INTEGRATED ASSESSMENT MODELLING OF GLOBAL CHANGE IMPACTS AND ADAPTATION (FINESSI)

PROGRESS REPORT: APRIL 2004

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Table of Contents

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1. Background and objectives

The problem of global change (e.g. climate change, air pollution, acidification) and its potential impacts (e.g. loss of biological diversity, changes in plant production/suitability, risks to water resources and water quality) requires an integrated and multi-disciplinary research approach. Numerous model-based studies of the impacts of global change have been conducted during the past two decades, both at the Finnish Environment Institute (SYKE) in particular, and in Finland as a whole. However, these studies are based on a *pot pourri* of impact models and scenarios, dispersed across different departments and institutes.

FINESSI, a three year project funded by SYKE during 2003-2005, seeks to consolidate and to integrate some of this dispersed knowledge by developing a computer-based evaluation framework for investigating the impacts of global change on various natural and managed systems in Finland. The framework is being designed to permit the application of existing impact models and scenarios on a common platform (Figure 1). The project addresses a major objective of the Research Programme for Global Change (GTO), which is to serve as a focal point for the study of global changes, their impacts and possible response measures. The modelling framework itself will be of scientific importance in addressing the impacts of environmental change across different disciplines. The project also has the potential to offer new insights into the ability of Finnish ecosystems and society to adapt to global change. Overall, the evaluation framework could offer a useful new policy tool for examining the long-term implications of global change across a range of ecosystems and economic activities, and for integrated sets of global change scenarios.

The specific objectives of FINESSI are:

1. to develop a Web-based modelling framework for estimating the impacts of a range of global change scenarios on several natural and managed systems in Finland along with their attendant uncertainties;
2. to stimulate new research into the modelling of global change impacts on species distributions using the abundant empirical information held at SYKE;
3. to use hydrological, water quality, forest management and possibly other models to investigate impacts and possible adaptation measures under a changing environment; and
4. to offer a tool for the dissemination of research results and a pedagogical device for displaying indicators of current and future environmental change in Finland and estimated impacts and adaptations in selected impact areas.

[1] Research Programme for Global Change (GTO)
[2] Research Programme for Biodiversity (LTO)
[3] Hydrological Services Division (HYD)

