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PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
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Background

The main aim in this WP1 Task 3.3 is to carry out a whole-lake experiment (THERMOS) to study climate change impacts on lake chemistry and biology by manipulating the lake stratification pattern (thermocline depth) of a small humic lake in Finland. The mercury work in WP5, task 3 is a part of the experimental design and therefore also some results on mercury are reported in this deliverable. There are also close links with the Norwegian THERMOS lake manipulation experiment, where a clear-watered deep mountain lake has been manipulated as part of a national project.

Detailed monitoring of several chemical and biological variables (mainly weekly-biweekly sampling) is on-going in a) the reference lake Valkea-Kotinen and b) the manipulation lake Halsjärvi (southern Finland). A subcontract with the Lammi Biological Station, University of Helsinki, has been made. The tasks described in the subcontract include assistance in field work, sample preparation and analyses. The planned schedule of the experiment has been to carry out preparatory work in 2004 (development of equipment, background monitoring, and physical modeling for experimental design), carry out two years of intensive manipulation studies in 2005-2006, and continue with background monitoring in 2007-2008. This report describes the preparatory work carried out for the manipulation experiment (year 2004 and first part of 2005).

Theory and hypotheses

The stratification cycle of lakes can be manipulated by artificially increasing the input of mixing energy. Controlled, experimental manipulation of mixing processes can thus open for the direct effects of climate change on lake ecosystems, *in situ*, in real time, and at the whole-ecosystem scale. The lowering of the thermocline will increase the total lake heat content of the lake, and thus the experimental manipulation of the thermocline depth is one way of simulating the effects of a warming climate.

The THERMOS manipulation also simulates the effect of increased wind speeds, and wind is expected to increase according to many climate change scenarios. Deepening of the epilimnion in ELA lakes (Canada) following forest fire in the catchment, increased fetch and increased mixing in a lake have been reported, which supports the experimental design.

The main aims of the experiment are thus to:

- To quantify the effects of controlled thermocline manipulation on biogeochemical cycles (including Hg), foodweb structure and productivity, and biodiversity in dystrophic systems.
- Compare results between the THERMOS experiments of two very different lake systems in Norway and Finland.
- Apply a thermodynamic model (MyLake) to the collected data and simulate the effect of climate change scenarios. The model is used also for the design of the manipulation experiment.

In the study lakes the thermocline determines oxygen availability to hypolimnion during summer stratification and the formation of thermocline is followed by a formation of oxycline, most of the hypolimnion being anoxic during the summer months.

In theory the climate change (and experimentally) induced lowering of the hypolimnion may affect the biogeochemical cycling of elements, including mercury, in several ways. Regarding mercury, we will focus on the formation of methyl mercury (MeHg), recycling/sedimentation of TotHg and MeHg and bioaccumulation of MeHg in fish. In lakes MeHg is mainly produced by sulphate reducing bacteria in hypolimnetic water and sediments. The production is controlled by ambient water temperature and oxygen conditions, reduced environment enhancing the production. An adequate supply of sulphate and $Hg^{(II)}$ may also be rate determining factors.

The lowering of the thermo/oxycline may change the Hg/MeHg cycle due to:

- increased volume of mixed epilimnion and decreased volume of reduced conditions in water
- decreased profundal anoxic sediment surface area
- longer period of ice-free season
- increased resuspension of littoral sediments and Hg
- chance of temperature in MeHg producing environments (water, sediment)

The overall effect of mixing may be an increase or a decrease of MeHg production and concentration in biota depending on which processes and environmental characteristics determine most of the production rate. For the bioaccumulation of MeHg and MeHg concentrations into biota many additive mechanisms may also be important, such as the overall response of the phytoplankton community and the food chain structure from the producers to the fish.

Site descriptions

Halsjärvi (experimental lake):
Lake area 4.7 ha
Lake depth 5.9 m
Lake volume 130 000 m^3

Valkea-Kotinen (reference lake):
Lake area 4.1 ha
lake depth 6.4 m
Lake volume 103 000 m^3

The two lakes are located in the Evo forested area, in southern Finland about 140 km from Helsinki. The Evo region is one of the main study areas of the Lammi Biological Station. The catchments of the lakes are forested (mainly spruce, pine and birch) and have till soils with some peatland areas. The catchment area of the reference lake Valkea-Kotinen is shown in Fig. 1.

