmospheric emissions is merely a mitigation measure and is better handled under that topic.

5. Conclusions

Recent climate change has already produced numerous impacts on biological diversity. The examples observed in Finland include advanced spring arrival and breeding of birds, expanding northern range limits of butterflies and moths and increasing multivoltinism of moths. During the last decade more than 100 hundred new, mostly southern butterfly and moth species has been observed for the first time in Finland. The changes in plants and vertebrate animals are not as remarkable but correspond to observations found in other northern areas in Europe. At the habitat level changes are often difficult to interpret but climate change has probably resulted in the decline of northern palsa mires.

Based on the most recent climate scenarios, increasing impacts on biota, including immigration of many new species mainly of southern origin, disintegration of the current communities and reconstruction of new assemblages of species, can be expected in the future. In most cases they will form new mixture assemblages with the recent species. Recent species of northern distribution, particularly those in an alpine habitat, will suffer. The timberline will probably shift northward and upward, though in certain mountain birch forest regions the reindeer overgrazing may pose a counteracting force, possible leading to the shrinkage of the total area of mountain birch forest ecosystems. The hydrological status of some mire types may change, and palsa and aapa mires may suffer. The coverage of open habitats (alpine heaths, open mires) will decline. The tree species composition in forests will change and deciduous trees will become more common. Combined with increasing primary productivity, this suggests changes in forest biodiversity. Productivity in aquatic systems will also increase, and ice free periods will lengthen. Algal blooms may become more frequent, and some fish species, particularly salmonids are likely to suffer. The risk of pests and diseases and the probability of storm damage will increase.

Many components of the Finnish biota may have a relatively good adaptive capacity but some habitats may be sensitive, e.g. alpine nature types or northern palsa and aapa mires. The resilience of northern oligotrophic waters is also low. Large uncertainties also exist in the abilities of species to shift northwards in the course of climate change, although Finnish landscapes are not as fragmented by human activities as many areas further south in Europe. A thorough sensitivity analyses for rare and threatened species and nature types would be of great value, as well as an assessment of PAs and their management for the likely effects of climate change. Actions suggested in the Finland's National Strategy for Adaptation to Climate Change (FNSACC) include many win-win measures that will potentially enhance autonomous adaptation. However, the biodiversity considerations of these measures should be assessed in more detail.

The FNSACC includes many planned adaptation actions, like evaluation, development and monitoring of the extent of the network of PAs and maintenance of biodiversity rich habitats. Further, regional landscape planning is often suggested as a tool to enhance possibilities of species to migrate to new areas. Ecological corridors and management of areas outside PAs could be potential tools for this goal. Practical knowledge on the effectiveness of the adaptation measures regarding biodiversity benefits are still missing, and there is an urgent need for such research. A national biodiversity monitoring system also incorporating climate change indicators would be necessary. The suggested habitat restoration measures are also of value, though a more thorough evaluation of the goals of habitat management in the context of climate change should be conducted.

5.1. Research gaps

Most of the research on climate change and biodiversity has hitherto concerned observed or predicted impacts, although large gaps still exist there too. For impact studies, systematic collecting of species-specific baseline data, and further development of the predictive modelling of individual species' responses, and downscaling scenarios to the scale of individual PAs and local succession models are considered important. Studies conducted at multiple spatial scales should be preferred. Knowledge on the effectiveness of the adaptation measures regarding biodiversity benefits is still largely missing, and there is an urgent need for such research.

Themes with the largest research gaps are listed below:

- regional modelling of relationships between climate change, ecosystem functioning and biodiversity
- assessment of species and habitats with high national and international conservation priority for their responses to climate change
- identification of species and habitats at risk of being significantly affected by climate change
- performance of the current habitat management and restoration measures under the future climate conditions
- assessment of PAs for the likely effect of climate change and, in the light of these assessments, revision of the methods of management
- assessment of the effectiveness of different adaptation measures, e.g. suggested in forestry and agriculture to improve biodiversity conservation
- possibilities to enhance forest biodiversity by favouring southern broad-leaved deciduous trees and alternative forest management practices
- characteristics of successful ecological corridors
- development of a indicator set to study impacts of climate change and the efficiency of adaptation measures
- modelling of distribution shifts
- studies on dispersal abilities of different model species
- studies on the effects on soil organisms
- assessment of potential pest insects and weeds
- studies on the effects of climate change in aquatic systems, including the Baltic Sea (see below) and inland waters
- hydrological changes and succession of surface structures in different mire and wetland types (changes in surface patterns of aapa mires and overgrowth of raised bogs)

