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PROJECT OBJECTIVES & STATE OF THE ART

Climate is changing rapidly, beyond the range of previous natural variability. Natural ecosystems, already under stress from land-use change and pollution, now face additional pressures from climate change, both directly and through interaction with other drivers of change. These pose serious threats to human society as the availability and quality of freshwater determines the functioning of every ecosystem, not least those on which people depend. Ecosystems are so complex that predicting and managing the ecological consequences of global change is a task that requires great expertise, new methods and comprehensive, new approaches. Euro-limpacs consequently had the following objectives:

- to improve understanding of how global change, especially climate change in its interaction with other drivers (land-use change, nutrient loading, acid deposition, toxic pollution) has changed, is changing and will change the structure and functioning of European freshwater ecosystems;
- to encapsulate this understanding in the form of predictive, testable models;
- to identify key taxa, structures or processes (indicators of aquatic ecosystem health) that clearly indicate impending or realised global change through their loss, occurrence or behaviour;
- to identify better approaches for the re-naturalisation of ecosystems and habitats in the context of global change that will lead to the successful fulfilment of the Water Framework Directive (WFD) in achieving good ecological status in freshwater habitats;
- to provide guidance, in the form of useable models, decision support systems and other appropriate tools to respond to the interactions between climate and other changes, in the best interests of conservation of the goods and services provided to the community by its freshwater systems;
- to communicate this information and understanding to users, stakeholders and the wider public.

During the past decade growing concern about global change and its environmental effects has led to great expansion of research. A literature survey conducted in conjunction with the Second International Conference on Climate and Water held in August 1998 in Helsinki resulted in 32,000 articles. Recent overviews of the effects of global change on water have been conducted in the USA, Canada and, of course, by the IPCC. According to the IPCC Third Assessment Report (2003) the global average surface temperature had increased by 0.6 °C since the late 19th century and the increase is projected to intensify during the 21st century. In Europe, precipitation is very likely to increase in most of northern Europe and to decrease in the Mediterranean. Precipitation extremes are projected to increase more than the mean and the frequency of extreme precipitation events is projected to increase almost everywhere. These overviews all drew heavily on scientific advances made within the five research approaches to be used in Euro-limpacs:

Analysis of long-term data-sets Consistent, high-quality monitoring records of freshwater ecosystems now often span more than 25 years and include climatic variations on episodic, seasonal and longer time-scales. Analyses of these data use both the traditional methods of time-series, multiple regression and other classical statistical tools as well as new techniques such as neural networks and fractal analysis. Recent developments in sensors and data-logging have produced continuous measurements of water quality to which new techniques can be applied, for example, the return-time analyses used in hydrology.
Palaeoecological methods Advanced statistical methods have increasingly been used to derive transfer functions and for analogue matching. Euro-limpacs attempted to take the next step, using traditional techniques and developing new techniques to analyse hydrochemical and ecological conditions in comparison with climatic variability over the last 200 years.
Space-for-time substitution This traditional approach is widely used in conjunction with models to predict, for example, global vegetation in a 2 x CO_2 world. Euro-limpacs sought, for the first time, to use consistent data for all Europe across the gradients in present-day climate using newly developed methods, such as regression trees and artificial neural networks.
Experiments Experimental techniques at all scales have improved dramatically during the past few decades. Whole-ecosystem experiments now play a central role in ecological research. Mesocosm facilities have also recently been brought to bear on climate change research. Computer-controlled environmental facilities as well as advances in data-logging and analysis greatly improve experimental conditions.
Models Development of ecosystem models is still hampered by insufficient quantitative understanding of processes. New advances in experimental ecology, such as use of stable isotopes of C and N to analyse food chains, and in theoretical ecology, such as ecosystem stoichiometry, are now being exploited in the development and evaluation of models. Recent techniques have been proposed to link or chain different models operating at a small scale to simulate whole-catchment and landscape scales. The exponential increase in computing power has opened new possibilities for model complexity and methods. Environmental models can readily be subjected to uncertainty analyses such as GLUE.

SYNTHESIS OF MAIN ACHIEVEMENTS / RESULTS WITH REFERENCE TO PLANNED OBJECTIVES AND STATE-OF-THE-ART.

In general terms, the main achievements of Euro-limpacs have been; i) to increase understanding of how climate change both directly and through interaction with other drivers (land-use change, nutrient loading, acid deposition, toxic pollution) has impacted and will impact on structure and functioning of European freshwater ecosystems; and ii) to translate this knowledge so that the implications for future management of European freshwaters are clearly set out and to incorporate this into the development of numerous management tools; and iii) to widely disseminate the information to users, stakeholders and the wider public. In succeeding in all these areas Euro-limpacs has fulfilled the key objectives set out at the start of the Project. However, the scope and ambition of the Project were such that many secondary objectives were identified at the start of the

Project. Given the breadth of work proposed, each work package, and indeed task, included a series of objectives which were formulated so that each would contribute to the key objectives of the project as a whole. Further, a number of key questions addressing the major findings arising from Project activities were highlighted. Over 50 were identified covering all aspects of the project and these are grouped using the work package structure. The answers to these key questons are included on the Project Web site http://www.eurolimpacs.ucl.ac.uk/index.php/content/blogcategory/35/37 and, for each work package, in the summary task reports for WPs1-9 (see **Deliverables 420** to **428**).

This section presents some of the main achievements of each work package and exemplifies these with some highlights from each.

WORK PACKAGE 1: Direct Impacts of Climate Change

Objectives

WP1 comprised 5 Tasks with the following objectives:

i. provide consistent climate scenarios for key sites of Euro-limpacs
ii. evaluate the direct impact of long-term changes in climate (in particular air temperature and precipitation) on the components of the hydrological cycle and on catchment mass fluxes at key sites, where changes in climate are the main drivers
iii. evaluate long-term changes in the seasonality of climate parameters as drivers of freshwater systems
iv. evaluate the response of lake physical structure to changes in climate (temperature, wind, precipitation)
v. assess the impact of changing air temperature and precipitation on wetland hydrology
vi. evaluate the long-term impact of changes in climate on the concentration of dissolved organic carbon in surface waters
vii. provide data required for modelling and evaluation in WP6-9

Achievements

The main achievements of WP1 can be summarised as follows:

i. Consistent climate scenarios were applied across many sites being investigated in Euro-limpacs.
ii. The impact of climate change on the water balance was investigated at key sites. The response of mass fluxes to climate change has been the focus of numerous tasks. Analysis of long-term data series, modelling, and experimental work were used to evaluate the various changes in water, substance and gas fluxes (see example below).
iii. Progress was made in increasing understanding of the complex processes involved in driving the increasing DOC concentrations in surface waters seen across North-America and parts of Europe. The importance of climate change as a driver of DOC release might have been overestimated at the beginning of the project (see example below).
iv. The impact of long-term climate variability on lakes in pre-cultural periods was evaluated and much effort was put in the development of new methods for sampling and analysis.
v. The response of lakes to climate change was evaluated by the analysis of long-term historical data, including the analysis of the hot summer 2003. The whole-lake mixing experiment THERMOS was successfully performed and data evaluation revealed the potential impact of a future climate on the physical, chemical and biological lake characteristics.
vi. The sensitivity of marginal wetlands to global change climate and land-use change was investigated in palustrian and terrestrial hydromorphic systems and statistical models were developed to predict changes in plant assemblages with respect to climate and land-use.

Example 1: Will climate change affect the quality and quantity of dissolved organic carbon release from soils?

As a contribution to WP1, Task 5 UCL led, with the input from several partners (NERC, NIVA, SYKE, HBI-ASCR, HBI-BCASCR, CGS) a major European and North American collation of DOC data. Monteith et al. (2007) assessed time series data from 522 remote lakes and streams in North America and northern Europe, and showed rising DOC trends between 1990 and 2004 to be explained by a simple model based solely on changes in deposition chemistry and catchment acid sensitivity. It was demonstrated that DOC concentrations have increased in proportion to the rates at which atmospherically deposited anthropogenic sulphur and sea salt have declined. It was concluded that acid deposition to these ecosystems has been partially buffered by changes in organic acidity and that the rise in DOC is integral to recovery from acidification. No clear relationships were found with temperature trends, and rainfall and land-use factors were too spatially variable to account for the consistency and extent of DOC increases. Similar results were found for 22 UK lakes and streams in the Acid Waters Monitoring Network by Evans et al. (2006).

There is also discussion on the impact of hydrology as a potential driver for increases in surface water DOC. Investigations from Finnish boreal lakes and river basins, performed by **SYKE**, revealed that there was little evidence that the observed long-term increase in total organic carbon (TOC) concentrations was related to changes in runoff (Vuorenmaa et al., 2006). However, large seasonal and inter-annual fluctuations in runoff seemed to affect TOC concentrations in certain years. Lepistö et al. (2008) found for the Simojoki River in the northern boreal zone of Finland that TOC concentrations appeared not to be linked to declines in sulphate and H^+ deposition. Hydrology plays an important role for TOC fluxes in this northern ecosystem. Increasing trends in flow during summer/late autumn and inter-annual runoff fluctuations with periods of dry and wet years control TOC fluxes.

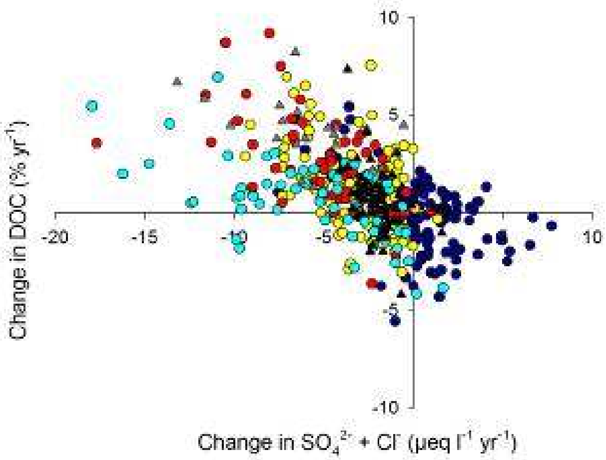


Figure 1: Relationship between relative DOC change (percentage of the site median) and the equivalent sum of sulphate plus chloride change, which is used as surrogate for changes in atmospheric deposition, at sites in Canada (dark blue circles), Finland (yellow circles), Norway (red circles), Sweden (light blue circles), the UK (grey triangles) and the USA (black triangles). (Modified from Monteith et al., 2007).

Example 2: Climate change effects on solute concentrations in high mountain lakes

In response to the observed increase in air temperature, high altitude lakes can experience a substantial change in chemical composition. UIBK investigated solute concentrations in two high mountain lakes situated in catchments of metamorphic rocks in the Central

European Alps. Thies et al. (2007) found that at Rasass See (2682 m, Italy) electrical conductivity has increased by a factor of 18 during the last 2 decades and concentrations of the most abundant ions magnesium, sulfate and calcium have reached the 68-fold, 26- and 18-fold values.

The pronounced change in lake water chemistry is attributed to the solute release from an active rock glacier in the catchment of Rasass See. Melt water draining into the lake has caused solute concentrations to increase since the 1990s, while the effects of bedrock weathering and atmospheric deposition on lake water chemistry are considered to be negligible. In addition to the increased amount of major ions, unexpected high nickel concentrations have been found exceeding the nickel limit for drinking water (20 $\mu g\ l^{-1}$) by one order of magnitude. This high value cannot be related to catchment geology and the original source of nickel still unclear.
Similar results, but with a less pronounced solute increase, were found by UIBK (Task 2.1) for another high mountain lake in the Alps (Schwarzsee, 2798 m, Austria) and there is recent evidence from rock glacier runoff at various sites in the Austrian and Italian Alps for an enhanced release of solutes to freshwaters.

Figure 2: Rasass See and major parts of its catchment. The white ellipsis indicates the position of the active rock glacier (Photograph by V. Mair).

WORK PACKAGE 2: Climate - Hydromorphology interactions

Objectives

The main objectives of WP2 were:

i. To identify global change driven processes leading to hydromorphological changes and related changes in biodiversity
ii. To identify the changes in and relations between land use, hydromorphology, habitat characteristics and biota on the catchment scale.
iii. To assess seasonal and annual variability in stream hydrology and to identify the effects of extremely high or low discharge on stream biota.
iv. To describe the effects of discharge regimes and dynamics on habitat stability and indicator species.
v. To identify key ecological and functional response indicators reflecting changes in land-use and hydromorphology.
vi. To examine habitat binding and causes of habitat binding of selected indicators species.
vii. To set the environmental conditions for the application of Cause-Effect Chains to climate – hydromorphology interactions.
viii. To assess the effects of lowland and mountain stream restoration on hydrology, morphology and biota.
ix. To understand in-stream nutrient retention and water transient storage.
x. To understand sediment accumulation rates from lakes across Europe and to evaluate the role of climate and land-use change on lake sediment accumulation rates.

Achievements

WP2 achievements can be split broadly into seven research strands.

i) Rivers and climate change, catchment scale

- The analysis of land use and hydromorphological data from 8 catchments throughout Europe underlined the importance of floodplain land use for hydromorphology, demonstrated that historical reconstruction is a main source of information to predict the effects of future land use changes on hydromorphology and resulted in the conclusion that land-use change in these areas will become of much greater importance than the effect of climate change.
- Seasonal and annual variability of hydrology, hydromorphology and biota as well as effects of extremely high or low discharges on the biota are both important in terms of explaining stream communities.
- Indicators (covering macrophytes, macroinvertebrates, and fish) for hydromorphology in lowland and siltation in mountain streams, and habitat, current and drought in lowland streams were identified.
- In northern European streams, the scale at which a system is observed is important when determining which factor(s) is/are influencing the structure of the stream ecosystem.
- In central European streams physical habitat degradation appears to be the most important threat to aquatic and riparian biota and siltation in mountain streams has a

great effect on taxa composition, a severe effect on abundances, on functional groups and on certain life stages.
- In southern European streams hydrological and related morphological constraints are crucial for the biota and droughts will result in many more ephemeral streams.

ii) Rivers and climate change, reach scale:
- Pool and riffle invertebrate assemblages differ significantly which confirms the importance the mesohabitat-scale (the pool-riffle gradient) as the main factor determining the taxon composition. Differences between pool and riffle areas structure macrobenthic assemblages, even under important environmental stress, like organic load.
- Differences between pools and riffles are more important then regional-scale characters, therefore an effective sampling protocol should include a separate analysis for erosional and depositional units, both from biotic and abiotic point of view.
- Pools are stable habitats with prevalent lentic flows for most periods and with rheophilic taxa. Conversely, riffle areas are characterised by extreme flow variability throughout the year, changing from lotic to lentic habitats in low flow periods with lentic taxa during low flow and lotic taxa during extreme hydrological events.
- Climate change decreases the lotic character and thus results in an increase of pool habitats in Mediterranean streams. Many more temporal or ephemeral water flows will occur.

iii) Rivers and climate change, habitat scale:
- Hydrological variables such as water velocity, Froude number and discharge are strong driving forces for macroinvertebrate communities.
- In general, sensitive indicators of discharge dynamics showed under experimental conditions rapid, individual responses to changes in current (discharge dynamics) and to physical disturbances (morphology disturbance). Both showed a trade-off between habitat binding and drifting.
- Both specialists and generalists are affected by higher current velocities, although generalists respond faster and in higher numbers.
- Low-flow experiments identified positive and negative indicators of low flows.
- Flow instability and disturbance, thermal regime and a few simple habitat features, are considered to affect aquatic taxa presence, distribution and secondary production.
- Habitat preferences of indicators in mountain streams and in lowland streams were established.
- Habitat preferences in mountain streams can be classified in channel margins (organic structures like macrophytes and roots), organic habitats in pools/low current patches), mosses in high current stretches, fine and coarse mineral substrates.
- Habitat preferences in lowland streams can bee classified according to leaves, gravel, sand, silt and detritus.
- Habitat preferences for macroinvertebrates are less specialised as is often assumed.
- Specialist taxa show habitat selection in time, especially after one day but this selection can vary over time. Ten to 20% of all specimens tested did not select a habitat type.

iv) Rivers and climate change, future assessment:

- Within a given life history of a species, its actual distribution may be strongly influenced by key habitat resources like places for egg-laying, feeding habitats, pupation etc. and less with water quality or hydromorphology.
- Taxonomic resolution can considerably influence the detection and selection of indicators. Thus identification to species level is needed. Potential indicators may be masked by identification on higher levels.

v) Rivers and climate change, restoration:

- Species that are resistant to disturbances are present even in the first years after restoration due to weather (climate variability) and post-disturbance conditions.
- High nutrient contents will hinder further stream development, especially after hydromorphological restoration.
- Dispersal problems must not be underestimated; it is possible that barriers for the species still play a major role in the colonisation.
- Biological recovery after restoration, even under good ecological conditions needs time (>5-10 years).
- Early and local effects of hydromorphological restoration are best detectable by riparian vegetation, while long-term effects and those on larger scales might be better reflected by benthic invertebrates.
- It appears that mountain stream restoration in its current form and extent is not effective in terms of enhancing macroinvertebrate diversity.
- Fine sediment suspension and deposition affects benthic invertebrates and results in the poorest fauna of all mesohabitats studied:
- Multiple-channels contribute more to regional diversity than the single-channel sections.
- Floodplain vegetation responds most strongly to multiple channel restoration (channel form and variety are main determinants), followed by riparian ground beetles (due to gravel bars). The aquatic biodiversity does not always respond as in-stream habitats do not change.
- Near-natural lowland streams show a significantly higher rate of change after a spate in comparion to straightened streams.
- Near-natural lowland streams are more stable and have higher community equilibrium than straightened streams in the course of a year.
- In near-natural streams refugia from high flows are present and manifold to support vital populations other than in straightened streams that are colonised mainly through drift and do not support self-sustaining populations.
- Discharge increase (an effect of climate change) is accompanied by suspended material transport, and extreme floods can in their turn destabilise a stream for at least one year
- Remeandering of deeply incised lowland streams, common in the north-western European plains, alters to a longer stream length, a greater slope, less pronounced incision, and a shallower water body.
- Discharge stabilisation through retention (building of a retention pond) will result in a higher substrate diversity as more organic substrates will settle and the number of organic dams will increase, thus overall a gain of habitats.

- After digging a new stream a large number of taxa that can not fly, such as snails, worms, mites and leeches will disappear. The new taxa that arrive after remeandering mainly use flight for dispersion.
- The effects of stream bed instability on macroinvertebrate community composition differ among the dominant taxa and between functional groups. Climate change inducing bed instability can lead to large changes in the community when functionally important species are affected.
- Increase in the size and magnitude of floods, resulting in a larger proportion of instable sediment, can negatively influence dominant groups preferring stable substrates by reducing the area of suitable habitat. This in turn can have important consequences for stream ecosystem functioning.
- Flow rates and variation positively change when wood is added to a stream, leading to subtle shifts in the macroinvertebrate composition.
- Projects with larger-scale additions of wood, monitored over longer periods, are strongly recommended.
- Development of macrophytes together with other stream bottom rise measures can cause gravel beds to disappear, which means a loss of an important habitat and thus active gravel introduction is needed.
- Remeandering together with floodplain level lowering better connect streams and their floodplains, give rise to organic substrates, heterogeneous hydromorphology, and a higher biodiversity.

Some general practical advice for water managers with respect to river restoration in the context of climate change, are:
Failures of stream restoration attempts are likely if:
- Stream restoration is performed at a local scale.
- Stream restoration tackles only one or few environmental conditions.
- Stream restoration ignores the riparian zone and the stream valley.
- Stream restoration focuses on one organism group and neglects the ecosystem as a whole.
- Stream restoration ignores dispersal potentials and barriers.
- Stream restoration targets are not specified.
- A lack of communication hinders stream restoration.
- Stream restoration is based on historical geography and neglects current environmental conditions.
- Different measures in stream and valley serve opposite objectives.

Success in stream restoration is likey when:
- Stream restoration should is integrated, including the whole stream and stream valley.
- Stream restoration is embedded in intrinsic landscape/catchment processes.
- Stream restoration has a clear and open communication between participants and is based on a well described, detailed common approach.
- Monitoring of stream restoration is undertaken.
- Stream restoration is in balance with other land use functions and human activities (e.g. recreation).

- Targets of stream restoration are clear, described in detail, relate to the process of the landscape and are communicated to stakeholders.
- Stream restoration identifies specific adaptations per catchment and stretch.
- Stream restoration has time to reach ecosystem recovery.
- Stream restoration includes aspects of maintenance into account in the stream restoration planning process.

vi) In-stream nutrient retention and water transient storage:
- Hydraulic parameters are affected by the introduction of substrata packs, thus a more heterogeneous stream bottom will lead to higher diversity in hydraulic conditions.
- Water transient strorage increases along the gradient from mud to sand to cobble substrates.
- Natural communities develop differently in each substrate type, and consequently, contribute differently to nutrient retention.
- Leave fall increases the decoupling between surface and subsurface stream compartments.

vii) Lakes, sediment accumulation:
- A sediment accumulation rate (SAR) database was developed providing estimates of SARs for lakes of different types. This is an important tool to assess the impact of future climate and land-use change on sediment erosion, transport and deposition.

Example 1: Perennial morphological dynamics and their effects on the macroinvertebrate fauna in near-natural and degraded small lowlands streams

<u>Objective</u>
This study investigated six small lowland streams. The change in substrate and macroinvertebrate community after spates was evaluated along a degradation gradient from near-natural morphology to straightened and fixed channel form. The objective was to find out if different morphological status has an influence on bottom substrates and the benthic community following flooding events, as expected through climate change.

<u>Key question</u>
What effect will changing hydrological conditions (both directly and through morphological change) have on stream aquatic communities at the habitat scale?

<u>State of the art</u>
Floods are integral parts of river systems. They occur (in central Europe) depending on the geographical area following the snow melt or after long rain periods in spring every year. Benthic invertebrates are adapted to these annually recurring events. The morphological status and floodplain availability of a stream determines the effects large water masses have on the river system. In narrow streams with high gradients the bottom substrate will potentially be transported into downstream sections, while in broader near-natural channels the substrate will be deposed. The impacts of high flood events on the invertebrate fauna were investigated in detail in many papers emphasising the effect which is called

"catastrophic drift". The combination of different morphological status and small spates which occur year-round was not yet investigated.

Methods

The streams were small sand bottom lowland streams (catchment area < 80 km^2). We evaluated the substrate composition in patches of 0.04 m^2. We evaluated substrate change and macroinvertebrate communities six times between March and September 2005. Metal frames were used for substrate recording. The metal frames are divided in 5 x 5 squares each covering an area of 0.04 m^2. Following the weather forecast and online data from gauging stations, sampling was conducted after every spate. The mineral substrate and the overlying organic matter were recorded in 5 % steps in each square of all frames. The underlying mineral substrate was fixed to 100 %, while the overlaying organic matter varied between 0 and 100 %. The substrate types were: clay, sand, gravel, macrolithal (fist-size stones in the banks of the degraded sites), fine particulate organic matter, coarse particulate organic matter, algae, macrophytes and dead wood. The three main habitats: sand, gravel and detritus (comprising FPOM, CPOM and emergent macrophytes) were sampled three times with a Shovel-Sampler (25 x 25 cm, 500µm mesh-size). The samples were washed, sorted and macroinvertebrates identified alive in the field and put back into the stream. Identification level was genus.

Results

Surprisingly, the near-natural sites showed the highest percentage of substrate changes in the course of the year (Figure 3). Mean values between 18.7 % and 41.1 % were classified into category 4 (heavily changed). In comparison the degraded sites had only between 0 % and 13.6 % in category 4. The category "no change" (1) accounted for about 50 % in all three degraded sites and between 23.5 and 31.4 % in the near-natural ones. Shannon-Weaver-Diversity is highest in the near-natural sites (Figure 4). Lowest means are calculated for the degraded sites. On the other hand mean standard deviations are highest in the degraded sites and lowest in the near-natural ones. The results show that after each spate Trichoptera, Plecoptera, Coleoptera and Odonata are more abundant and more frequently found in the near-natural/restored sites than in the degraded sites. Ephemeroptera, Crustacea and Diptera are not affected differently in terms of the morpological status of the site. In particular Crustacea (in this case *Gammarus pulex*) are present in almost every sample.

Implications in terms of climate change

Near-natural stream sections show a higher substrate turnover rate in the course of a year but conversely provide more and different substrates to the invertebrate community. Refuge areas from small spates are manifold. In the degraded sites habitats did not change much but refuge areas are scarce in case of flooding events. Climate change impacts in the lowlands will include more and higher flooding events in unusual seasons (e.g. summer). The benthic communities of degraded stream section will suffer more from these impacts than the communities of near-natural stream section where the morphology has a smoothening effect on the extreme event.

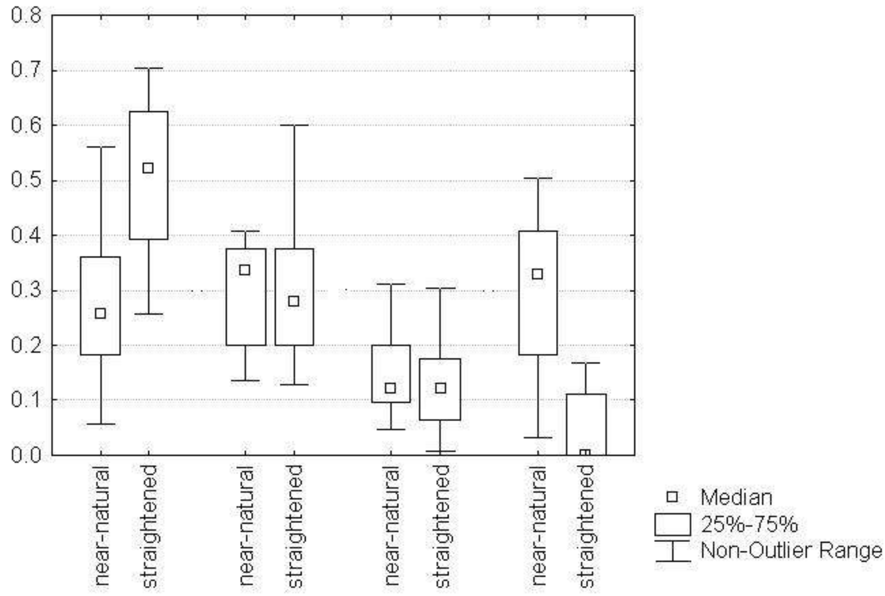


Figure 3. Mean substrate changes in the course of the year. Mann-Whitney U-Test: * $p < 0.001$.

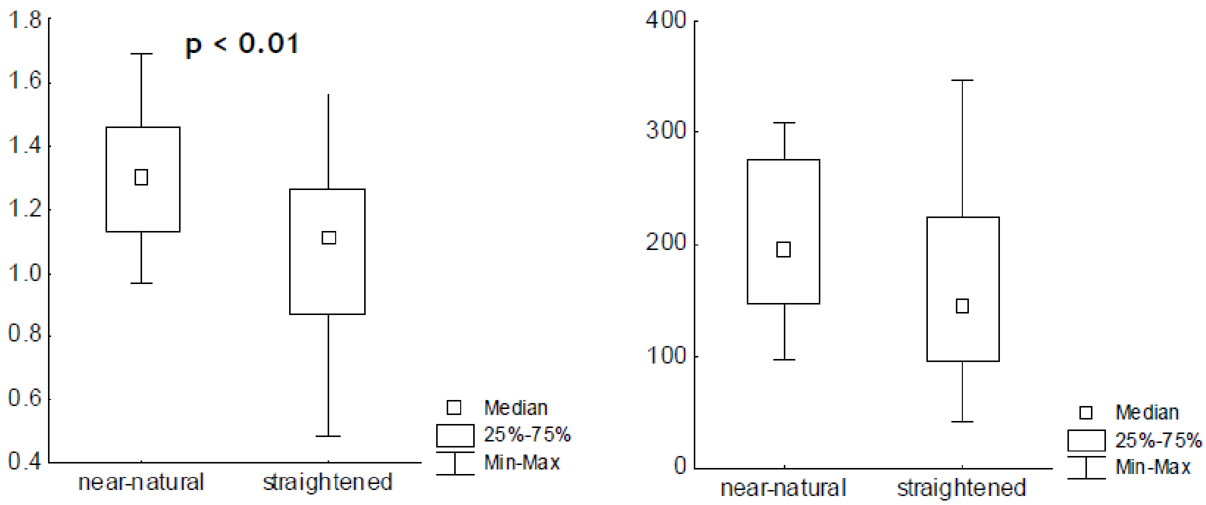


Figure 4. Shannon-Wiener Diversity (a) and abundance (Ind./m2) (b) of macroinvertebrate samples in near-natural and straightened sites.

Example 2: Hydrological changes and aquatic taxa

Objective

Following a targeted review of mesohabitat and flow preferences of macroinvertebrates in UK streams, a short-list of gravel and riffle inhabiting taxa was compiled that were potentially the best indicators of discharge disturbance. The responses of these and other taxa to variations in flow were then tested experimentally. The aim was to assess the suitability of the selected freshwater macroinvertebrate species as indicators of climate change in terms of the strength of their response to experimental low-flow treatments.

Key question

Can we identify suitable indicator species that occur in groundwater-fed rivers that are suited for the climate change scenarios that have been predicted to occur in the UK.

State of the art.

The importance of the hydrological regime in determining the physical nature of a stream as well as influencing the biota that the stream supports is well established. There has been a substantial amount of work investigating macroinvertebrate responses to discharge regimes through their association with particular in-stream mesohabitats. Much of this work was based on observational data in real systems. We sought to experimentally verify some of these reported species-flow associations. Artificial channels have been used effectively in various experiments relating to invertebrate growth and survivorship, disturbance, colonisation dynamics, interactions between nutrients and macrophytes, algae and herbivores, predators and their prey, toxicity testing and ecological risk. They have also been used to simulate high discharge events.

Methods

The experiment was carried out using artificial streamside channels (each channel is 12m long and 0.3m wide) located at the Freshwater Biological Association River Laboratory in East Stoke, Dorset, UK. Within each of the four blocks of three channels, each channel was assigned to one of three treatment levels: control channels with relatively high discharge rates, medium discharge channels, and low discharge channels. Macroinvertebrate samples were taken from these channels with a Surber sampler before and after six and 12 weeks of treatment. The substrates in the artificial channels were regularly mapped to quantify the change in habitat in response to the treatments, since invertebrate preferences are likely to be for certain habitat types.

Results

Taxa such as *Serratella ignita*, *Caenis luctuosa* group, Chironomidae, *Gammarus pulex, Polycentropus flavomaculatus* and *Hydropsyche contubernalis* were all found to associate strongly with control flows, suggesting that they could act as positive indicators of low flows (Fig. 5). Beetle larvae of the species *Nebrioporus depressus elegans* and family Hydrophilidae associated more with low flows, and therefore could act as negative indicators of low flow conditions. *S. ignita* and *G. pulex* were the most clearly sensitive species to low flow conditions. As such they were confirmed as indicator species. Invertebrate abundance and diversity also decreased significantly under low flow conditions. The low-flow treatment also experienced a greater rate of siltation of the benthic substrates and more filamentous algal growth over the course of the experiment.