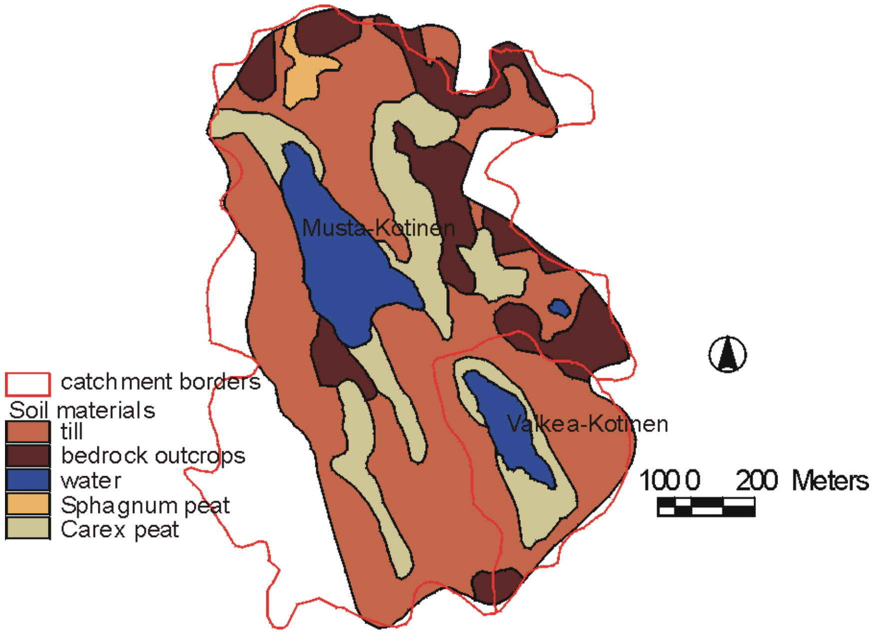


Figure 1. Catchment area and surroundings of the reference lake Valkea-Kotinen.

Main experimental characteristics

The mixing equipment used in lake Halsjärvi is shown in Fig. 2. The technique is a further development of a much used MIXOX aeration equipment developed by the Finnish company Vesi-Eko Oy/Water-Eco Ltd. The equipment was tested during autumn/winter 2004-2005 in lake Ahvonlampi and installed in lake Halsjärvi on May 4th 2005 (Fig. 3).

Figure 2. Mixing equipment (MIXOX) used in Lake Halsjärvi.

Figure 3. Installation of the mixing equipment (MIXOX) in lake Halsjärvi, May 4th 2005.

The experimental design is shown in Fig. 4. By adjusting the depth of the equipment, the thermocline can be adjusted with good precision (ca. 20-30 cm).

