Forest Condition Monitoring in Finland – National report

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Valkea-Kotinen – long-term results from a Finnish ICP Integrated Monitoring (IM) catchment

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Summary

Intensive and multidisciplinary ecosystem monitoring has been carried out in the Valkea-Kotinen Integrated Monitoring (UNECE IM) catchment since 1987, which is located in the Kotinen Nature Reserve area, Evo, Hämeenlinna. IM-progamme focuses on monitoring the long-term effects of air pollution and climate change to ecosystems. In this report we present the long-term effects of air pollutants and climate variation on forest condition, water chemistry and aquatic biota, and soil and ground water at Valkea-Kotinen Integrated Monitoring site. Furthermore, future scenarios for climate change and air pollutants, and their ecosystem effects in the Valkea-Kotinen area, are also assessed.

Introduction

The International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM), like the ICP Forests programme, is part of the Effects Monitoring Strategy under the Convention on Long-range Transboundary Air Pollution (LRTAP). In Finland, the ICP IM programme was started in 1987 at four catchments: Valkea-Kotinen (Kotinen Nature Reserve area, southern Finland), Hietajärvi (Patvinsuo National Park, eastern Finland), Pesosjärvi (Oulanka National Park, northeastern Finland) and Vuoskojärvi (Kevo Strict Nature Reserve area, Lapland). Since 1999, the terrestrial ICP IM programme carried out on the intensive permanent monitoring plots in Hietajärvi and Valkea-Kotinen catchments has been integrated into the ICP Forests/EU Forest Focus Intensive Monitoring (Level II) programme, and monitoring activities at the two northernmost sites has been reduced. Since 2000, the entire ICP IM programme has been carried out in the Valkea-

Kotinen and Hietajärvi areas, and in 2006, the intensive and multidisciplinary ecosystem research and monitoring carried out on the Pallas area (Pallas-Yllästunturi National Park, Lapland) was integrated into the ICP IM programme. The IM areas Valkea-Kotinen and Pallas belong also to the Finnish Long-Term Socio-Ecological Research Network (FinLTSER).

In over 20 years of intensive research and monitoring in collaboration with universities and research institutes, the Valkea-Kotinen Integrated Monitoring site has gained invaluable scientific information on different ecosystems components. In this report we present some of our results on the long-term effects of air pollutants and climate variation on forest condition, water chemistry and aquatic biota, and soil and ground water at Valkea-Kotinen Integrated Monitoring site (see also Vuorenmaa et al. 2011). Furthermore, future scenarios for climate change and air pollutants, and their ecosystem effects in the Valkea-Kotinen area, are also discussed.

The ICP IM Programme

Integrated monitoring of ecosystems means the physical, chemical and biological measurements over time of different ecosystem compartments simultaneously at the same location. In practice, monitoring is divided into a number of compartmental subprogrammes that are linked by the use of the same parameters (cross-media flux approach) and/or same or close stations (cause-effect approach).

The main objectives of the ICP IM are:

- To monitor the biological, chemical and physical state of ecosystems (catchments/plots) over time in order to provide an explanation of changes in terms of causative environmental factors, including natural changes, air pollution and climate change, with the aim to provide a scientific basis for emission control.
- To develop and validate models for the simulation of ecosystem responses.
- To carry out biomonitoring to detect natural changes, in particular to assess effects of air pollutants and climate change.

The ICP IM sites (mostly forested catchments) are located in undisturbed areas, such as nature reserve areas or national parks. The ICP IM network presently covers 43 sites in 15 countries. The international Programme Centre is located at the Finnish Environment Institute in Helsinki. A manual detailing the protocols for monitoring each of the necessary physical, chemical and biological parameters are applied throughout the programme.

The Finnish ICP IM programme is coordinated by an expert group consisting of scientists from the key participating governmental institutes (Finnish Environment Institute, Finnish Game and Fisheries Research Institute, Finnish Meteorological Institute, Finnish Forest Research Institute, Geological Survey of Finland, Centres for Economic Development, Transport and the Environment in Häme, Pohjois-Karjala and Lapland) and Universities of Helsinki and Eastern Finland. The many others key Finnish research institutes, regional authorities and universities involved in environmental research have participated in the ICP IM Programme and have made considerable contributions.