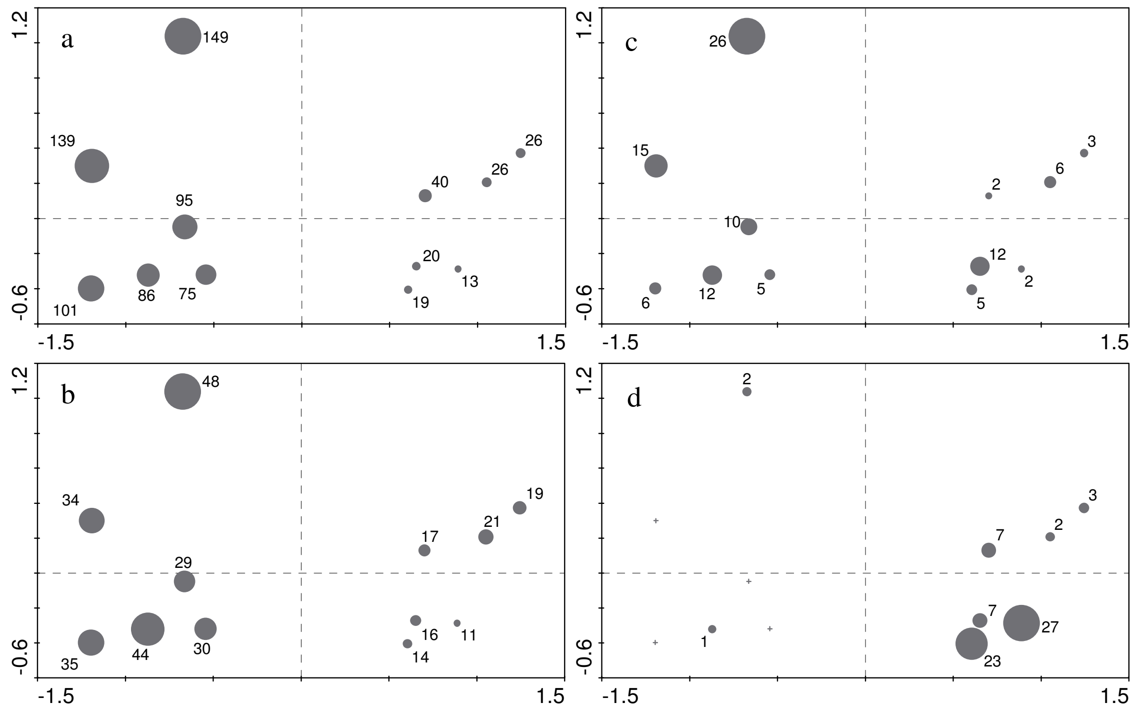


Figure 5: Abundance of potential indicator species in relation to flow. Low-flow replicates are to the right and control and moderate flow channels to the left of the ordination space. (a) *Gammarus pulex*, (b) *Ephemerella ignita*, (c) *Caenis luctuosa* group and (d) *Nebrioporus depressus elegans* larvae.

Implications in terms of climate change

Serratella ignita and *Gammarus pulex*, could all act as positive indicators of low-flow conditions in chalk streams. Beetle larvae of the species Nebrioporus depressus elegans and family Hydrophilidae could act as negative indicators of low flow conditions. The density of non-Chironomidae individuals could also be an indicator of low flow conditions. This experiment has also shown that low-flows can alter the physical stream environment. We would expect species that prefer stable clean gravel habitats to decrease under low flow conditions, whilst those that prefer fine sediment habitats would increase. As human-induced climate change will cause major changes in the frequency and severity of extreme disturbance events such as drought, it is vital that we are aware of the links between such disturbance events and their results, such as changes in faunal diversity. Identification of highly responsive invertebrate indicators will help us to monitor the extent of serious ecological damage, and hopefully prevent it.

WORK PACKAGE 3: Climate– eutrophication interactions

Objectives

Many influences of human activities are brought to bear on freshwaters and freshwater ecosystems. Indeed because all rivers and lakes are associated with a catchment area of land from which they derive their water, all activities on that land have some influence on the quantity and quality of water that reaches the rivers and lakes. All land is part of the catchment of one or other river but each individual catchment has a wider dimension in that rain that falls on it is influenced by the chemistry of the atmosphere over a much wider area. It is not surprising that freshwaters are among the most damaged ecosystems on Earth.

The damage comes primarily from alteration of the catchment for human settlement and agriculture, manifested primarily in fossil fuel burning, destruction of natural ecosystems and production of manufacturing and excretal wastes. Natural ecosystems have evolved many mechanisms for conserving the twenty or so nutrients absolutely required by living organisms and largely recycle them when their plants decay and the component animals excrete them. Agricultural systems, towns and cities, in contrast are very inefficient at conserving nutrients and must even import them from mineral deposits or make them from atmospheric gases to compensate fro the losses to the rivers and ultimately the ocean, to remain functioning. These nutrients, in particular nitrogen and phosphorus compounds, cause severe problems, collectively called eutrophication in the receiving freshwaters. They cost, globally, some billions of euro and include changes to fisheries, fish deaths from increased alga production and night-time deoxygenation, increases in aquatic weed problems for navigation, increased flooding risk from weed build up, increased costs for water supplies in filtering water, and sometimes deaths of stock and rarely humans, from production of toxic algal blooms of cyanobacteria (blue-green algae).

Nutrients are key to functioning of living systems and so is temperature. There are few processes not influenced by temperature and in aquatic systems also by precipitation and the availability of water. Influences rarely act separately so the strong expectation at the outset of this project was that there would be many interactions among symptoms of eutrophication and manifestations of climate change. Previous experimental work on small systems had suggested that the role of climate change might be relatively small given the already substantial effects of severe eutrophication in Europe, but a wider view of bigger systems was that this might underestimate the seriousness of the situation. Experimental studies give precise information that is often unambiguously interpretable, but has to be small-scale and unable to incorporate effects for example of very different floras and faunas in different places. Our approach was thus to use both experimental (Task 1.3, Tasks 2.1, 2.2) and synoptic observational (Tasks 1.1,1.2,3.3) approaches, salted by a study of how climate change and eutrophication might have interacted in the past (tasks 3.1, 3.2) to gain a handle on how the two, perhaps most important present drivers of the state of freshwater ecosystems on a world-scale would interact in the future.

We did not know what the end results would be. There is no logical point in doing research where the answer is already known. We did not know whether climate and eutrophication would act strongly together or remain largely independent. It was clear that climate change would be considerable and manifestly clear just how severe a eutrophication problem now prevails but that very severity might mean that interacting effects if present would be additively minor. The best way of tackling this was by experiments using experimental designs that could separate the effects of temperature and nutrients and also reveal the interactions between them. We used heated mesocosms and also naturally warmed streams and wetlands in Iceland.

We had considerable experience of restoring lakes from eutrophication using nutrient control and restructuring of the food webs by fish removal (biomanipulation), which has been very effective in the cold temperate region. Fish eat smaller animals, which eat algae. Temporary removal of fish leads to increase in these animals, more grazing and clearing of algae from the water. This treats a major symptom of eutrophication and sometimes had lead to more fundamental changes in the system that had longer lasting effects. But there were hints that the differing fish communities of warmer regions, from the Mediterranean to the tropics might make biomanipulation less effective but we were uncertain why. We anticipated that studies on the communities and food webs of a range of streams and lakes covering most of the latitudinal range of Europe and incorporating some warm lakes in the southern hemisphere would throw light on this but at the outset we did not know what the patterns would be, only that if they existed they could suggest how freshwaters in the presently cooler regions of Europe might change on warming.

Our palaeoecological work was designed to find out whether light could be thrown on the climate/eutrophication interaction by past events in a longer term than can be covered by experiments, synoptic investigations or even our longest sets of records covering several decades. Again we could not anticipate the actual results. Though palaeolimnology has achieved great sophistication in recent years, the record on which it operates is not unbiased and there is limited understanding of the ways that it might give a slanted picture of past events. It does however provide the only way of looking at the interaction of climate and nutrient change beyond a human lifespan or two.

A final question was the extent to which living organisms might rapidly evolve to cope with changing temperature. Natural selection is very powerful and acts continually and sometimes gives rapid effects. No one would be so naïve as to think that living systems will keep pace with such comparatively rapid temperature changes as we are currently experiencing so that no problems will be manifest, but we anticipated some scope for adjustment and incorporated suitable experiments to discover the extent of this.

Overall we were confident at the outset that there would be interactions between climate change and nutrient status and that at least some of these could have more than trivial consequences, but we could not be certain of any of the details. Our hypotheses were well founded but we would not know whether they could be accepted or not until the work had been accomplished.

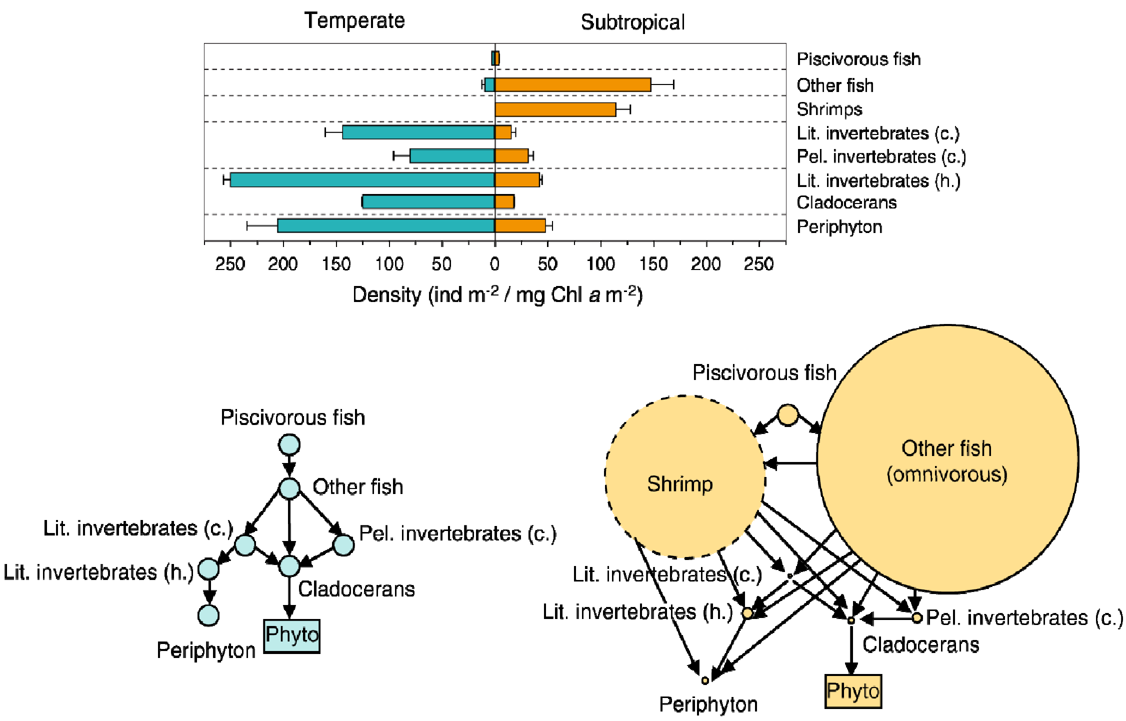
Achievements
WP3 has very considerably advanced our knowledge of eutrophication and its links with climate change. This has primarily been because of its strongly experimental approach, its

access to naturally warmed sites in Iceland, its geographically wide scope in gathering synoptic data, its access to good, long-tem data sets and the sophistication of its palaeolimnological techniques and statistical approaches.

We have selected four key achievements to illustrate what has been a generally very successful work package. These are (i) our increased understanding of the role of differing fish communities in lakes over a warming gradient and its implications for future European fisheries; (ii) the difficulty in projecting future balances of carbon exchange in wetland and shallow lake systems as climate warms, but the strong likelihood that carbon stores will be metabolised giving marked increased carbon dioxide release to the atmosphere and possible runaway greenhouse effects after the 4C temperature increase now predicted has been passed; (iii) the rapid evolution of a zooplankton species in response to warming; and (iv) the increase in nitrous oxide emission from fertilised soils but not from warmed soils.

Example 1: Role of differing fish communities in lakes over a warming gradient and its implications for future European fisheries:
Fish communities in warmed lakes will become depleted in top predators, will have more omnivores and there will be lower zooplankton populations, less grazing and more algae. Standards for nutrients under the Water Framework Directive will need to be revised downwards to achieve the intended values of chlorophyll *a* for good ecological status. Offshore islands will be particularly vulnerable as extinctions of native fish will not be compensated for by immigration of equivalent species because of the marine barrier. Introduced, very damaging species like common carp are likely to take over the communities of many lakes and ponds. Figure 6 shows the contrast in food pyramids between warm and cool lakes illustrated from Denmark and Uruguay.

Figure 6: Contrast in food pyramids between warm and cool lakes illustrated from Denmark and Uruguay



Example 2: Mesocosm experiments to assess effects of 4C rise in temperature

Estimates vary but all three mesocosm experiments show that the shallow lake systems were net heterotrophic meaning that they were respiring stored organic matter even at ambient temperatures. This is now thought to be normal for lakes. They depend to some extent on organic matter imported from the catchment. In most cases in the mesocosm experiments, this net heterotrophy increased (more organic matter was respired) on warming. Table 1 shows the worst case, from the UK experiment, which would mean an increase in global carbon emissions of about 65% over 1990s values given a 4C temperature rise. This would mean a runaway global warming effect.

Table 1 Worst case, from the UK experiment

Mean values ($mg\ O_2\ L^{-1}\ day^{-1}$)	Ambient	+4°C	P
Gross photosynthesis	28.3	13.2	0.003
Net photosynthesis	1.15	-0.33	ns
Net ecosystem production	-4.08	-6.73	0.0004
Heterotroph respiration	5.96	7.88	0.09
Plant respiration	27.1	13.5	0.003
Total community respiration	32.4	19.9	0.007
Ratio of community respiration to gross photosynthesis	1.41	1.85	0.047

Example 3: Rapid evolution of a zooplankton species in response to warming

Simocephalus vetulus, sampled from heated mesocosms had a low temperature optimum. Its offspring, a few generations later had evolved a much higher optimum (Fig. 7). This should not be taken to imply that all organisms, including those like fish with long life histories will evolve temperature adaptation, but there may be a great deal of accommodation in small species and microorganisms

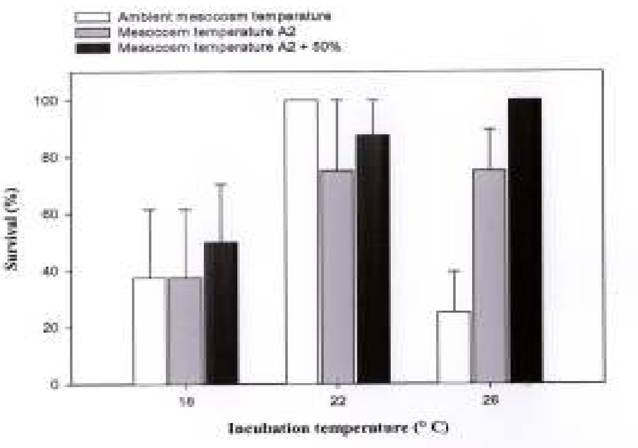


Figure 7: Results from zooplankton incubation experiments

Example 4: Increase in nitrous oxide emission from fertilised soils
Nitrous oxide is a greenhouse gas. Its emissions were not increased by warming alone but increased emissions of it are likely wherever land is fertilised. Future food demands mean that more land will be fertilised more intensively, again leading to positive feedback effects on warming, though in this case indirect rather than direct. In Figure 8, light panels in each case represent a wetland system at 16C and dark panels a simlar system at 26C in Iceland

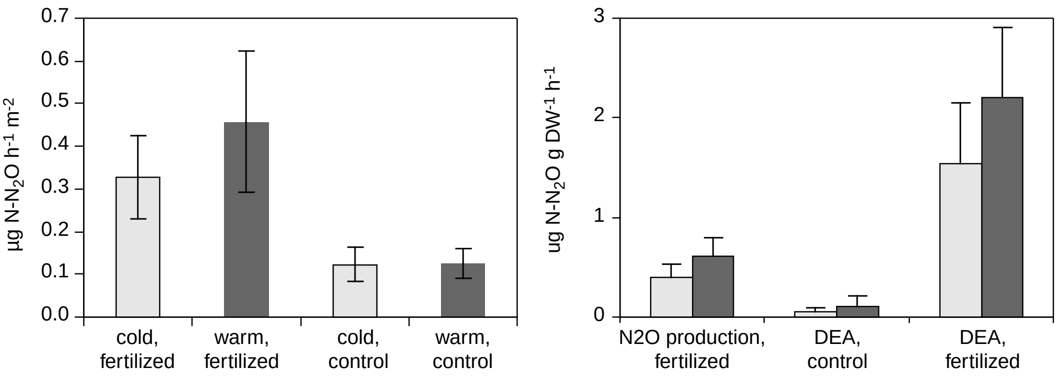


Figure 8: Results from paired field experiments in Iceland. DEA means denitrification enzyme activity.

WORK PACKAGE 4: Climate– acidification interactions

Objectives

WP4 dealt with climate-acidification interactions in stream and lake ecosystems. Particular focus is on the effect of short- and long-term changes in climate on the recovery of aquatic ecosystems from damage caused by acid deposition. This is due to concern that climate change may delay recovery of acidified aquatic ecosystems. Data come from acid-impacted areas of Europe as well as eastern North America. Large-scale experiments with altered climate have been conducted in small catchments and lakes. Long-term datasets (30+ years) from key sites have been analysed with various statistical techniques to elucidate empirical evidence linking variations in acid deposition and climate on water chemistry and biology, at time scales ranging from short-term episodes to decades. Together the experimental and empirical data have been used to develop, modify, and calibrate statistical and process-oriented models. These models then have provided tools to project ecosystem changes given future scenarios of acid deposition and climate.

The objectives of WP4 were:

(i) to determine the effects of long-term and seasonal changes in temperature and precipitation on the leaching of nitrogen (N), dissolved organic carbon (DOC) and sulphate (SO4);
(ii) to determine the effects of increased frequency of episodic inputs of water and sea-salts on acidification pulses
(iii) to determine the effects of these factors on the recovery of acidified freshwaters.

The work was concerned with lakes and streams that have been acidified and that are now undergoing recovery following major reductions in S and N emissions. The central hypothesis is that the impact of climate change on acidification recovery is dependent on hydrological and hydrochemical processes at the catchment scale.

Despite major reductions in the emission of acidifying compounds, surface water acidification remains a serious threat to Europe's surface waters. Recovery is slow and recovery processes may increasingly be influenced by changing climatic patterns. Interactions between climate change and surface water acidification processes occur on all time-scales, from individual storms to changes in seasonality and to decadal trends. The major mechanisms operate through the catchment, and through changes in runoff chemistry and discharge, and the most significant ecological impacts will occur in response to changes in water chemistry. Good empirical relationships relating water chemistry to key biological indicator groups have been established through previous major national and international projects across Europe. The priority for this WP therefore was to understand chemical responses of acid waters to climate change, and then use existing databases to predict probable biological and ecological response.

WP4 used four research approaches to study the effects of acid deposition and climate change on surface waters. The first (Task 1) was experimental, either in the laboratory, mesocosms or large-scale whole ecosystem experiments in the field. The second (Task 2) was the analysis of empirical data collected regularly at one site over time to record temporal variations, or at many sites at one point in time to record spatial variations. The third (Task 3) was the use of space for time analogues. The fourth (Task 4) involved the use of statistical and process-oriented models to evaluate effects of various future scenarios for acid deposition and climate. These approaches are inter-related: trends seen in analyses of empirical data give rise to hypotheses of cause-effect relationships that can be tested by experiments. The results can then be used to develop and calibrate models. Modelling can reveal shortcomings and gaps in the empirical data which can then form the basis for new monitoring or measurements.

Achievements

Projections of the synergistic effects of acid deposition and climate change on freshwater ecosystems are, of course, inherently fraught with the uncertainty that such projections are, for climatic conditions, not currently experienced. For many of the climate scenarios the projected mean temperature in the future will be well above that observed even in extreme years during the period of observation (maximum 30 years for most ecosystems). The ecosystem responses are probably not linear; thus extrapolation from observations, even those spanning several decades, entails going outside the range of observations.

It is acid deposition that is responsible for the widespread acidification of surface waters in sensitive areas of Europe, eastern North America and elsewhere in the world. This means that measures to reduce acidification problems can continue to be focussed on reducing emissions of S and N compounds to the atmosphere. Although reductions in emissions of S and N compounds have led to dramatic improvements and recovery in acidified freshwater ecosystems, the problem will remain in many areas for decades to come. Further reductions are required if the goal is to permit recovery of all impacted ecosystems.

Climate change is a *confounding factor* in that it can exacerbate or ameliorate the rate and degree of acidification and recovery, both with respect to chemical as well as biological effects. The absence of recovery following reduction in acid deposition, therefore, may simply be the result of the confounding influence of climatic variations. The time-scales of recovery from acid deposition are in many respects similar to those of chronic changes in climate, in part because both drivers act by affecting large pools of S, N, C and base cations in catchment soil. But extreme climatic events, such as droughts, cause extreme responses that set back the biological recovery process, and slow down the progress towards a stable ecosystem. The interactions are complicated and manifold, and thus the outcomes on ecosystems are difficult to predict and generalise.

Both acid deposition and climate change are caused by emissions of gases to the atmosphere, and largely due to the same types of human activities – burning of fossil fuels and other industrial processes. Clearly there are substantial "co-benefits" to be gained: reductions in emissions of CO_2 by switch to renewable energy sources, for example, will also bring about a reduction in S and N emissions. At the policy level much might be gained by coordinating future emission controls, now dealt with separately under the UNECE LTRAP Convention and the UN Framework Convention on Climate Change.

WORK PACKAGE 5: Climate – toxic substance interactions

Objectives

The aim of WP5 was to study how climatic change may determine redistribution of pollutant in the freshwater ecosystems. That is, what will be the redistribution of toxic substances as consequence of temperature changes and how climatic dependent changes such as dust transport, soil erosion, organic matter degradation, surface hydrology and drainage patterns, etc. may influence the redistribution of long-range transported pollutants.

Work package 5 seeks to address five key questions;

1. How will climate change affect the loading of toxic substances to headwater systems?
2. What effect will temperature change have on the redistribution and uptake of toxic substances?
3. Will increases in precipitation enhance the mobilisation of mercury and methyl mercury in soils?
4. Will climate change accelerate the release of toxic substances from soils to freshwater ecosystems?
5. How will changes in river discharge affect trace metal remobilisation from floodplain sediments?

Achievements

The main achievements relate to the progress made with addressing the five key questions.

How will climate change affect the loading of toxic substances to headwater systems?
Temperature increases for long-range transport of pollutants results in increases in diffusion rates, shift in partition equilibria from condensed phases to the gas phase, increases in biotic metabolism and abiotic reaction rates, higher concentrations of hydroxyl radicals in the atmosphere and changes in rain, wind and convective mixing patterns among others. The results obtained in Euro-limpacs indicate that temperature increase will be more relevant for persistent organic pollutants than for heavy metals. It will involve a general increase of concentrations of these organic compounds in the atmosphere at remote sites and some degassing from areas where they are now retained (cold spots). It will also enhance the long-range transport of semi-volatile compounds recently introduced into the environment such as polybromodiphenyl ethers. The global concentrations of these compounds have not reached "steady state" conditions yet.

Long-range transported metals, polycyclic aromatic hydrocarbons and semi-volatile organochlorine compounds in headwater systems accumulate in the food web and fish, the higher headwater predators. Intake by these organisms depends on lake characteristics (e.g. water depth for Polycyclic aromatic hydrocarbons (PAHs)), and organism properties (e.g. metabolic efficiency for different organic pollutants and trophic status). Euro-limpacs has shown unambiguous deleterious impact on the health of the organisms living in these remote ecosystems as consequence of exposure to these long-range transported pollutants.

There is a clear estrogenic impact in fish as consequence of the presence of PAH and (organochloride) OC in these ecosystems. Toxicity associated with ectopic activation of the aryl hydrocarbon receptor has also been observed to increase in fish following the concentrations of these organic compounds. Oxidative effects involving the activation of the Cytochrome p450 system or the enhancement of reduction mechanisms such as the gutathion sulphide-disulphide system have also been observed in fish. The observation of some of these effects have required the development of new toxicity tests such as the measurement of messeger RNA by quantitative methods which have been implemented in Euro-limpacs for the first time. The identified damaging effects are expected to increase in the future as higher temperatures may enhance transport of semi-volatile and persistent organic pollutants from emission sites to remote headwater systems.

What effect will temperature change have on the redistribution and uptake of toxic substances?

Legacy persistent semi-volatile organic compounds are widely distributed in the geosphere including headwater ecosystems. Currently used pesticides are also found in these remote areas and exhibit high concentration differences between sites. As observed in Euro-limpacs, all these compounds are present in the waters of these remote sites. Snowpacks constitute a significant seasonal polychlorobiphenyl (PCB) reservoir in all lakes and snow trapping is a main mechanism for the incorporation of these pollutants and those of present use in the lakes situated in the coldest sites. Those exhibiting highest temperature dependences are the least volatile (vapour pressures lower than $10^{-2.5}$ Pa) which differs from altitudinal dependences observed in other sites and may be related with the specific winter temperature ranges in the studied areas, e.g. Pyrenees, Alps, Tatras.

Once in the water column these compounds accumulate in aquatic organisms. The OC concentrations in aquatic insects change depending on the metamorphic stage. A non-selective enrichment from larvae to pupae has been observed. These concentration increases may result from the weight loss of pupae during metamorphosis mainly as consequence of protein carbon respiration and lack of feeding. Despite the lack of change in total amount, the concentration increases from larvae to pupae are very relevant for the pollutant ingestion of the higher predators. Intake by trout (or any other predator) are between two and five-fold higher per calorie gained when predating on pupae than on larvae. Although there is an overall effect of higher body burden at increasing fish age a significant accumulation of the more hydrophobic and less volatile compounds is already observed among the younger specimens (1 year old). These highly hydrophobic and low volatile compounds also accumulate in the lake sediments.

A model was elaborated to explain the composition of these persistent semi-volatile organic compounds found in the waters and sediments of these headwater systems. The model took into account the interactions between atmospheric depositional and biogeochemical processes and was used to assess the importance of internal cycling and biogeochemical processes in the accumulation of these pollutants. Seasonal and annual mass balances were investigated. The model captured the essential processes driving the sink of organochlorine compounds. It highlighted the importance of internal lake processes with respect to differences in sediment accumulation, with burial fluxes being an order of magnitude higher for the less than the more volatile compounds, despite near-equal atmospheric inputs. It has also confirmed that the occurrence of these compounds in these lakes is driven by direct atmospheric inputs with limited influence from the watersheds. Diffusive air-water exchange dominated the lake dynamics of the more volatile compounds. A weak temperature dependence of lake sediment concentrations for the more volatile compounds contrasting with enhanced PCB sediment sequestrations at low temperature for the less volatile compound is observed.

The study of persistent semi-volatile organic compounds currently used such as the polybromodiphenyl ethers (PBDEs) in remote areas was performed for the first time in Euro-limpacs. Analyses of these compounds in fish from Pyrenean lakes distributed along an altitudinal transect showed higher concentrations at lower temperatures, as predicted in the global distillation model. Conversely, no temperature-dependent distribution was observed in a similar transect in the Tatra mountains (Central Europe) nor in fish from high mountain lakes distributed throughout Europe. The fish concentrations of PCBs examined for comparison showed significant temperature correlations in all these studied lakes. Cold trapping of both PCBs and PBDEs involved the less volatile congeners. In the Pyrenean lake transect the concentrations of PCBs and PBDEs in fish were correlated despite the distinct use of these compounds and their 40 year time-lag of emissions to the environment. Thus, it was observed that temperature effects have overcome these anthropogenic differences constituting at present the main process determining their distributions. In contrast, the cases of distinct PBDE and PCB behavior in high mountains is likely to be a reflection of the early stages in the environmental distribution of the former since they have been under secondary redistribution processes over much shorter times than the latter.

2,2′,3,3′,4,4′,5,5′,6,6′-decabromodiphenyl ether (BDE-209) is the primary component (>97%) of commercial deca-BDE, the mixture of polybromodiphenyl ethers that is not under restricted use. The low vapour pressure (subcooled vapour pressure = $10^{-8.7}$ Pa) and high hydrophobicity (log Kow = 9.97) of this compound suggest limited atmospheric transport. However, identification of this compound in rock biofilms, macroscopic algae and sediments, but not in fish, from high mountain lakes of the Pyrenees and the Tatras shows that this compound can be transported over long distances. This is again a result obtained for the first time in Euro-limpacs.

The observed temperature dependences of the above compounds suggest that a general remobilization of OC accumulated in high mountain areas could take place as consequence of the general warming of these areas, currently forecasted in climatic change studies. Warming should involve higher volatilization to the atmosphere of the compounds retained in soils, snow and water. This has in fact been observed in Euro-limpacs when comparing the seasonal differences in atmospheric deposition of these pollutants. Increases in atmospheric concentration will involve greater contamination of organisms, including humans.

Will increases in precipitation enhance the mobilisation of mercury and methyl mercury in soils?

Experiments simulating increasing precipitation in lake catchments have shown that climate change may lead to higher transport of methylmercury (MeHg) from forest soils to streams and lakes. In addition, the THERMOS experimental changes in lake stratification simulating variations in wind speed and total lake heat content showed that MeHg only occurred in the oxygen free layers. Thus, oxygen concentrations seem to determine MeHg production at layers with intensive sulphate reduction. The climate induced changes in oxygen and heat content of lakes may consequently affect MeHg production in lakes. This will be highly dependent on lake characteristics and stratification pattern.

Studies on the influence of liming in the accumulation of MeHg in fish have shown that $CaCO_3$ neutralization results in lower accumulation of Hg in fish. Food web studies with stable isotopes indicate that these accumulation processes are more related with water quality and its subsequent influence on the formation of MeHg than on food web intake.

<u>Cathment irrigation experiment (Gårdsjön)</u>

This experiment sought to investigate the impacts of increased precipitation on leaching of total mercury and methylmercury from forest soils. Forest soils in Boreal regions have accumulated large stores of mercury and external factors such as forestry have been shown to enhance the formation and leaching of methylmercury. Climate change in boreal areas is expected to involve changes in precipitation and therefore changes in soil water saturation and hydrological flowpaths.

The main irrigation of a small catchment from the Gårdsjön area was performed during May- October 2005. Sampling and measurement of total- and methylmercury (and basic water chemistry parameters) in run-off was conducted at high frequency during the experimental period and continued at a lower frequency until the end of the project (January 2009).

The initial results (Figure 9) showed dramatic increases in methylmercury from the catchment 2 months after start of the the irrigation period. This was attributed to the appearance of anaerobic conditions in the partially water saturated forest soils possibly enhanced by relatively warm and wet conditions in the summer period. After the completion of the irrigation experiment, methylmercury concentration decreased slightly but not back to initial levels. Periods of increased concentrations of methylmercury were observed occasionally 2 years after increased irrigation

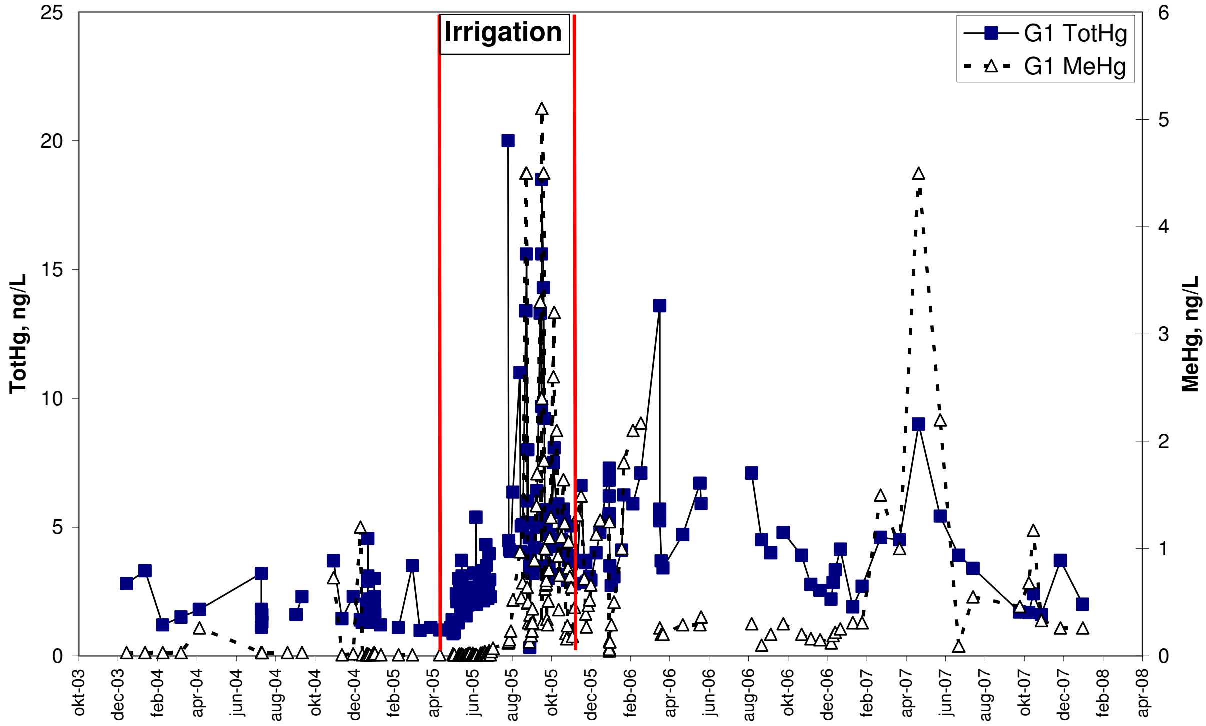


Figure 9. Concentrations of methylmercury in run-off water from experimental catchment. The irrigation experiment was continued from May to October 2005.