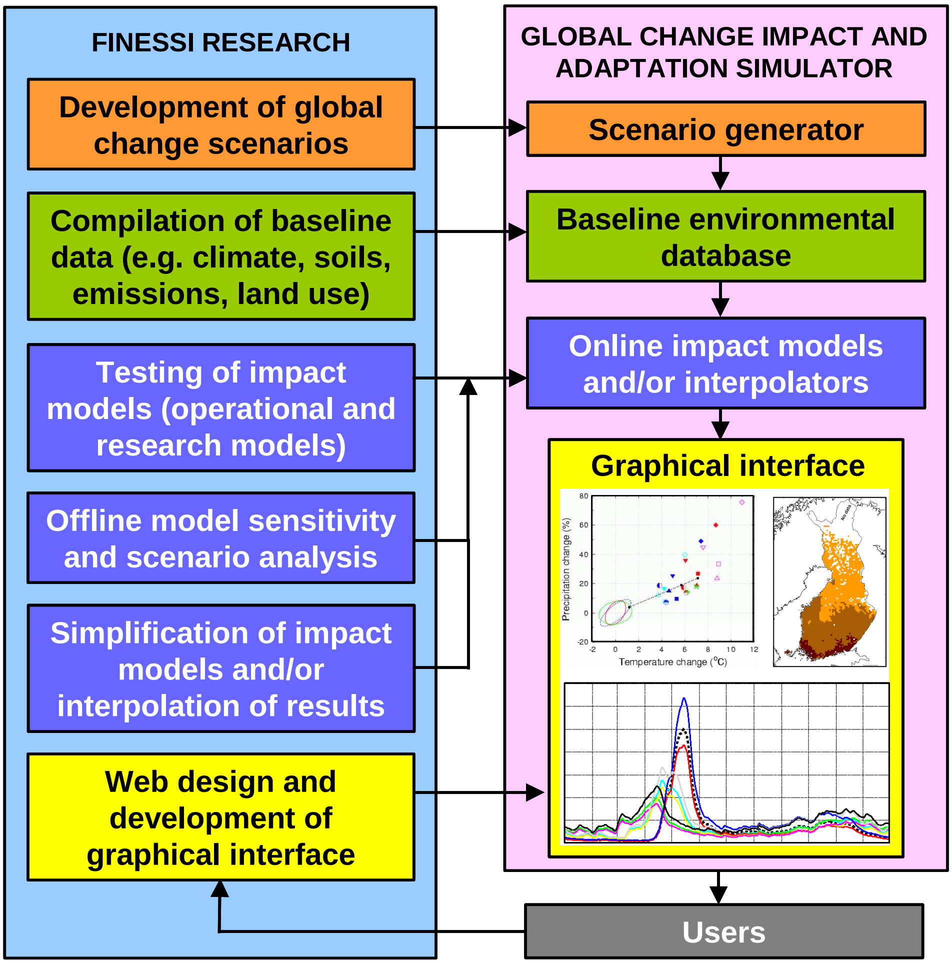


Figure 1 The FINESSI project: research tasks are shown on the left; evaluation framework on the right

This document is a brief progress report summarising the work conducted in FINESSI and presenting some preliminary results. Some of this information is included in a one-page document (finessi_progress_0404.doc) submitted to the SYKE Advisory Group (Johotryhmä).

To date (April 2004), the project has focused on the selection of impact models and their testing under a range of scenarios of future climate (taken from the FINSKEN project). Individual projects are summarised in the following sections. Section 2 describes work by Varpu Mitikka (LTO/GTO), who is developing models relating land use and climate to biological indicators of environmental change (butterflies) in Finland. In connection with this work, Niko Leikola (LTO) is converting species distributional information from atlas data into digital form for use in biogeographical modelling. In section 3, work by Stefan Fronzek (GTO) to develop models of key habitats for biodiversity in relation to climate is described. Section 4 describes research by Merja Suomalainen (HYD) to test methods of emulating the behaviour of SYKE's operational national hydrological model in order to offer an online tool for estimating runoff, discharge and snow cover under different scenarios of future climate. Finally, section 5 outlines plans for the remaining period of FINESSI through to December 2005.

2. Modelling and mapping biological indicators of climate change

Butterflies were selected in this study because their historical distribution is well documented, and because they are a sensitive indicator of the observed and potential effects of climate change on biodiversity. In the current study, Varpu Mitikka has collated the detailed distribution history and spatial occurrence data for the study species, the map butterfly (*Araschnia levana* – see Figure 2) for a modelling study of the impact of climate change on insect distributions.

Figure 2 The map butterfly (*Araschnia levana*) has two distinctive generations with conpicuously differing appearance. The first generation (*A. levana*) shown in the picture is orange with black and white markings. The second generation (*A. levana f. prorsa*), developing only in warm summers in Finland, is black with white markings. Photograph by Juha Sormunen.

The map butterfly has a palearctic distribution from the Far East throughout Asia to Europe. In recent years the species has expanded west- and northwards at the boundaries of its range, for example in Denmark, southern Sweden and Finland. In Finland it has been expanding since 1983 (Figure 3). The first observation was made in 1973 and no further sightings were recorded until 1983 when a stable population was established in Ilomantsi. During the first years the populations in eastern Finland were fairly local but later on a trend of westward and northward dispersal can be detected. The first observation in southern Finland was made in 1992. The warm summer of 1999 brought a lot of migrants from Estonia to the southern coast of Finland and ever since then the expansion has accelerated in southern Finland as well.

The expansion of the map butterfly is most likely due to warming summer temperatures, making it an appropriate study species for modelling the potential influence of climate change. The larvae feed on common nettle (*Urtica dioica*) which is widespread in Finland and thus not a restriction on the distribution of the butterfly. However, on the basis of published literature and observations, the butterfly is known to have some habitat preferences. These are introduced into the modelling approach to examine the effect of habitat availability on distribution.

The objective of the modelling study is to simulate the distribution of the map butterfly in Finland using information on local habitat and climatic conditions as predictors. Work has focused on identifying the factors most influential in explaining its distribution, and the ultimate goal is to predict the future distribution range. The biology of map butterfly will be extensively studied in field experiments to provide reliable biological data for the modelling. An in depth study of one species is likely to be a useful exercise for modelling the potential effects of climate change and habitat availability on the distribution of other butterfly species.