The Valkea-Kotinen IM catchment

The Valkea-Kotinen catchment is located in the Kotinen Nature Reserve area in southern Finland (61° 14’ N, 25° 04’ E). It can be considered remote and is unaffected by local sources of air pollution. The study catchment is the smallest of the Finnish sites belonging to the ICP IM network. The catchment covers an area of 30 ha and has a range in relief of 25 m (Fig. 1). Map of the Valkea-Kotinen Integrated Monitoring area.). Upland forests cover about 62% and peatlands 25% of the total area. The

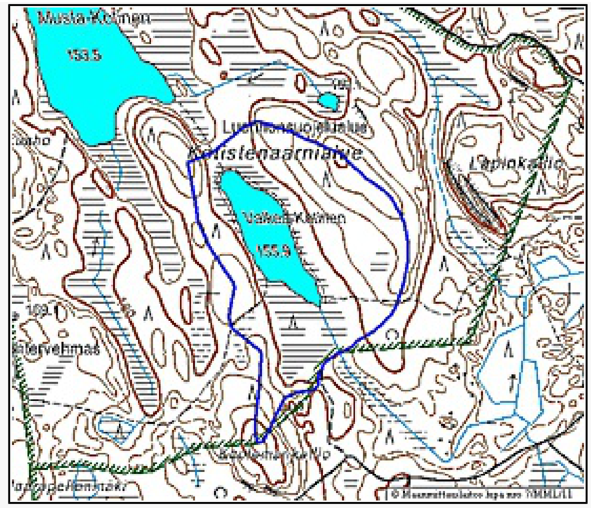

Figure 1. Map of the Valkea-Kotinen Integrated Monitoring area.

forests are mainly old virgin forests with several canopy layers. The area has a lot of dead standing trees and fallen decaying logs. The dominant trees are 100–170 years old Norway spruce (*Picea abies*). Old birch (*Betula spp.*), aspen (*Populus tremula*) and Scots pine (*Pinus sylvestris*) occur among the spruce. The oldest emergent trees are Scots pine over 350 years old. Traces of forest fires can be seen on old tree trunks. Forest fires occurred every 25–30 years in the late 18th and 19th centuries. The fires usually affected only a small part of the catchment.

The study catchment contains one headwater lake, Valkea-Kotinen. It is a small (3,6 ha), humic (mean TOC and water colour 12,9 mg l^{-1} and 110 mg Pt l^{-1}, respectively), acidic (mean pH-value 5,4 and alkalinity 0,021 mmol l^{-1}) and mesotrophic (mean total P 17 µg l^{-1}) lake. Lake Valkea-Kotinen is quite shallow (max. depth 6,5 m and mean depth 3,5 m) and usually frozen over between November and April. Runoff from the catchment is via a small outlet stream that flows southwards from Lake Valkea-Kotinen.

Most of the terrestrial monitoring has been carried out at eight permanent plots, in which two of plots (2 and 3) the monitoring of throughfall, stemflow, soil water and litterfall has been carried out.

The bedrock at the Valkea-Kotinen catchment is part of an old peneplane. The dominant bedrock type is 1900-million-year-old mica gneiss which had originally been clay and sand sediments. These sediments were then thoroughly metamorphosed so that their original structures are no longer apparent. The area is supra-aquatic, i.e. above the highest shoreline of the former stages of the Baltic. The highest coastline of the postglacial Yoldia Sea in the area is about 139 m above sea level. The area is covered with a 1-3-m-thick silty till. Histosols (peat) acount about one fifth of the the land area of the catchment and are located mainly around the lake. Most of the the nonorganic soil may be classified as dystric cambisols with transition to podzols, particularly on the upper slopes.

The annual mean (1971–2000) temperature is +3,9 °C, and precipitation averaged 631 mm per year. During the period 1989–2009, the annual mean runoff was 200 mm per year (Vuorenmaa and Horppila 2011).

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Deposition of acidity and heavy metals

Bulk deposition in open

The monitoring of air quality and deposition started in 1987. Valkea-Kotinen is situated in a background area, without nearby sources of air pollution. Most of the deposition has been transported long distances and from beyond Finland. The air masses reaching Valkea-Kotinen are mostly from the west, and different directions between the north and south-west. Climatological data from nearby meteorological stations have also been used in modelling exercises and in evaluating IM data.