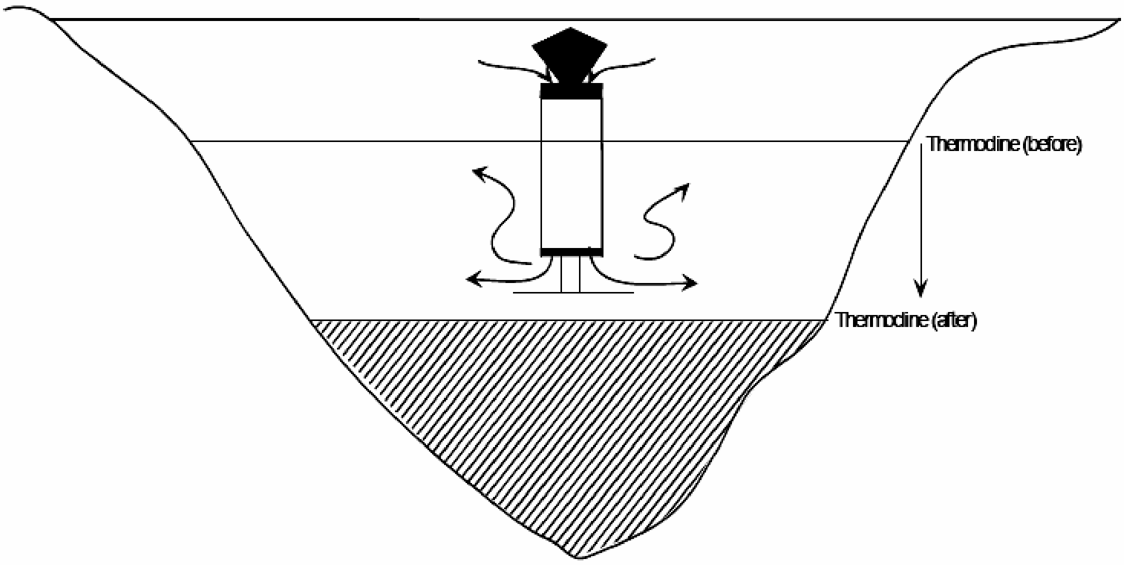


Figure 4. The experimental design in lake Halsjärvi.

According to the results from the MyLake model application (see below), the lake thermocline was lowered in 2005 with about 1 m (to about 3 m) to simulate the effects of the A2 climate change scenario.

Application of the thermodynamic model MyLake

The thermodynamic model MyLake has been set-up and calibrated at lakes Valkea-Kotinen and Halsjärvi in 2004-2005, and both model sensitivity tests and model runs with climate change scenarios have been carried out. For this work, lake depth measurements for lake Halsjärvi were made and lake depth profile digitized. Climate scenarios were obtained from SMHI. These scenarios have already been derived for the Lammi region lakes in the CLIME project, and are the same as those to be used in EURO-LIMPACS.

After a successful set up of the MyLake model, the sensitivity of the model output to different parameter values was studied with help of the FAST method (Fourier Amplitude Sensitivity Test). This method was very helpful in choosing the correct parameters for model calibration as well as in verifying the correct functioning of the model code. After the sensitivity analysis, the model was calibrated against observed lake temperature profiles, using the two light attenuation coefficients as calibration parameters. The calibrated model could simulate the thermocline depth and its seasonal variation well. The model simulated the observed water temperature profiles also well, with a standard deviation of ~1 ºC when local meteorological forcing data was used. This gave good confidence in the model's suitability for simulations of lake response to climate change and increased input of mixing energy.

The main aim in the first phase of the modeling was to assess how much the thermocline of Halsjärvi should be lowered in order to simulate estimated increases in wind speed and total lake heat content of the high-change climate scenarios. The model runs indicated that the increase in total heat content of the A2 high-change scenario corresponds to a lowering of the thermocline depth of about 1 m, to a mean depth of about 3. Consequently, this was set as a target for manipulation experiment. An example of the MyLake simulation results for Halsjärvi is shown in Fig. 5.

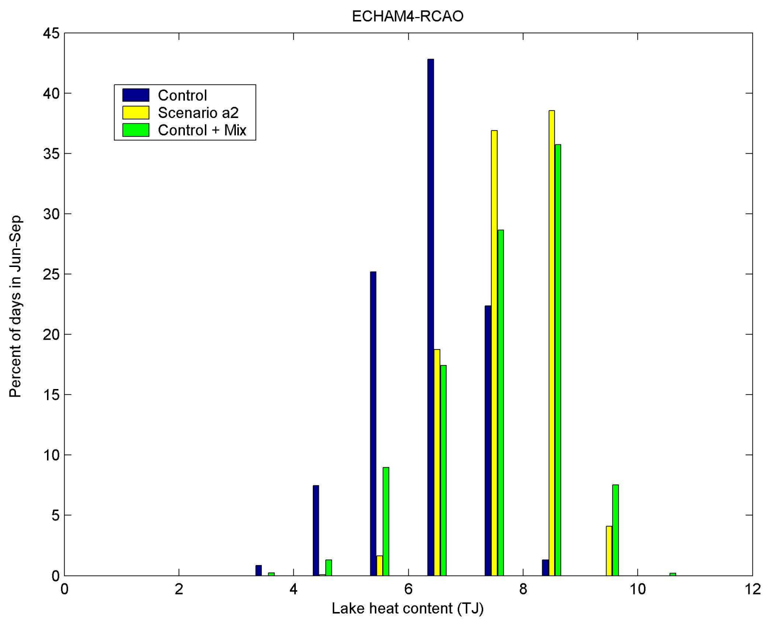


Figure 5. Change in lake heat content for the control, A2 and control+mixing scenarios for lake Halsjärvi using the thermodynamic MyLake model.