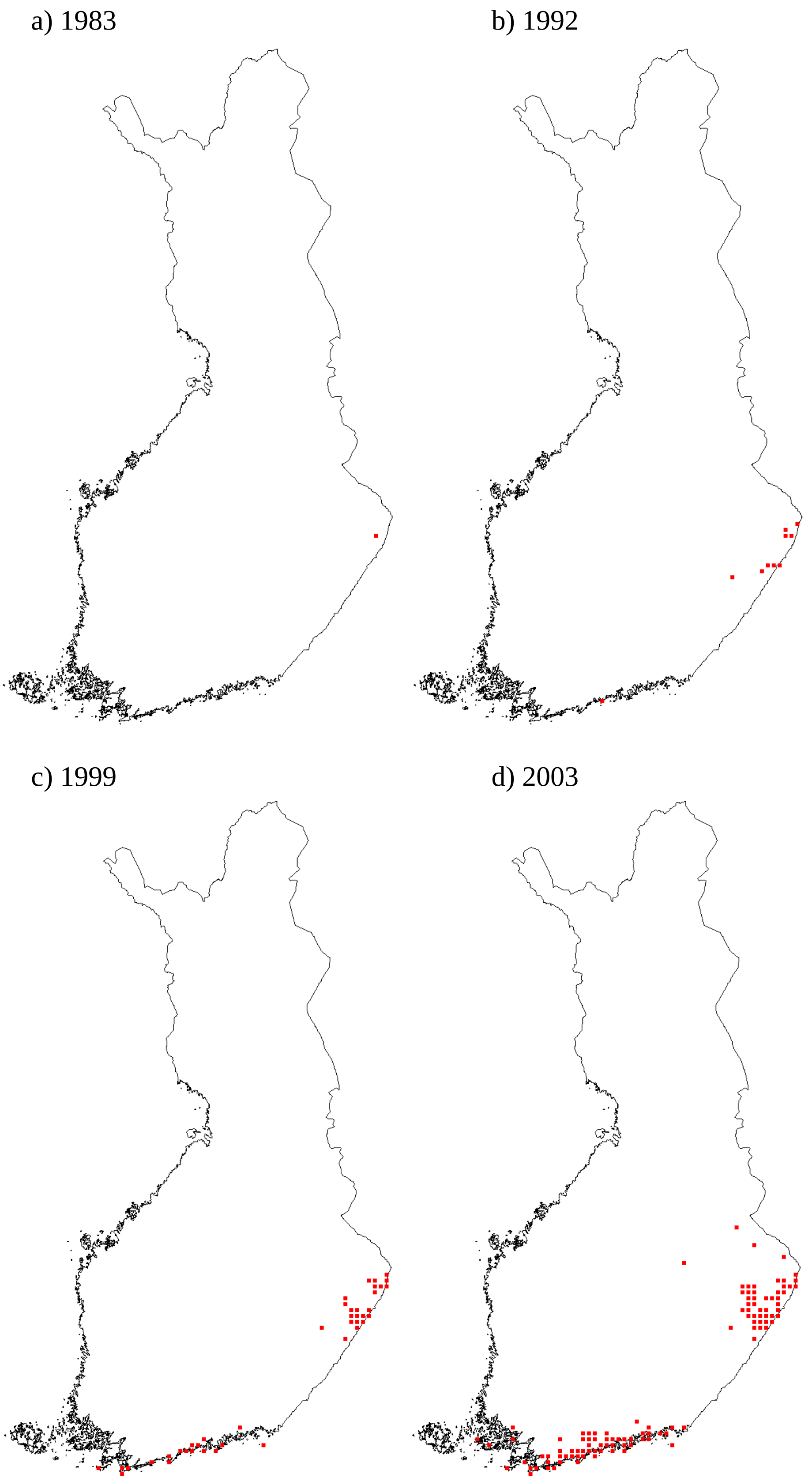


Figure 3 Distribution of the map butterfly (*A. levana*) during four years from the first recorded population a) 1983 to the present situation d) 2003. Red dots represent 10 * 10 km squares in which the species was recorded. Records are shown cumulatively from previous years.