The monitoring results clearly confirm the success of international emission reduction measures. The acidity and associated concentrations of sulphate (SO_4) in precipitation have strongly declined over the period of monitoring

(Fig. 2) (Ruoho-Airola et al. 2004, 2011). The acidifying sulphate deposition in the area has decreased by around 70% from the levels of late 1980s. Ammonium (NH_4) concentrations in precipitation have declined similarly as those of sulphate. Concentrations of nitrate (NO_3), however, have declined much more slowly. Decreasing trend for concentrations of ammonium, nitrate and hydrogen ion (H^+) was leveled off in the mid-1990s, and changed little in recent years.

A decrease was also detected in deposition of harmful substances. Heavy metal deposition has been monitored at Valkea-Kotinen since 1990, and forms one of the longest time series in Finland. The deposition load of trace elements has decreased, particularly those of aluminium (Al), arsenic (As), lead (Pb) and mercury (Hg) (Kyllönen et al. 2009; Wännberg et al. 2010; Ruoho-Airola et al. 2011). Unfortunately, a favourable development cannot be seen for all heavy metals. For example, concentrations of chrome (Cr) in precipitation have increased significantly during the past 10 years (Fig. 3). The deposition of persistent organic pollutants (PCDD/F, dioxin-like PCB compounds) has decreased during the past ten years of monitoring (Ruoho-Airola et al. 2011, Korhonen et al. 2012).

Canopy interactions and throughfall

Because of the reactivity and large surface area of the canopy, forests are particularly effective receptors of airborne material arriving in both wet and dry forms. Thus, precipitation is intercepted and modified (substances withdrawn or added) by the canopy, and the loads of substances reaching the forest floor, termed throughfall, differs from the bulk deposition recorded in the open (see previous section).

Concentrations of base cations, SO_4 and dissolved organic carbon (DOC) are higher in throughfall than in open area bulk deposition, while concentrations of inorganic nitrogen compounds, NO_3 and NH_4, in throughfall are less than in open area bulk deposition (Table 1, pdf). Enrichment of ions in throughfall is due to the washing-off of dry deposition intercepted by the canopy or by canopy (tissue) leaching, while depletion is due to canopy uptake, either by foliage or canopy dwelling epiphytes.

As with bulk deposition, throughfall has shown a marked decline in acidity over the monitoring period, with concentrations of sulphate declining by an average of 0.05 mg l^{-1} a^{-1} (Fig. 4), Ukonmaanaho et al. 2009). Increasing trends of base cation concentrations and ANC (Acid Neutralizing Capacity), indicating recovery from acidification, have also taken place over the monitoring period. It is interesting that increasing trend of DOC concentrations in throughfall are detected during the past 20 years, at the same time than recovery from acidification. This may be due to improved forest conditions, resulting in increased tree biomass and litterfall, and consequently, increased decomposing organic matter.

Changes in aquatic and terrestrial ecosystems

Continuous measurement of runoff and regular monitoring of physicochemical properties of surface waters in the Valkea-Kotinen catchment started in 1987. Regular biological monitoring of aquatic ecosystem started in 1990. Aquatic biota, such as algae, zooplankton, macroinvertebrates and fish are sensitive indicators of environmental change, reflecting changes in the physical and chemical conditions of the aquatic ecosystem. Valkea-Kotinen is an important national reference lake in biological and chemical studies, since there are no direct human impacts on the biota and water quality. Permanent monitoring plots for forest and soil research were established in 1988/89.

Decreased anthropogenic deposition load has resulted in positive responses both to the aquatic and terrestrial ecosystems. For example, recovery from acidification in surface waters has taken place, indicated by decreases in sulphate, and increases in alkalinity and pH (Fig. 5). There are no clear signs that aquatic biota in the Lake Valkea-Kotinen has been affected by acid deposition (Arvola et al. 2011, Rask et al. 2011, Sairanen et al. 2011). Instead, the fish populations in Lake Valkea-Kotinen have been exposed to mercury, but the accumulation of mercury in fish over the long-term has decreased (Fig. 6) .

There are also indications of a recovery in the forest ecosystem (see above). However, the chemistry of soil-water and groundwater has not changed as markedly as that of lake water.