Will climate change accelerate the release of toxic substances from soils to freshwater ecosystems?

The studies comparing the composition of toxic substances in soils and lake sediments show that heavy metal transfer from catchment to lakes (or freshwater ecosystems) may eventually increase at higher ambient temperature due to increasing rates of soil organic matter degradation. Organic content in soils is one of the main properties determining retention capacity for metals and also semivolatile organochlorine compounds. However, the observed heavy metal inputs into the lakes that have been considered for study in this WP are mostly related to atmospheric deposition of geochemically unreactive forms.

Higher retention of semivolatile organochlorine compounds in lake sediments than in catchment soils has been observed. The difference may be related to the low temperatures that are currently encountered at the bottom of the lake water column and the consequent depletion of sediment bioturbation in these cold environments. In contrast, air transported polycyclic aromatic hydrocarbons (PAH) exhibited better preserved distributions in the superficial layers of soils than in lake sediments which points to significant PAH degradation processes, e.g. during lake water column transport, before accumulation in the latter. Post-depositional transformation was also different in both types of environmental compartments. Thus, lake sediments exhibited higher preservation of the more labile PAH involving lower degree of post-depositional oxidation. According to these observations increasing temperatures must give rise to less retention and higher degradation of PAH than organochlorine compounds.

How will changes in river discharge affect trace metal remobilisation from floodplain sediments?

The experiments performed within this WP have shown higher soil to water heavy metal transfer at higher temperatures. This increased mobility is enhanced by higher rate of organic matter decomposition and therefore less soil retention. Flood re-wetting is also increasing metal mobility.

WORK PACKAGE 6: Integrated catchment analysis and modelling

Objectives

WP6 had the following specific objectives: (i) to develop a state-of-the-art modelling tool-kit to analyse and understand hydrochemical, and ecological behaviour occurring in aquatic ecosystems; (ii) to apply this modelling tool-kit to a range of catchments being studied in WP1-5; (iii) to investigate the process interactions that occur within these catchment systems and to investigate the interactions occurring between rivers, lakes and wetland systems; (iv) to utilise the models to assess the impacts of climatic change, land-use change and changes in atmospheric deposition across Europe and deliver scenario results to WP7-9; (v) to use the modelling tool-kit together with the socio-economic tools being developed in WP9 to evaluate the impacts of socioeconomic-driven change and deliver these results to WP7-9; and (vi) to investigate methods of mitigating the impacts of environmental change across Europe.

At the end of the Project a number of end-results were envisaged: a state-of-the-art toolkit for modelling aquatic ecosystems; reports of investigations into river, lake and wetland interactions; reports assessing the effects of climate change and changes in land use and atmospheric deposition on aquatic ecosystems across Europe; reports on the effects of socio-economic-driven change on aquatic ecosystems; and some investigation of methods of mitigating the impacts of environmental change across Europe. This report shows that WP6 has achieved these aims, sometimes in partnership with other workpackages, though the work has of course not gone precisely as planned when Euro-limpacs was designed six years ago.

Achievements

It is very difficult to select highlights to represent the whole effort of research in the Workpackage over 5 years. Nevertheless, a number are summarised below.

Example 1 Calibration of INCA models – an example

This represents an activity that many WP6 partners have engaged in: calibrating one of the INCA family of models to a dataset and using it to make climate change predictions. In this case, INCA-N was calibrated to two catchments in Finland (Figure 10). The calibrated models were used to make climate change predictions with different scenarios (Figure 11). It is clear that the patterns of nitrogen flux change considerably as the climate alters.

In Savijoki, the snowmelt-induced flow peak disappeared with all climate change scenarios, and N mineralization increased in autumn, leading to a 30-70% increase in N flux. In Mustajoki the hydrological changes were more varied, including deeper winter snowpacks in some scenarios and hence more runoff. Overall there was a 10-30% increase in nitrogen fluxes.

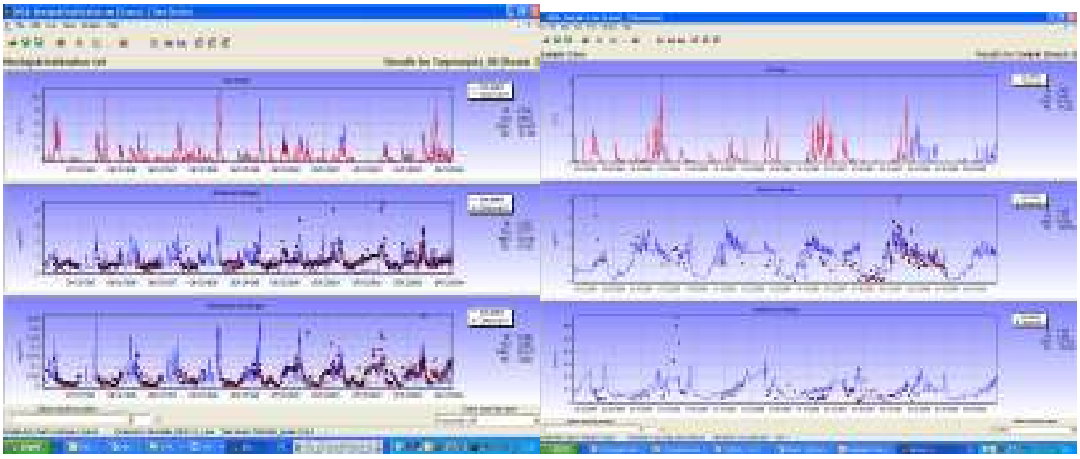


Figure 10: INCA-N calibrated to the Savijoki (left) and Mustajoki (right) catchments in Finland. Red=data, blue=modelled, and the boxes from top to bottom are flow, nitrate and ammonium concentrations.

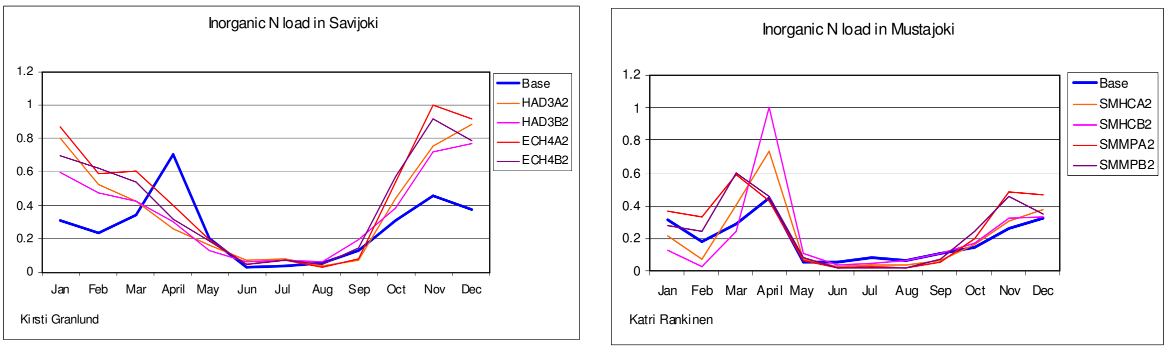


Figure 11: Seasonal pattern of nitrogen flux in Savijoki and Mustajoki at present and with various climate change scenarios.

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Example 2: Modelled N Export from the Terrestrial to the Aquatic Environments in Finland

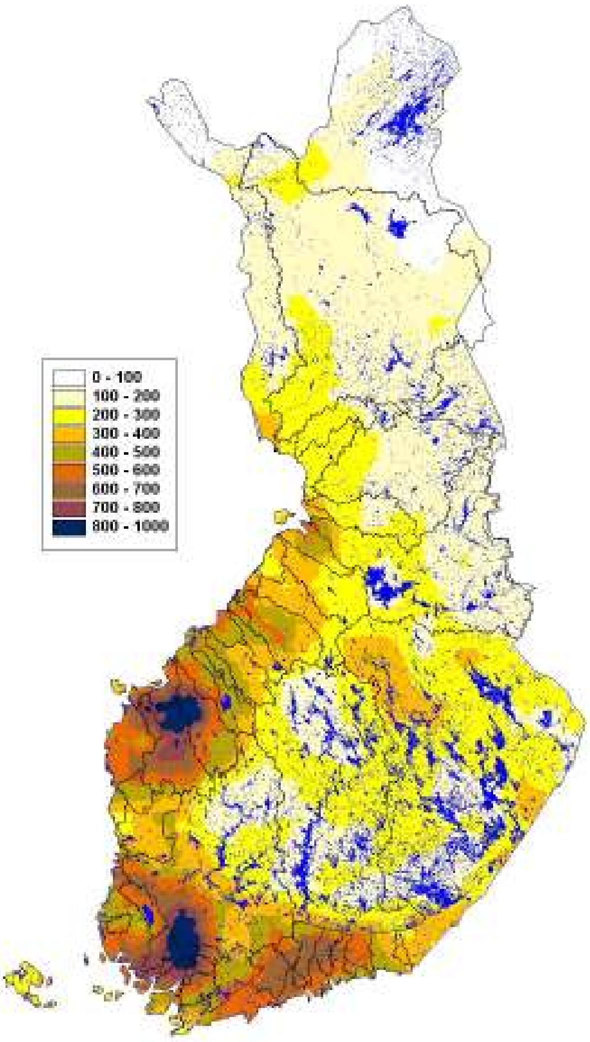


Figure 12: Modelled N Export from the Terrestrial to the Aquatic Environments in Finland

The second example, also from SYKE in Finland, is a reminder that dynamic, mechanistic models are not the only ways in which models can be used to assess the effects of climate change. Figure 12 is a map of Finland which shows the total N export (kg N $km^{-2}a^{-1}$) from soil into water on a 1 x 1 km scale (Lepistö et al, 2006). This has been produced using a GIS-based model N_EXRET. The estimated total export from river-basins in Finland was 119 000 tonnes N a^{-1} for the period 1993 to 1998 based on N export from different land use types, incorporated with estimates of N inputs from atmospheric deposition and point sources. Agriculture contributes 38% of the total export, varying from 35-85% in the south-western basins and 0-25% in the northern basins (Fig. 12). This estimate of N export from agriculture was based on regional N balances together with data from small agricultural research catchments. Forestry contributes on average 9%, with increasing dominance towards eastern and northern parts of the country. Of the total N input to Finnish river-systems, 0 to 68% was retained in surface waters and/or peatlands, with a mean retention of 22%. The highest retention of N (36-61%) was observed in the basins with the highest lake percentages. The lowest retention (0-10%) of N was in the coastal basins with practically no lakes. In the national N mass balance, 38

000 tonnes N a^{-1} (32%) was estimated as lake retention and 4 000 tonnes N a^{-1} (3%) as retention in peatlands (Lepistö et al, 2006).

Climate change operates on a global scale, and so modelling must be capable of being scaled-up to an appropriate scale also. The EU Water Framework Directive is also based on the reactions of large river basins. This work has not only produced something of fundamental interest but also provides a basis for informed decision-making.

Reference

Lepistö, A., Granlund, K., Kortelainen, P. & Räike, A. (2006). Nitrogen in river basins: Sources, retention in the surface waters and peatlands, and fluxes to estuaries in Finland. *Science of the Total Environment* 365, 238-259.

Example 3: Using monitoring and modelling data to increase process understanding - the Simojoki River in northern Finland (Lepistö et al, 2008).

In common with many northern hemisphere rivers, a significant increase in total organic carbon (TOC) concentrations has occurred in the Simojoki (Fig. 13). There is also a lot of variability. Statistically significant upward trends were also detected for TON concentration and flow of the river during 1976-2005. The annual runoff was 27% higher during the 1990s than during the 1980s, accounting for only part of the increase in the TOC and TON outputs which increased by 38% and 42% respectively. Hydrological fluctuations, including longer drought/wet periods are important. For example the drought period of 1994-1997 with low concentrations was followed by high TOC and TON concentration peaks in 1998-2000. Average soil temperatures in winter (January-April) in the 1990s were 1.6-2.1 °C higher than in the 1980s. This increase may have contributed to increasing trends in organic N concentrations particularly during winter low flow, due to increased organic matter decomposition rates during the dormant season. These changes in decomposition rates might further intensify in warmer climatic conditions (Lepistö et al, 2008). Higher TOC and TON concentrations were detected during high flows in Autumn in particular. There were increasing trends organic N concentrations particularly during winter low flows. This may be first the sign of increased organic matter decomposition rates which might further accelerate with climatic warming, though changes in both hydrological dynamics and in catchment soils probably contribute in this catchment.

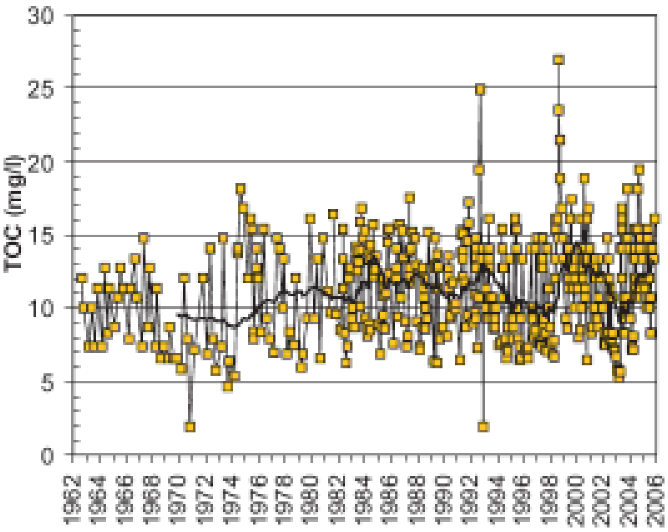


Figure 13. TOC concentration time-series at the Simojoki river outlet during 1962-2005. Single observations are shown together with the 30 point moving average (Lepistö et al., 2008).

Example 4: Using monitoring and modelling data to increase process understanding - the Piburger See in Austria).

Figure 14 shows measured data and model simulations using the INCA-N model. The INCA-N model (blue line) was calibrated to the 2003-7 period, and fits the observed data (red squares) reasonably well over that period. However, if the calibrated model is used to hindcast (estimate past concentrations) to 1987, it can be seen that the model over-predicts concentrations in the past. This is a sign something may have changed in the catchment to increase nitrogen outputs. Neither air temperature, precipitation, deposition nor fertiliser application has changed significantly since the mid 1980s. Forest covers more than 80% of the catchment, and increasing forest age may be reducing the amounts taken up by trees, or possibly increasing nitrate release from forest soils. At least this generates a hypothesis for further investigation.

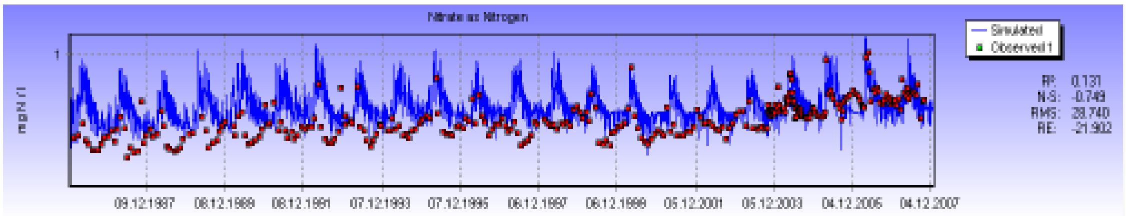


Figure 14. Measured and modelled nitrate-N concentrations at the Piburger See, Austria

Example 5: Extending the MAGIC-lite model

The MAGIC-lite daily time step soil acidification model was extended to include additional organic aluminium processes and improved integration of with the surface water flow model PEARLS/routing. The models were run for the Conwy catchment using daily climate change scenario data from 2002-2100 derived from the ECHAM4 model run by SMHI (Sweden) for the SRES scenarios A2 and B2. This gave daily estimates of ANC reach by reach in the Conwy river network. Monte Carlo estimation for both scenario and soil drainage variables provided empirical probability distributions of ANC. The MAGIC-lite/PEARLS/routing models now form an integrated catchment-scale model in a framework which is applicable to a range of water quality variables. A major achievement under this Euro-limpacs task has been the completion of the MAGIC-lite model to provide a causal link to the pre-existing PEARLS/routing model, allowing stream water quality to respond directly to atmospheric deposition drivers, while accounting for key soil processes. As an example, Figure 15 shows the predicted acid neutralising capacity (ANC) for the years 2095-2099 at the mouth of the River Conwy in North Wales.

Each point is the mean of twenty realisations involving Monte Carlo sampling of the input parameters. The pronounced seasonal variation is obvious, as is a considerable amount of day-to-day variation. Both these are seen in current observed data, highlighting the ability of the model to reproduce realistic patterns of behaviour. The A2 scenarios tend to produce higher values than the B2 scenarios in summer, but lower values in winter. The ANC in general is higher than the modelled values for current conditions, showing continued recovery from acidification in spite of climate change. However, the modelled values are biased on the high side compared to observations, and the reasons for this are still being investigated.

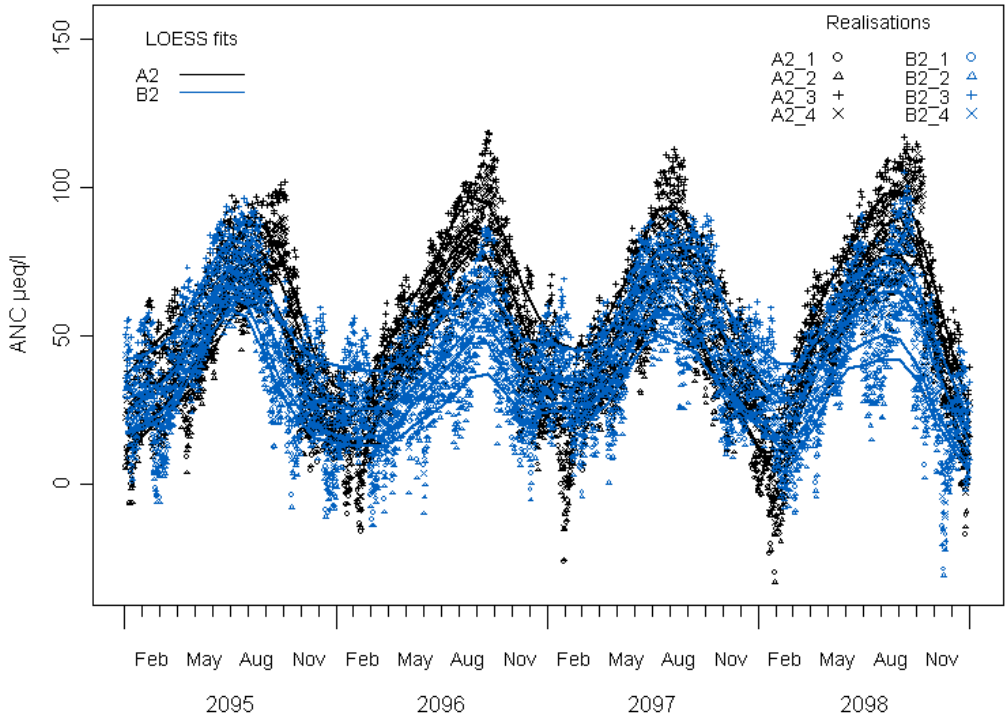


Figure 15. Predicted ANC at the mouth of the River Conwy in North Wales (NERC)

WORK PACKAGE 7: Indicators of ecosystem health

Objectives

Climate change will lead to complex cause-effect chains, the link between them provided by many interacting environmental parameters, which are directly or indirectly influenced by temperature and precipitation. The response of the biota is, therefore, less predictable than the response of chemical or hydrological variables. On the other hand, biotic parameters such as species richness, community composition or functional diversity integrate the complex effects of many stressors on freshwater ecosystems, including those directly or indirectly associated with climate change. This has been the reason for using biotic communities (such as phytoplankton, invertebrates or fish) for monitoring the ecological integrity of European surface waters, as stipulated by the EU Water Framework Directive. The recently established Europe-wide monitoring programmes, however, are mainly targeted at detecting the effects of those stressors that have been dominant in the past, such as eutrophication, organic pollution, acidification or hydromorphological degradation. Climate change is not specifically targeted by the Water Framework Directive, though the climate-induced pressure on European aquatic ecosystems is likely to increase in future.

The direct and indirect effects of climate change on the biota of lakes, rivers and wetlands will depend on ecoregion, ecosystem type, and on other stressors affecting the water body. Owing to the natural variability of European surface waters and the effects of many other stressors, no simple dose-response relationships among climate change and biotic effects can be expected; the linkages between climate change and biodiversity patterns cannot be understood without having the overall complex picture in mind.

The objectives of WP7 are to suggest indicators for the effects of climate change on lakes, rivers and wetlands, their pathways, importance, and the magnitude of change. The term "indicator" is used here in a broad sense, i.e. a simply detectable sign of a complex process that can be used as an early warning of ecosystem change. Indicators may be chemical, hydrological, morphological, biological or functional parameters, which reflect key processes influenced by climate change and which are relatively simple to monitor.

In summary, WP7 addressed the following questions:

1) Which parameters are suitable as indicators for climate change effects on freshwater ecosystems?
2) How can the knowledge base on (particularly biological) indicators be extended to improve detection of various stressors and to enable indication of climate change effects?
3) How can extended knowledge on indicators be best integrated into existing assessment and monitoring systems and can climate change effects be incorporated into monitoring programs for freshwater ecosystems?
4) How can different types of indicators (chemical, 'functional', biological) be used in concert?

Achievements

A detailed description of the workpackage achievements is given in the Key questions part of the Project web-site, in the WP Task summary report (**Deliverable 426**) and in the description of work below. Here we give a brief summary quantifying the workpackage output, in terms of reports, journal articles, books, databases and websites. We further describe in detail three case studies of WP7 results, relating to books produced by WP7, a journal article and a website.

Given the applied approach of WP7 the focus was more on producing databases and websites rather than journal articles. Overall, WP7 has produced two websites providing data on distribution patterns and ecological preferences on about 18,000 European freshwater taxa (www.freshwaterecology.info) and on different indicator types (www.climate-and-freshwater.info), six books (two of which have already been published), 45 reports and 27 journal articles (16 of which have yet appeared). The journal articles and reports are listed in the Project bibliography.

Reports and deliverables

Overall, WP7 produced 45 deliverables, one of which relates to Task 1 (meta database), five to Task 2 (chemical indicators), four to Task 3 (functional indicators), 30 to Task 4 (biological indicators), three to Task 5 (linking different indicator types) and two to Task 6 (assessment and spatial extrapolation).

Books

Two books produced by WP7 were published during the lifespan Euro-limpacs, four more books will appear soon after the end of the Project:

- Maltby, E. (ed.) (2009): Functional Assessment of Wetlands; towards evaluation of ecosystem services. Woodhead Publishing, Cambridge.
- Schmidt-Kloiber A. & Hering D. (eds.) (2008): Graf W., Murphy J., Dahl J., Zamora-Muñoz C. & López-Rodríguez M.J.: Distribution and Ecological Preferences of European Freshwater Organisms Volume 1 – Trichoptera. 388 pp. **(see case study 1)**
- Schmidt-Kloiber A. & Hering D. (eds.) (2009): Graf W., Lorenz, A.W., Tierno de Figueroa, J.M., Lücke, S., López-Rodríguez, M.J. & Davies, C.: Distribution and Ecological Preferences of European Freshwater Organisms Volume 2 – Plecoptera. 262 pp. In print. **(see case study 1)**
- Schmidt-Kloiber A. & Hering D. (eds.) (2009): Buffagni, A., Armanini, D.G., Cazzola, M., López-Rodríguez, M.J. & Alba-Tercedor, J.: Distribution and Ecological Preferences of European Freshwater Organisms Volume 3 – Ephemeroptera. In print.
- Schmidt-Kloiber A. & Hering D. (eds.) (2009): Schmutz, S., Grenouillet, G. et al. Distribution and Ecological Preferences of European Freshwater Organisms Volume 4 – Fish. In prep.
- Schmidt-Kloiber A. & Hering D. (eds.) (2009): Besse-Lotoskaya, A., Coste, M. et al. Distribution and Ecological Preferences of European Freshwater Organisms Volume 5 – Diatoms. In prep.

Journal articles and book chapters

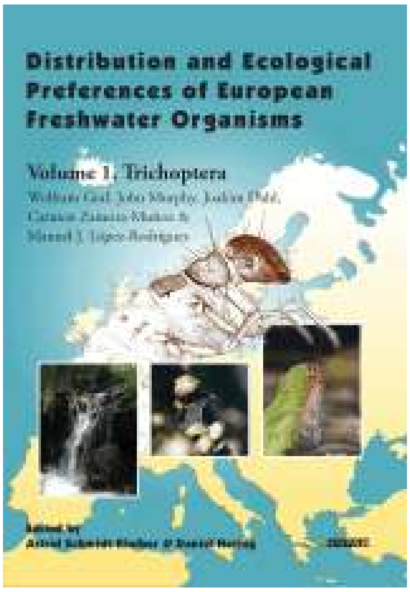
See Project bibliography and **Deliverable 426**

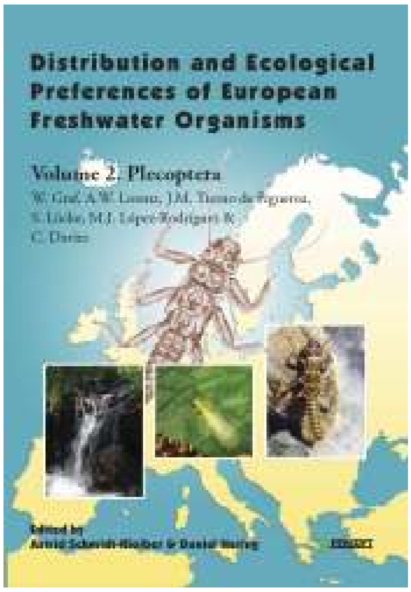
Websites

- The main outcome of the central Task 4 of WP7 is the website www.freshwaterecology.info. It lists ecological preferences and distribution patterns for more than 18,000 European freshwater taxa (about 9,500 benthic invertebrates, 320 fish, 8,800 diatom taxa), as a searchable online database. For each of the organism groups a different number of ecological parameters (macro-invertebrates: 34; fish: 21; diatoms: 36) with different numbers of classified species are available.
- The website www.climate-and-freshwater.info provides an overview of different indicator types and their suitability to detect the direct and indirect impact of climate change on European freshwater ecosystems. It is described in detail under **case study 3** (see below).

Example 1: Book series "Distribution and ecological preferences of European freshwater organisms" (Pensoft Publishers)

This book series provides comprehensive information on the distribution and ecological preferences of European freshwater organisms. The first issue summarises the current knowledge on European caddisflies (Trichoptera), based on the evaluation of more than 1,400 literature references. The distribution within the European ecoregions (including Turkey and the Caucasian region) is given for 1,426 European Trichoptera species and subspecies, categorised into 136 genera and 23 families. A wide variety of ecological preferences is presented as numerical codes, including feeding types, habitat and current preferences, temperature and altitude preferences, life duration and flight periods, and the response to environmental stress.





The second volume on stoneflies (Plecoptera) has been compiled by reviewing more than 1,400 literature references. It covers 571 European stonefly species, categorised into 40 genera and 7 families. Three more issues are about to be printed (on mayflies, fish and diatoms).

This compilation is a unique tool for analysing freshwater biota, both for basic and applied purposes such as ecosystem monitoring and the implementation of European directives in the field of environmental protection.

Example 2: Fish community changes in relation to climate change (from Deliverable 384, Grenouillet et al.)

The aim of this study was to investigate the potential impacts of climate change on stream fish assemblages in terms of species and biological trait diversity, composition and similarity. We predicted the potential future distribution of 35 common stream fish species facing changes in temperature and precipitation regime at 1110 stream sections in France. Seven different species distribution models were applied and a consensus forecast was produced to limit uncertainty between single-models. The potential impacts of climate change on fish assemblages were assessed using both species and biological trait approaches. We then addressed the spatial distribution of potential impacts along the upstream-downstream gradient.

Overall, climate change was predicted to result in a global decrease in species and trait diversity (Fig. 16). Species and trait composition of the fish assemblages was also projected to be highly modified especially in the upstream and midstream sites. In our study changes in assemblage diversity and composition were found to be spatially autocorrelated and exhibited patchy spatial patterns at the national scale. However, at a finer scale, these changes differed strongly along the upstream-downstream gradient. We also predicted a global increase in species and trait similarity between pairwise assemblages indicating a future species and trait homogenization of fish assemblages. Nevertheless, we found that upstream assemblages would differentiate whereas midstream and downstream assemblages would homogenize. Our results suggested that colonization could be the main driver of the predicted homogenization while local extinctions could result in assemblage differentiation.

This study demonstrated that climate change could lead to different impacts on fish assemblage structure and diversity depending on the position along the upstream-downstream gradient. These results could have important implications in terms of ecosystem conservation, as they could be useful in establishing the areas that would need priority protection.

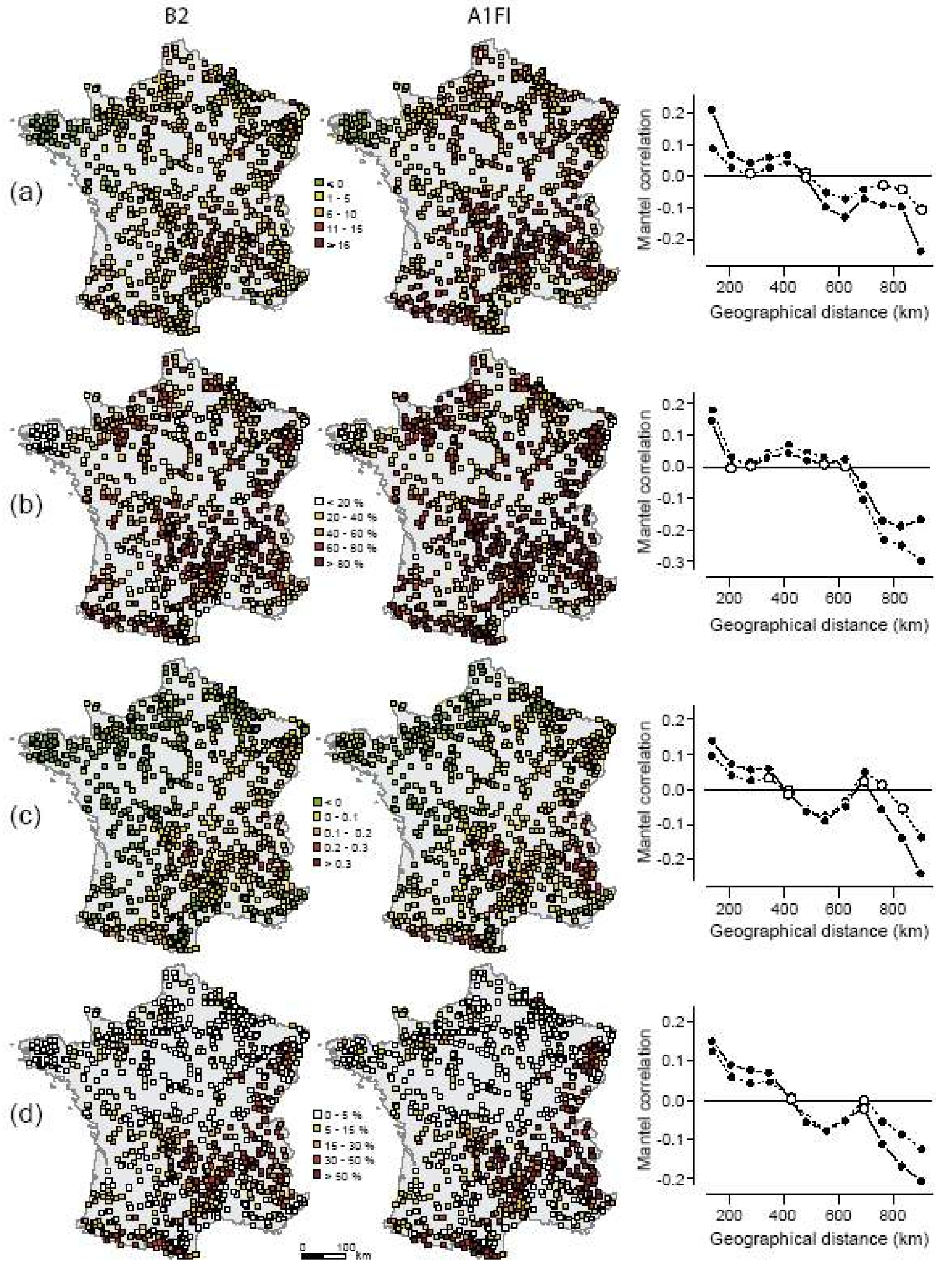


Figure 16: Spatial distribution of predicted impacts of climate change on fish assemblages under B2 (lefthand column) and A1FI (middle-hand column) climate change scenarios: (a) change in species richness, (b) species turnover, (c) change in biological trait diversity and (d) trait turnover. The right-hand column shows partial Mantel correlograms for spatial autocorrelation under A1FI (solid line) and B2 (dashed line) scenarios. Dark circles indicate significant correlations (assessed using a Bonferroni correction) between site dissimilarity and geographical distance (upper class limit in km), given the position along the upstream-downstream gradient (from **Deliverable 384**, Grenouillet et al.)