A large part of the distribution data of *A. levana* has been collated from the databases of the Lepidopterological Society of Finland and the National Butterfly Recording Scheme (NAFI), both consisting of records from voluntary amateur and professional lepidopterists. In addition, attention has also been directed to achieving finer spatial scale records in the distribution area of eastern Finland, which was used in the first phase of modelling for this study. This was done by personally contacting the recorders for more information. The grounds for selecting the eastern distribution area for modelling included the fact that the population was first established there and practical considerations concerning the manageable size of the area and the small number of recorders. This facilitated the collation of additional data in a rather short time. Moreover, suitable habitats are more readily distinguishable from the surroundings (woodland and mire areas) in the eastern study area compared to southern Finland, which has significantly more agriculture and urban areas. Habitats at the boundary between forest and agricultural land or other open areas seem to be preferred by the map butterfly. Niko Leikola in LTO has compiled the digital spatial land cover and habitat data for the study, using GIS techniques. The distribution in southern Finland will be modelled in the future to compare the different habitat availability with the eastern study area.

The collated distribution and habitat data have already been used in preliminary modelling using MIGRATE, a grid based modelling framework developed by Dr. Yvonne Collingham at the University of Durham, UK. After summer fieldwork, the modelling will be continued using species-specific biological variables. In addition, a corresponding model framework developed at the University of Helsinki may also be used. Climatic variables obtained from the Finnish Meteorological Institute will be used in additive modelling approaches.

The work is being supervised by Risto Heikkinen and Timothy Carter at SYKE and Ilkka Hanski at the University of Helsinki.

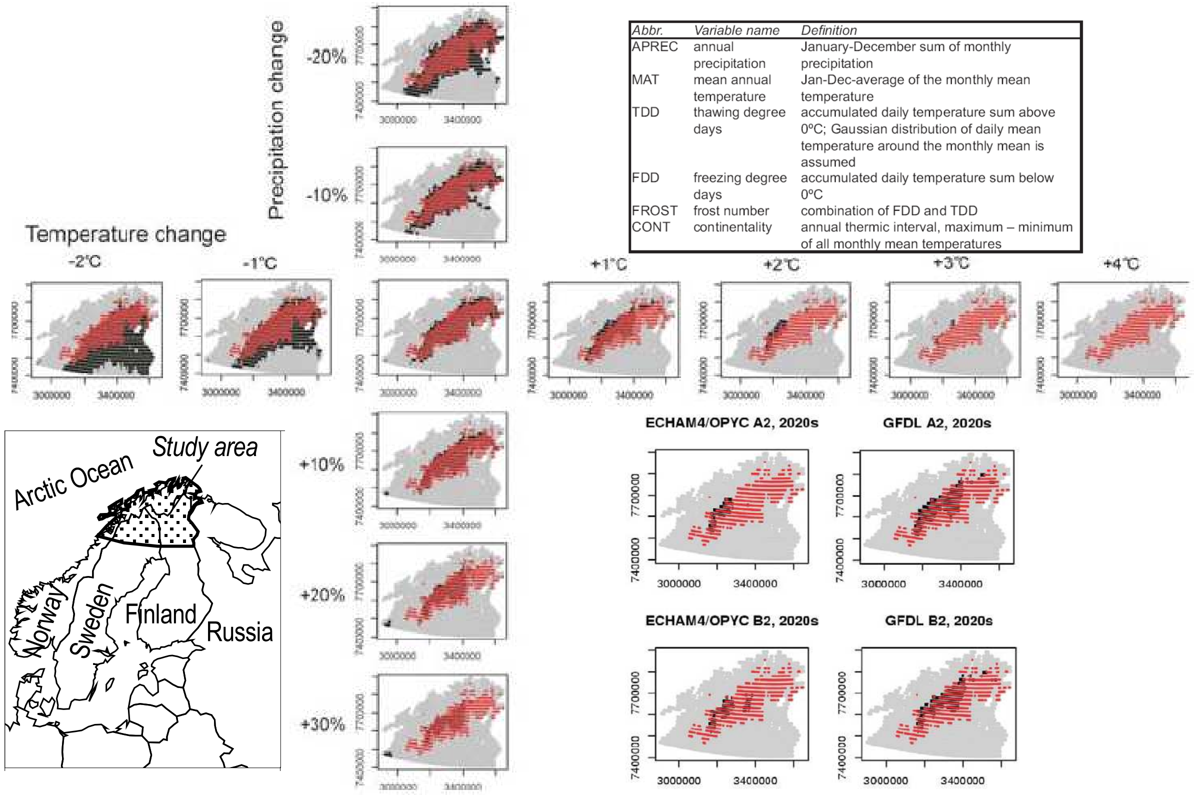
3. Distribution of palsa mires in northern Europe

Palsas, small mounds with a permanently frozen peat and mineral soil core, are characteristic geomorphological features of subarctic mire landscapes (Figure 4). They are known to be biologically heterogeneous environments offering habitats that sustain a rich bird species diversity. The marginal locations of palsa mires make them sensitive to climatic fluctuations. The European distribution of palsas includes areas of the Kola Peninsula in Russia, Norway, Finland, Sweden and Iceland. The distribution in northern Fennoscandia is shown in Figure 5.