Impacts of climate change

At the same time, the Valkea-Kotinen area has experienced change in its local climate. During the last 50 years, the air temperature in Häme has risen by some 0.3–0.4 degrees per decade. In two decades, it is estimated that temperatures in Häme will be 1–2 degrees higher than in the reference period 1971–2000 (Fig. 7, Jylhä et al. 2011). A similar trend can be seen in research results for the whole of Finland (Tietäväinen et al. 2010). Researchers also forecast a rise in annual precipitation in Häme (Fig. 8, Ylhäisi et al. 2009, Jylhä et al. 2011). In the coming decades, however, this increase is expected to be slight in comparison to natural variations in rainfall. Although the relative increase in precipitation amounts is higher in winter than in summer, summertime rainfall will continue to be heavier than in wintertime. Heavy precipitation will intensify in all seasons. The proportion of precipitation falling as snow will decrease and snow cover diminish, especially in the early and late winter months.

Conditions in the water body of Valkea-Kotinen have changed due to a rise in air temperatures, which is affecting the functioning of ecosystems in small forest lakes. A clear indicator has been the length of ice-cover period, which has shortened by approximately 1,5 days each year in the course of the last 20 years (Fig. 9). During the same period, the temperatures of the lake's surface water layers have risen and the spring overturn of water column i.e. mixing of the lake water in May has weakened (Vuorenmaa and Horppila 2011). This has caused deteriorated oxygen conditions in the bottom and middle layers of the lake, and consequently, resulted in increased release of phosphorus from the bottom sediment.

The interaction of climate change with changing deposition has resulted in increasing leaching of organic carbon from the catchment, and increasing organic carbon concentration in the lake (Fig. 10). As the water colour turns darker, this will have an impact on temperatures. Weaker light will decrease phytoplankton production and the amount of zooplankton in the lake (Fig. 11, Arvola et al. 2011). With regard to fish, the slowdown in perch growth is the clearest change (Sairanen et al. 2011). Some of the changes can also be related to the food-web interactions.

Modelling the future

The large and long-term data sets of Valkea-Kotinen have been used for modeling purposes as well. According to the modeling results international emission control programmes for long-range transported air pollutants and greenhouse gases may have a great role in determining the future environmental conditions and ecosystem services during the next 100 years in the study area. For example, concentrations of DOC in the Lake Valkea-Kotinen are anticipated to increase due to climate change and changes in sulphate deposition (Fig. 12, Futter et al. 2009, Forsius 2011). The impacts of climate change on hydrological processes of Valkea-Kotinen have been studied using MyLake model (Saloranta et al. 2009). The results with model predict (according to SRES A2 scenario) an increase in lake surface temperatures of 4,6–5,1 °C in April and 3,5–4,6 °C in May by 2100. Correspondingly, the length of ice-cover period will be shortened by 56–89 days. These changes would probably have substantial effects on chemical and biological properties of the lake.

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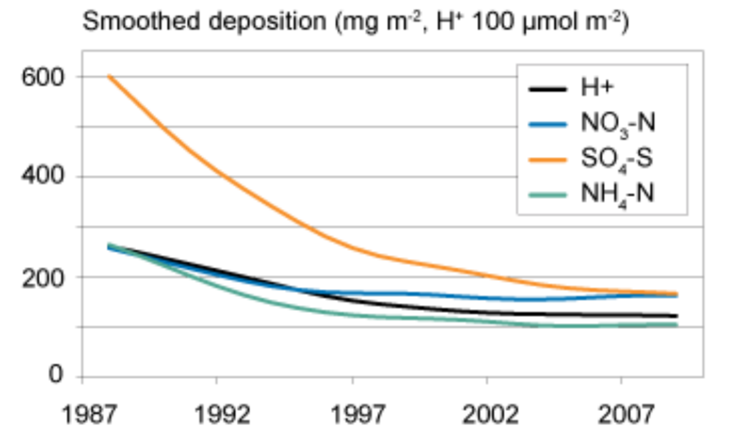
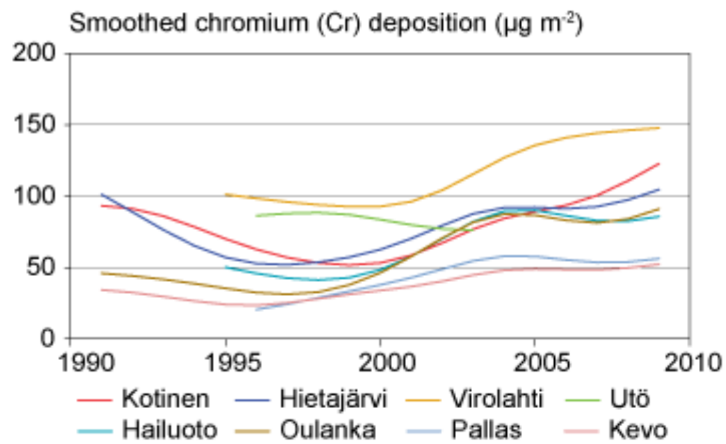
Figure 2