Sampling scheme and schedule

Detailed monitoring of chemical and biological variables (mainly weekly-biweekly sampling) is on-going in the reference lake Valkea-Kotinen and in the manipulation lake Halsjärvi.

For mercury, which has complicated biogeochemistry and expensive chemical analyses, three different important steps in lake mercury cycle as end points have been selected:

A. Total Hg and MeHg in lake water (Halsjärvi, Valkea Kotinen)

Total Hg, dissolved Hg (0.4 µm) and total MeHg and dissolved MeHg (0.4 µm) was measured during spring turnover (May) 2004 and at the end of summer stratification (late August) at several depths (1m, 2m, 3m, 4m, and 5m) and after autumn overturn (early December). The same protocol will be accomplished in 2005 during experimental mixing. Net MeHg production rates will be calculated as the difference between the waterborne mass during spring mixis and the mass during late summer. The concentration profiles will also be used to investigate the most active methylation sites (depths) in the lakes. The production pattern and the rates will be compared between experimental lake and reference lake and before and during experiment.

B. Total Hg and MeHg sedimentation (Halsjärvi, Valkea Kotinen)

Sediment traps were installed at epilimnion/hypolimnion transect and at 1 m above the bottom at the deepest sites of both lakes in May 2004 and collected for cross sedimentation (wet, dry matter) measurements and for the determination of total Hg and MeHg. The sampling was done at 6-7 week intervals up to early December in 2004. The same procedure will be accomplished in 2005. Differences in sedimentation rates will be studied between experimental lake and reference lake and before and during experiment.

C. MeHg in fish

Small perch *(Perca fluviatilis)* were collected in September 2004 for the determination of MeHg in muscle. The length, weight and age were determined and samples were taken for MeHg and stable isotope analysis (SIA) (the rate of the heavy to the light isotopes expressed relative to a standard, $\delta^{13}C$‰ or $\delta^{15}N$‰). SIA will be used to study possible changes in the trophic position of fish. The fish sampling will be repeated in 2005, 2006 and 2007.

Preliminary results for the calibration period

The analysis of the results is still in progress but some first results regarding lake temperature, oxygen concentrations and mercury are shown below.

Due to unexpectedly warm and calm weather after ice break in May 2004 neither of the lakes had spring overturn. In the reference lake (Valkea-Kotinen) MeHg concentration increased in hypolimnion but not in the experimental lake (Halsjärvi) (Fig. 6). During summer MeHg concentration increased in both lakes but with somewhat different pattern. The increase in Valkea-Kotinen was most pronounced in hypolimnion than in epilimnion as expected. Halsjärvi experienced a more even and moderate increase, which may be due to groundwater leaching to lake hypolimnion and inundation of lake shore during heavy rains in June-August. This was judged by eyesight and water quality data but needs to be confirmed by additional sampling of groundwater and/or modeling.

Net MeHg formation rates and TotHg and MeHg sedimentation rates have been calculated for the calibration year 2004.