Example 3: The website www.climate-and-freshwater.info

WP7 has produced databases and case studies for indicating different stress types related to climate change in freshwater ecosystems. The tasks within WP7 were working on different indicator types: chemical indicators (Task 2), functional indicators (Task 3) and biological indicators (Task 4). In addition to these detailed studies the different types of indicators were merged (Task 5). The common product is an "indicator selection tool" available on www.climate-and-freshwater.info.

The indicator selection tool is a searchable website. For broadly defined freshwater ecosystem types, it:

- lists parameters, which are monitored in current monitoring programmes, e.g. for the Water Framework Directive,
- provides information about the major changes in structure, function and communities, which are expected as a result of climate change,
- suggests parameters, which are suited as indicators for the expected changes.

It is based on the literature survey of WP7 (Task 1), the results of the other WP7 tasks and it includes results of other Euro-limpacs workpackages.

The indicator selection tool mainly aims at a broad overview of expected changes in European freshwater ecosystem types following climate change and of parameters suited to detect these changes. Its main purpose is to inform agencies responsible for national monitoring programmes about possible future directions of freshwater monitoring, which have yet not sufficiently been taken into account. The main sections of the website are:

- Water type description: As the website is devided into different water types in different ecoregion types, these paragraphs give a short overview of the pristine status, the most important human impact and supposed climate change impact for each of the types.
- Indicators in current use: These sites describe which types of indicators are presently being used for monitoring European freshwater ecosystems. For selected regions and water types all indicator schemes currently being used or under development (mainly for the purpose of the Water Framework Directive) are listed and described – including the potential impact of climate change on the indicators in question.
- Indicators for climate change impacts: These sites list specific indicators, which are according to WP7 results suitable for detecting the impact of climate change on freshwater ecosystems. The indicators are presented in a standard template, comprising the parameters "Climate region", "Ecosystem type", "Stressor type", "Responding parameter group", "Responding parameter", "Response description", "Secondary effects", "Specification of relevant ecosystem type", "Relevant ecoregion(s)", "Suggested indicators", "Justification of indicators", "Mitigation measures".
- Species affected by climate change: These sites contain a broad selection of species, which are (potentially) endangered by or benefiting from climate change. These are also presented in standard templates. The selection covers a broad range of organism groups and all European ecoregions.


Climate Change
and Freshwater
"indicating the status of freshwater ecosystems under changing climatic conditions."
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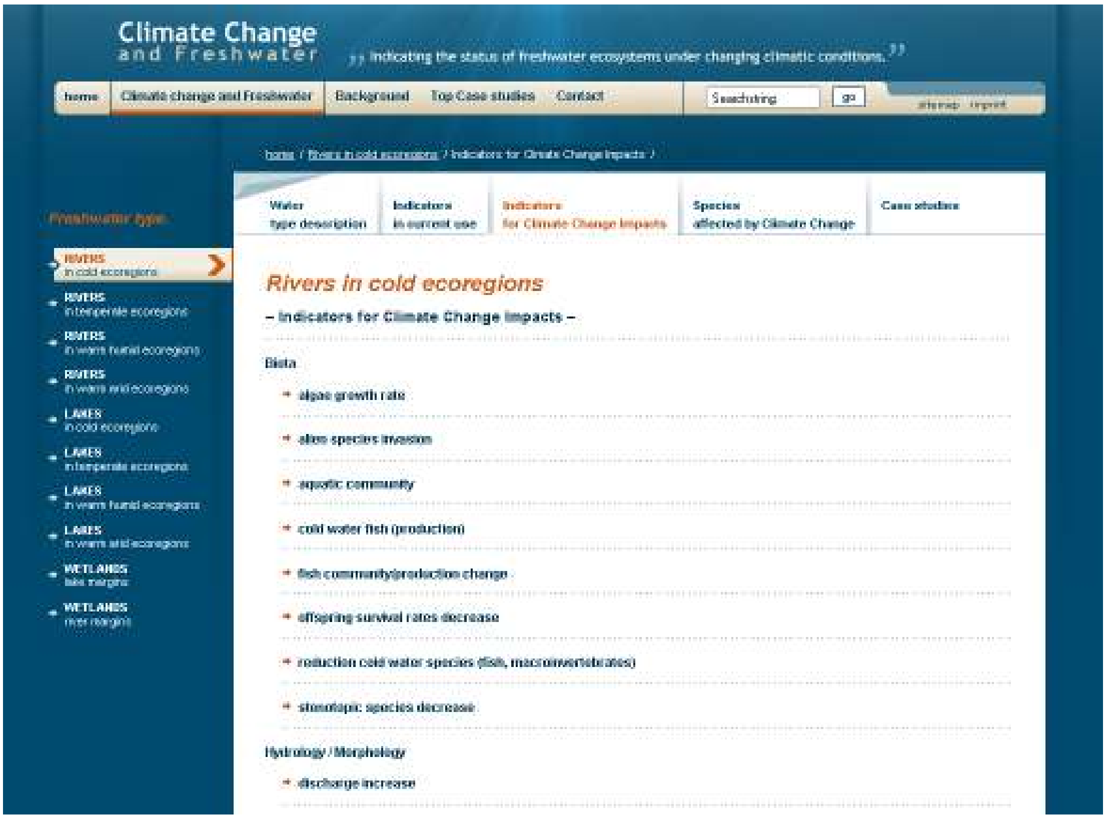
Freshwater type
RIVERS in cold ecoregions
RIVERS in temperate ecoregions
RIVERS in warm ecoregions
LAKES in cold ecoregions
LAKES in temperate ecoregions
LAKES in warm ecoregions
WETLANDS in cold ecoregions
WETLANDS in temperate ecoregions
WETLANDS in warm ecoregions
Climate change - a threat to aquatic ecosystems
Rivers, lakes and wetlands are under intense pressure from multiple use, pollution and habitat degradation. The services that aquatic ecosystems can provide to society have been reduced, and the biota is strongly affected, with several aquatic species disappearing from entire ecoregions.
In Europe, the principal legal instrument to halt the deterioration of aquatic ecosystems is the Water Framework Directive, which aims at restoring aquatic ecosystems back to good status; this is a task for generations. Many indicators have been developed to reflect the status of water bodies and the success of restoration.
Climate change, however, may counteract attempts to restore aquatic ecosystems. It adds additional threats (such as increase in water temperature) and it interacts in complex ways with other stressor types, such as eutrophication.
This website aims to give an overview on how Climate Change affects freshwater ecosystems in Europe and worldwide, and how it could be regarded in freshwater ecosystem monitoring. Individually we provide information on:
Presently used assessment systems for aquatic ecosystems in Europe and how they address Climate Change effects
Case studies addressing the effects of Climate Change on aquatic ecosystems
Indicators potentially suited to detect the effects of Climate Change on European aquatic ecosystems
Aquatic species which are affected by (or benefiting from) Climate Change
Please select the major ecosystem type you are interested in to find out more.
Climate Change and Freshwater
Lowland river
Complex interactions of the river and surrounding wetlands: affected by intense land use and droughts.
Alpine lake
Nutrient poor (oligotrophic) lakes: increased water temperature alters nutrient status and food chains.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Water type description
Indicators in current use
Indicators for Climate Change Impacts
Species affected by Climate Change
Case studies
Freshwater type
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RIVERS in temperate ecoregions
RIVERS in warm humid ecoregions
RIVERS in warm arid ecoregions
LAKES in cold ecoregions
LAKES in temperate ecoregions
LAKES in warm humid ecoregions
LAKES in warm arid ecoregions
WETLANDS lake margins
WETLANDS river margins
Rivers in cold ecoregions
– Indicators for Climate Change Impacts –
Biota
algae growth rate
alien species invasion
aquatic community
cold water fish (production)
fish community/production change
offspring survival rates decrease
reduction cold water species (fish, macroinvertebrates)
stenotopic species decrease
Hydrology / Morphology
discharge increase

- Case studies: The contents of more than 500 papers are being presented, describing individual studies on how climate change is affecting individual sites, organism groups or regions.

All these main categories are divided by broadly defined water types and ecoregions. Further devision comprises biotic, chemical and functional indicators separately for each water type. Response descriptions as well as relevant ecoregions and suggested indicators are mentioned, underlined by literature reference or project output.

WORK PACKAGE 8: Reference conditions and restoration strategies

Objectives

The landscape of much of Europe has been altered for centuries, rendering the isolation of pristine or even relatively minimally disturbed reference sites difficult for the majority of ecosystem types. Nevertheless, a central feature of the European Water Framework Directive (WFD) is that deviations in ecological quality are to be established as the difference between the observed and the expected or reference condition (European Commission 2000). In brief, Member States are required to identify reference conditions to establish the upper anchor of the high – good ecological classification boundary and subsequently to identifying departures from expected that may be caused by anthropogenic stress.

Within this context the main objectives of WP8 were:
i) to improve and demonstrate methods needed to establish reference conditions for different ecosystem types (rivers, lakes and wetlands);
ii) to develop methods for reference condition validation;
iii) to develop and improve methods needed to establish restoration targets;
iv) to evaluate the success or failure of current restoration strategies, and to assess the role of climate change (events, seasonality and long term trends) in influencing recovery; and
v) to assess how restoration targets for different driver-response systems may need modification to accommodate the future impact of climate change.

Achievements

A number of different approaches such as the use of contemporary time series, palaeoreconstruction, historical data, spatial typology and modelling have been used to establish reference condition of selected lakes across Europe. These studies have established reference conditions for selected sites across Europe and contributed to the development of new methods to infer past water chemistry and the identification of spatial reference sites. UCL, CNR and WRI-RAS have completed their work on establishing reference conditions of selected lakes using palaelimnology. Some of the main achievements include CNR's and UCL's development of new methodology to establish reference conditions and the construction of a meta-database.

A major achievement of task 1.1 was the development of a palaeolimnological meta-database ("LakeCores") by *UCL*. This partner also analysed the data to determine the timing and extent of acidification and eutrophication of lakes across Europe, and to define the period that best represents reference conditions (see Deliverable 241, Battarbee et al., accepted).

Approaches commonly used to establish reference conditions have been compared to better understand the uncertainty associated with the use of different methods. As anticipated, our findings indicate that substantial variability exists among methods commonly used to establish reference conditions of European lakes and streams. In brief, CNR has compared the use of different modelling approaches for establishing reference conditions for phosphorus in Italian lakes (see below). Good agreement was found between models of P-loading and diatom-inferred P concentrations. This work was also used to validate a spatial (typology) approach for inferring P concentrations. Regarding acidification, UCL has recently characterised the biological reference conditions for a set of 120+ acid-sensitive lakes in the UK using palaeoecological data. Use of modern statistical data mining techniques to fit palaeoecological transfer functions were found to provide better model fits and reconstructions in circumstances where current techniques have trouble. This work "Assessing the accuracy of diatom-based transfer functions in defining reference pH conditions for acidified lakes in the UK", is published in The Holocene by Battarbee et al. (2008). Comparison of different spatial approaches for establishing reference conditions showed that use of categorical data (like the 'system A' approach described in the EU Water Framework Directive) resulted in poorer discrimination in detecting human-induced change. SLU compared the use of spatial and model-based approaches for detecting change. Comparison of the precision and sensitivity of two different modelling approaches using phytoplankton assemblages to detect human-induced change to nutrients, acidification and urbanization by SLU showed that decision tree models outperformed RIVPACS models in predictive accuracy. This work is being summarised in a paper (Comparison of RIVPACS community models and decision tree species-by-species models for detecting human-induced change) as part of the special issue being put together under Task 3.

The work on the use of reference conditions to establish restoration targets has focused on the use of different methods, such as palaeoreconstruction, analogue matching and modelling, to establish reference condition in areas where contemporary sites are poorly represented or lacking. The Project has seen the extension of the analogue matching approach to different sites and lake types across Europe using diatom and environmental data in the European Diatom Database Initiative (EDDI) combined total phosphorus dataset. The errors associated with using hindcasting methods (i.e. export coefficient models and diatom phosphorus transfer functions) to determine reference conditions have been assessed. The use of palaeolimnological techniques to establish reference conditions for acidified lakes have been evaluated and the use of reference conditions as restoration targets has also been thoroughly assessed during the course of the project.

The role of ecosystem and landscape connectivity in restoring freshwater ecosystems in a climate-proof way has been assessed (see overview paper on the 'Operational Landscape Unit' (OLU) concept by UU-Bio and IVM (Verhoeven, J.T.A et al., 2008: An Operational Landscape Unit approach for identifying key landscape connections in wetland restoration. *Journal of Applied Ecology* 45: 1496-1503). The OLU concept is a tool to aid restoration and conservation management in applying restoration and conservation efforts at the rights scales and to the right components of a landscape, to ensure species survival and ecosystem functioning on a long-term and in a climate-proof way. The OLU approach as a tool has been discussed with stakeholders at stakeholder meetings in the Netherlands and has been presented as a concept at international scientific meetings.

Example 1: The use of sedimentary pigments to establish the reference conditions of lake ecosystems

The example presented here highlights the work that CNR has done on developing new methodology to establish reference condition of lake ecosystems from sedimentary pigments, particularly carotenoids. Inference of past total phosphorus concentrations using sedimentary pigments (in particular total carotenoids) were found to agree generally well with TP values measured by long-term water quality monitoring programs and with diatom-inferred TP. Past studies have shown that sedimentary total carotenoid (TC) and total chlorophyll derivative (CD) concentrations are highly correlated with primary productivity estimates made during the period of sediment deposition. From these studies CNR developed equations for determining lake reference conditions in terms of algal productivity.

A comparison between different TP reconstructions in a core form Lake Maggiore shows that the pigment method here proposed better approximate the actual total P value measured in lake water during recent times (Fig. 16). The three P models are in good agreement for the older periods.

From a practical point of view (i.e. for defining a restoration target) the difference between present and past phosphorus concentrations (the 'state-changed scheme' according to Battarbee 1999) indicates the degree of human impact on lakes in past decades. Furthermore, the calculated values for the past approximate what should be achieved, in terms of nutrient abatement, with the use of treatment plants. All the information needed for any restoration programme should, however, be verified and evaluated against the recent oligotrophication phase of many lakes and the impact of increasing temperature.

One methological gap in the pigment approach is the paucity of knowledge about the sedimentological processes and mechanisms of deposition and degradation of chlorophylls and carotenoids for some lake. The pigment and P model should be evaluated for natural lakes not stressed by human impact, in order to disentangle eutrophication from climate warming. Other limiting factors of primary productivity (e.g. nitrogen) should be evaluated and more lakes with different trophic features added to the database.

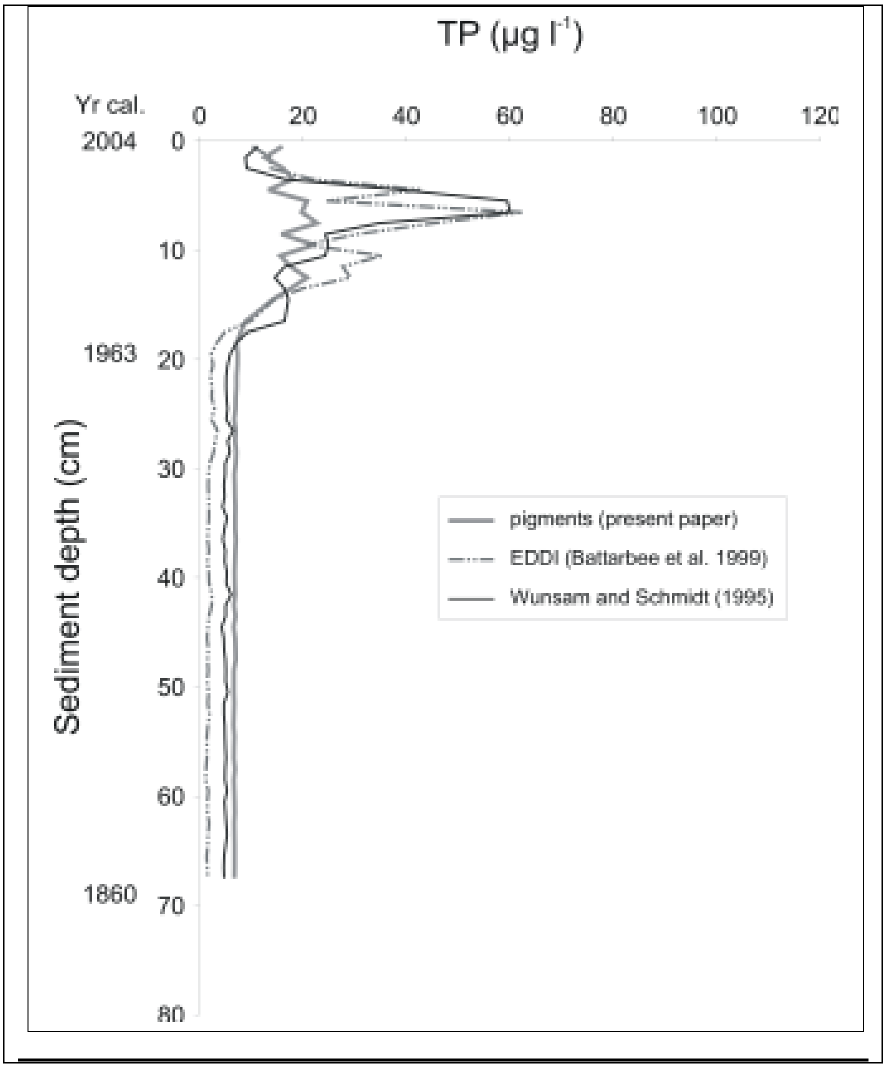

Figure 16 Comparison among different TP model reconstructions in a core of Lake Maggiore using the model proposed by Guilizzoni et al. and the two models based on diatom remains: a weighted averaging model calibrated on the pan-European "EDDI" data set, and a similar model calibrated on a regional central-European data set elaboration (Wunsam and Schmidt 1995).

Example 2: Comparison of methods used to establish reference conditions

Battarbee et al. (2005) is used to illustrate the use of different methods to establish reference condition. These authors used contemporary monitoring data (pH and diatoms from 1991 to the present day) from the Round Loch of Glenhead, an acidified Scottish loch (cf. Flower & Battarbee 1983), to evaluate the performance of three pH inference models. Each of the pH inference models, based on different calibration training sets, was used to reconstruct pH from the diatom assemblages of three cores taken in different years, resulting in nine reconstructions of pH (Fig. 17). Taking the year 1800 AD as the reference date, the pH values for this date, derived using the transfer functions, were compared with the pH inferred using a diatom-cladocera modern analogue technique and with hindcast values using the MAGIC model (Model of Acidification of Groundwaters In Catchments).

Comparison of the different methods showed that the inferred reference pH for the Scottish loch in 1800 AD varied by less than an order of magnitude (between 5.5 and 6.1). Relatively good agreement, with respect to both between-core and between-training set differences, was found between the diatom-pH transfer functions. Diatom-pH transfer functions indicated a reference pH of between 5.5 and 5.7, and the weighted average pH using the modern analogue method gave a similar value (5.8). By contrast, the MAGIC-model hindcast estimate for 1850 was somewhat higher (6.1). Although there is no way to ascertain which estimate is the most accurate, the discrepancy between the MAGIC hindcast and the diatom-based values is the most striking, and this discrepance may be due to MAGIC not allowing for DOC concentrations to have been higher in the past when sulphur deposition was lower.

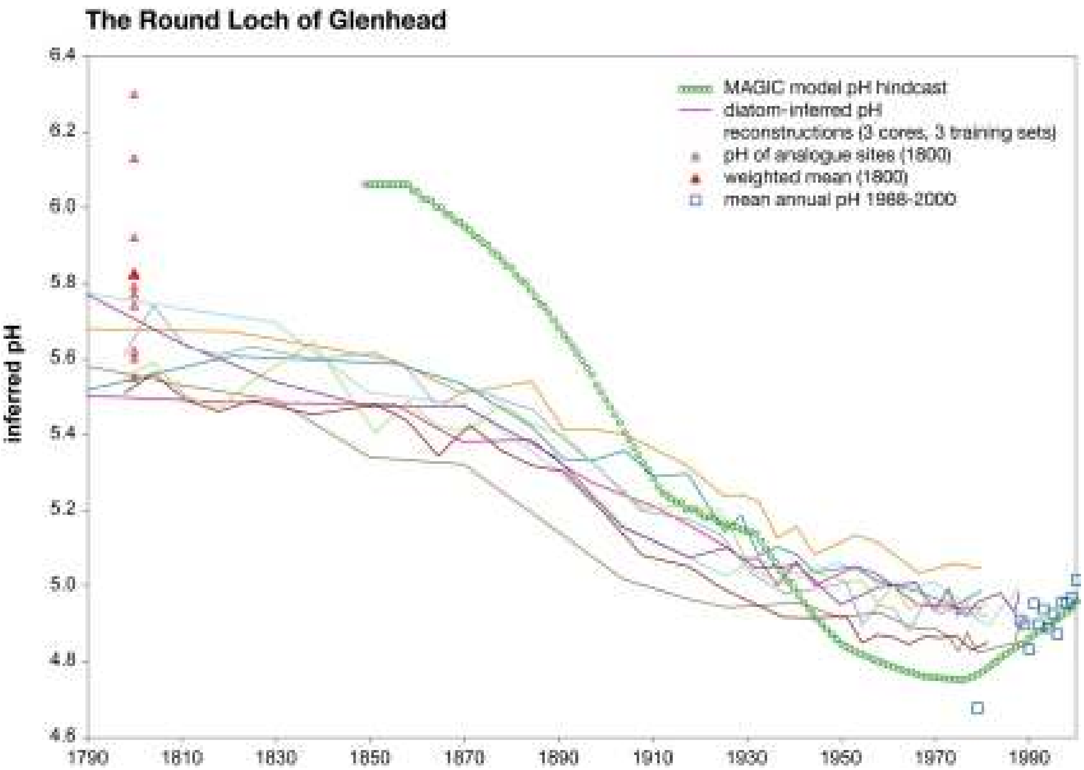

Figure 17. Comparison of pH reconstruction outputs and annual measured pH. Chronology of diatom inferred pH according to SWAP (The Surface Water *Acidification* Programme), UK and EDDI models (fine lines) for 210Pb dated samples from three sediment cores (RLGH 81, RLGH 3 and K05). The RMSEP of the SWAP, UK and EDDI training sets are 0.38, 0.31, and 0.25 pH units respectively. Modern annual pH of nine lakes providing the strongest biological analogues for a pre-acidification (circa 1800) sediment sample (open triangles) and the weighted average of these (filled triangle). MAGIC model pH reconstruction (open circles) and mean annual average pH for the period 1988e2000 and the year 1979 (open squares). From Battarbee et al. (2005).

This study clearly demonstrates the usefulness of hindcasting methods for establishing the reference condition of lakes where no present-day spatial analogues exist. However, the modelling and contemporary time-series also indicate substantial variability on decadal and yearly time scales; trends that are clearly the result of human-generated changes in surface water quality. More knowledge is needed concerning how climate change, both relatively short- (interannual) and long-term (shifts in baseline conditions) variability, affects our ability to detect degradation and recovery. The latter is particularly important as many European countries move towards restoring the ecological quality of inland waters as mandated by the Water Framework Directive.

Example 3: Operational Landscape Unit approach for identifying key landscape connections in wetland restoration.

The Operational Land Use (OLU) concept is a tool to aid restoration and conservation management in applying restoration and conservation efforts at the appropriate scales and to the appropriate components of a landscape, to ensure species survival and ecosystem functioning on a long-term and in a climate-proof way. Figure 18 shows the main steps to be taken in the OLU approach. The OLU concept indicates that restoration strategies are currently often focussed on too narrow a spatial scale, and do not take into account (sufficiently) the importance of connections between sites and ecosystems in the landscape. For sustainable conservation of natural sites in a future world of climate change, the connections between a restoration site and the whole landscape needs to be considered when devising restoration plans. The OLU approach as a tool has been discussed with stakeholders at stakeholder meetings in the Netherlands and has been presented as a concept at international scientific meetings.

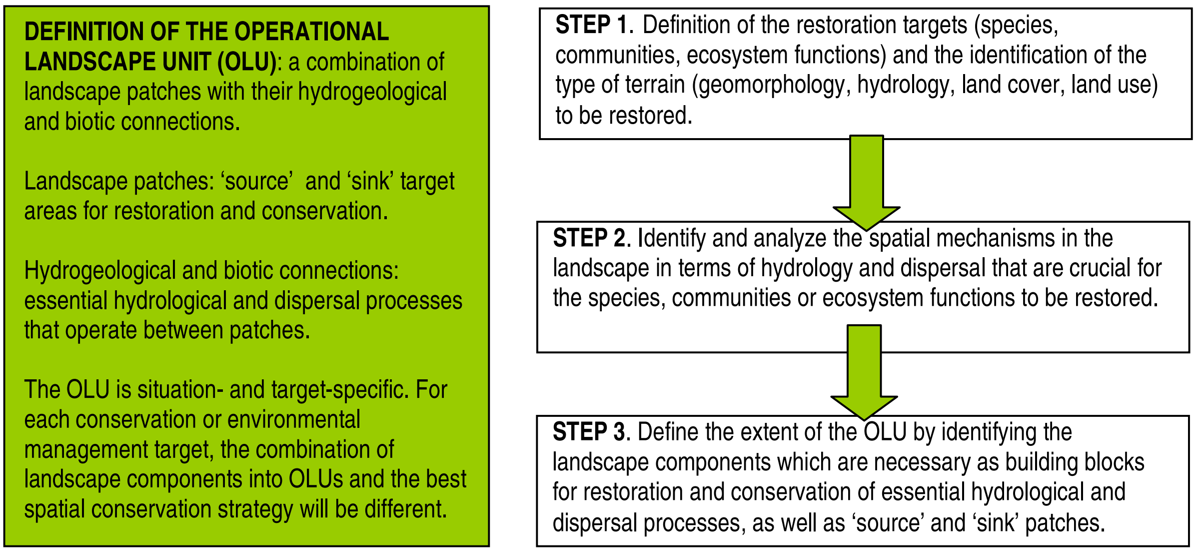

Figure 18. Overview of the OLU approach as a tool to aid restoration and conservation management in applying restoration and conservation efforts at the rights scales and to the right elements of a landscape, to ensure species survival and ecosystem functioning on a long-term and in a climate-proof way.

To apply the OLU concept and ensure a long-term climate-proof, landscape-scale approach to restoration and conservation efforts, knowledge is needed on hydrological and biological (dispersal) connections. Scientific understanding on the strength and functioning of ecosystem connections via dispersal of plants has been deepened, with results being made available to the wider scientific community through 4 publications by UU-Bio (Soons, M.B. and J.M. Bullock (2008) Non-random seed abscission, long-distance wind dispersal and plant migration rates. *Journal of Ecology*; Soons, M.B., Cet al., (2008) Small seed size increases the potential for dispersal of wetland plants by ducks. *Journal of Ecology*; Soons, M.B., et al., (ready for submission) Wetland plants disperse their seeds selectively to the best sites for germination and growth.; M.C. Wichmann et al., (2009) Human-mediated dispersal of seeds over long distances. *Proceedings of the Royal Society B.*) and through presentations at numerous international scientific meetings. Summarizing, wetland plants are dispersed, depending on their plant and seed traits, by wind, water, waterfowl and humans. Water and waterfowl have the potential to disperse seeds of some species over very long distances (up to 100s of km), but most species will be dispersed only over landscape scale distances by any dispersal vector. This means that the dispersal capacity of plant species should not be overestimated and taken into account when restoration sites are selected, especially when biodiversity targets need to be attained in short time spans. Thus, restoration projects will be most successful (in terms of attaining target biota) if they are located near to, and connected well to, sites where these biota are already present. Spatial connections at the landscape scale are thus very important in any future restoration projects.

Example 4: Restoration of in-stream woody debris in mountain and lowland streams

To assess restoration of streams, two measures in particular were investigated: restoration of in-stream woody debris in mountain and lowland streams and re-meandering of mountain and lowland streams (Alterra, UDE and BOKU). In general, replacing of large woody debris and removing of embankments resulted in increased habitat heterogeneity in the streams, but biodiversity developments were slow and not always successful. In re-meandering mountain and lowland streams, macro-invertebrates did not reach species compositions close to natural references within a few years after restoration (UDE, Jaehnig SC, et al., (2008) Hydromorphological parameters indicating differences between single- and multiple-channel mountain rivers in Germany, in relation to their modification and recovery. *Aquatic Conservation: Marine and Freshwater Ecosystems*; Jaehnig SC, et al., (2009) Habitat mosaics and macroinvertebrates - does channel form determine community composition? *Aquatic Conservation: Marine and Freshwater Ecosystems*; Alterra, Deliverable 232). Wood additions have been shown to have positive effects on some fish species (UDE: Kail J., et al., 2007 - The use of large wood in stream restoration: experiences from 50 projects in Germany and Austria. *Journal of Applied Ecology*). After adding woody debris in lowland streams in the Netherlands, no differences between number of taxa, families and macroinvertebrate abundance recorded in control and restored sections were observed. However, changes in feeding and habitat groups provided support for community functional changes due to wood addition (Figure 17), in favour of some WFD macroinvertebrate indicator species. These findings suggest that re-introducing wood is an appropriate restoration technique to improve the hydromorphological and ecological status of Dutch lowland streams (Alterra, Deliverable 323). This means that colonisation by macro-invertebrates in particular is generally slow, and consequently, migration of these species following climatic changes may also be slower than expected – or even problematic.