Research gaps specific to the Baltic Sea:

- Studies of how climatic forcing affects the distribution, populations dynamics and productivity of indigenous and non-indigenous biota in the Baltic Sea region including microbes together with pathogens and diseases (including harmful algal blooms), plankton, fish, benthos, water birds and marine mammals
- An investigation of how the impact of changes and seasonality of the ice cover will change spring bloom and autumn dynamics
- An assessment of possible future sea level rise and its impacts on coastal habitats
- Assess biodiversity values of the current Baltic Sea PAs in the course of projected climate change, and identify new such areas

6. Acknowledgements

This work was supported by the Finnish Cluster Research Programme, coordinated by the Ministry of Environment. We thank Dr. Seppo Neuvonen for informing us about the unpublished manuscript on long-term changes in the pine timber-line in Lapland. Prof. Tim Carter gave valuable comments on the manuscript. Finally we wish to thank the experts who gave up their time to answer and return the questionnaire on adaptation measures.

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Appendix

CLIMATE CHANGE ADAPTATION AND BIOLOGICAL DIVERSITY

QUESTIONNAIRE

ABOUT THE QUESTIONNAIRE

This Seminar has been arranged as a contribution to Work Package 3 (WP3) of the FINADAPT consortium (Climate change adaptation and biological diversity). In addition, a report is currently under preparation to identify possible climate change adaptation measures concerning biodiversity and nature conservation in Finland. To assist in the finalisation of our report, we would like to take the opportunity of this Seminar to request feedback from you, the participants. We would therefore be very grateful if you could spare a few minutes to fill out this short questionnaire that includes specific questions on the topic. Completed forms may be returned to the organizers at the end of the seminar or by mail to: Juha Pöyry, Finnish Environment Institute (SYKE), P.O. Box 140, FIN-00251 Helsinki, Finland.

BACKGROUND

Recent scenarios[1,2] indicate that the following changes in the Finnish environment relative to present conditions can be expected by the 2050s:

- the concentration of carbon dioxide in the atmosphere will rise to between about 490 and 590 ppm (from 375 ppm in 2003)
- mean annual temperature will rise by 1.8 – 5.2ºC
- warming will be greatest in the winter and spring
- total annual precipitation will increase by up to 30%, though there may be decreases in summer
- the intensity of extreme rainfall events will increase
- the thermal growing season will begin earlier in the spring and end later in the autumn
- the snow cover season will be shorter and average snow depth reduced
- the ice cover period in coastal and inland waters will shorten

The productivity of ecosystems is estimated to increase, e.g. forest growth is expected to accelerate by 10-15 % in southern Finland and by 25-35 % in northern Finland[3]. Flora and fauna are predicted to become more diverse as southern species spread northwards (shifts in bioclimatic zones of several hundred kilometres have been estimated, but the realization of this will depend on the dispersal ability of a species and the availability of suitable habitats). In contrast, northern species are predicted to decline and even go extinct. The tree line will rise in the fells of Lapland. New harmful plant diseases and parasites are likely to colonize the country.

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[1] Carter, T.R., Fronzek, S. and Bärlund, I. 2004. FINSKEN: a framework for developing consistent global change scenarios for Finland in the 21st century. *Boreal Environment Research*, 9(2), 91-107.

[2] Jylhä, K., Tuomenvirta, H. and Ruosteenoja, K., 2004. Climate change projections for Finland during the 21st century. *Boreal Environment Research*, 9(2), 127-152

[3] Ministry of Agriculture and Forestry, 2005. Finland's National Strategy for Adaptation to Climate Change. *Publications of the Ministry of Agriculture and Forestry 1/2005*. 276 pp. [in Finnish with English summary]

RESPONDENT DATA **(Please circle your answers)**

Name (optional):__________________________ Gender: Female
Male

Age: <25 Education: Doctoral degree
25-34 Masters degree
35-44 Bachelors degree
45-54 Other, what?_______________
55-64
≥65

Position: adviser Affiliation: government
manager government research institute
official non-government organization
researcher private company
other, what?_______________ university
other, what?_______________

Representing sector: agriculture
energy production
forestry
nature conservation
planning
research
other, what?____________________

GENERAL QUESTIONS

Please indicate if your responses reflect the views of your organisation or your personal opinions (**please circle**):

Organisational
Personal

1) What do you regard as the main threats of climate change to the native biodiversity?