Figure 4 Palsa mire in the Paistunturit area, Utsjoki, northern Finland, August 1999. Photograph by Maria Rönkkö.

Stefan Fronzek has studied the current distribution of palsa mires in relation to climate in co-operation with Miska Luoto, Timothy Carter and Risto Heikkinen. A strong link to climate variables was found, showing the potential risk of thawing in a warming climate (Luoto *et al*. 2004). The distribution of palsas in Fennoscandinavia has been mapped onto a regular grid with a cell size of 10'x10' using aerial photography and previously published maps. A baseline climate at the same spatial resolution with monthly mean values for temperature and precipitation for 1961-1990 has been used to derive explanatory variables (Figure 5). The climatological variables were related to the palsa presence/absence data to calibrate a multiple logistic regression model. This palsa distribution model was studied with respect to its sensitivity to changes in temperature (-2°C to +6°C changes applied to all months of the year) and precipitation (-20% to +30% changes applied to the annual precipitation total). The model was also applied to climate change scenarios derived from seven atmosphere-ocean general circulation models (AOGCMs) for the 2020s, 2050s and 2080s, each for the Intergovernmental Panel on Climate Change SRES emissions scenarios A2 and B2. Results for the 2020s from four of these scenarios are shown in Figure 5.

A critical climate change was reached with increased temperatures of more than 3°C, for which our model predicted the total disappearance of palsas in the study area. However, the **reduction in areas suitable for palsas is already considerable with smaller temperature changes: the number of palsa-carrying grid cells was reduced by a half with 1°C and to less than one-fifth with 2°C warming (Figure 5). Increases in precipitation also led to a considerable loss of palsas. Temperature and precipitation changes were studied separately in the sensitivity analysis; a combination of both changes might still intensify the impact.



Abbr.	*Variable name*	*Definition*
APREC	annual precipitation	January-December sum of monthly precipitation
MAT	mean annual temperature	Jan-Dec-average of the monthly mean temperature
TDD	thawing degree days	accumulated daily temperature sum above 0ºC; Gaussian distribution of daily mean temperature around the monthly mean is assumed
FDD	freezing degree days	accumulated daily temperature sum below 0ºC
FROST	frost number	combination of FDD and TDD
CONT	continentality	annual thermic interval, maximum – minimum of all monthly mean temperatures

Figure 5 Modelled effects of climate change on palsa distribution in northern Fennoscandia. The map, bottom left, shows the study area and palsa distribution in Fennoscandia. The table, top right, shows the climatological explanatory variables used in the model. Coloured maps show predictions of palsa distribution under changed climate (relative to the baseline climate, 1961-1990). Sensitivity to systematic changes in temperature (at 1˚C intervals between –2˚C and +4˚C) is shown in maps organised from left to right, and precipitation (at 10% intervals between –20% and +30%) in maps organised from top to bottom. Predictions for the 2020s according to four GCM-based climate scenarios, ECHAM4/OPYC and GFDL both for SRES A2 and B2 emission scenarios are also shown in maps at the bottom right. Predictions (black grid cells) are superimposed on observations (red).

GCM-based scenarios do combine both temperature and precipitation changes, and showed reductions to less than half of the current palsa areas by as early as the 2020s for all seven GCMs in both the A2 and B2 SRES emission scenarios (Figure 5). Two scenarios predicted the total disappearance of palsas by the 2050s; for the 2080s, only one scenario showed areas with palsas. Work is proceeding to test a number of alternative statistical models in order to quantify some of the uncertainties in model estimates (Fronzek *et al*., 2004).

4. Hydrological modelling

The main aim of this pilot study (Sep 2003 – Jun 2004) is to develop a method of generating scenario-based estimates of hydrological impacts of climate change for an agreed set of key variables. The work has been carried out by Merja Suomalinen and supervised by Bertel Vehviläinen and Timothy Carter.

The first completed step was to modify the hydrological model to simulate arbitrary climate change scenarios. The model runs were conducted for scenarios of changes relative to the reference climate (1961-1990) in mean annual temperature (+2ºC and +4ºC) and mean annual precipitation (–10% and +20%), independently and in combination. The 8 combinations are summarised in Table 1. It was noticed that a single run of the hydrological model takes more than 30 minutes, which means that a subsequent interpolation method is necessary for any online applications.