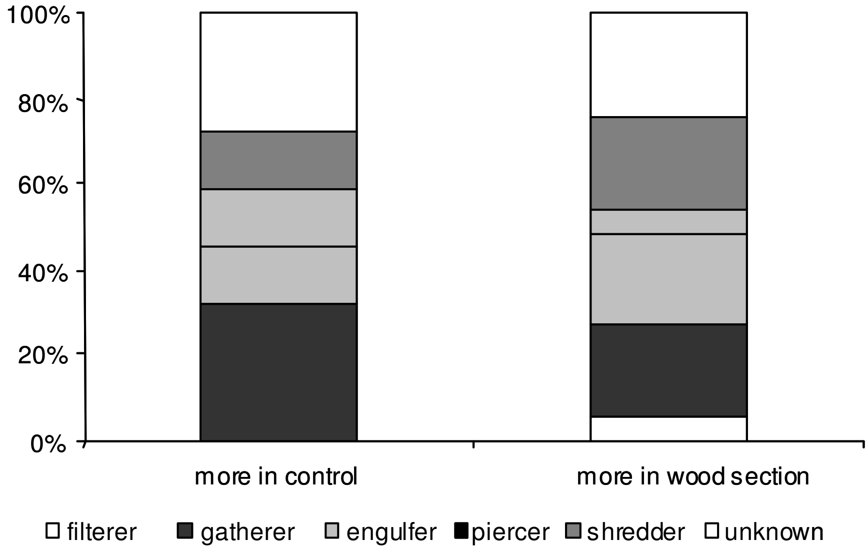

Figure 19. Percentage taxa belonging to different functional feeding groups, of species that explain the difference between the section with added large wood and the control section (no wood added). In left column are species that declined relatively in the wood section and were thus more abundant in the control section. In right column are species that were relatively more abundant in the wood section. These results show that, although biodiversity did not increase following wood addition, the functional community structure of macroinvertebrates did change. Hence, adding wood does improve the ecological status of Dutch lowland streams.

WORK PACKAGE 9: Tools for catchment management and decision support

Objectives

The key objectives of the workpackage have been:

1. to investigate the socio-economic pressures on catchment management with reference to global change and develop methods for the socio-economic valuation of freshwater systems;
2. to analyse which policies and structures at both European and national level influence catchment management;
3. to consult stakeholders at the European, national and catchment levels to ensure that management strategies are appropriate and useable; and
4. to develop a user-friendly integrated DSS for the effective management of freshwaters now and in the future.

Achievements

The key achievements are highlighted using the examples below

Example 1: Investigation of the socio-economic pressures on catchment management with reference to global change and development of methods for the socio-economic valuation of freshwater systems.

This objective was pursued by tasks that looked at how future climate policies might affect the emissions and deposition of pollutants across Europe, the potential effect of future climate scenarios on agricultural practices and stakeholder perceptions and valuations of the effects of climate change and the management responses to it.

The results have included modelling of future emissions of SOx and NOx based on IPCC climate change scenarios A2 and B2. These emissions scenarios provided the basis for the modelling of deposition of atmospheric pollutants across Europe. The results from the work have provided time series of sulphur and nitrogen depositions on a country-by-country basis and for individual catchments where Euro-limpacs modelling was undertaken. This work is important as it provides the possibility of adjusting models to account for changes to deposition of sulphur and nitrogen that may happen as policies are implemented to address climate change.

Application of the Climate and Landuse Allocation Model (CLUAM) has provided a greater understanding of the role of climate change in influencing landuse changes through direct climate effects as well as indirectly through socio-economic effects related to regional and global agricultural markets. The CLUAM model has been applied to the UK as a whole and downscaled to the catchment level for several catchments including two key project case-study catchments (Kennett and Tamar) where the results from the model have been integrated within other modelling tasks.

The final piece of work that addressed this objective was the application of a choice experiment in the Cheimaditida wetland catchment, Greece. The aim of this task was to capture the non-use value of changes in the quantity and quality of environmental resources. The choice experiment methodology was used to estimate the economic value of changes in ecological, social and economic functions of the Cheimaditida wetland. Pair-wise comparisons of alternative wetland management scenarios and the costs necessary to implement those management options were presented to a number of stakeholders to elicit preferences. By integrating the choices of many stakeholders an average stakeholder valuation can be calculated for each different management options. The results indicate that there are positive and significant benefits associated with the ecological, economic, and social attributes of the Cheimaditida wetland of greater than €400M.

Example 2: Analysis of which policies and structures at both European and national level influence catchment management.
The policy context of catchment management, at both a European and national level, has an important influence on the practical outcomes that can be achieved with respect to the effective management of freshwater ecosystems. One of the objectives of this workpackage was to critically analyse policies that are currently in place that influence catchment management. The policy framework set by the EC is a key driver of national legislation and this work looked at the key Directives that influence catchment management and how they are implemented in a number of member states (Denmark, Norway, Netherlands, UK, Germany, Greece). The analyses build on three main data sources. Firstly, EU Directives and regulations that directly or indirectly affect catchment management were reviewed and qualitative as well as quantitative policy objectives identified. The policy issues included in the assessment were limited to the environmental variables most relevant for catchment management, i.e. diffuse pollution, sedimentation and erosion, acidification, flooding and biodiversity. For the member state analyses, national legislation databases were searched systematically for mention of these directives or for mention of the policy issues. Furthermore, national policy analyses were examined in order to generate data about policy instruments that have implemented and considered their effects.

Example 3: Consultation of stakeholders at the European, national and catchment levels to ensure that management strategies are appropriate and useable.
To ensure that tools and management strategies developed as part of the workpackage are appropriate for end-users and useful for them, consultation at different levels (European, national and catchment) is necessary. Work carried out for Euro-limpacs has contributed to the identification of the best methods for engaging stakeholders in the catchment management process from the European level, member state level and catchment level. Valuable lessons have been learned regarding the difficulty of engaging stakeholders without providing them with adequate incentives to participate in the development of tools, in particular making the tools obviously and directly relevant to their immediate tasks (e.g. implementing the Water Framework Directive). This work also highlighted the knowledge gaps perceived by stakeholders implementing catchment management measures regarding climate change and its potential consequences at a spatial scale appropriate to them. The focus on stakeholder consultation has been at the catchment level as this is the level at which the DSS is targeted. The emphasis on stakeholder engagement within individual DSS case-studies varies from catchment to catchment with some having a very strong emphasis on the stakeholder element of the application and alignment of the application with stakeholder

needs. For example, the case-study application to the Dinkel catchment has built on the on-going development of tools for reaching consensus between different stakeholder groups (farmers, water managers and conservationists) on water management. The novel use of touch-table technology for stakeholder engagement has shown to be a powerful tool for developing compromise strategies between stakeholder groups with conflicting views.

Example 4: Development of a user-friendly integrated DSS for the effective management of freshwaters now and in the future

One of the key outputs from this workpackage of the project has been the development of a Decision Support System (DSS) to support the effective management of freshwater ecosystems under climate change. The DSS is designed to address catchment management problems using a spatially explicit multi-criteria analysis (MCA) approach. The DSS acts as a framework for integrating already existing modelling or monitoring data across a spectrum of environmental, social or economic variables. It is based on a GIS platform so that it allows users to compare alternative catchment management strategies at a sub-catchment level using MCA. This allows users to spatially target management interventions by identifying key geographical areas within catchments where action is needed or where management interventions will be most effective. The flexibility offered by integrating the DSS within a GIS environment also allows users to incorporate outputs from the DSS with other GIS data that may already be used for catchment management. Typical problems that the DSS is designed to address are, for example, to identify the areas of a catchment where resources should be targeted or to identify which measures most effectively tackle particular catchment management problems.

The outputs from these applications have demonstrated the potential utility of the DSS for catchment managers. They show how the DSS can be used to spatially target management measures within catchments, design appropriate management interventions to adapt to climate change and identify key attributes to be targeted by managers. Figures 20 and 21 highlight example outputs from the DSS applications from the Bjerkreim and Tamar case studies, respectively.

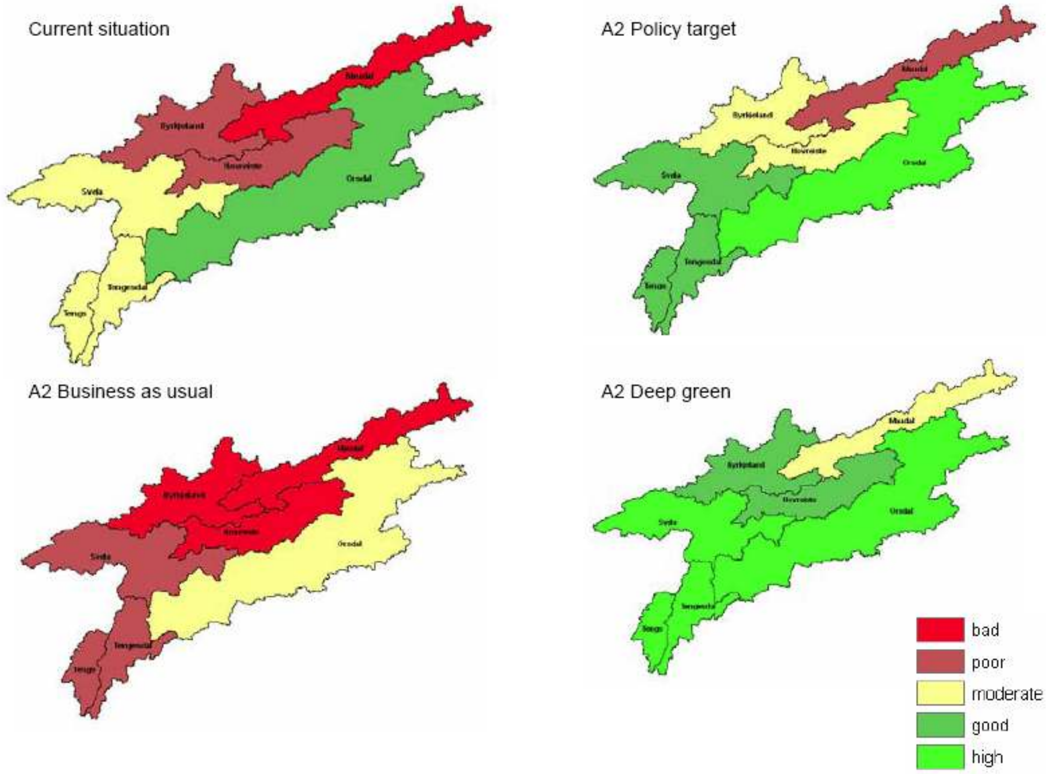

Figure 20: Example output from Bjerkreim application of the DSS: Conditions for salmon with climate scenario A2 in combination with different management scenarios. Considering water quality (ANC) only.

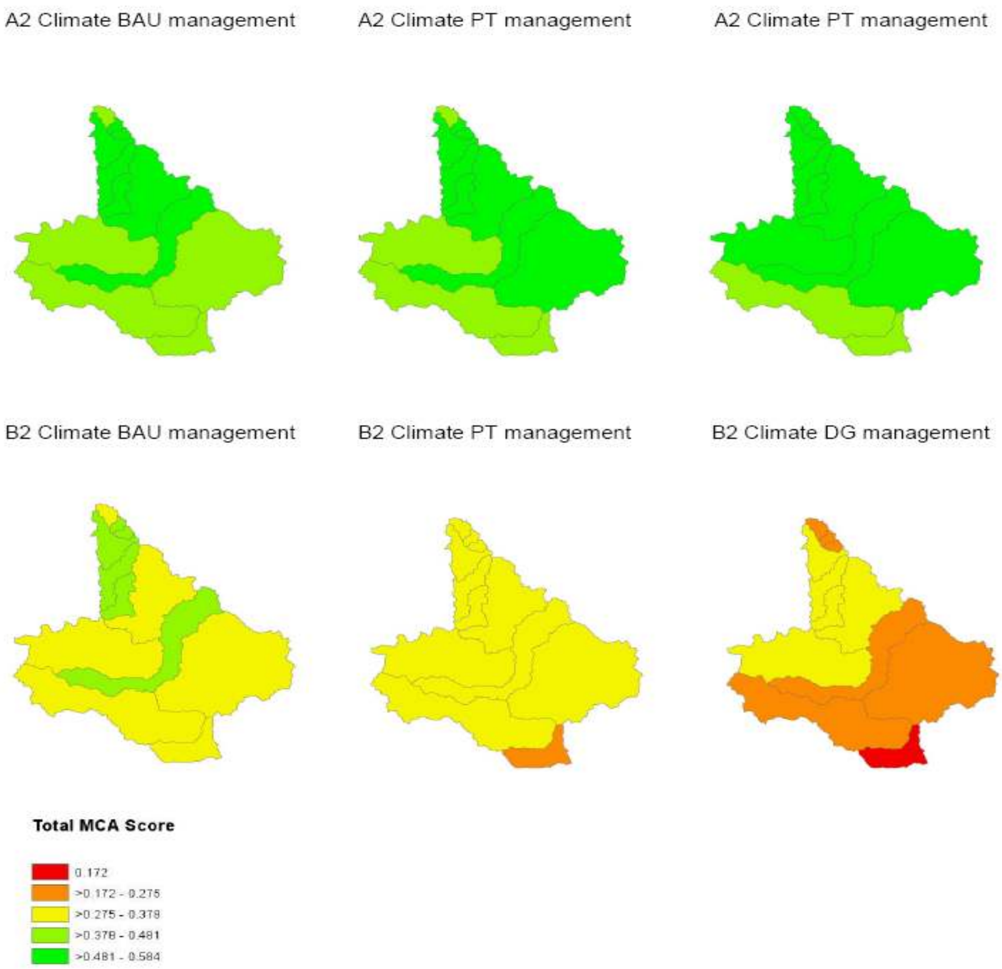

Figure 21: Example ouput from DSS application to Tamar catchment: Categorised total MCA score for each subcatchment and management-climate combination.

WORK PACKAGE 10: Dissemination and training

Objectives

Communication of reliable and useable information was an important objective of Euro-limpacs. These activities occurred throughout the work programme but were co-ordinated in work package 10 by UCL. The objectives of WP10 were:
(i) to co-ordinate project dissemination, reporting and publicity activities;
(ii) to engage end-users and stakeholders;
(iii) to disseminate the key tools developed in WP6-9;
(iv) to co-ordinate key methodological approaches, especially within WP1-5; and
(v) to co-ordinate database activities and develop a project meta-database.

Central to Project dissemination and publicity was the design, development and maintenance of the Euro-limpacs web-site containing both public and Project-specific private components. The development and maintenance of the website was vested with a single participant (UCL), who had the appropriate facilities, expertise and experience of developing Project web sites. All partners were experienced in communicating results of scientific research to appropriate end-users and, collectively, the consortium had links with a vast array of international, national, regional and local stakeholders with vested interests in aquatic ecosystems.

Euro-limpacs brought together premier freshwater scientists in Europe to address the central question of how freshwater ecosystems will respond to future global change. An holistic approach was taken that embraced all surface freshwater types (lakes, rivers and wetlands) within an integrated catchment context, that covered a full range of spatial and temporal scales, and combined observational, experimental, palaeoecological and modelling methodologies. The Consortium had wide experience of the five key research approaches used in the Project, namely analysis of long-term data sets, palaeoecological methods, space-for-time substitution, experiments, and modelling.

All the scientists involved had international reputations and proven records in delivering research of the highest quality. The consortium provided integration at the ecosystem level (rivers, lakes, wetlands, and catchments), at the ecoregion level (boreal, Atlantic, continental, alpine, Mediterranean) and range of skill (e.g. experimentation, numerical analysis, modelling, social science and management). The scientists and institutions cover hydrology, biogeochemistry, ecology and socio-economics and have considerable experience managing or participating in multi-disciplinary projects. A wide geographical spectrum of countries were included, with 12 EU countries, two Candidate countries (Czech Republic, Romania), three Associated countries (Norway, Iceland and Switzerland), one Other Associated country (Russia) and one Other country (Canada)

The work programme was ambitious and innovative, and aimed to achieve a level of integration that took freshwater ecosystem science to a new level and that further enhanced the reputation of European science in the wider world. Part of the remit of WP10 was to ensure that this integration was achieved by overseeing the development of cross cutting themes, through a comprehensive mid-term review and by organising workshops bringing together the different elements of the Project.

The expected end results included the generation of results which would enable appropriate strategies to be developed to:
i) attain the appropriate balance between use and protection of Europe's freshwaters especially through the stronger underpinning of the policy framework;
ii) ensure that the freshwater resource and associated ecosystems can continue to provide the necessary benefits essential to quality of human life, biodiversity and environmental maintenance together with preserving European landscape and heritage;
iii) implement appropriate and well-targeted restoration efforts to recover the historical losses and degradation which have occurred due to human impacts;
iv) develop approaches and identify priorities for dealing with the effects of future global change scenarios relating to climate and hydrology, land-use and nutrients, acidity and toxic substances.

The role of WP10 was to ensure these results were disseminated in such a way as ensure these outcomes.

The approach and anticipated outputs were innovative in a number of key respects:
i) for the first time the three major ecosystem components of surface freshwater systems (rivers, lakes and wetlands) were brought together into a single framework for analysis and management thus breaking down sectoral scientific, technical and institutional barriers that have hitherto impeded integrated solutions;
ii) the use of state-of-the-art techniques in time-series analysis, space-for-time substitution, palaeolimnology, experimentation, modelling and ecosystem functional analysis linked at the catchment scale and used together with consolidated data-sets from across Europe supported attempts to disentangle the effects of various stressors and climate. This had never been attempted before;
iii) a unique consortium was been assembled to address the ambitious objectives of this Project. The consortium drew on scientists and experts in disciplines ranging from limnology and hydrology to economics and policy. Participants were drawn from across Europe representing both the public and private sectors. Euro-limpacs was therefore in a position to provide decision makers at all levels of authority in Europe with the single, definitive scientific voice needed to ensure the sustainable development of Europe's freshwater ecosystems into the future.

WP10, in close co-operation with WP9 (and, to a degree, with other work packages) were to be pivotal ensuring that the practical application of the results and engagement of end-users was an attainable goal for the Project. This was to be done by:
i) integration of end-users and stakeholders into the Project and especially their close involvement with drawing up the specifications of the range of tools envisaged, in particular the decision support system at start-up;
ii) ongoing engagement of stakeholders at the catchment scale to take account of pan-European diversity of interest and potential application;

iii) engagement of focal points responsible for implementation of relevant international conventions;
iv) development of annexes to assist in the guidance process in the Common Implementation Strategy for the WFD; and
v) preparation of technical support documents for Conference of Parties of the target International Conventions.

The key deliverables were expected to be:
i) a comprehensive Project web-site incorporating public and private components;
ii) an Integrated Project and associated meta-database;
iii) collation and maintenance of Project bibliography;
iv) two major conferences and an annual workshop for end-users and stakeholders;
v) production and co-ordination of scientific special journal issues.

Training within Euro-limpacs was to comprise internal workshops, seminars and short courses for end-users and stakeholders, and the development of postgraduate and post-doctoral opportunities. Internal workshops and short courses were to be undertaken within each of WP1-9 and phased through the project. These were to be designed and run by WP leaders but centrally co-ordinated and administered by **UCL**. End-user workshops and short courses were also be administered by UCL. Specialist external workshops based on specific components of the project were also planned. Postgraduate and post-doctoral training were to be facilitated by: (i) developing and adapting existing short courses in participant institutes to address key components of the Project; (ii) encouraging and creating postgraduate opportunities within participant institutes that develop key project issues; (iii) co-ordinating a Project-based application for a Marie Curie Training Network that builds upon the themes and activities of the Project (UCL).

Achievements
The focus of WP10 was dissemination, reporting and training. As such, this work package was not instrumental in advancing thet state-of-the-art with regard to understanding the effects of climate change on aquatic ecosystems. Rather, WP10 was responsible for ensuring that such advances made in other WPs were disseminated as widely as possible, on top of the dissemination efforts within individual work packages and by institutes and scientists independently.

Most of the key objectives specified at the start of the Project were achieved.

<u>i) To co-ordinate project dissemination, reporting and publicity activities;</u>
UCL has successfully co-ordinated dissemination, reporting and publicity activities. These were ongoing through out the Project and were undertaken centrally (by UCL) and by institutes and individual partners. There were a number of key elements to the dissemination effort and these constitute the main highlights;

Publication of papers in the peer review literature. The Euro-limpacs bibliography provides a comprehensive inventory of scientific manuscripts and reports.

Over four hundered papers in the peer review literature were published during the lifetime of the Project and many more are currently in press or being prepared. Eleven special issues dedicated to Euro-limpacs output were published or are in preparation including volumes of *Freshwater Biology*, *Journal of Applied Ecology, Fundamental & Applied Limnology, Hydrology & Earth System Sciences*, *Ecological Modelling*, *Ambio, Science of the Total Environment, Journal of Palaeolimnology* and *Hydrological Research.* Table 2 below gives a list of journals in which Euro-limpacs papers have been published. This illustrates the multi-disciplinary nature of the Project and the contribution that Euro-limpacs has made to a broad range of scientific research. A full list of publications produced (published, submitted or in preparation) is given in Annex 1. Other publications include books/book chapters (53), contributions to conference/meeting proceedings (26), reports (37) and PhD and Masters theses (40).

A Euro-limpacs book "Climate Change impacts on Freshwater Ecosystems – direct effects and interactions with other stresses" published by Blackwell will be in print within months of the completeion of the Project. This follows on from the publication of a 'Distribution and Ecological Preferences of European Freshwater Organisms Volume 1: Trichoptera', the first of a series five issues which will also cover Mayflies, Stoneflies, Fish & Diatoms. Other books published during the Project inlcude one book on restoration of Danish lakes and one bringing together two decades of EU and other funded reseach on Lochnagar, an upland loch in Scotland. Additionally Euro-limpacs contributed Chapter 7.4: 'Freshwater Ecosystem Responses to Climate Change: the Euro-limpacs Project' to the Wiley book 'The Water Framework Directive' ecological and chemical status monitoring.

Presentation of Euro-limpacs results at international conferences and meetings.
By the end of the Project over 700 oral and poster presentations of Euro-limpacs objectives and results had been given at national and international conferences (see Plan for dissemination). The locations of the meetings have been global - many European countries, USA (including Alaska), Canada, Brazil, Mexico, Bolivia, Uruguay, China, Japan, Australia, New Zealand, South Africa, India, Egypt, Thailand, South Korea. In addition, special sessions at four high profile international conferences (ASLO 2005 & 2006, SIL 2007 and SETAC 2008) were organised to provide a forum for Euro-limpacs results to be presented to international audiences.

Presentation of Euro-limpacs results on the Project Web site.
Once the Web site had been developed sufficiently to provide a means of communication within the Project (for circulation and archiving of documents, minutes, reports, deliverables etc), the main effort was transferred to the Public part of the Web site. This now provides a focus of all Euro-limpacs output. It provides a comprehensive description of the objectives and methods employed in the project and, over time, the focus of dissemination has shifted towards providing progress with work addressing specific issues. The key questions are updated annually to reflect progress being made across the Project. The redesigned public part of the Web site provides a summary of each individual deliverable with public access to those which are freely available. The Web site will continue to be 'live' after the Project is completed, providing a legacy that will ensure the results of the Project are available to stakeholders in an easily accessible way in future.

Presentation and discussion of Euro-limpacs activities to stakeholders at national and international meetings and workshops including those organised by member state environmental protection agencies and conservation bodies.
In addition to the presentation of Euro-limpacs results at scientific conferences, WP10 (and also WP9) sought to ensure that output from the Project was presented directly to potential stakeholders by: i) organising meetings to which stakeholders were invited; and ii) facilitating attendance by Euro-limpacs scientists at meetings organised by, for example, member state environmental protection agencies, the EEA and conservation bodies. UCL organised a one day meeting on 'Climate Change and Aquatic Ecosystems in the UK: Science, Policy and Management' in May 2007. Over 100 members of the freshwater community attended representing a wide spectrum of interests – research scientists, conservation and regulatory agencies, non-government organisations, learned societies and water companies. A proceedings volume from the meeting has been published and circulated which included papers from the presenters, a summary transcript of a panel discussion and a statement on '*Climate change impacts on freshwater ecosystems in the UK: research priorities to support adaptation responses*'. In addition UCL represented Euro-limpacs at a number of EEA workshops on climate change, freshwater quality and biodiversity.

<u>(ii) to engage end-users and stakeholders;</u>
End user / stakeholder enagagement has continued throughout the Project with many initiatives taken independently by participating institutes, in particular those involved in WP9. UCL has collated these on an annual basis and these are summarised in the 'Plan for Use and Dissemination of Knowledge'. Dissemination to end-users has been wide-ranging, both in terms of the level of contact made (local, catchment, regional, national, international) to the wide variety of end-users (e.g. members of the public and local groups; lake and stream managers; catchment managers; regional water authorities and county councils; national environment/environmental protection agencies; government departments; conservation bodies; water research institutions and universities). Contacts with the media (television, radio, newspapers) have aided the dissemination process.

WP10 has been involved in a number of broad scale dissemination activities. UCL collated the Euro-limpacs contribution to "Impacts of Europe's changing climate - Chapter 5 Section 6 - Freshwater quality and biodiversity" and EEA report published in 2009. UCL also led work on the Euro-limpacs Position Paper "Impact of climate change on European freshwater ecosystems: consequences, adaptation and policy", which aimed to summarise current understanding of the impact of climate change on freshwater ecosystems in Europe based principally on the outputs of Euro-limpacs project but also drawing upon the results of related international and national projects.

<u>(iii) to disseminate the key tools developed in WP6-9;</u>
Dissemination of the key tools developed in WP6-9 has been undertaken by partners involved in these work packages and also as part of the dissemination effort described above.

(iv) to co-ordinate key methodological approaches, especially within WP1-5; and

A key aspect of WP10 activities which underpinned much of the integration across the Project (particularly with respect to the methodological approaches employed) was the co-ordination of methodological cross curring themes, in collaboration with other partners including CNRS-UPS and NERI/AU (Space-for-Time substitution) and AERC (process based modelling). Under WP10 a number of workshops were organised bringing together partners from across different workpackages to ensure consistency, suitability and proper application of palaeoecological and time-series methods. These led ultimately to the publication of two special issues of *Freshwater Biology* and *Journal of Paleolimnology*.

(v) to co-ordinate database activities and develop a project meta-database.

Since the start of the project, basic site data has been collated for wetland, lake, river and terrestrial sites. These data are stored in a database and may be edited and queried on the Euro-limpacs web-site. There are site data for 113 sites, an example is shown in Deliverable 38. For each site there is a list of associated work package sub-tasks. Detailed metadata forms were prepared for WP6 and examples are shown in Deliverable 38. The data were subsequently edited by the originator and viewable by all partners. Metadata entry for other work packages is under discussion. Two other meta-databases have been assembled as part of work in WP7; Deliverable 30 (Meta-database on Indicators for Climate Change impacts on freshwater ecosystems) and Deliverable 31 (Macro-invertebrate Taxa and Autecology Database). The former are fully integrated into the Euro-limpacs web-site. The latter meta-database is hosted externally and is accessible from the Euro-limpacs web-site. A palaeoecological meta-database 'LAKECORES' has also been developed bringing together information about lake sediment cores. Over the last three years of Euro-limpacs an attempt has been made to identify all published information about lake sediment cores that have been used to reconstruct the recent ecological history of lakes in Europe. BOKU prepared and maintained a web-based database under WP 7, Task 4 (www.freshwaterecology.info) with a link form and to the project's website. It was decided not to develop a Project meta-database encompassing the entire scope of Euro-limpacs activities. This would have been a severe drain on resources given wide ranging scope of research undertaken and the disparate nature of data employed. More resources were subsequently devoted to ensuring that the Public part of the Project Web site provided easily navigable access to Project output and therefore, to information about sources and types of data used.

IMPACT

The impact of Euro-limpacs in the research field and beyond cannot be determined comprehensively without enough time lapsing for the effects to be shown. Impacts of research in the environmental field typically have a lag time of about twenty-five years. Nevertheless, reaction to our results among the research community at conferences and in readiness to publish our papers (see below) has been highly favourable, but it is too early to be able to quote meaningful citation data.

The short term potential impact of Euro-limpacs within the research field can primarily be gauged by the number of scientific publications produced using results generated by the Project or enabled by the Project. Over four hundered papers in the peer review literature were published during the lifetime of the Project and many more are currently in press or being prepared. Eleven special issues dedicated to Euro-limpacs output were published or are in preparation including volumes of Freshwater Biology, Journal of Applied Ecology, Fundamental & Applied Limnology, Hydrology & Earth System Sciences, Ecological Modelling, Ambio, Science of the Total Environment, Jouranl of Palaeolimnology and Hydrological Research. Table 2 gives a list of journals in which Euro-limpacs papers have been published. This illustrates the multi-disciplinary nature of the Project and the contribution that Euro-limpacs has made to a broad range of scientific research. A full list of publications produced (published, submitted or in preparation) is given in the Plan for Using and Dissmination Knowledge and is available via the Euro-limpacs bibliography on the Project Web-site at (http://www.eurolimpacs.ucl.ac.uk/index.php/content/view/176/46/). Other publications include books/book chapters (53), contributions to conference/meeting proceedings (26), reports (37) and PhD and Masters theses (40). Additionally By the end of the Project over 700 oral and poster presentations of Euro-limpacs objectives and results had been given at national and international conferences (Plan for Using and Dissmination Knowledge). The locations of the meetings have been global - many European countries, USA (including Alaska), Canada, Brazil, Mexico, Bolivia, Uruguay, China, Japan, Australia, New Zealand, South Africa, India, Egypt, Thailand, South Korea. In addition, special sessions at four high profile international conferences (ASLO 2005 & 2006, SIL 2007 and SETAC 2008) were organised to provide a forum for Euro-limpacs results to be presented to international audiences.

Beyond the research field, the impact of the Project has been widespread in the areas relating to freshwater management, legislation and policy. End users and stakeholders have been engaged in a two-way dialogue with the Project throughout the lifetime of the Euro-limpacs. This has been undertaken at international, national, regional and local levels and a comprehensive list of thse activities is provided in the Plan for Using and Dissmination Knowledge. Some of the key contributions from Euro-limpacs are highlighted in the Work Performed section below (WP10 activities).

An addition to the publication in international journals, presentation of results at international conferences and direct stakeholder enagement activities, a number of impacts specific to individual work packages can be identified.

Table 2: Journals in which Euro-limpacs papers have been published

Acta Hydrobiologica Sinica	Journal of Chromatography A
Acta Societatis Botanicorum Poloniae	Journal of Ecology
Advances in Ecological Research	Journal of Ecology and Field Biology
Ambio	Journal of Environmental Monitoring
American Naturalist	Journal of Environmental Quality
Applied Geochemistry	Journal of Geophysical Research
Applied Vegetation Science	Journal of Hydrology
Aquatic Conservation: Marine & Freshwater Ecosystems	Journal of Paleolimnology
Aquatic Ecology	Journal of Plankton Research
Aquatic Ecosystems Health and Management	Journal of Plant Nutrition & Soil Science
Aquatic Sciences	Journal of Statistical Software
Atmospheric Environment	Journal of the North American Benthological Society
Basic and Applied Ecology	Journal of the Royal Statistical Society
Biogeochemistry	Lake & Reservoir Management
Biologia	Landscape Ecology
Canadian Journal of Fisheries & Aquatic Sciences	Limnetica
Chemosphere	Limnologica
Diversity and Distributions	Limnology & Oceanography
Ecography	Limnology & Oceanography Methods
Ecological Applications	Marine Ecology Progress Series
Ecological Indicators	Microbial Ecology
Ecological Informatics	Mountain Research and Development
Ecological Modelling	Nature
Ecology	Nederlandse Faunistische Mededelingen
Ecology of Freshwater Fish	Neural Networks
Ecosystems	Oceologia
Ecotoxicology & Environmental Safety	Oikos
Environmental Journal of Phycology	PAGES News
Environmental Monitoring & Assessment	Philosophical Transactions of the Royal Society B
Environmental Pollution	Plant & Soil
Environmental Science & Policy	Proceedings of the National Academy of Sciences
Environmental Science & Technology	Proceedings of the Royal Society B
Environmental Toxicology and Chemistry	Quaternary International
Environmetrics	Russian Journal of Ecology
Fisheries Research	Science
Freshwater Biology	Science of the Total Environment
Freshwater Reviews	SIL News
Fundamental & Applied Limnology/Archiv für Hydrobiologie	Silva Gabreta
Geoderma	Stochastic Environmental Research and Risk Assessment
Geophysical Research Abstracts	The Holocene
Geophysical Research Letters	Vand & Jord
Global Biogeochemical Cycles	Verhandlungen Internationale Vereinigung für theoretische und angewandte Limnologie
Global Change Biology	Water Research
Hydrobiologia	Water Resources
Hydrological and Earth System Sciences	Water Resources Management
Hydrological Processes	Water Resources Research
Hydrological Sciences Journal	Water Science & Technology: Water Supply
Hydrology Research	Water, Air & Soil Pollution
Journal of Animal Ecology	Water, Air & Soil Pollution: Focus
Journal of Applied Ecology	Wetlands
Journal of Archaeological Science	

In WP1 work undertaken has stimulated research cooperations across Europe and beyond. Ongoing and planned research programs and projects, both on national and international level relate to the experience acquired under the Euro-limpacs project. End users have shown interest in research results generated under WP1 including public authorities, private companies, the tourist sector, local drinking water supplies and high mountain farmers.