____
____
____
____

2) Are adaptation measures needed at all in nature conservation and for maintaining biodiversity? Please give reasons for your answer.

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____
____
____

3) What approaches are required to maintain high genetic diversity in protected areas (PA) and managed ecosystems?

4) How should forests outside PAs be managed to enhance their adaptive capacity to climate change?

5) How should aquatic ecosystems be managed to enhance their adaptive capacity to climate change?

6) What kind of research on climate change impacts and adaptation is needed? Some possible examples are given below:
- modelling relationships between climate change, ecosystem function, and biodiversity
- modelling relative responses of individual species to climate change and predicting community structures under climate change scenarios
- Estimation of the potential of *ex situ* and *in situ* conservation under climate change
- Evaluation of threats connected with climate change at the levels of ecosystems and individual species

7) What kinds of monitoring activities should be developed to assess the impact of climate change on biodiversity and what are the indicators that should be monitored?

ADAPTATION MEASURES

IPCC definition[4]: "Adaptation is adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions, or activities to climatic change and variability"

In the following, some proposed measures for the adaptation of species and ecosystems under a changing climate are listed. You are invited to assess 1) their *effectiveness* and 2) their *realism* under Finnish conditions, using the following assessment scales **(please circle your answers)**:

Effectiveness:	Realism:
1 – very effective	1 – wide applicability
2 – effective	2 – local applicability
3 – ineffective	3 – unrealistic
4 – very ineffective	4 – very unrealistic
5 – no opinion	5 – no opinion

8) An extensive / representative protected area (PA) network
- a network that is spatially even in all parts of the country

Effectiveness 1 2 3 4 5
Realism 1 2 3 4 5

Comments:

____
____
____
____

9) Large and heterogeneous PAs
- climatic refugia that exhibit high habitat diversity and, where relevant, great topographic variation. These are predicted to better maintain populations of plants and animals in the course of expected climate change

Effectiveness 1 2 3 4 5
Realism 1 2 3 4 5

Comments:

____
____
____
____

[4] IPCC, 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. and Johnson, C.A. (eds.)]. Cambridge University Press, Cambridge and New York, 1032 pp.

10) Extensive corridors connecting the existing nature conservation areas
- requiring landscape-ecological planning to set up the corridor network, buffers and stepping stones

Effectiveness		1	2	3	4	5
Realism	1	2	3	4	5	

Comments:

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____
____

11) Management of PAs. **Please circle** the management alternative you prefer:

- Static: continuation of management and protection of current habitats and species within current protected area boundaries, using current goals
- Passive: acceptance of ecological responses to climate change and allowing evolutionary processes to take place unhindered
- Adaptive: maximization of the capacity of habitats and species to adapt to climate change through active management (e.g. species translocation or suppression of invasive species), either to slow the pace of ecological change or to facilitate ecological change towards a new climate-adapted state
- Hybrid: some combination of two or more of the management types above (if selected, please specify)

Comments:

____
____
____
____

12) Restoration and management of valuable habitats, e.g. wetlands and different kinds of peatlands

Effectiveness		1	2	3	4	5
Realism	1	2	3	4	5	

Comments:

____
____
____
____

13) Biodiversity-oriented management of landscapes outside the PAs (the non-conserved matrix) incorporated into agricultural and forestry practises
- to support populations of plants and animals outside the focal nature conservation area
- to provide further connectivity along the corridors
- to maintain key biotopes

Effectiveness 1 2 3 4 5
Realism 1 2 3 4 5

Comments:

____
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____

14) Translocation of plant and animal populations to more suitable areas
- including captive breeding of the vulnerable species

Effectiveness 1 2 3 4 5
Realism 1 2 3 4 5

Comments:

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____

15) Please suggest other important adaptation measures within or outside PAs

____
____
____
____

THANK YOU FOR YOUR CONTRIBUTION

Documentation page

Publisher	Finnish Environment Institute	Date December 2005
Author(s)	Juha Pöyry and Heikki Toivonen	
Title of publication	Climate change adaptation and biological diversity	
Parts of publication/ other project publications		
Abstract	This report examines possible climate change adaptation measures concerning biodiversity and nature conservation in Finland. The study is based on a literature survey and an expert questionnaire. It also draws on feedback from an international expert seminar arranged on 9 May, 2005. Recent climate change has already produced numerous impacts on biodiversity. The examples observed in Finland include advanced spring arrival and breeding of birds, immigration of new species, expanding northern range limits of butterflies and moths and increasing multivoltinism of moths. Increasing impacts on biota, including disintegration of the current communities and reconstruction of new assemblages of species, can be expected in the future. Marked changes are projected in forest composition and in wetland species diversity. Finland's National Strategy for Adaptation to Climate Change (FNSACC) proposed several measures that could help the adaptation of natural biota to climate change, such as monitoring and devel-opment of a protected areas (PAs) network, restoration of habitats, conservation and management of habitats important for biodiversity and eradication of alien invasive species. Goals and methods of PA management may need to be revised in the future. Most measures suggested in FNSACC are beneficial for biodiversity, but our understanding on their effectiveness is still insufficient. Knowl-edge gaps concerning impact and adaptation research include regional modelling of relationships between climate change and biodiversity, assessment of PAs for the likely effect of climate change, and identification of species and habitats at risk of being significantly affected by climate change.	
Keywords	Climate change; adaptation; biodiversity; FINADAPT; nature conservation; protected areas; phenology; distributional shift; National Adaptation Strategy; habitat management and restoration; ecological corridors; landscape planning	
Publication series and number	Finnish Environment Institute Mimeographs 333	
Theme of publication		
Project name and number, if any	FINADAPT A01025	
Financier/ commissioner	Finnish Environmental Cluster Research Programme	
Project organization		
	ISSN 1455-0792	ISBN 952-11-2102-5 952-11-2103-3 (PDF)
	No. of pages 46	Language English
	Restrictions public	Price
For sale at/ distributor		
Financier of publication	Finnish Environment Institute, PO Box 140, FIN-00251 Helsinki, Finland	
Printing place and year	Edita Prima Ltd, Helsinki 2005	
Other information		

Kuvailulehti

Julkaisija	Suomen ympäristökeskus	Julkaisuaika joulukuu 2005
Tekijä(t)	Juha Pöyry ja Heikki Toivonen	
Julkaisun nimi	Ilmastonmuutokseen sopeutuminen ja luonnon monimuotoisuus	
Julkaisun osat/ muut saman projektin tuottamat julkaisut		
Tiivistelmä	Tässä raportissa selvitetään mahdollisia ilmastonmuutokseen sopeutumisen toimia luonnon monimuotoisuuden suojelemiseksi Suomessa. Taustatietojen keräämiseksi järjestettiin aiheesta kansainvälinen asiantuntijaseminaari 9. toukokuuta 2005 Suomen ympäristökeskuksessa. Työtä jatkettiin tekemällä laaja kirjallisuusselvitys ja kirjallinen kyselytutkimus asiantuntijakokouksen osanottajille. Viime aikainen ilmastonmuutos on jo aiheuttanut lukuisia vaikutuksia luonnon monimuotoisuuteen. Suomessa havaitut esimerkit käsittävät muuttolintujen kevätmuuton ja pesinnän aikaistumista, uusi-en lajien levittäytymistä, perhosten levinneisyysrajojen siirtymistä pohjoiseen ja yöperhosten vuo-sittaisten sukupolvien määrän kasvua. Tulevaisuudessa voidaan odottaa yhä lisääntyviä vaikutuksia eliöstöön, mukaan lukien nykyisten eliöyhteisöjen hajoamista ja uusien yhteisöjen muodostumista. Metsien puulajisuhteissa ja kosteikoiden rakenteessa tapahtuvien muutosten arvioidaan olevan huomattavia. Ilmastonmuutoksen Kansallinen Sopeutumisstrategia esitti useita toimia, joilla voitaisiin edistää luontaisen eliöstön sopeutumista ilmastonmuutokseen. Nämä sisälsivät luonnonsuojelualueverkon seurannan ja kehittämisen, elinympäristöjen ennallistamisen, luonnon monimuotoisuuden kannalta tärkeiden elinympäristöjen suojelun ja hoidon sekä haitallisten vieraslajien torjunnan. Suojelualuei-den hoidon tavoitteet ja menetelmät on mahdollisesti arvioitava uudelleen tulevaisuudessa. Useim-mat Kansallisessa Sopeutumisstrategiassa esitetyt toimenpiteet ovat luonnon monimuotoisuuden suojelun kannalta hyödyllisiä, mutta ymmärrys niiden tehokkuudesta on yhä puutteellista. Ilmas-tonmuutoksen vaikutuksia ja sopeutumista koskevat tutkimustarpeet käsittävät ilmastonmuutoksen ja luonnon monimuotoisuuden välisen suhteen alueellisen mallintamisen, suojelualueiden arvioin-nin ilmastonmuutoksen todennäköisten vaikutusten selvittämiseksi sekä ilmastonmuutoksen vuoksi merkittävän uhan kohtaavien eliölajien tunnistamisen.	
Asiasanat	ilmastonmuutokset; sopeutuminen; luonnon monimuotoisuus; FINADAPT; luonnonsuojelu; suojelu-alueet; fenologia; levinneisyyden muutos; Kansallinen sopeutumisstrategia; elinympäristöjen hoito ja ennallistaminnen; ekologiset käytävät; alue-ekologinen suunnittelu	
Julkaisusarjan nimi ja numero	Suomen ympäristökeskuksen moniste 333	
Julkaisun teema		
Projektihankkeen nimi ja projektinumero	FINADAPT A01025	
Rahoittaja/ toimeksiantaja	Ympäristöklusterin tutkimusohjelma	
Projektiryhmään kuuluvat organisaatiot		
	ISSN 1455-0792	ISBN 952-11-2102-5 952-11-2103-3 (PDF)
	Sivuja 46	Kieli englanti
	Luottamuksellisuus julkinen	Hinta
Julkaisun myynti/ jakaja		
Julkaisun kustantaja	Suomen ympäristökeskus, PL 140, 00251 Helsinki	
Painopaikka ja -aika	Edita Prima Oy, Helsinki 2005	
Muut tiedot		