Table 1 Scenario combinations of temperature and precipitation change used in the sensitivity analysis

Changes	T (1961-1990)	T + 2ºC	T + 4ºC
P (1961-1990)	Scen0	Scen1	Scen2
P – 10%	Scen3	Scen4	Scen5
P + 20%	Scen6	Scen7	Scen8

The work for generating an interpolation method has started and a simple interpolation between national scale maps is already available. The method can also be applied for evaluating the linearity of the measures. The examination of effectiveness of summarizing and presenting different measures as maps, graphs, diagrams and tables is proceeding and can be finished after identifying the key hydrological measures (a list of possible/improvable measures is below). After that a sensitivity analysis can be started. As in the beginning only mean annual changes were taken into account, we now concentrate on seasonal changes and on the variability. Climate model estimates of future climate suggest that changes in temperature and precipitation can be higher than we have so far analysed. Therefore, we plan to adjust the range of sensitivity experiments, testing the robustness of the model with, for example, changes in temperature of up to + 8ºC.

Examples of the information produced so far are listed below, along with sample figures:

- National scale maps (absolute value / absolute change / percentage change)

  - average total precipitation (mm/year)
  - average total evaporation (mm/year)
  - average total lake evaporation (mm/year)
  - average maximum water equivalent of snow (mm) – see Figure 6
  - average duration of snow cover (days with > 0.95 snow cover)
  - dry summers (days; runoff < 0.5 mm/day in June-August)
  - floods (days; runoff > 8 mm/day)
  - average maximum soil moisture deficit (mm)

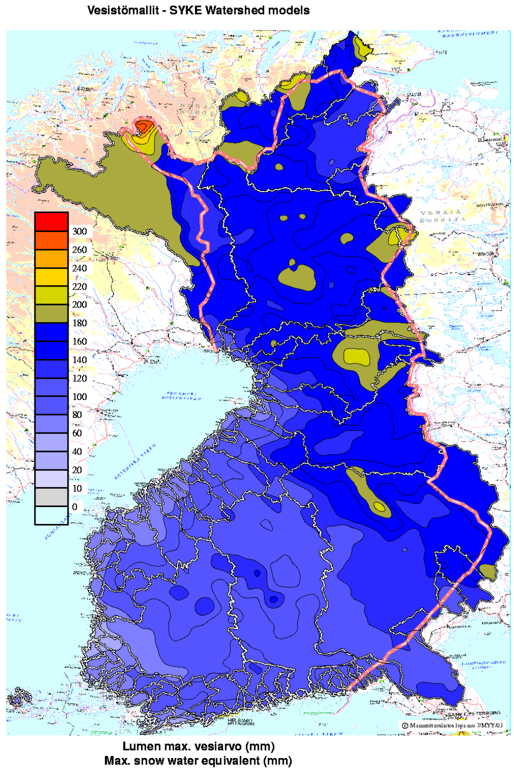


Figure 6 Maximum snow water equivalent under present-day (1961-1990) climate

- Site-specific information (for some sub-basins)

  - average total runoff (mm/year) – see Figure 7
  - discharge (m^3/s) – see Figure 8
  - water level
  - average seasonal behaviour of soil moisture deficit (mm)
  - average seasonal behaviour of runoff (mm)
  - floods (changes in maximum discharge) – see Figure 9

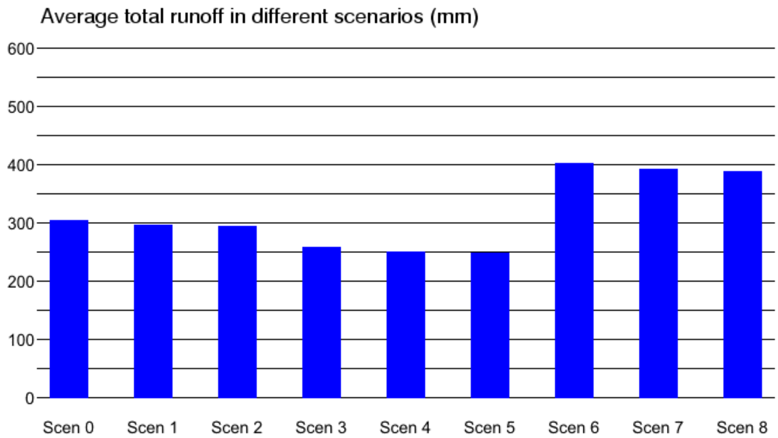


Figure 7 Average total runoff in a catchment in northern Finland under different combinations of temperature and/or precipitation change relative to Scen 0 (baseline, 1961-1990). For explanation of scenarios, see Table 1.