In WP2 an number of databases were developed which may have wider application with the end of the Project including those on the Vecht catchment, River Waldaist, Emå, Neajlov, dour-Garonne, Lahn/Eder, Lambourn and Becva River. Additionally a sediment accumulation rate database was developed which will be available to users together with databases on mountain lake restoration and lowland stream restoration projects. WP2 expanded a number of other databases on autecology, fish, macroinvertebrates, diatoms and including the expansion of the AQEM/STAR database.

For WP4 the mechanisms of the interactions between climate effects and acidification effects are still poorly understood. Experiments, continued monitoring and analysis of long-term data series, and modelling are complementary approaches that lead to new insights and knowledge on possible interactions. Research is particularly challenging in this field because the goal is to make projections for the future under climatic conditions that for many ecosystems have never been experienced previously. It is certain that climate change will have an increasing impact on freshwaters in the foreseeable future. There will certainly be effects not yet identified, and current assessment of total impact on freshwaters is probably underestimated.

The work performed in WP5 has led to a considerably increase in our understanding of the mechanisms of accumulation of toxic organic substances in the headwater systems. Eighty-six papers have been produced as consequence of the research performed within this work package. Fifty-nine of the papers have already been published. Some papers generated within WP5 have been selected for the headlines of leading environmental journals such as *Environmental Science and Technology*, e.g. Bartrons, M., Grimalt, J.O., Catalan, J. 2007. Concentration changes of organochlorine compounds and polybromodiphenyl ethers during metamorphosis of aquatic insects. Environmental Science and Technology, 41: 6137-6141. One important book summarizing the knowledge achieved in relation to Lochnagar, which is one of the reference headwater systems within Eurolimpacs, has been published: Rose N.L. (ed.) 2007. Lochnagar: The Natural History of a Mountain Lake. Developments in Paleoenvironmental Research. Volume 12. Springer. Dordrecht. 534pp. In addition, a special session devoted to the Eurolimpacs project was performed within the 2008 SETAC conference in Warsaw for reporting the main results of this work package to the scientific community. This session was attended not only by project partners but by scientists from many other European and North American research groups. The results on mercury have been presented to the Swedish Environmental Protection Agency and at training courses at the Swedish Agricultural University at several occasions. They have contributed to the decision of the Swedish Environmental Protection Agency to fund a research programme on climate change impacts on the Swedish National Environmental Objectives (including acidification, euthrophication, air quality and toxics) expected to be launched in late 2009. Additionally, work from WP5 was fed into the preparation of official document on regional-scale dynamic modelling results for the meeting of the UN/ECE Working Group on Effects, Convention on Long-Range Transboundary Air pollution (see ECE/EB.AIR/WG.1/2008/10, Links between climate change and air pollution effects using site-specific data: www.unece.org/env/lrtap/WorkingGroups/wge/27meeting.htm).

In WP6 the ultimate goal of the catchment modelling work-package was to provide the tools for a pan-European assessment of the likely impacts of climate change on the flow regimes and water quality of river-systems representative of key climate types across Europe. At the end of the project, the toolkit is there, though there has not been time as yet to apply it comprehensively. Some of the individual tools in the kit have been applied, however, and useful assessments have been obtained. This is not to say that the individual tools do not need some refinement, some more than others. Euro-limpacs is not the only project addressing the prediction of climate change in aquatic ecosystems even in Europe, let alone worldwide. The models developed in WP6 are a worthwhile contribution to this modelling effort, and have in turn been influenced by developments elsewhere. Thus the statistical models predicting fish presence or absence in the future are influencing the rapidly-developing science of ecological modelling as well as making predictions of use to managers. The mechanistic, dynamic models are in many cases state-of-the-art expositions of what can be done with current knowledge and techniques. Large-scale models like the GIS-based N transport model EXCET, which was applied to the whole of Finland, and the PEARLS model, which looks at the mixing of waters and the prediction of effects in whole river basins, have shown that models can be scaled up to sizes appropriate for management purposes, especially concerning the EU Water Framework Directive with its focus on large river basins. But one of the achievements of WP6 has been the development of a standardised method for downscaling climate data, running model assessments, at present with INCA-N, and estimating model uncertainty. At the moment no model is flexible enough to be applied unmodified to the diverse range of aquatic ecosystems in Europe, and especially Mediterranean climates seem to cause difficulties. However, WP6 has developed and modified a range of models which have greatly expanded our ability to make these assessments. So far the scientific community has been rightly cautious in making too much of some of the more alarming predictions about aquatic ecosystems which models and experimental work have thrown up. The uncertainties attached to the modelling of such complex and inter-related processes are very clear, but work in WP6 has gone some way towards quantifying and reducing them. It now seems clear that the hydrological changes which will stem from a changed climate will have a profound effect. There are numerous examples in the results below covering a range of European climates: reduced ice cover on boreal lakes in Finland; increased winter snowpacks leading to spring flooding; reduced summer rainfall leading to low summer flows in English rivers; even less water available to sustain the flow of rivers in the Mediterranean region. On water quality, the picture is less clear, but many (but not all) modelling studies indicate a small increase in nitrate concentrations and/or fluxes, leading to an enhanced risk of eutrophication in the rivers themselves and also in receiving waters like lakes, fjords and estuaries. This may also increase the risk of acidification in poorly-buffered waters. However, better understanding of the underlying processes in both the aquatic and terrestrial environments is needed to firm up on these predictions. For phosphorus the modelling is in a less advanced state. Uncertainty about future water quality also affects the modelling of the effects of climate change on aquatic organisms. Where the response of an organism is due principally to temperature changes, however, prediction seems to be on a firmer basis. Great advances have been made in modelling the effects of climate change on aquatic ecosystems, but there is a lot of research still to do.

The impact of WP7 can be evaluated against standard criteria of scientific impact, i.e. output and citations of scientific publications, and against numerical criteria of the World Wide Web. Furthermore, we give estimation on how useful the results will be for selected areas of science and water management.

i) Journal publications: With 16 journal articles plus 10 manuscripts WP7 has produced less journal publications than other workpackages. This is mainly due to the focus of WP7 being on the generation of web pages and on books. The database www.freshwaterecology.info will be subject to many more scientific publications by WP7 partners and other groups, which is already indicated by the high number of external registered users of the database.

ii) Books Two books have been produced in the project's lifespan, four more will appear shortly afterwards. A main outcome is the series "Distribution and Ecological Preferences of European Freshwater Organisms" (Pensoft Publishers), with an initial print run of 300 copies for distribution by Pensoft and 50 copies for distribution by the authors.

iii) Websites The main outcome of the central Task 4 of WP7 is the website www.freshwaterecology.info. For more than 18,000 European freshwater taxa (about 9,500 benthic invertebrates, 320 fish, 8,800 diatom taxa) it lists ecological preferences and distribution patterns, as a searchable online database. For each of the organism groups a different number of ecological parameters (macro-invertebrates: 34; fish: 21; diatoms: 36) with different numbers of classified species is available. About 150 external users have been registered with more than 19,000 recorded visits and queries. The number of sessions (external access) per month varies between 19 and 43 with an average of 30 sessions per month (evaluated for year 2008). Google page ranking is 4. From the start in March 2008 until now www.climate-and-freshwater.info became very popular. Visitors of www.climate-and-freshwater.info are coming from all over the world. The overall number of page visits from the launch until early February 2009 is more then 27,000. The average number of page visits for the last three month is more then 4,000/month. Google page ranking is currently 5.

iv) Data Several products of WP7, in particular the book series and the two websites, aim a making data, which have been hidden in thousands of publcations and databases, publicly available. This was only possible by a Europe-wide consortium to which publications in many different languages were accessible. For www.freshwaterecology.info about 9,000 publications have been evaluated.

v) Science and application WP7 has built a link between the Euro-limpacs project, other scientific initiatives and the implementation of the EU Water Framework Directive. It has made ecological data from many sources operational for water managers, e.g. by transferring ecological data into numerical values to be used in indices (www.freshwaterecology.info) and by defining criteria and indicators for assessing the impact of climate change on freshwater ecosystems (www.climate–and-freshwater.info). Besides the use by water managers the products will be used for future projects, e.g. WISER (www.wiser.eu).

vii) Scientific progress Besides the applicability of the results for water managers the scientific outcome of WP7 contributed to the progess in several fields, e.g. the coupling of catchment and lake models (Task 2), the development of functional indicators (Task 3) and the use of temperature preferences for ecological assessment (Task 6). Main outcomes relate to the sensitivity analysis of European freshwater biota, e.g. the strong latitudinal gradient regarding the occurrence of climate sensitive taxa and the predicted overall decrease in species and trait diversity

WP9 was one of the main areas of the project where stakeholders responsible for implementing catchment management at the catchment level, and those influenced at the catchment level, were engaged. This was the case particularly for the DSS case studies that focussed on, or had a large component of, stakeholder engagement (e.g. Dinkel, Tordera). In this respect the work undertaken for this workpackage has had significant, localised, grass-roots impact.

As WP10 was primarily a dissemination, training and reporting work package with no scientific research undertaken, this question has limited applicability in this case. Some research however was undertaken into the stakeholder engagement process, following the experiences of those involved in the Project. This is summarised in **Deliverable 305**, a report on end user / stakeholder engagement across the Project. This brings together the Project experiences with stakeholder engagement and will is intended to provide a useful guide for other EU Projects

WORK PERFORMED (WITH CONTRACTORS INVOLVED)

Euro-limpacs comprised ten themes (Work packages (WP)) sub-divided into tasks. There were four major sections: (i) WP1-5 were concerned with understanding the key freshwater driver-response processes and their interaction with climate change; (ii) WP6 was concerned with integrated modelling at the catchment scale and used the process-based understanding and site data of WP1-5 for model development and testing; (iii) WP7-9 focused on the development of methods (indicators, restoration strategies and decision support systems) needed to apply the results of WP1-6 to the management of European freshwater ecosystems; and (iv) WP10 was concerned with dissemination and training especially with regard to the user, stakeholder and science communities. Socio-economic assessment was integrated within WP9, which dealt with catchment management and decision support systems. The WP structure did not separate rivers, lakes and wetlands. The project recognised the integration of these systems at the catchment scale, although, for convenience, they were often considered separately within WP1-5. A catchment-based approach was followed throughout and a key aim over the duration of the project was to bring together the science and scientists needed for such integration.

Within the project, each WP had its own objectives and coherence, and the project as a whole was fully integrated between WPs. This was ensured as follows: WP6 was designed to take output from WP1-5, and WP7-9 included elements specific to each driver-response system in WP1-5. Themes that cut across the work packages (e.g. associated with different methodologies) had leaders specifically appointed to assure appropriate linkages between WPs.

Euro-limpacs employed a range of techniques each tailored to particular problems that had not previously been assembled in an integrated project. Central to the Project was a consideration of all freshwater ecosystem types (rivers, lakes and marginal wetlands) both as individual systems and as systems connected at the catchment scale (WP6), and its organisation on the basis of driver-response systems combining a process-based approach (WP1-6) with the development of management tools (WP6-9). The key approaches and their relevance to the objectives were:
Scenarios In all experiments and modelling scenarios of future climate, pollution and land-use change derived from current EU, UNECE and other national and international directives and protocols were taken into account. For climate scenarios the approach of the EU-CLIME project will was adopted whereby dynamic down-scaling using Regional Climate Models, nested within the global circulation model, are used to generate climate scenarios at the individual water body and catchment scale for key sites across Europe. This activity was largely external to Euro-limpacs but was be co-ordinated by WP1 and made available for use in other WPs in combination with land-use change (WP2), nutrients (WP3), acid deposition (WP4) and toxic substances (WP5).
Sites and geographical coverage Euro-limpacs ambition was to use sites that represent the full span of European climate zones and freshwater types from north to south, from maritime to continental and from lowland to alpine. Key sites were data-rich in terms of data quality, range of variables and length of time-series, and included lakes, rivers,

wetlands and catchments. These included experimental sites where new work was carried out (WP1,3-5), sites with long data-sets for time-series analysis (WP1-4) and instrumented catchments for integrated modelling (WP6) and DSS demonstration (WP9).
Temporal scales Euro-limpacs sought to understand the response of aquatic ecosystems to global change on a range of different time-scales. The premise was that future climate change will have an impact on natural ecosystems and human society on very short time-scales associated with shifts in the magnitude and frequency of extreme events, at the seasonal scale concerned with ecosystem functioning and life-cycle strategies, and at inter-annual and decadal scales concerned with longer term ecosystem trends and responses. These three time-scales, each with a separate co-ordinator, formed cross-cutting themes in WP1-5.
Data and databases Whilst extensive new data-sets will be generated by Euro-limpacs based on new field and laboratory studies, the Project drew extensively on the major data holdings assembled by the consortium as a result of previous EU projects on rivers, lakes and wetlands. It also assembled additional data needed for long-term data analysis (WP1-5), modelling (WP6), ecosystem health indicators (WP7) and reference conditions and restoration targets (WP8).

This section summarises work undertaken by each of the work packages within Euro-limpacs.

WORK PACKAGE 1: Direct impacts of climate change

Work package 1 comprised 5 Tasks with activities undertaken described below.

Task 1: Climate scenarios (UIBK, NERC)

The objective was to provide consistent climate scenarios for key Euro-limpacs sites. **UIBK** has supported all partners of Euro-limpacs in applying climate scenario data at selected key sites. UIBK has produced a guide for the data download from the EU-PRUDENCE web-page and has organized workshops on the download and application of climate scenario data. UIBK has contributed to workshops of other WPs and has collaborated with other partners regarding the downscaling of climate scenario data. Climate scenario data from different Regional Climate Models can be downloaded from the EU-PRUDENCE web-page (http://prudence.dmi.dk/) for the period 2071-2100. It was agreed to consistenty apply data from the Rossby Centre coupled regional climate model RCAO (SMHI, Rossby Centre, Sweden) (using HadAM3 and ECHAM4/OPEYC3 Global Circulation Models and the IPPC emission scenarios A2 and B2) – cf **Deliverable 41**. Transient scenarios for the time period 1961-2100, using the latest version of the Rossby Centre regional climate model RCA3 (with ECHAM4/OPEYC3 Global Circulation Model and IPPC emission scenarios A2 and B2) have been provided by the Rossby Centre (SMHI, Sweden; http://www.smhi.se/).

Task 2: Impact of climate change on the hydrological cycle (UIBK)

Task 2.1 The potential impact of changing air temperature and precipitation on chemical mass flux using time-series analysis of long-term data-sets (UIBK, NIVA, SYKE, HBI-ASCR, HBI-BCASCR, HSCU, CNR)

Task 2.1 sought to evaluate the impact of changing air temperature and precipitation on the components of the water cycle at key sites and assess the impact of climate change on mass fluxes at selected key sites. The approach was to collate and analyse long-term meteorological, hydrological and biogeochemical data series to assess long-term trends in catchment mass fluxes at key sites, use paleolimnological data, where available, to provide additional information on climate change at key sites and apply climate scenario data to estimate the potential impact of future climate change on mass fluxes

The impact of climate change on the water cycle was investigated at key sites and results reported in **Deliverable 81** (**UIBK, SYKE, HBI-ASCR, HSCU, CNR**). Site specific work on the impact of climate change on mass fluxes has been summarised in **Deliverable 215** (**UIBK, NIVA, SYKE, HBI-BCASCR, HSCU, CNR). UIBK** worked on long-term data on climate and water chemistry of high altitude surface waters in Austria and Italy to investigate the potential impact of increasing air temperature on rising solute concentrations. (Thies et al., 2007). **UIBK** performed water sampling, meteorological and hydrological measurements at Piburger See and its tributary, and extended existing data series. **SYKE** investigated the reasons behind the observed increase of DOC in surface waters in Europe and North America by analysing long-term data series. The process-based model INCA-C was developed in collaboration with

TRENTU to study how climate change controls seasonal and interannual patterns of DOC in the catchment of Valkea-Kotinen. A new data-set on DOC fluxes, soil and water chemistry, site characteristics and climate variables was created in the study catchment. **NIVA** performed statistical analyses of long-term data series from 4 Norwegian catchments, and developed multiple regression models with climatic parameters as independent variables (drivers). **NIVA** measured weekly concentrations and fluxes of NO_3 and DOC in streamwater as dependent variables (de Wit et al., 2008; de Wit and Wright, 2008). **CNR** studied historical trends in water chemistry in relation to changing temperature and precipitation at high altitude lakes (Lakes Paione and Boden) and performed a survey of 28 alpine lakes located in the Ossola and Sesia Valley (Piedmont, Italy) to examine long-term changes in lake chemistry in relation to changing atmospheric deposition and weather patterns. **CNR** performed water sampling at 4 high altitude lakes (Lakes Paione and Boden) and the collection of meteorological data at Lake Paione Superiore to extend already existing data series. **HBI-ASCR** and **HBI-BCASCR** worked in the catchment-lake systems of Plešné and Čertovo lakes (Bohemian Forest, Czech Republic) and investigated long-term trends in chemistry (Al, Fe, P) and biology (Cladocera remains, pollen, chironomides and diatoms) in Plešné Lake sediment, spanning the whole lake history since its deglaciation ~14,600 to determine the major factors responsible for long-term changes in P cycling in lake water and sediment, the temperature impact on the decomposition rate and nutrient (N, P) release from plant litter as well as the terrestrial export from the catchments and studied temperature and precipitation impacts on changes in terrestrial Si export. Results are reported in **Deliverables 209** and **252**) and in 14 published papers (Jankovská 2006; Kaňa and Kopáček 2005; Kopáček et al. 2005a, 2005b; Kopáček and Vrba 2006; Kopáček et al. 2006a, 2006b, 2006c, 2007; Pražáková et al. 2006; Šantrůčková et al. 2006; Štefková 2008; Tátosová et al. 2006; Veselý et al. 2005). **HSCU** collaborated with **HBI-ASCR** in the data evaluation of Cladocera remains and chironomids in the long-core of Plešné Lake sediment (Bohemian Forest). **HSCU** evaluated the impact of changing air temperature and precipitation on water balance, mass budget and fluxes in the forested catchment of the headwater part of Litavka river and collected meteorological, hydrological and hydrochemical data in three lake catchments in the Tatra Mts. Several theses and manuscripts have evolved in the course of the project (Stuchlík et al., 2006; Horecký et al., 2005; Hardekopf, 2008; Hardekopf et al. 2008; Křeček et al., 2006; Šporka et al., 2006; Tátosová, 2008; Stuchlik et al., submitted; Benčoková et al., submitted).

Task 2.2 Impacts on ecological functioning as a response to changing discharge regimes (UB, NERI AU,, NERC)

Task 2.2 sought to examine the impact of climate change on in-stream nutrient uptake by observing the temporal variability in nutrient uptake in two streams exhibiting contrasting hydrological regimes (i.e. permanent stream versus intermittent stream), the spatial variability in nutrient uptake among streams located along an altitudinal gradient using a space-for-time substitution approach and by conducting experimental short-term nutrient additions at reach scale

UB conducted short-term nutrient additions at 3 selected streams in the Montseny (Spain) including regular biweekly to monthly monitoring of stream water chemistry, discharge and nutrient retention during 4 hydrological years. Further experiments were undertaken in 14 streams in the Central Pyrenees located along an altitudinal gradient (2100 to 700 m) to measure nutrient retention and metabolism. Results are presented in **Deliverables 42, 82, 216,** and **308**) and in papers and a book chapter (von Schiller et al., 2008; Martí et al., in press; Martí et al., 2009 in press).

Task 2.3 Glacier retreat and extreme events in alpine regions (UIBK)
The objective of Task 2.3 was to assess the impact of climate change on the runoff in glacierized and non-glacierized alpine river basins by collating and analysing long-term data on air temperature, precipitation and runoff in the selected basins, applying a conceptual hydro-meteorological model to selected alpine river basins and simulating basin runoff under varying climate scenarios

UIBK collated long-term data series on river discharge, air temperature and precipitation in selected river basins in the Central Eastern Alps. The conceptual hydro-meteorological model (OEZ 2.1) was applied to non-glacierized basins and basins with varying degree of glacierization. The model simulated Basin runoff was simulated under different scenarios of climate change. The work has been subject to four master theses at the Institute of Meteorology and Geophysics, University of Innsbruck (Bacher, 2008; Meingassner, 2008; Rastner, 2008; Wieser, 2009) and has been reported in **Deliverables 49** and **148**.

Task 3: Climate change impact on lakes (SYKE)

Task 3.1 Long-term direct climate change impacts on surface waters (EAWAG, UCL)

Task 3.1 attempted to evaluate the response of water temperature in lakes and rivers to climate warming, assess the impact of climate change on lake ice phenology and evaluate the paleolimnological evidence for climate effects on surface waters. This was to be achieved by collating and analysing long-term data series of water temperature in lakes and streams and of ice phenology and by exploring and developing techniques for the analysis of paleolimnological time series.

EAWAG collated and analysed long-term historical water temperature and ice phenology data and conducted several analysis on these data. Results were summarised in Deliverables **Deliverables 9** and **149** and reported in several papers (Livingstone, 2005, 2007; Weyenmeyer et al., 2004, 2005). **UCL** performed an analysis of water temperature time series data from over 3000 locations in England and Wales and provided a document describing practical advice on analysing such data using the R statistical software via generalized additive mixed models, and employing spatial correlation structures and variance functions to model the covariance matrix for the model residuals. **EAWAG** was involved in 2 large-scale analyses on long-term changes in lake water temperatures across Europe and conducted studies on the regional coherence of lake and river water response to climatic forcing (Dokulil et al., 2006; Blenckner et al., 2007; Livingstone and Hari, 2008; Hari et al., 2006). **EAWAG** collaborated with **UCL** and external partners to study the short-term fluctuations in surface water temperatures in relation to regional climate (Livingstone and Kernan, in press; Šporka et al., 2006). Oxygen and temperature distribution in Swiss lakes and the response to climate forcing (including the impact of the hot summer 2003) were investigated by **EAWAG** (Jankowski et al., 2006; Rempfer, 2007). **UCL** performed paleolimnological analyses of past natural variability inferred from sediment records and took sediment cores from Loch Leven and Esthwaite Water (UK). The sediment core of Lochnagar (UK) was ^{210}Pb dated. Over the course of the project, the focus of the **UCL** effort in WP1 moved away from some of the detailed paleoecological analysis, but moved towards methodological developments and applications of these methods at sites with existing data. **UCL** developed protocols for analysing sediment core data and focused on fitting statistical models to time series data from non-laminated cores, where the data in the series are irregularly sampled in time. The variability analysis in sediment sequences from Lochnagar and Loch Coire Fionnaraich (UK), the use of statistical analysis applied and the problems associated with irregular sampling in non-varved sediment sequences were reported in **Deliverable 150**. **UCL** also developed statistical methodology for the analysis of variability in multivariate datasets. These methods have been exemplified using a varved sediment sequence from Kasjøn (Sweden) using a sequence from 500 BC to 500 AD. Changes in temperature (inferred from tree ring records) and mineral accumulation rates were referred to changes in the diatom species composition across this period. The Kasjøn study was written up for publication. The methodological work and Kasjøn example are also presented in **Deliverable 79**. **UCL** developed a free, open-source software for calculating a measure of multivariate dispersion, a multivariate analogue of Levene's test, including a permutation test. This software was contributed to the R package "vegan" and is currently available in the development version of vegan on the R-forge website (http://r-forge.r-project.org/projects/vegan/).

Task 3.2 Climate sensitivity of different types of lakes and their response to extreme events (NERC, UIBK)

Here the objective was to evaluate the response of lakes to short-term changes in weather by establishing and maintaining a network of automatic monitoring stations in the UK and Austria and assessing high-frequency meteorological and limnological data at selected lakes

WORK PERFORMED

NERC and **UIBK** have run Lake Dynamic Monitoring Stations to assess the physical responses of lakes to local weather. The network of monitoring stations in the UK and in Austria has been established under previous EU-projects. Acquired data support the quantification of lake sensitivity to short-term changes in the weather. A detailed description of the UK network was given by **NERC** in **Deliverables 43** and **80/151**. **UIBK** and **NERC** reported on the impact of weather on the thermal structure of 2 lakes in the UK and in Austria (Windermere, Piburger See) in **Deliverable 217**.

Task 3.3 Lake response to increased input of mixing energy (SYKE, NIVA)

Task 3.3 aimed to evaluate the lake response to an increased input of mixing energy and how how changes in the lake thermocline affect ecosystem functioning and structure The approaches were to perform a whole-lake mixing experiment (THERMOS) in a small lake in Finland (Lake Hälsjärvi), quantify the effects of controlled thermocline manipulation on biogeochemical cycles (including Hg), foodweb structure and productivity and on biodiversity in dystrophic systems and apply a thermodynamic model (MyLake) to the collected data and simulate the effect of climate change scenarios

NIVA conducted a modelling case study using the new model MyLake at the two Finnish lakes Valkea-Kotinen and Halsjärvi. Observational data for model forcing, set up and calibration were provided by **SYKE**. MyLake was coupled with automatic model calibration, uncertainty- and sensitivity analysis tools. Climate scenario data (RCAO using HadAM3 and ECHAM4 for A2, B2 sceanarios) were applied to the MyLake model to simulate the lake's response to a projected future climate in 2071-2100 and to support the design of the manipulation experiment. Modelling results are described in: Saloranta and Andersen, 2007; Saloranta et al., in press. The mixing experiment in Lake Hälsjärvi was run by **SYKE** applying MIXOX aeration equipment (see **Deliverable 78**). Between 2004 and 2007, weekly to biweekly sampling for water chemistry and biological analyses were performed at a nearby reference lake (Valkea-Kotinen) and at the experimental lake Hälsjärvi. Results are described in 2 manuscripts (Forsius et al. in prep.; Arvola et al., in prep.). The Finnish mixing experiment is compared with a previous experiment, which was performed at a Norwegian deep-water lake. **NIVA** has published results of the Norwegian THERMOS experiment (Lydersen et al., 2008).

Task 3.4 Integrated modelling of ecological thresholds at climatic extremes (CSIC)
The objective of Task 3.4 was to assess ecological thresholds in lakes at extremes (alpine, sub-arctic and semi-arid lakes) using statistical techniques to empirically identify ecological thresholds from databases including species distribution and environmental values for cold lakes (alpine, subarctic) and semi-arid lakes (Mediterranean in-land lagoons) and by develop a biogeodynamic lake model (Comsol Multiphysics software) to simulate ecological thresholds. Ecological thresholds are here defined as points in environmental gradients were the species rate of change is higher than at points distant from them.

CSIC studied species assemblage patterns of diatoms, rotifers, chydorids, planktonic crustaceans and chironomids were studied in 235 high mountain lakes in Europe. Lake clustering for each taxonomic group and discriminant analyses to investigate the environmental influence on these assemblage patterns was performed. The results were reported in **Deliverables 45**, **152** and **153** for alpine lakes, Arctic lakes and semi-arid lakes, respectively. Manuscripts for publication are in preparation (Catalan et al. Ecological thresholds in alpine lakes. Freshwater Biology (submitted)). The results obtained have also been applied into the development of the Water Framework Directive for the water masses in Catalonia (NE Spain), a joint publication with the Catalan Water Agency of protocols for the evaluation of the ecological status in lakes of Catalonia was produced. Some aspects developed for this specific case are now being applied in a broader context in several European countries. General aspects of the results on ecological thresholds were included in the assessment of the effects of climate change on Spanish ecosystems. Another activity within this task was the development of a biogeodynamics model for small lakes.

With regard to the modular set of physical and biogeochemical models implemented using Comsol Multiphysics (formerly FEMLAB), due to slower progress in the collation and empirical treatment previously reported and time allocation to WP5 tasks, which during the development of the project provided very new and challenging results, this activity did not achieved the final result expected at the beginning (**Deliverable 309**), however, it is planned to continue with the model development in the future.

Task 3.5 Impact of climate change on deep and large lakes (HYDROMOD, SYKE, NIVA, CNR)
The aim of Task 3.5 was to evaluate the impact of climate change on deep large lakes. This was to be achieved by building a database containing long-term hydro-meteorological and limnological data for modelling, applying coupled hydro-physical and ecological models to selected deep large lakes and using climate scenario data to estimate the potential changes in frequency and intensity of extreme events by the end of the 21^{st} century

HYDROMOD built a database with hydro-meteorological and limnological data of the 4 selected deep large lakes (Lago Maggiore, Hornindalsvatn, Loch Lomond, Bodensee) in collaboration with **CNR**, **NIVA** and **SYKE –Deliverables 44** and **154.** Climate scenario data were statistically downscaled using the SDSM software. Modelling work was performed by **HYDROMOD** in collaboration with **SYKE** and **NIVA,** including hydrological, hydro-physical and nutrient load modelling. The Loch Lomond – River Endrick system was used for an integrated catchment – lake study. Model results were reported in **Deliverable 155** by **HYDROMOD** in collaboration with **CNR**, **NIVA, SYKE** and **NERC**.

Task 4: Impact of climate change on marginal wetlands (RHBNC, ULIV)

Task 4.1 Changing hydrology and biogeochemical processes (RHBNC, ULIV)
The aims here were to study the effects of temperature and flooding on denitrification rates and net greenhouse gas emissions in a river marginal wetland (Tamar catchment, UK) and evaluate the impact of future climate change on greenhouse gas emissions under projected temperature and flooding scenarios. The intention was to use climate controlled mesocosms for the incubation of soil cores from hydrogeomorphic units, apply a hydrological model to the Tamar catchment and construct a model of potential future catchment fluxes of greenhouse gas emissions (N_2O, N_2O+N_2) for flooded and unflooded conditions and upscale fluxes to catchment scale

Soil sampling and incubation experiments were performed by **RHBNC** and **ULIV.** Incubations of soil cores from three types of floodplain wetland were carried out at temperatures between 2 and 25°C for up to 24 hours under non-flooded and flooded (with NO_3-ammended water) conditions to assess the impact of temperature and nitrate-amended flood-water on denitrification rates and greenhouse gas production. Two hydrological models were developed by **EKBY**, and run with climate scenario data from PRUDENCE (RCAO model, ECHAM4/OPYC and HadAM3H). **ULIV** has reported results in **Deliverables 52** and **310** (in collaboration with **EKBY**).

Task 4.2 Changes in plant communities dependent on temperature and hydro-period (UR1, EKBY)
The objectives were to evaluate the sensitivity of wetland plant communities to different drivers (hydrology, nutrient availability, land-use) and determine whether changes in plant communities of river and lake marginal wetlands dependent on temperature and hydro-period.

Space for time substitution analysis was undertaken at the European scale together with data from long term ecological surveys. Phytosociological analyses (classification, table analyses of plant assemblages) and multidimensional analyses were were employed and Ellenberg indicator value procedure was used for assessing major habitat ecological factors.

UR1 applied multivariate analytical techniques to evaluate possible changes in plant communities focusing on palustrian standing water systems and perennial plant communities from available phytosociological data sets across Europe. European wetland habitats were coded according to the EUNIS classification system (cf **Deliverable 51**). The effects of climate change on European terrestrial hydromorphic wetlands were reported in **Deliverable 311.** A database was produced using existing literature on European wetlands, selecting 960 syntaxa, which represent the major wetland habitats (palustrian and terrestrial hydromorphic). The database and field surveys in France were used to develop a model and to find indicators to predict changes in EUNIS habitats in response to climate and land-use change (cf. **Deliverable 313**).