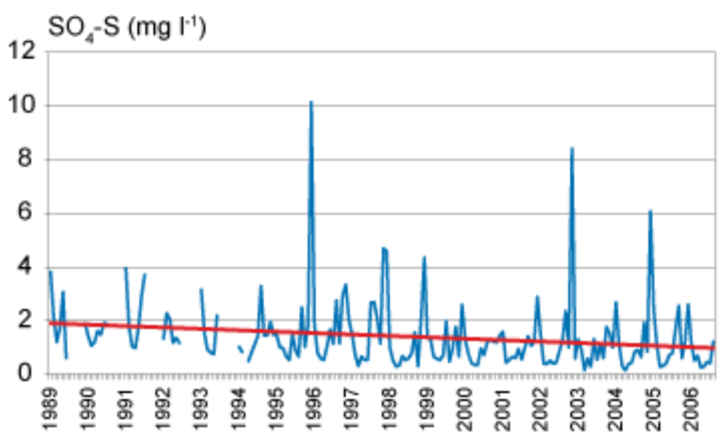
Change in the sulphate (SO_4-S), hydrogen ion (H^+), nitrate (NO_3-N) and ammonium (NH_4-N) deposition at Valkea-Kotinen Integrated Monitoring site in 1988–2009. Unit mg m^{-2} per year, except H^+ 100 µmol m^{-2} per year. Smoothed,weighted time series.

Figure 3



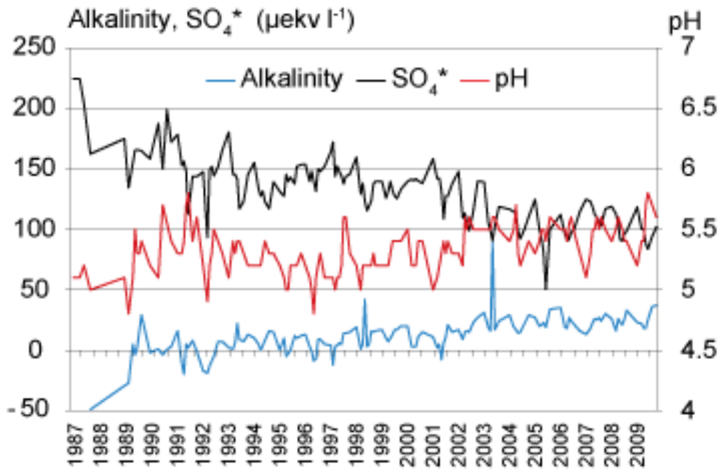
Fluctuation in the annual chromium deposition at the Finnish background stations in 1991–2009, unit µg m^{-2}, smoothed, weighted time series.

Figure 4



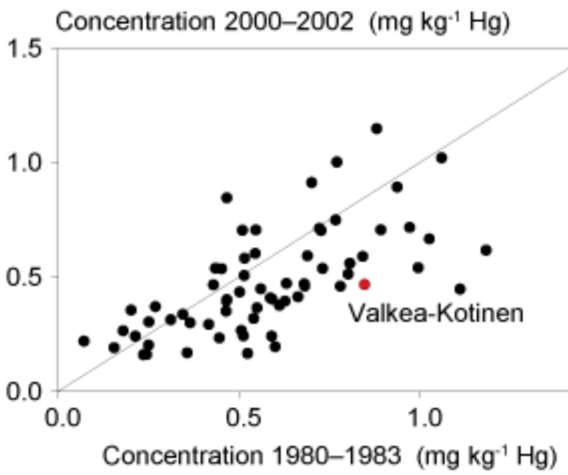
Sulphate concentrations in throughfall at Valkea-Kotinen Integrated Monitoring site during 1989–2006 (Ukonmaanaho et al. 2009).