ISBN 952-11-2102-5
ISBN 952-11-2103-3 (PDF)
ISSN 1455-0792

This report examines possible climate change adaptation measures concerning biodiversity and nature conservation in Finland. Recent climate change has already produced numerous impacts on biodiversity such as advanced spring arrival and breeding of birds, immigration of new species, expanding northern range limits of butterflies and moths and increasing multivoltinism of moths. Increasing impacts on biota, including disintegration of the current communities and reconstruction of new assemblages of species can be expected in the future. Based on a literature review and an expert questionnaire, proposals by Finland's National Strategy for Adaptation to Climate Change are evaluated. Most suggested measures are beneficial for biodiversity, but knowledge on their effectiveness regarding biodiversity benefits is still insufficient. Knowledge gaps concerning impact and adaptation research are also identified in the report.

Tässä raportissa selvitetään mahdollisia ilmastonmuutokseen sopeutumisen toimia luonnon monimuotoisuuden suojelemiseksi Suomessa. Viime aikainen ilmastonmuutos on jo aiheuttanut lukuisia vaikutuksia luontoon. Suomessa havaitut esimerkit käsittävät muuttolintujen kevätmuuton ja pesinnän aikaistumista, uusien lajien levittäytymistä, perhosten levinneisyysrajojen siirtymistä pohjoiseen ja yöperhosten vuosittaisten sukupolvien määrän kasvua. Tulevaisuudessa voidaan odottaa yhä lisääntyviä vaikutuksia eliöstöön, mukaan lukien nykyisten eliöyhteisöjen hajoamista ja uusien yhteisöjen muodostumista. Ilmastonmuutoksen Kansallisessa Sopeutumisstrategiassa esitettyjä toimia arvioidaan kirjallisuusselvityksen ja asiantuntijoille suunnatun kyselytutkimuksen pohjalta. Useimmat sopeutumisstrategiassa esitetyt toimenpiteet ovat luonnon monimuotoisuuden suojelun kannalta hyödyllisiä, mutta ymmärrys niiden tehokkuudesta on yhä puutteellista. Ilmastonmuutoksen vaikutuksia ja sopeutumista koskevia tutkimustarpeita tuodaan selvityksen pohjalta esille.

This report is also available at the FINADAPT Web site:
http://www.ymparisto.fi/syke/finadapt or from www.environment.fi/publications
Finnish Environment Institute, Box 140, 00251 Helsinki, Finland, tel: +358 9 40 300

FINADAPT (Assessing the adaptive capacity of the Finnish environment and society under a changing climate) is a consortium co-ordinated at the Finnish Environment Institute (SYKE). It is part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment.

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Research Programme