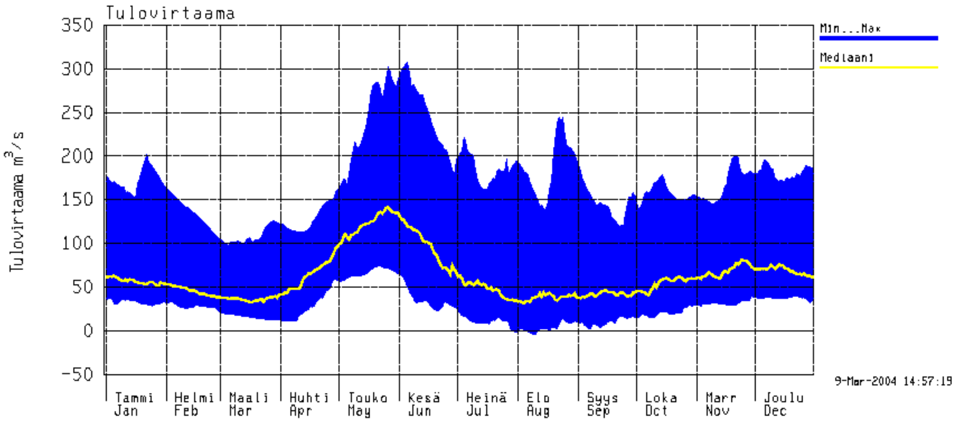


Figure 8 Average (median - yellow line) and range (blue shading) of daily inflow to lake Näsijärvi under the baseline climate (1961-1990).

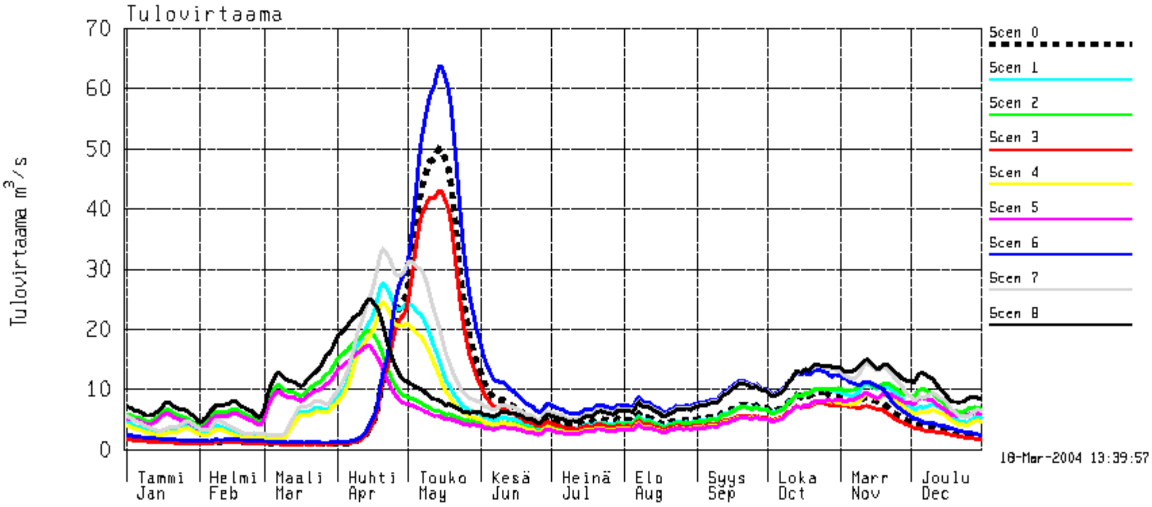


Figure 9 Median inflow to lake Oijärvi during 1961-1990 (black dotted line) and under different scenario combinations of temperature and/or precipitation change (different coloured lines). For explanation of scenarios, see Table 1.