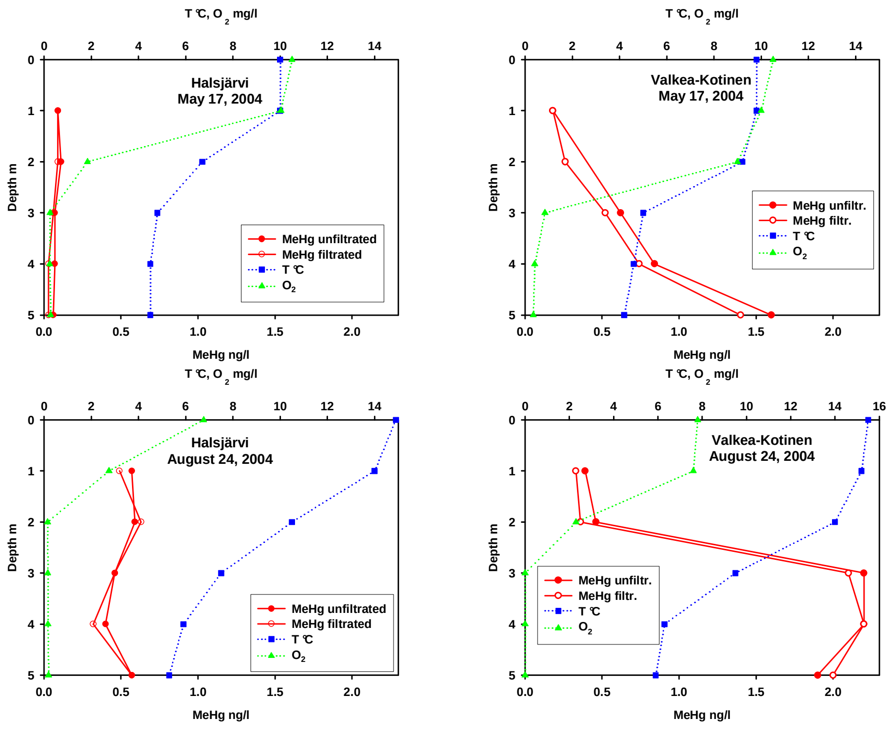
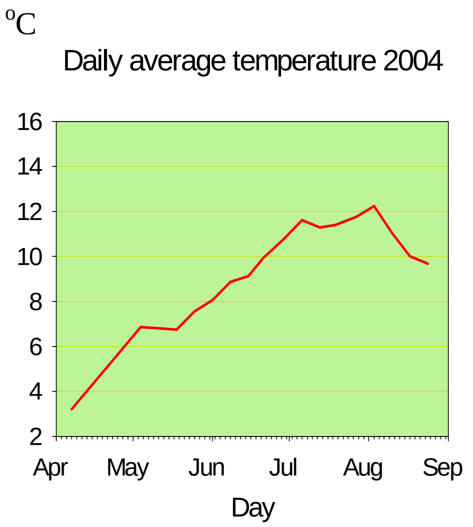


Figure 6. Temperature, oxygen and methyl mercury concentrations (MeHg, dissolved, total) in the manipulation lake (Halsjärvi) and in the reference lake (Valkea-Kotinen) in May and in August 2004.



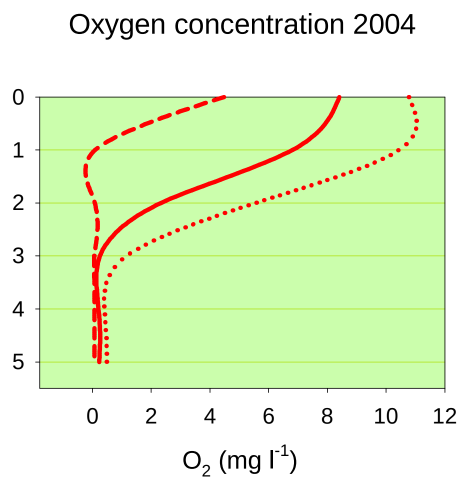


Figure 7. Daily average temperature and mean, minimum and maximum oxygen concentration profiles in lake Halsjärvi in 2004.

Dissemination

The experiment is still in an early phase but so far the following dissemination activities have been carried out:

Presentations:

2nd Euro-limpacs meeting, Athens, Greece, Sept. 5-9.2005:

- Finnish termocline manipulation experiment (THERMOS). Presentation by M. Forsius.
- THERMOS-Hg experiment. M. Verta, P. Porvari, M. Korhonen and J. Munthe. Presentation at WP5 workshop by M. Verta.

Abstracts**:**

Verta, M., Porvari, P., Korhonen, M., Munthe, J. and Wängberg, I. Thermocline change has an effect on methyl mercury cycle in small boreal lakes. Abstract submitted to Mercury2006 Conference, Madison, USA, August 6-11, 2006.