UR1 and **EKBY** analysed vegetation dynamics in Cheimaditida lake (Greece) over 50 years using remote sensing documents, plant community analysis, and ecological factors such as peat accumulation into Typha rafts. This work is complementary to the analysis presented previously (cf. **Deliverable 51**). Results are presented in **Deliverable 312**.

Long-term ecological surveys were used to analyse habitat dynamics due to land abandonment in the Atlantic European Wet grasslands (France). **UR1** reported in **Deliverable 83** on the succession of plant functional groups and plant assemblages in response to changing environmental drivers.

Analysis of shallow lake marginal habitats in the south-west of France was undertaken by **UR1**, in particular the assessment of potential changes in marginal wetland plant assemblages between the early 1960s and 2006 (cf **Deliverable 156**).

Task 4.3 Changes in wetland plant nutrient dynamics and productivity (UU-BIO)
This task attempted to quantify direct effects of climate change on wetland plant nutrient dynamics and productivity through modelling.

UU-BIO used the Van der Pijl model to study effects of changes in hydrology on wetlands. However, this was only a modelling study and a study relatively isolated within the Eurolimpacs programme. Therefore, **UU-BIO** proceeded to investigate effects of temperature changes on wetlands. This research was well-embedded within Euro-limpacs and was undertaken in tandem with work done in the paired wetland sites in WP3. Results are described under WP 3. The specification of the Van der Pijl model was described in **Deliverable 53**.

Task 4.4 Climate change impacts on the relationship between marginal wetlands and adjacent surface waters (UNIBUC-ECO)
This task had two key objectives; i) Evaluate the effects of changing hydrology and biogeochemical processes on plant communities, nutrient dynamics and productivity in marginal wetlands in the Lower Danube Wetland System/ Small Island of Braila; and ii) Evaluate the impacts of climate change on the buffer capacity of river marginal wetlands Study the relationships between riparian wetlands and adjacent surface waters. These were acheived through collation of long-term hydrological, meteorological and biological data and statistical evaluation of data series and model development (using Stella software)

UNIBUC-ECO developed a database comprising climatic, hydrological, soil and water quality data**,** and data on phyto- and zoo-plankton, aquatic, terrestrial and wetland vegetation, terrestrial and benthic invertebrates, fish, small mammals and birds. New field data and laboratory work completed existing data sets. Work was described in **Deliverables 50**, **84** and **213**. Statistical analysis of data series was performed to discriminate the influence of climate changes, mainly though hydrology and other climatic parameters like light, temperature and wind regime, including photoperiod and seasonality and to study effects of changing hydrology and biogeochemical processes on structural and functional dynamics of riparian communities. The effect of climate change on the buffer capacity (sediment /nutrient retention, and processes like mineralization rate and denitrification) of the floodplain wetlands was evaluated.

Task 4.5 Riparian wetland snow-cover and soil temperature manipulation (SLU)
Task 5.4 sought to evaluate how soil frost regimes control the quality and quantity of DOC in stream runoff during spring flood and to evaluate how changes in the extent and duration of soil frost in the riparian soil affect concentration and bioavailability of DOC. The methods involved experimental manipulations of riparian wetland snow cover-soil temperature and examination of multi-decadal time-series of water quality with respect to short-term climatic variation to assess how the water quality, especially with respect to dissolved organic carbon, responds to the timing and amount of precipitation/snow

SLU performed a soil frost manipulation experiment in Svartberget (Sweden). Soil temperature and unfrozen water content were continuously monitored at various depths. In addition to the DOC concentration measurements, the UV-VIS absorbance measurements were used to study the quality of the DOC. A preliminary bioassay experiment (based on bacterial activities) was also conducted. A model of how the riparian zone serves as the template for runoff water was developed. SLU presented results in **Deliverables 46, 214, 314** and **315**, and several papers (Mellander et al., 2007; Öquist et al., 2008; Cory et al., 2007; Köhler et al., 2008; Yurova et al., 2008).

Task 5: Climate change impacts on dissolved organic carbon levels (NERC)

Task 5.1 Climate manipulation experiment on DOC concentrations (NERC)
This task represented an attempt to evaluate the sensitivity of surface water DOC concentrations to climate change, focusing on the effects of warming and summer drought using a replicated plot-scale field experiment.

NERC used an established plot-scale climate experiment at Clocaenog, Wales (UK) (from the EU-CLIMOOR project) to examine the effects of summer drought and increased temperature on DOC leaching from a typical UK heathland soil by manipulating climate conditions by means of retractable roof systems to (1) induce night-time warming (about 1 ºC) by reducing heat loss, and (2) to reduce summer rainfall (by about 60%). Soil solution DOC was measured in the organic and mineral soil horizons using lysimeters. NERC also measured the recalcitrant phenolic component of DOC and the activity of the key phenol oxidase enzyme in the soils. Results were described in **Deliverables 10** and **316** and in 2 publications by Toberman et al. (2008).

Task 5.2 Catchment-scale modelling of DOC concentrations in surface waters (NERC, UCL)
Here the objectives were to evaluate and predict the spatial and temporal controls on surface water DOC concentrations at the large catchment scale and develop a catchment-scale DOC model. The approach was to undertake model-based surveys of headwater streams representing the major landscape classes within the selected catchment, characterise the mean and variation of drainage water quality associated with each landscape class and apply the PEARLS meta-model to simulate DOC inputs to each location within the drainage network, with a hydrological routing model used to simulate DOC downstream transport

The Conwy catchment (North Wales, UK) was selected by **NERC** as a representative river system draining a range of soils and land-use (peat moorland, mountain grassland, conifer forest and lowland pasture) in a region where rising DOC has been recorded. Repeated surveys were undertaken of small streams draining representative areas of each major soil-land use combination, together with downstream locations within the drainage network. Samples were analysed for DOC, a range of other chemical determinands, and (for a subset of samples) the radiocarbon (^{14}C) content of DOC. Data were used to parameterise a version of the GIS-based PEARLS water quality model (developed in WP6). **NERC** described results in **Deliverables 47, 157** and **317**, and in 2 publications (Evans et al. 2006; Evans et al., 2007).

Task 5.3 Long-term trends in DOC (UCL)

Task 5.3 sought to evaluate the extent and environmental drivers of increases in surface water DOC concentrations and examine historic DOC variations by means of palaeolimnological reconstructions. The approach combined the use of long-term monitoring data to evaluate increases in surface water DOC concentrations and the exploitation of information on changing proportions of diatoms from different lakes habitats (e.g. epilithic (stone dwelling), epipsammic (sand dwelling) and epipelic (mud dwelling)) to reconstruct paleoecological changes in water transparency, and hence DOC, over the last few hundred years

UCL selected about 30 upland oligotrophic lakes in Wales and Scotland (UK) for bathymetric and photosynthetically active radiation (PAR) profiling during 2004 and 2005. Water chemistry samples were also taken and analysed for DOC and absorbance at a range of wavelengths between 254-400 nm. At one lake in southern Scotland, detailed surveys were carried out of the depth distribution and substrate dependence of diatom species.

UCL investigated the relationships between DOC-related light penetration in the Round Loch of Glenhead (UK) and the composition and abundance of epipelic diatoms in the lake. Epipelic diatoms grow in low light conditions on and in the surface of sediments and their abundance and distribution within the lake can be assumed to vary with changes in DOC through time. **UCL** has developed a new method of sampling and analysing epipelic diatoms (see Yang & Flower, 2009; Yang et al., submitted), monitored changes in diatom composition and abundance with water depth over a period of two years, mapped the distribution of epipelic diatoms across the lake basin, and developed a method of reconstructing DOC from sediment cores in the lake using his newly developed epipelic approach. The method was applied to a new sediment core from the lake and the results were compared with other methods, principally the NIRS approach and the diatom-DOC transfer function method. Results were presented in **Deliverable 158.**

UCL and **NERC** collated long-term monitoring datasets from over 500 surface waters draining semi-natural catchments across Northern Europe and North America. Trends in DOC concentration were analysed in relation to trends in sulphate concentration (as a proxy for sulphur deposition), chloride concentration (as a proxy for sea-salt deposition), and long-term temperature records. Results were presented in several papers (Monteith et al., 2007; Evans et al., 2005, 2006, 2008).

WORK PACKAGE 2: Climate Change – Hydromorphology interactions

WP2 comprised 5 tasks and the activities undertaken in each of these are outlined below. The connections between land use and river hydromorphology for the selected study catchments throughout Europe, were analysed and reported. The study of the same relationships between climate/land use/hydrology/hydromorphology and river biota by analysing existing European datasets (AQEM-STAR), supported the catchment scale analyses. Data on time series were analysed to assess seasonal and annual variability and to identify the effects of extremely high or low discharge on the biology. Key taxa or functional groups, identified in the study catchments, were subject to more in-depth investigation in field and laboratory studies. Habitat binding of selected indicators species was examined by habitat specific sampling in the field and causes of habitat binding were analysed by autecological field and laboratory studies. The effects of discharge regimes and current velocity pattern on habitat stability and indicator species were studied using field and laboratory experiments. Paired site studies were performed in mountain streams to examine the effects of braiding and of siltation and in meandering lowland rivers to understand the effects of scouring, habitat and current variability, on hydromorphological features, benthic invertebrates, riparian fauna and flora. Experiments on in-stream nutrient retention and water transient storage took place. Sediment accumulation rates were evaluated from lakes across Europe.

Task 1: Climate - hydromorphology interactions through changes in land-use and discharge (ALTERRA)

Task 1.1 Rivers (ALTERRA, BOKU, NERC, CNR, MasUniv, SLU, UDE, UNIBUC-ECO)
The objective of task 1.1 was to analyse and predict the effects on hydromorphology of two different potential changes in land-use following climate change, based on a review of literature and data from 8 different catchments (each partner dealt with one catchment: **Alterra**, **BOKU**, **NERC**, **CNR**, **MasUniv**, **SLU**, **UDE**, **UNIBUC-ECO**).

A questionnaire on study catchments description and data availability was performed. Each partner collected historical and present existing data on his own catchment. One partner (**UNIBUC-ECO**) collected new data. A joint workshop was held (2004) to agree on common parameters, methods (**Deliverable 12**) and reach common objectives. Analyses of each catchment, on land-use – hydromorphology interaction and effect of floodplain changes (prediction of land-use) were undertaken using using multivariate analysis techniques. Modelling and prediction was done for the Lambourn (**NERC**), Vecht (**Alterra**), Becva (**MasUniv**) and Nealjov (**UNIBUC-ECO**).

The data and results were taken further in Task 2.1 (biotic component of the studied catchments) and 2.4.

Task 1.2 Lakes (HYDROMOD, UCL)
The objective of Task 1.2 was to study the sediment accumulation rates from lakes across Europe using multivariate techniques to evaluate the role of climate and land-use change on lake sediment accumulation rates. The key research questions are addressed were i) What is

the role of climate and land-use change on lake sediment accumulation rates based on analyses of existing records and additional sediment cores taken within Eurolimpacs?; ii) How will the changing quantity and temporal variation of sediment load and discharge of tributaries influence large lakes including processes related to the accumulation of sediments in river deltas, waterlevel fluctuations, aeriation of deep water bodies and suspended matter intrusion in the pelagial and profundal regions of lakes?; and iii) What lake types are most susceptible to changes in sediment accumulation rate and, in particular, how susceptible are shallow lakes?

A sediment accumulation rate (SAR) database was compiled containing 338 sediment cores from 279 European lakes for each 25 year period from 1850 to 2000 (where available) (**UCL**). Sites in the database were classified into 36 classes using lake typology data. Where new sediment core data was available from other Euro-limpacs activities, these were also included. Temporal changes (rates, scales) in SAR for all lake types were identified in order to assess the types most 'at risk'. An assessment of the reference condition concept for sediment accumulation rates was considered (link to WP8) and reference SARs identified for the eight lake types with the most members. This allowed an assessment of SAR 'exceedence' for contemporary SAR. Factors driving contemporary bulk SAR and SAR change since 1850 in selected lake types was undertaken in order to assess likely impacts of future climate change (**UCL**).

Data on a number of hydrological and morphological parameters in three main tributaries to Loch Lomond and the Alpenrhein (Bodensee) were collected and analysed by using the INCA model (**HYDROMOD**). Comparison between measured sediment accumulation rates and computed river loads were made.

Task 2: Hydromorphological changes and aquatic and riparian biota (ALTERRA)

Task 2.1 Review and data collation (BOKU, NERC, CNR, MasUniv, SLU, UDE, UNIBUC-ECO)

The objective of Task 2.1 was to analyse the relationships between hydrology/hydromorphology and species composition, and to find species or biological parameters that are good indicators for changes in hydrology/hydromorphology.

Historical and present day biological data on 8 study catchments were collated (**BOKU, NERC, CNR, MasUniv, SLU, UDE, UNIBUC-ECO, CNRS-UPS**). Multivariate analyses of catchment land use and hydromorphological data for the the selected catchments were undertaken to describe relationships and to extract indicators. A literature review was completed (**MasUniv**).

Databases were build for the Vecht catchment (**Alterra**), River Waldaist (**BOKU**), Lambourn (**NERC**), Emå (**SLU**), Neajlov (**UNIBUC-ECO**), Lahn/Eder (**UDE**), Becva River (**MasUniv**), and Adour-Garonne (**CNRS-UPS**). From these databases a joint analysis extracted indicators of hydromorphological conditions within macrophyte, macroinvertebrate and fish communities. A review of all catments data was performed (**Mas Univ**).

Task 2.2 Detailed study of indicators at the habitat scale (Alterra, BOKU, NERC, CNR, MasUniv, SLU, UDE, UNIBUC-ECO)

The objective of Task 2.2 was to identify species or functional groups bound to key habitat structures. Randomly selected sections of unpolluted rivers with different hydromorphological characteristics were sampled using a pre-designed sampling framework allowing species or functional groups bound to key habitat structures to be identified. To assess the impact of future climate and land-use change on sediment erosion, transport and deposition the ECOHYDRO model (see WP1) was tested at Loch Lomond and its inflow, the River Endrick.

A joint database on macroinvertebrate and habitat parameters was compiled (**Alterra**, **BOKU**, **NERC**, **CNR**, **MasUniv**, **SLU**, **UDE**, **UNIBUC-ECO**). Field monitoring took place to study temperature, discharge and macroinvertebrate habitat distribution (**Alterra**, **SLU**, **UDE**) and life cycles relations (**CNR**), special attention was given to riparian and marginal wetland fauna (**BOKU**). The Becva (**MasUniv**), Springendal stream, including re-meandering (**Alterra**), river Waldaist, including siltation (**BOKU**), nine streams (**UDE**), four streams (**CNR**), Izvoru (**UNIBUC-ECO**) and Knipan (**SLU**) were chosen as the 'model' streams. PCA, index of representation, correlation analysis of abiotic features with species abundance, cluster analysis and NMS were applied. The key taxa (indictors) of habitat stability were indentified and analysed (**ALTERRA, BOKU, NERC, CNR, MasUniv, SLU, UDE, UNIBUC-ECO**). Field experiments were undertaken to test the habitat preferences in relation to substrate stability as well as current velocity (**Alterra**).

Task 2.3 Autecological and laboratory experiments (ALTERRA, UDE)
The objectives of Task 2.3 were to test (i) the habitat preference and (ii) the tolerance for habitat instability, of selected indicators. To achive these aims autecological laboratory experiments (artificial channels), involving up to 10 indicator species/life stages of species, were undertaken to examine the causes of habitat binding and tolerances to change with emphasis on preferences for selected physical habitat features and the resistance to habitat changes due to flow extremes will be designed and performed.

UDE and **Alterra** carried out field studies using the same methods and investigating the same indicator species. Indicator species were selected based on the results of Task 2.1 and 2.2 and experiments were combined with Task 3. Indicator species for natural and disturbed situations were sought (**UDE**). Paired sites were selected (Gartroper Mühlenbach, Rotbach, Schwarzbach, one degraded and one near natural section). Habitat specific benthic invertebrate sampling took place once during base flow and after high discharge events. Data were processed and analysed. Indicator taxa were selected. **Alterra** completed comparable field work in the Springendal stream; a near natural, semi-natural and hydromorphologically degraded section of the stream. **Alterra** prepared the artificial stream channels for laboratory experiments and completed preference and disturbance experiments were done. Experiments for three Trichoptera species (indicator species resulting from the German field study and former studies from comparable sites in the Netherlands) were performed.

Task 2.4 Examination of relationships between habitat and morphology and land-use (ALTERRA, BOKU, NERC, CNR, MasUniv, SLU, UDE)
Task 2.4 sought to model relationships between land-use, hydromorphology, habitat characteristics and biota. Examination of the relationship between biota and the complex habitat, hydromorphology and land-use allows the comparison of the effect of each factor. Up to 10 indicator species were targeted to be used to examine the causes of habitat binding and tolerances to change. This work was supported by data generated from other tasks within WP2, as well as other data included in the Meta-database.

From data collected within the Euro-limopacs consortium and previous EU projects, a database for diatoms, macroinvertebrates and fish sampled across Europe was developed (**CNRS-UPS**, with data provided by **Alterra**, **BOKU**, **NERC**, **CNR**, **MasUniv**, **SLU**, **UDE**). A detailed database for the Adour and Garonne basins in France was compiled (**CNRS-UPS**). Artificial neural network techniques within a multilmodel approach were used to analyse the data. Using Generalized additive models and hierarchical partitioning, ecological responses of 28 fish species to a set of 5 environmental predictors were modelled, and the independent effect of each predictor was quantified.

Task 2.5 Examination of existing time-series data (SLU)
The objective of Task 2.5 was to assess seasonal and annual variability and identify the effects of extremely high or low discharge on the biology. This was done using existing time-series data.

Data availability was assessed for the eight study catchments (plus a ninth catchment in France), when time-series data were available these were collected and analysed. The only partner with 50-100 observations, a long data series, was **NERC**. **SLU** collected further data series from **Alterra**, **BOKU**, **UDE** (lowland and mountain rivers) and two Swedish datasets (one from the Emå catchment).

NERC has modelled the relationship between monthly rainfall, air temperature and discharge for the period 1974-1995, and then applied that relationship to projected rainfall and air temperature for the period 2071-2100 (RCAO model and HadAM3H under IPCC B2 scenario) to generate a predicted time series of discharge. It then quantified the temporal variation in contemporary biotic communities that can be attributed to discharge fluctuations and identified potential indicator taxa that could be susceptible to the projected changes. The historical development of climate, land-uses and hydromorphology of the river Vecht and its tributaries, all situated in the North-West European plain, were described (**Alterra**). Data from samples ranging from 1980 up to 2004 from the river Dinkel were analysed. A description of phenomena related to climate changes in discharge was studied in a regulated river (effects of flow extremes, flow variation, altered thermal regime, changed sedimentation regime downstream of a dam). The response of macroinvertebrates to altered environmental characteristics (seasonal variation, downstream pattern) was evaluated

(**MasUniv**). Alterra provided long-term data series (river Ruenbergerbeek) to **SLU** for analysis. Indicator information was indentified and was transferred to WP7.

Task 3: Hydrological changes and aquatic taxa (ALTERRA)

Task 3.1 Field experiments to examine the effects of discharge dynamics (ALTERRA, NERC, MasUniv, UDE)
The objective of Task 3.1 was to study the effect of discharge regime on habitat stability and diversity (indicator species).

A field monitoring network was set up at selected sites for monitoring discharge regime at selected sites to examine the potential effect of increased flooding intensity (extreme discharge events as well as extended drought periods) and decreased flood intervals on habitat and community composition under field conditions. **UDE** combined the work with Task 2.3. Three more field experiments to test discharge extremes were performed (**Alterra**). The history of river habitats in relation to seasonal flow regime and to evaluate the hydraulic preferences of macroinvertebrates was evaluated (**MasUniv**). A literature review supporting the experiments on discharge was studied (MasUniv).

The Dutch discharge dynamics gradient was located in the Springendal stream and Frederik-Bernhard stream catchments (**Alterra**). Both gradients comprised a reference site, a moderately disturbed site (slight changes in morphology and stronger ones in hydrology) and a degraded site. Based on the data collected the hydromorphology gradient was analysed, and relations were described and key indicator species were selected. Habitat stability was recorded under different discharge conditions using a sediment trap, macroinvertebrates were collected at the same time (**Alterra**). This was repeated in three streams for sand substrates (see also Task 2.2).

A field experiment (Before-After-Control-Impact design) to test discharge extremes by blocking the stream and simulating a discharge peak (and a higher peak frequency as predicted due to climate change) was undertaken (**Alterra**).

The hydromorphological gradient in the Frederik-Bernhard stream was monitored by continuously recording discharge, macroinvertebrates were sampled and chemical and morphological parameters were recorded to validate the Springendal hydromorphological gradient.

Task 3.2 Laboratory experiments (ALTERRA, NERC)
The objective of Task 3.2 was to study the effect of discharge regime shifts (disturbance) on habitat stability and indicator responses. Key taxa or functional groups reflecting discharge dynamics were selected following a desk study and from field data. An experimental set-up was drawn up for in-door artificial channels including the hypotheses to be tested, the first indicator species were. Similar experiments in outdoor stream channels were set up to test drought effects.

A targeted review of the literature and existing datasets on mesohabitat and flow preferences of macroinvertebrates in UK streams was completed (**NERC**). A short-list of gravel and riffle inhabiting taxa was compiled that are potentially the best indicators of discharge disturbance for laboratory experiments (**Alterra**, **NERC**). Habitat preference optima were found for 128 non-randomly distributed species. The IR analysis results were transformed to a 10-habitat type ranking system, which can be a useful tool for water managers (**Alterra**). Habitat preference as well as disturbance experiments for six indicative trichopterans species (three specialists, three generalists) were performed to establish species responses to both current and substrate/food over time as well as the substrate either or not current disturbances related responses (**Alterra**). The species were selected based on the field collection results obtained by all partners involved in the lowland stream research (**UDE**, **SLU**, **NERC**). A literature review on the autecology of the six trichopterans supported the experiments (**Alterra**). Statistical analyses were undertaken on the results.

Low-flow experiments were carried out at FBA River laboratory experimental flow-though facility (**NERC**). The treatments were coupled with medium and control flow channels to discover what effect flow had on resident fauna. Macroinvertebrate samples were taken and the substrates were regularly mapped. Sites in mountain streams with near-natural (not affected by siltation) and degraded (affected by siltation) hydromorphological conditions were studied (**BOKU**).

Task 4: Key - processes in mountain streams (UDE)

Task 4.1 Paired studies of straight and braided channels (UDE, BOKU, CNR)
Task 4.1 aimed to study the effects of on hydromorphological restoration (braiding and siltation) on the biodiversity in mountain streams.

Paired study sites were selected in braided and straight sections where hydromorphological investigations (braiding Germany, Italy; siltation Austria) and benthic invertebrate collections took place. The analyses of silted and not-silted sites comprised macroinvertebrate taxa patterns on reach level and species number (Jackknife estimation), species diversity and similarity indices - considering different life stages - and a comparison of habitat specific feeding type. The habitat specific biotic data were analysed, including analysis of the temporal and spatial distribution of species and life stages, using PCA, index of representation, correlation analysis of abiotic features with species abundance, cluster analysis and NMS.

A comparative analysis of restoration effects on hydromorphology, floodplain vegetation, riparian ground beetles and benthic invertebrates in multiple-channel mountain rivers was performed (**UDE**, **BOKU**). A large dataset was used to compare effects of restoration measures in mountain streams in three European countries.

Task 4.2 Experiments on tracer additions (UB)
The objective of Task 4.2 was to quantify in-stream nutrient retention, as well as water transient storage and hydraulic parameters through experiments in mountain streams.

Three reference study sites in the Tordera catchment, northern Spain, were selected in two small streams. At each section, tracers and nutrients were added to examine the effects of leaf-fall as a natural driver over-imposed on the geomorphological template. The hydrologic and hydraulic parameters were obtained from solute additions which provided integrated information about the entire stream section. A second experiment examined the influence of channel morphology on the surface-subsurface hydrologic interaction and its implications for stream nutrient dynamics (**UB**, **CSIC**).

Surface-subsurface hydrological and chemical linkages due to the accumulation of FBOM in the sediments during leaf fall were analyzed by placing 29 wells to the hyporheic zone at 5 m intervals along a 140 m stream reach.

Task 5: Key - processes in meandering lowland streams (ALTERRA, MasUniv, UDE)
Taks 5 planned to study the effects of hydromorphological restoration (re-meandering, woody debris addition, hydrological stabilisation) on the biodiversity in lowland streams.

Pairs of sites with near-natural and degraded hydromorphological conditions in the selected catchments were identified and sampled according to a standardised protocol (BACI design) (the Netherlands (Springendalse stream, Juffer stream, Geeserstroom), Germany (Lippe), Sweden (Emå), Czech Republic (Becva), and Romania (Nealjov) to examine the opposing processes of restoration that affect habitat stability in lowland streams with different discharge regimes. Both individual analysis per project and a joint data analysis of all results of restoration sites (mountain and lowland streams) was undertaken. (**UDE**, **MasUniv**, **SLU**, **Alterra**). A "Causes of failure and success" of lowland stream restoration, summarising the knowledge developed in WP 2 was completed (**Alterra**).

The partners worked on different study subjects related to the climate related problems in their own catchments:
Remeandering of streams: One straight and one meandering site in the Schwalm and the Gartroper Mühlenbach in Germany were studied (**UDE**). A re-meandering experiment in the middle course of the Springendal stream and in the Geeserstroom was studied in the Netherlands (**Alterra**). **UNIBUC-ECO** completed the selection of sites with similar hydrological conditions and different natural and anthropic hydromorphology conditions were studied in Romania.
Comparing high versus low discharge: **SLU** tested the effect of a high discharge on macroinvertebrates in the Knipå stream (Sweden).
Hydrological stabilisation: **MasUniv** undertook analyses of historical maps showed changes with the Becva channel following regulation and changes in the riparian zone.
Addition of woody debris: In the Jufferbeek stream, a middle course of a slow flowing lowland stream, wood was added and the effects were monitored (**Alterra**).Using before-after-control-impact (BACI) designed experiment, investigating both an experimental and a control section, **Alterra** examined restoration-induced changes in stream substrate patterns and aquatic macroinvertebrate community composition.

WORK PACKAGE 3: Climate – eutrophication interactions

Task 1: Food-web, nutrient and climate interactions (NERI)

Task 1.1 Using space-for-time data (NERI, AU, NIVA, UIBK, SYKE, UB, UICE, UU-BIO, SLU, KULeuven, EKBY, UGR, ULIV, ALTERRA)

There was extensive work by all partners on this Task, some of it co-operative and highly directed data analysis *(***NERI, NIVA, UIBK, SYKE, UB, UICE, UU-BIO, SLU, KULeuven, EKBY, UGR, ULIV, Alterra***)*, some by direct experimentation (**NERI**) and some carried out on a more individual basis that nonetheless informed the general theme *(***NERI, NIVA, UIBK, SYKE, UB, UICE, UU-BIO, SLU, KULeuven, EKBY, UGR, ULIV, Alterra***)* . Particularly valuable were the experiments carried out by **NERI** on paired lakes in Denmark and Uruguay (**Deliverable 171**), analyses of fish communities along a tropical /arctic gradient using American data (**ULIV**) and the conclusions of a workshop attended by all the partners *(***NERI, NIVA, UIBK, SYKE, UB, UICE, UU-BIO, SLU, KULeuven, EKBY, UGR, ULIV, Alterra**) and invited outsiders (organised by **ULIV**) on the effects of warming and nutrients on freshwater biodiversity (**Deliverable 333**). The final chapter of the Euro-limpacs book was an extension of WP3 work in which most partners contributed to deriving scenarios for the major types of freshwater ecosystem in Europe given warming by 2 and 4C with associated changes in precipitation.

Considerable work was done by **EKBY** in creating a picture of the ecology of the larger lakes of northern Greece, which will become models for lakes in central Europe in the future (paper Freshwater Biology, FWB-A-Jun-08-0293) and by **UB** on the ecology of nutrient uptake in streams served by catchments with differing land uses. **UB** used a multivariate approach to examine how structural and functional (i.e. nutrient retention and metabolism) attributes of streams are related to catchment variables, including land use. The study was done in 13 streams located within a single Mediterranean catchment, but draining sub-catchments with contrasting land use. **UB** also used ^{15}N-labelled nitrate (NO_3^-) additions to investigate nitrogen (N) cycling at the whole-reach scale in three Mediterranean streams surrounded by contrasting land uses (i.e. forested, urban and agricultural) to explore among-stream differences in: (i) the magnitude and relative importance of NO_3^- retention (i.e. assimilatory uptake), and removal, (i.e. denitrification), (ii) the relative contribution of the different primary uptake compartments to NO_3^- retention, and (iii) the regeneration, transformation and export pathways of the retained N. **Deliverable 339** resulted from this work with two further papers published in Freshwater Biology.

NERI and **AU** contributed a great deal to this task. A comprehensive comparative study of the structuring role of submerged macrophytes and floating leaved plants along a nutrient gradient in 10 shallow lakes in Uruguay (subtropics) and 10 in Denmark was completed. NERI has published two papers in Global Change Biology and Freshwater Biology in 2007 and two other papers are underway. Further comparative studies were made in European lakes. These confirm the results from the Uruguayan and Danish lakes and also from Florida lakes. A study of bacterioplankton abundance in >1600 samples from Brazilian was also undertaken and these studies are now being followed up experimentally.

Experimental studies by **NERI**, and separately by **ULIV** were conducted, along a salinity gradient, to evaluate predictions that salinity will be a major effect of warming. New studies of the role of plants on trophic structure, size distribution and dynamics in saline lakes in cold Denmark and warm Catalonia have been conducted in 2007-08. Papers from this experiment are in progress. This study was followed up by a comparative analysis of survey data sampling 35 and 42 brackish lagoons (salinity ranging from 0.3 to 55 ‰) in Mediterranean Catalonia (NE Spain) and northern-temperate Denmark, respectively.

A comparative study of North European lakes has been undertaken by **NERI** to assess the role of nitrogen in eutrophication and possible interactions with climate and **SLU** and **NERI** have published a paper in Limnology and Oceanography, discussing also the consequences for lake water quality. **ULIV** has published two papers documenting effects of nitrate on species richness of macrophyte communities. **NERI** has finished a paper analysing variations in fish community structure along a climate gradient from Sweden via Denmark to Germany showing differences, which challenge the idea of using ecoregions as a common unit in the Water Framework Directive. **NERI** conducted a 3-month mesocosm experiment in summer 2007 on the north-western coast of Turkey with a Mediterranean climate. Another study of the role of nitrogen for macrophyte presence in lakes was conducted with *Vallisneria* in tank experiments in China and published in Freshwater Biology, 2008.

In collaboration with **KULeuven**, **NERI** has finished a study on multi-trophic biodiversity (BIOMAN) in 96 shallow lakes from Denmark, Belgium and Spain. To estimate the potential of using hatching of resting eggs in the surface sediment as an indicator of taxon richness of crustaceans, hatching experiments using sediment from all three regions have been undertaken under different conditions of light, temperature, pre-isolation versus intact sediment, etc. The results are now being compared with contemporary data. Six papers have been published.

A workshop on seasonality was held April 2005 in Silkeborg, Denmark to analyse and discuss how the interactive effects of climate change and eutrophication can be expected to influence the seasonality and temporal dynamics of freshwater systems. This objective was addressed by looking for changes in trophic structure and seasonal dynamics in streams and lakes along a nutrient and a climate gradient and in results from controlled climate-eutrophication experiments (**Deliverable 171**).