5. Future plans

The main tasks during the remaining 20 months of FINESSI are as follows:

1. To develop a computer-based Web interface for running impact models under a range of user-specified environmental change scenarios.
2. To complete the testing and analysis of the species, habitat and hydrological models described above, and implement these on the Web interface.
3. To undertake model testing and scenario analysis of additional impact models for representing catchment-scale and regional-scale water quality and forest management, and to implement these models on the Web-based interface.
4. To report the results of these sub-projects in the scientific literature.

Task 1 will require the recruitment of a Web designer and programmer. We anticipate a requirement of at least 6 person-months for this task. The new appointee will work closely with Stefan Fronzek (GTO), who maintains the FINSKEN Scenario Gateway. Fronzek has already set up a web server that will be used for the integrated impact assessment tool (**http://www.finessi.info**).

Task 2 will be carried out using additional resources from FINESSI (hydrology and habitat modelling) as well as resources from the LTO strategic project: "Effects of climate change on biodiversity in Finland" and the FP6 ALARM project: "Assessing LArge-scale environmental Risks with tested Methods" (species modelling). A one-month study visit to SYKE by Dr Miguel Arauja, an expert on biogeographical modelling of species distributions in Europe from the University of Evora, Portugal, has been arranged for May 2004.

The study of water quality modelling in Task 3 will be carried out by researchers in GTO and the Research Programme for Integrated River Basin Management (VTO) led by Maria Holmberg (GTO). It will be mainly funded by FINESSI but will also draw on resources from the FP6 Euro-Limpacs project: "Integrated project to evaluate impacts of global change on European freshwater ecosystems". Work on forest management modelling will be conducted by Jari Liski (GTO) using resources from FINESSI, core SYKE funds and in co-operation with researchers in the FINADAPT Consortium.

Task 4 will be the joint responsibility of all researchers in FINESSI. Some papers are already in preparation (see reference list) and others will be prepared when results are available.

The budget and timetable for the three years are shown in Table 2 and Table 3.

Table 2 Budget (values in thousand Euro)

Item	2003	2004	2005	Total
Personnel (GTO)	19.2	33.5	49.7	102.4
Personnel (LTO)	10.0	0.0	0.0	10.0
Personnel (HYD)	3.0	9.3	6.4	18.7
Personnel (VTO)	0.0	5.4	11.0	16.4
Travel	0.2	0.5	0.5	1.2
Consumables	0.0	2.5	0.0	2.5
Subtotal (Strategic)	**32.4**	**51.2**	**67.6**	**151.2**
SYKE salaries	**12.0**	**14.9**	**20.3**	**47.3**
TOTAL	**44.4**	**66.1**	**88.0**	**198.5**

Table 3 Timetable and person-years of work (pyw)

	pyw	Year			
Main tasks (FINESSI-funded)		**2002**	**2003**	**2004**	**2005**
Compilation of species distribution, land use and climate data and modelling of indicator species*	0.18				
Digitising of atlas species distribution data*	0.08				
Habitat modelling and scenario analysis	0.92				
Hydrological modelling and scenario analysis	0.42				
Development of online Web-based modelling and scenario interface	0.83				
Water quality modelling and scenario analysis	0.50				
Forest management modelling and scenario analysis	0.42				
Reporting	0.50				
TOTAL	**3.85**				

* This work is continuing in the LTO-led strategic project: Effects of climate change on biodiversity in Finland

References

Luoto, M., Fronzek, S. and Zuidhoff, 2004. Spatial modelling of palsa mires in relation to climate in northern Europe. *Earth Surface Processes and Landforms* (accepted).

Fronzek, S. Luoto, M. and Carter, T.R. 2004. Impacts of climate change on the distribution of palsas in the discontiniuous permafrost zone of Northern Europe. Unpublished manuscript.

Posters and Presentations

Fronzek, S., Luoto, M. and Carter, T.R. 2003. Impacts of climate change on the distribution of palsas in the discontinuous permafrost zone of Northern Europe. Poster presented at the AVEC International Summer School: Integrated Assessment of Vulnerable Ecosystems under Global Change, Peyresq, France, 14-27 September 2003 and at the Wengen-2003 Workshop: Regional Climatic Change in Europe: Processes and Impacts, 29 September – 3 October 2003, Wengen, Switzerland.

Fronzek, S. 2003. Impacts of climate change on the distribution of palsas in the discontinuous permafrost zone of Northern Europe. Presentation at the 2nd SYKE Research Symposium: "Methodological Approaches in Environmental, Nature Conservation and Social Studies", November 20-21, 2003, Lammi Biological Station.