Figure 5



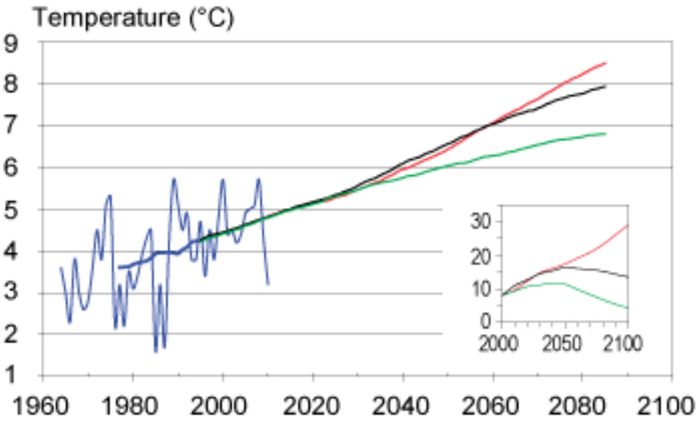
Time series for alkalinity, pH and non-marine sulphate (SO_4*) in the Lake Valkea-Kotinen in 1987–2009.

Figure 6



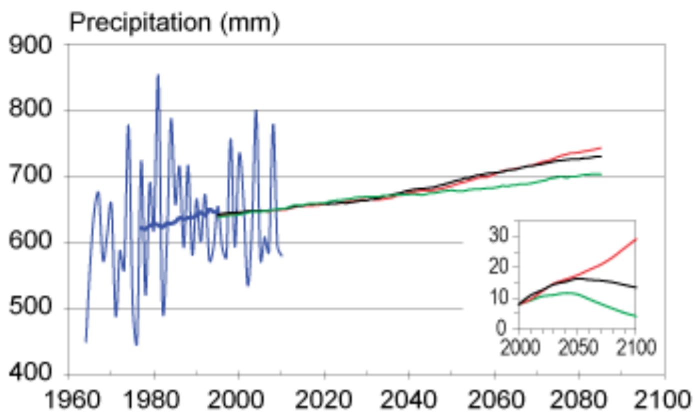
Change of pike mercury concentration in 66 Finnish lakes between 1980 and 2002 (Paloheimo 2005). Each dot represents mercury concentration in 800 g pike in a single lake. A location of dot below the crossline indicates a decrease in pike mercury concentration.Lake Valkea-Kotinen is plotted as a red dot.

Figure 7



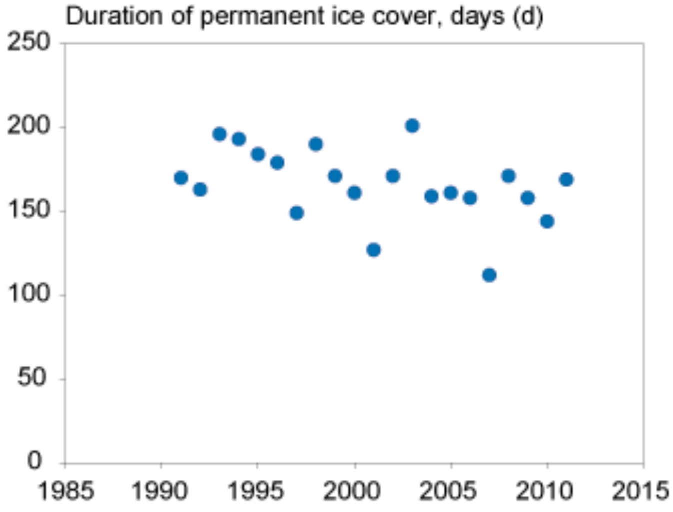
The annual mean temperature at the Lammi Biological Station. The observed values in 1964–2010 are shown by a thin blue curve, and the thick blue curve depicts 30-year running means. Projections of how these long-term averages might evolve in the future are given separately for three greenhouse gas emission scenarios: SRES A2 (red curve), A1B (black) and B1 (green). The projected changes in temperature are multimodel mean estimates based on 19 global model simulations. The corresponding CO_2 emission scenarios are given in the right corner (PgC a-1). For more information, see Jylhä et al. (2009).

Figure 8



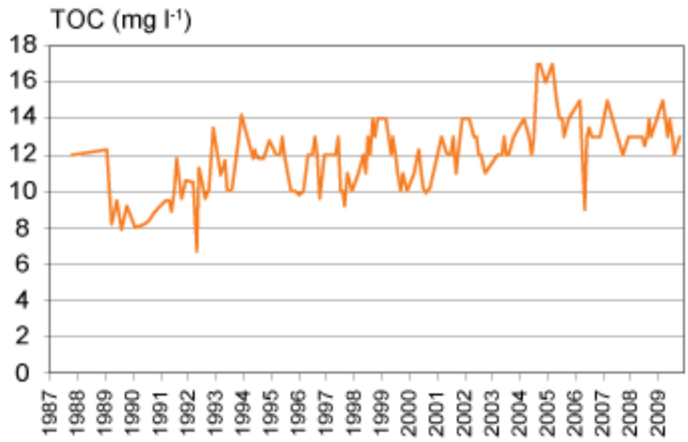
Observed time series of annual precipitation amount at the Lammi Biological Station in 1964–2010 (thin black curve), the observed 30-year average (black line) and three future projections (2010–2085) for SRES-emission scenarios B1 (green), A1B (black) and A2 (red).

Figure 9



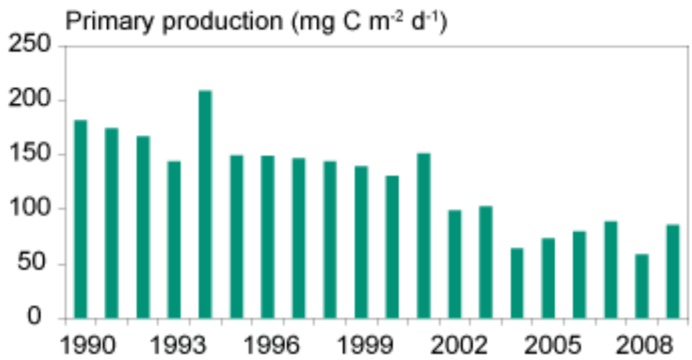
Duration of permanent ice cover (days, y-axis) on Lake Valkea-Kotinen in 1990–2011.

Figure 10



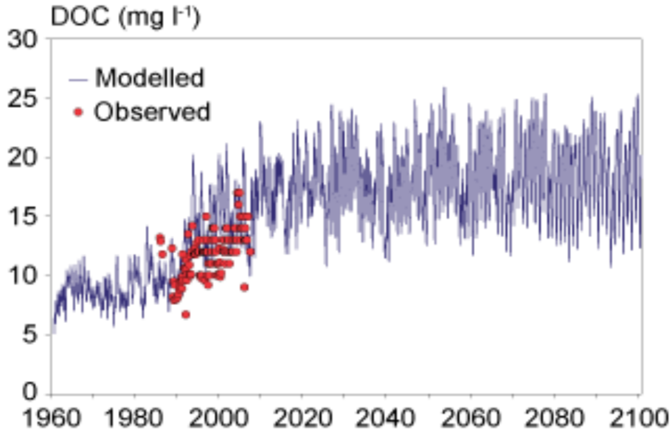
Time series for total organic carbon (TOC) concentration in the Lake Valkea-Kotinen in 1987–2009.

Figure 11



The mean phytoplankton primary production during the weeks 20–40 in 1990–2009. In the data there is a statistically significant decreasing trend (z=–4,51, p<0,01; Mann-Kendall).

Figure 12



Modelled (blue) and observed (red) daily concentrations of dissolved organic carbon (DOC) in lake Valkea-Kotinen (1 m) from 1961–2100, according to INCA-C model simulations (modified from Futter et al. 2009). Climate change is assumed to follow the SRES A2 scenario and sulphur deposition the maximum feasible reductions scenario (MFR = strong reductions in sulphur deposition).

Table 1. Average solute concentrations in bulk deposition (BD), throughfall (TF), soilwater (SW) and stemflow (SF) at Valkea-Kotinen Integrated Monitoring site during 1991–1997 (Ukonmaanaho and Starr 2002, Starr and Ukonmaanaho 2004).

	BD	TF	SW 15 cm	SW 35 cm	SF, Norway spruce*	SF, Birch*
			1991-1997		1992-1999*	
SO_4S	0.70	1.82	3.53	3.86	8.28	5.73
NH_4N	0.31	0.22	0.05	0.06	0.93	0.31
NO_3N	0.35	0.26	0.01	0.01	0.18	0.10
Ca	0.18	1.01	2.82	3.21	10.78	5.12
K	0.10	2.90	1.71	1.71	11.71	19.63
DOC	3.70	14.0	20.1	9.5	129.86	91.93
H	35.55	38.00	15.73	13.09	171.780	112.88

*unpublished data