UIBK has analysed long-term chemical and biological data series from Piburger See. Special emphasis has been put on the climate impact on chemical and biological parameters, in particular on the response of phytoplankton and nutrients to the hot and dry summer 2003 compared with the cooler and wetter summers in 2002 and 2004. The results have been fed into to a paper on eutrophication led by **UCL**. The paper contributes to a Special Issue of *Journal of Paleolimnology* (cf Task 3.1). Results will also be part of collaborative paper on climate impacts on Piburger See, which is led by **UIBK** as contribution to a Special Issue of *Freshwater Biology.* An extended abstract of this paper has been compiled as **Deliverable 248** (cf Task 3.1)

Data on BOD trends over the last 25 years were gathered from two regions in the Netherlands by **Alterra**, and will become part of a manuscript on developments in stream eutrophication in Europe. **Alterra** collected macroinvertebrate samples from streams where also chemical variables (nutrients) were measured. More than 500 samples were collected from water authorities and from the **Alterra** database to establish the relationships between functional feeding groups of macroinvertebrates and nutrient levels in lowland streams.

KULeuven contributed with BIOMAN data-set to the space for time analysis, and contributed to discussions and data-analysis. **NIVA** finished collating additional data on phytoplankton composition and dynamics in Norwegian lakes with contrasting climate (north-south; coastal-continental). These data form the basis for **Deliverable 335** "Report on results from Norwegian sites". **SYKE** has performed an analysis on three selected large lakes (Lake Pääjärvi / Southern Finland, Lake Lappajärvi / Western Finland, Lake Inarinjärvi / Northern Finland). **ULIV** analysed data from its 2000 climate mesocosm experiment for seasonality for the workshop on seasonality in Silkeborg, planned, organised and managed the workshop on Biodiversity, Nutrients and Climate Change, Bristol, 2007 and completed, edited and submitted a major joint paper specifically directed at policy makers and written with virtually no technical terms (**Deliverable 336**) .

UICE completed an intensive sampling in 2004 in collaboration with **NERI** of 9 lakes in NE-Iceland. The lakes covered a large range in depth, altitude, temperature-budget and trophic structure. Sampling was quantitative and included physico-chemical variables, invertebrates from the littoral and pelagic habitats and fish. The exercise was repeated in 2005 on 4 lakes in S- and SW-Iceland in collaboration with **NERI** and **UCL**. A PhD project on chironomids in soft sediment from Euro-limpacs and ESIL lakes, dealing with community structure and environment, including contrasting temperature regimes was completed as were MSc projects on the surf zone chironomids in relation to environmental variables Euro-limpacs and ESIL lakes and the trophic ecology and life history traits of three-spine stickleback (*Gasterosteus aculeatus*) in relation to contrasting lake temperature regimes. Two papers have been published.

Task 1.2 Using stable isotope analysis (NERI, AU, NIVA, UIBK, SYKE, UB, UICE, UU-BIO, SLU, KULeuven, UGR, ULIV, ALTERRA)

Stable isotope analysis has become a widely used tool in freshwater ecology. Its basis is very simple. Land plants in taking up carbon dioxide tend to discriminate against the heavier stable isotope of carbon, ^{13}C, whilst aquatic plants and algae, using bicarbonate derived from geological deposits are less discriminatory and are using a source that is relatively richer in ^{13}C than the air. In lakes and rivers, some of the energy used by the system is derived from organic matter washed in from the land (low ^{13}C) and some from organic matter produced within the aquatic system (higher ^{13}C). The ratio of ^{13}C to ^{12}C in freshwater organisms thus gives a snapshot picture of the relatve influence of the catchment in energy supply. Organisms also take up the stable isotope of nitrogen, ^{15}N as well as the commoner ^{14}N. They excrete the ^{15}N more slowly than the ^{14}N and thus become enriched in ^{15}N. This effect is magnified up the food chains at about the same rate for each step in the chain, so that the ratio of ^{15}N to ^{14}N increases with steps from the primary producers to the top predators. Our intention in this task was to find out whether climate, relected in a latitudinal gradient from Greenland to Turkey imposed a pattern on the balance of use of terrestrial and aquatic energy sources or had a major influence on the length of the food chains. On current analysis there appears to be no simple relationship. We also carried out supplementary research on isotopes to explore the use of the technique in a wider set of habitats than it has been previously used.

The objective of the **UB** contribution was to examine the variation in aquatic and terrestrial energy sources for consumers using the natural abundance of stable isotopes using deuterium as well as ^{13}C to examine which of these stable isotopes was better indicator of the origin of food sources. This study was done in 13 streams within the la Tordera catchment draining sub-catchments with different land use composition. Some of the data are still being analyzed and a manuscript is almost ready to be submitted.

Stable isotopes of carbon are the primary tool for distinguishing algal-based productivity from terrestrial derived leaf litter in the food of stream invertebrates and fish. In many rivers however the isotopic signal of carbon is not sufficiently different between algae and leaf litter to be an effective tracer. **UB** compared the efficacy of hydrogen to carbon isotopes to differentiate between algae and leaf litter and to describe the dominant food source in two aquatic insects. It sampled algae, leaf litter and two insect species with specific diet preferences, heptageniid mayfly larvae that feed on algae, and tipulid larvae that feed on leaf litter, in 13 Mediterranean streams

NERI co-ordinated the main work on the Greenland to Turkey gradient using data collected by **ULIV**, **SYKE**, **Alterra** and **UICE** with the help of **EKBY**. It prescribed protocols (**Deliverable 18**) for collection and processing of samples by the partners and has collated the data and carried out the preliminary statistical analyses. Data collection for this task took substantial amounts of time by each partner. **NERI** also carried out some developmental work on retrospective use of the technique. **NERI** and **AU** have examined the effects of two commonly used preservation substances of freshwater invertebrates, ethanol and lugol's iodine, on $\delta^{13}C$ and $\delta^{15}N$ of various planktonic and benthic taxa. Follow up studies are now being conducted on several lakes in Denmark with stored samples of zooplankton, benthic invertebrates and fish scales

NERI and **AU** also used carbon stable isotopic composition of the different primary producers to elucidate differences in degree of CO_2 limitation in the Danish mesocosms experiment (Task 2.1). A paper has been published in Freshwater Biology, 2008. **NERI** tested the hypothesis that increased temperatures should theoretically stimulate primary production and, by extension, secondary production on a series of stream sites in Iceland covering a 5-43°C temperature gradient by quantifying the individual body mass and condition of the top predators (brown trout), and by using stable isotope analysis to characterise their "trophic height".

Task 1.3 Using paired sites with contrasting water temperature (NERI, UICE, UU-BIO, ULIV, ALTERRA)

Direct experimentation is the most reliable means of investigating effects of rising temperatures on ecosystems, but where mesocosms have to be used it is extremely expensive in energy costs. An alternative is to use naturally heated and less heated sites in geothermal regions. The paired sites have the disadvantage that they are rarely exactly similar in other respects, but with careful choice sites at different temperatures can be reasonably matched. We used paired streams (**UICE**, **ULIV** and **NERI**) and wetland grasslands (**UU-BIO** and **UICE**) in Iceland to carry out experiments n the combined effects of nutrient addition and warming.

With **UICE**, **NERI** and **ULIV** studied ten first-order Icelandic streams differing in geothermal influence in separate catchments (**Deliverable 57**). Several papers have been published and others are underway. **UICE** has supported two PhD and one MSc project during this study and investigations on diatoms in the streams are being completed. **ULIV** was involved in the supervision and training of the student concerned. A paper is in press in Freshwater Biology.

UU-BIO carried out the wetland experiments with support from **UICE**. They selected naturally heated and ambient wetland plots in a valley with geothermal activity in Iceland, and applied N and N+P fertilizer to half of each plot, while the other half served as a control. They monitored vegetation growth and species composition over three years of fertilizer application and at the end of the study period harvested vegetation biomass, took soil samples, collected litter and measured soil respiration. In the lab, they analysed vegetation and soil samples for N and P content, soil samples for total soil organic carbon, used the soil samples to measure respiration under controlled conditions and used the litter to measure decomposition under controlled conditions. **Deliverables 17, 57, 235, 341** and **342** resulted from this work and three manuscripts are in the final stages of preparation.

Alterra used the same approach of paired sites but in a stream where thermal effluent gave rise to different thermal regimes in different places. It placed seventeen dataloggers in different sections of the Springendal stream from sources (south and north) to middle and lower course to record temperature. In autumn an inventory sampling of macroinvertebrates and diatoms took place to establish temperature distribution relationships. This was to detect those sites suited to paired site experiments. Ancillary studies were made on eleven groundwater fed streams (constant temperature) and rainwater fed streams (high summer and low winter temperature). In all these streams nutrient contents are low. Additionally, it took macroinvertebrate samples in these streams. An analysis of indicators for the functional structure of the macroinvertebrate community under different temperature regimes, and the impact of eutrophication was done. Two experiments in artificial streams were performed to test temperature effects on macroinvertebrates, macrophyte, and diatoms. Indicators in this short term temperature rise experiment are 3 trichopterans, 1 macrophyte and diatoms. Response parameters were growth (macrophytes length and biomass, macroinvertebrate head capsule width) and diatom species composition (see also Task 2).

Task 2: Mesocosm experiments (ULIV)

Task 2.1 Climate - eutrophication interactions in lakes (NERI, AU, ULIV, KULeuven)
Mesocosm experiments were carried out three locations (Denmark (**NERI** and **KULeuven**) and UK (**ULIV** and **KULeuven**) for Task 2.1 and Switzerland (**EAWAG**) for Task 2.2), with emphasis particularly on decomposition process in the littoral zone in the latter and production processes in the former.

NERI carried out its experiment at Lemming, Denmark, involving a sophisticated set of 24 thermally controlled tanks with three temperature scenarios (one unheated and two heated relative to the IPCC climate scenario A2 and A2+50%, respectively) and two nutrient levels (enriched and non-enriched). Planktivorous fish (male sticklebacks, *Gasterosterus aculeatus*) were stocked in accordance with the nutrient level. Oxygen was continuously measured in the mesocosms, which allowed calculation of gross and net primary production (GPP, NPP) and ecosystem respiration (ER) from 24-hour changes in concentrations.

The UK experiment fell into two phases: the first in 2006 when the mesocosms did not contain fish, and the second in 2007 when fish were present in half of the mesocosms. Ambient and +4C temperature regimes were used with three nutrient treatments (no nutrients, low and high nitrate addition against a background of high phosphorus). There were 48 tanks and temperature control was very reliable. Deliverables **178** and **343** relate to this work and several more papers are in preparation

KULeuven contributed an additional dimension to both the Danish and UK mesocosm experiments by using them to investigate possible evolutionary change and adjustment among the zooplankters to warming. It monitored evolutionary changes to temperature change in the cladoceran *Simocephalus vetulus* in the NERI mesocosm experiment. This involved intensive monitoring in the field (population density, parasites, genetic diversity), isolation of genotypes from different mesocosms, establishing laboratory cultures and testing these under standardized conditions for life history traits at three different temperatures. A first paper on this analysis has been published in Global Change Biology 13 (2007). Monitoring evolutionary changes to temperature change in the **ULIV** mesocosm experiment involved inoculating all mesocosms with a genetically diverse and standardized population of the cladoceran *Daphnia magna*, monitoring population density, genetic diversity and parasite prevalence through time, and sampling animals to establish laboratory cultures. These genotypes were tested for their life history traits at different temperatures in the laboratory. A parallel experimental evolution trial was run in aquaria at **KULeuven**. One paper has been submitted and is currently under revision and one is being submitted in February 2009. **KULeuven** also quantified the extent to which evolutionary adaptation to increased temperature increases the capacity of resident populations to reduce establishment success of immigrant southern genotypes. This was done by carrying out competition experiment between non-adapted and warm-adapted UK clones with clones from Southern France and Spain. These results have been written as a manuscript that is currently under revision, and a further paper is being submitted in February 2009.

Monitoring evolutionary changes to temperature change in the **ULIV** mesocosm experiment involved inoculating all mesocosms with a genetically diverse and standardized population of the cladoceran *Daphnia magna*, monitoring population density, genetic diversity and parasite prevalence through time, and sampling animals to establish laboratory cultures. These genotypes were tested for their life history traits at different temperatures in the laboratory. A parallel experimental evolution trial was run in aquaria at KULeuven. One paper has been submitted and is currently under revision, one is being submitted in February 2009. **KULeuven** also quantified the extent to which evolutionary adaptation to increased temperature increases the capacity of resident populations to reduce establishment success of immigrant southern genotypes. This was done by carrying out competition experiment between non-adapted and warm-adapted UK clones with clones from Southern France and Spain. These results have been written as a manuscript that is currently under revision, and a further paper is being submitted in February 2009.

Task 2.2 Climate – nutrient interactions in littoral wetlands (EAWAG, UU-BIO)
Littoral wetlands are perhaps the components of lakes where most of the biological activity takes place and wetlands in general have an importance in the global carbon cycle that is underestimated by their relative area. Task 2.2, carried out largely by **EAWAG** was our contribution to understanding in this area for it focussed on decomposition processes. The general approach was to assess community and ecosystem responses to warming and nutrient enrichment in a series of enclosures (mesocosms) set up in the littoral reed stand of a typical peri-alpine lake. Half of the enclosures were heated and half fertilised in a two-factorial design with four-fold replication. Four additional unfenced areas in the reed stand of the same size as the enclosures were also included as controls. Calcium nitrate was added at four-week intervals to raise nitrate levels five fold above ambient. The targeted temperature increase of 4 °C was not completely achieved, but on average temperatures were considerably higher in the heated enclosures. The enclosures were maintained, heated and fertilised throughout the project duration. Water was partly exchanged at four-weekly intervals and water samples taken each time before and after addition of calcium nitrate. Water-chemical analyses included standard parameters such as phosphate, nitrate, ammonia, alkalinity and pH. Experimental nutrient addition increased nitrate levels in enclosures as desired but concentrations always declined to background levels within less than four weeks, even after four years of fertilisation. The first experiment focused on decomposition rates of leaf litter of the plant composing the reed stand, *Phragmites australis*. Decomposition was studied with the litter-bag method and involved both coarse-mesh and fine-mesh litter bags to distinguish between microbial decomposition and invertebrate consumption of the leaf litter. In addition to leaf mass loss and leaf-associated respiration rates, we determined several other parameters characterizing microbial communities associated with the decomposing leaves. These included fungal biomass, growth rate and production as well as bacterial biomass, growth rate and production. In addition, we evaluated by means of denaturing gradient gel electrophoresis (DGGE) whether experimental warming and nitrogen enrichment, or both, affected bacterial community profiles. Overall, the results of these analyses revealed very little detectable effect of warming and nitrogen enrichment on litter-associated microbial communities.

Effects of warming and nitrogen enrichment on the decomposition of stem litter of *Phragmites australis* were assessed in a separate experiment that involved periodical sampling of stem litter from litter bags over two full years. Another decomposition experiment was undertaken involving litter from six different species of riparian trees that had been exposed, or not, to elevated carbon dioxide concentrations in the atmosphere during plant growth. The main purpose of this experiment was to test in a controlled experimental setting the influence of a third important factor of global environmental change that may affect plant litter decomposition.

The idea that warming, fertilisation, or both, during plant growth can affect litter quality was also tested in a fourth decomposition experiment. Litter produced in each of the enclosure types was collected and left to decompose, in a fully crossed design, in all enclosure types.

To expand the range of responses from decomposition and decomposers to whole-ecosystem metabolism, we measured changes in oxygen concentrations in enclosures over diel cycles. This information allowed us, together with gas exchange rates that we determined empirically by monitoring the fate of a pulse of inert tracer gas (SF_6), to calculate gross primary production (GPP), ecosystem respiration (ER) and net ecosystem production (NEP) in enclosures under different warming and fertilisation regimes.

Notwithstanding the strong focus on heterotrophic ecosystem processes, a side study addressed responses of the plankton communities in enclosures to experimental warming and nitrogen enrichment, with special emphasis on the microbial loop.

The findings from this work have given rise to two complete PhD dissertations, a portion of a third dissertation, and a total of eight manuscripts for publication in scientific journals (see **Deliverable 346**). Two more manuscripts are envisaged.

Task 2.2 was carried out entirely by **EAWAG**. The intended **UU-BIO** component proved easier to do using the wetland sites in Iceland and is described under Task 1. However, **Alterra** contributed an unscheduled component with a pilot experiment in artificial streams studying the growth of the caddisfly *Agapetus fuscipes* at different temperatures (8, 12 and 16 °C) to see what the effect of climate change will be on the timing of the life cycle of this species.

Task 3: Long-term nutrient - climate change interactions from sediment records and long-term data-sets (UCL)

Task 3.1 Palaeolimnology (NERI, AU UCL, CNR, UIBK, UIC, KuLeuven)

This task was conceived as a relatively open-ended one to ascertain whether the techniques of palaeolimnology could be used to reconstruct climate change effects especially against a background of major nutrient changes over the past century or so. In general this has proven difficult but there have been many instances where climate effects have been demonstrated. Complete separation has not been possible, however; the effects of climate are subtle and those of warming often similar in direction to increased nutrients. There has been much collaboration among laboratories each skilled in different techniques and there is no doubt that the collective effort was productive and worthwhile. The problem can be illustrated by a conceptual diagram illustrating the various factors that combine to make up the sediment record of Lake Myvatn in Iceland. Other lakes have parallel suites of variables.

NERI and **AU** continued analyses of cladoceran remains from surface sediment sampled in Greenland (70 lakes), The Faroe Islands (31 lakes), Canada (20 sites), Finland-Sweden (10 sites), Denmark (60 sites), Belgium (32 sites), Spain (15 sites) Poland (10 sites), Iceland (60 lakes) and Uruguay (18 lakes) from earlier studies or sampled within the Eurolimpacs project during 2004 (sites in Iceland and Uruguay). The aim was to describe changes in trophic dynamics from the high arctic to the sub-tropics. Additional samples were taken in Iceland (with **UICE** and **UCL**) and in Greek lakes (together with **EKBY**). A paper is now conditionally accepted in Freshwater Biology and describes complex response to nutrients, pH, salinity and direct climate variables

The work undertaken together with University of Turku, Finland, on a contemporary and sediment data from large mesotrophic Finnish lake, Lake Pyhäjärvi has continued. Also here both changes in loading from the catchment and recent climate effects are seen, indicating that climate warming may in part counteract effects of measures implemented to restore lakes from eutrophication. A paper is planned for a Euro-limpacs special in 2009.

Together with **UU-BIO NERI** worked on pigment data from 84 shallow lakes sampled along a climate gradient from Natal in Brazil to Terra de Fuego in Argentina. The results were presented at the last shallow lakes conference in Uruguay in November 2008 – a paper will be finished in 2009. It continued the work on a 7Kyr record of aquatic and terrestrial environmental changes at Lake Aborre (Denmark) as indicated by marker pigments, pollen and stable isotopes, and a laminated sediment core from Lake Sarup (Denmark) from the 8.2 Kyr cooling event, and together with **KULeuven** and two Estonian groups continued analyses of the size structure of resting eggs and features of carapaces of *Bosmina* (mucro length, curvature of antennae, size of carapaces) in the surface sediments from shallow lakes in Denmark, Belgium and Spain, which were studied intensively in an earlier EU project (BIOMAN) following a common protocol. The aim was to evaluate how the predation pressure on zooplankton changes along a nutrient, macrophyte and climate gradient.

Together with **UCL**, **NERI** published a review paper about comparative studies of contemporary limnology and palaeoecology for evaluating the effects of changes in external nutrient loading to lakes with special focus on the recovery phase. (Freshwater Biology , 2005) and in co-operation with GEUS, Denmark an analysis has been made of changes in trophic structure in Lake Dallund during the past 7,000 years (paper currently in press in The Holocene).

Together with GEUS, Denmark, **NERI** also developed salinity-diatom transfer functions allowing a reconstruction of salinity back in time (Can. J. Fish. Aquat. Sci., in press), which may be used to study effects of climate changes on salinity in the past. **NERI** and **AU** has also finished two papers on the influence of salinity on trophic dynamics in brackish lakes (in press in J. Paleolimnology and Arch. Hydrobiol.) based on analyses of cladoceran remains in the sediment and has published a paper on cladoceran remains from 31 lake in The Faroe Islands and contributed to two papers (**UCL** in the lead) on relationships between contemporary zooplankton data and cladoceran remains in the surface sediment and relationships between remains in the sediment and macrophytes and fish in shallow lakes based on data from 39 English and Danish lakes (J. Pal, Freshwater Biology). Moreover **NERI** has contributed to a comparative study of long-term data of zooplankton and sediment records in Lago Maggiore (**CNR** in the lead) showing nicely how well the sediment record tracks the contemporary series and also how the sediment records complement each other when reconstructing the tropic dynamic and changes in fish predation in the lake. A book chapter has been published on how cladoceran resting eggs in the sediment can be used to track anthropogenic changes in lakes.

CNR reviewed existing palaeolimnological data in order to identify need for new cores, begin an intercomparison of existing cores and re-analysis of data, particularly for Lago Maggiore, a large well studied lake in northern Italy. This study involves multi-proxy analysis (geochemistry, diatoms, plant pigments, chironomids and Cladocera) of multiple cores covering the past ~150 years. Palaeoecological results have been compared with long term datasets. A transfer function has been employed to reconstruct total phosphorus (TP) concentrations and primary productivity based on diatoms and pigment assemblages, respectively. At the same time **CNR** conducted a detailed, high resolution study of the cladoceran remains in a 1.5 m sediment core from the Pallanza Basin of Lake Maggiore to reconstruct environmental change over the past six decades.

UIBK and **CNR** performed a paleolimnological study on Piburgersee, Austria, collecting several sediment cores (length of ca. 70 cm) in June 2004. Two cores were sliced immediately after collection and two further cores were measured for magnetic susceptibility, sub-sampled, photographed and their lithology described. **CNR** have processed sub-samples for water content, LOI (total organic matter) and pigments. In 2005 **CNR** continued the collation of paleolimnological data from cores taken in Italian lakes to assess the degree of change among limnological communities. Among the Italian sites new sites were explored: lake Alserio and Tovel. **CNR** contributed to the meta-database on “sediment accumulation rate in European lakes” co-ordinated by **UCL**. In 2006 detailed work on the Lake Maggiore sediment was started with a thin section analysis in order to relate some layers along the core to climate events such as rainstorms and floods. Accumulation rates have been measured using sedimentation traps in the Pallanza Basin with the collaboration of **EAWAG** (see WP5). New short cores spanning the last century from Lago Grande di Monticchio (Southern Italy) have been collected and the geochemical and biological analyses are still in progress. The metadata base on Italian palaeolimnological studies (manly based on sediment accumulation rates) was completed. A transfer function study has been performed on calibration data for P and temperature reconstruction was undertaken in many Italian lakes in collaboration the University of Utrecht. An analysis of algal and bacterial pigments in Loch Leven was started. In 2007 collation of the paleolimnological and limnological database for Lake

Maggiore was completed and a multi-proxy analysis was carried out of the sediment record for the last 200 years with particular emphasis on the human impacts on the lake, namely eutrophication. In 2008 analysis of thin layers in sediment cores from Lake Maggiore commenced and much activity was dedicated to the preparation of a special issue paper on Lake Maggiore, long-term data sets, paleo and neo limnology.

NIVA contributed data from sediments from Lake Mjøsa, Europe's third largest lake. Analyses included Pb^{210} dating (by **ULIV**), diatoms (by **UCL**), cladocera (by **NIVA**) and algal pigments (by **NIVA**). **NIVA** have compiled climate data for the Lake Mjøsa watershed (1850-2005) from various sources, and explored approaches to analyse the data in relation to variability in nutrient levels and climate. The Lake Mjøsa study will contribute one paper to a special issue of Freshwater Biology on palaeo-decadal studies (in conjunction with long-term datasets). Deliverable 347 relates to this work.

KULeuven engaged in detailed "resurrection ecology" analysis, reconstructing evolutionary change in response to habitat degradation and restoration in Lake Ring, Denmark. This involved characterizing and aligning sediment cores; taking additional sediment cores, hatching *Daphnia magna* eggs from different depth horizons to establish clones; testing those clones for antipredator behaviour, life history traits, competitive traits and anti-parasite traits. These results have been incorporated into manuscripts: one is published and the second is finalized and will be submitted in February 2009. A third has made good progress.

UCL undertook palaeolimnological studies of two key sites (see below) with additional supporting analyses on cores being studied by other partners (Piburgersee, Pyhajarvi, Mjoesa, Apavatn, Laugarvatn) to achieve new insights into the ways that climate has influenced nutrient loading in the past and may exacerbate the symptoms of eutrophication in the future. It conducted diatom analysis at a high resolution on new dated sediment cores from two eutrophic lakes in the UK: Loch Leven, Scotland (see **Deliverable 246**) and Esthwaite Water, England (see **Deliverable 247**). The data were used in combination with existing diatom records from previous cores and long term datasets of phytoplankton, nutrient and climate variables held by **NERC** (link to Task 3.3), to track environmental change. Several manuscripts are currently in preparation and will be submitted to a Freshwater Biology Special Issue on "Climate influence on lakes: evidence from observational and palaeolimnological records" in spring 2009.

In conjunction with WP8 Task 1.1, existing palaeolimnological datasets for UK lakes have been explored by **UCL** to determine reference conditions for lakes impacted by eutrophication based on diatoms (see **Deliverable 242**). Additional and unplanned *ad hoc* analyses to contribute to other's work programmes have been carried out. In particular, these included the use of radiometric techniques and spheroidal carbonaceous particles to provide chronologies for sediment cores and the record of historical contamination respectively at a range of key WP3 sites including Piburger See (Austrian Tyrol), Pyhajarvi (Finland), Apavatn and Laugvatn (both Iceland), Esthwaite Water and Loch Leven (both UK) and a water meadow core from Boxford (UK). This work has contributed to a number of Deliverables and manuscripts.

UIBK took sediment cores in Piburger See in June 2004. The following parameters were determined: pigments, loss of ignition and dry weight by **CNR**, SCPs and isotope dating by **UCL**, diatoms by IASMA, and sediment phosphorus analyses by **UIBK** which has also contributed to a collaborative paper on eutrophication with respect to sediment diatoms. **This** paper is led by **UCL** and is part of a Special Issue of *Journal of Paleolimnology*. **UIBK** leads a collaborative paper on climate impacts on Piburger See, which combines observational and palaeo records. The paper contributes to a Special Issue of *Freshwater Biology*. An extended abstract of this paper has been compiled as **Deliverable 248**.

In Iceland, **UICE** has had a main aim in Lake Myvatn to get a high-resolution palaeo-record of a well-studied lake in order to disentangle the impacts of man, climate and groundwater on the cyclic behaviour of the biota recorded during the last 3 decades of monitoring. The palaeolimnological work has focused on four main topics: (1) establishing an age model for the sediment, based on tephrochronlogy, (2) establishing the true nature of laminations in the sediment and the associated variation in the biota, especially chironomids, Cladocera and diatoms, (3) compare the palaeo-record with the monitoring record from the lake and also with historical harvest records (fish, duck eggs) from the lake and (4) to extend the palaeorecord back to periods of well documented climatic change. Freeze cores were taken in two secluded bays along the eastern shore of the lake turned out to be excellent. The sediments in both bays were dated by known tephra layers. Work then focused on the Höfdi site using other types of cores that would better preserve the microfossils. The cores were analysed for pigments, stable isotopes, chironomid head capsules, chironomid egg capsules (a novelty in the field of palaeolimnology), cladoceran exuviae, diatoms, loss on ignition, carbon and nitrogen. The flux of wind-transported sand in the cores was also estimated. Samples of sand peaks were analyzed chemically in the hope that some of them turn out to be tephra from historical 19th-20th century eruptions. This analysis was delayed due to difficulties in accessing the microprobe in Edinburgh. Fine-tuning of the age-depth model of the sediment relies on this result.

Task 3.2 Wetland palaeoecology (UCL, NERI)
Palaeolimnology is well established on lakes and wetland basins but has not been much explored in floodplain wetlands where a climate record related to flood heights as well as a history of changing land use and eutrophication might usefully be preserved. Task 3.2 was to explore the possibilities using a single wetland site, Boxford Water Meadows in England.

A master core was selected from a subset of eight cores taken along a transect and an approximate chronology for the last 150 years was established using spheroidal carbonaceous particles (SCP) (see **Deliverables 59** and **100** for details). Diatom analysis by **UCL** and Cladocera analysis by **NERI** were undertaken. A manuscript (**Deliverable 239**) is currently in preparation.

Task 3.3 Long-term data-sets (NERC, CNR, HYDROMOD, UCL)
Task 3.3 complemented Tasks 3.1 and 3.2 by attempting analysis of long-term (generally a few decades) sets of data collected from lakes to attempt a parallel separation of climate and

nutrient driven changes. Such analyses have the advantages of more comprehensive data and of less bias in what is recorded compared with palaeolimnological analyses but the disadvantage of short histories in situations where changes over centuries might be most relevant. Development of sophisticated time-series analyses during the project allowed clearer separation of nutrient and climate effects, though the time scales do not allow us to set these into long-term trends.

NERC used two approaches, statistical analyses and lake modelling to complement the palaeolimnology. The approaches were tested and compared using data from Loch Leven, Scotland, which comprised a 36-year record of about 150 variables recorded at weekly/fortnightly/monthly intervals. The results of this work are reported in **Deliverable 11** and have since been applied to a range of long-term datasets.

The phytoplankton community model, PROTECH, was used to explore the impacts of changing climate and nutrient availability on a range of lakes. The effect of changes in nutrients and weather on silica dynamics in Windermere, Esthwaite Water and Blelham Tarn were explored using data spanning 1946 to 2005. The effects of raised temperatures and increased nutrient loads on phytoplankton succession and productivity were investigated in Bassenthwaite Lake, UK. The impacts of changing water temperature and nutrient load on phytoplankton in Loch Leven, Scotland, UK were investigated. Using temperature profiles simulated by **HYDROMOD** partners, the predicted changes in phytoplankton in response to future climate conditions were modelled for Lago Maggiore, Italy.

Long-term monitoring records from Loch Leven were analysed to assess how environmental changes (climate change and recovery from eutrophication) impact upon water quality and phytoplankton abundance and composition. For this work, new statistical methods were developed for analysing long-term environmental datasets to detect climate change impacts. Phytoplankton (diatom) and macrophyte records from long-term monitoring datasets have been compared with palaeoecological records (Loch Leven) by **UCL**; the work examined how records can be used together to get a more complete picture of ecological responses to environmental change.

CNR has analysed long-term data on Lake Maggiore. Information on historical records of exceptional floods and/or complete turnover events was collated. **CNR** was involved in regular collection of hydrological and meteorological data for the parameters previously identified as trophic status indicators; preliminary analysis of the phytoplankton data set for evaluating the data to be used for testing the Protech Model in Lago Maggiore; collection of lake catchment data. The forecast models have not yet been fully tested but it has been possible to evaluate the effect of warming on the phytoplankton dynamics in Lago Maggiore. This has been done in collaboration with **NERC.** In 2008 Lake Maggiore zooplankton limnological record was re-analyzed to assess the consequences of climatically anomalous years.

CNR proposed a new ecological index based on phytoplankton (MedPTI) was proposed, as a tool to verify the impacts of eutrophication in Mediterranean reservoirs. Biological quality data for Mediterranean lakes and reservoirs are very sparse, and before MedPTI only two indices had been proposed for evaluating The proposed index was designed to comply with the requirements of the European Directive 2000/60/CE, Water Framework Directive (WFD). Multiple data sets were employed to develop the MedPTI index. A calibration data set included data collected from 30 Sardinian reservoirs. A list of 44 selected taxa was obtained and used for index calculation. A second dataset including 48 averaged annual values from 10 reservoirs was used as validation data set. This activity is described in **Deliverable 294** and in a paper published in the volume 69 of the Journal of Limnology.

NIVA compiled 1972 – 2005 Lake Mjøsa monitoring data and these have been made available to other partners for analysis.

NERI and **AU** worked intensively on data from long time series from 20 Danish lakes to disentangle nutrient loading signals from climate signals. The results have been included in several overview papers in press and in the Euro-limpacs book-chapter 5. **AU** has further analysed the effect of loading reduction and changes in climate on species richness and turnover.

At **HYDROMOD**, work concentrated on long-term water quality model investigations on deep lakes (Loch Lomond and Lago Maggiore) with emphasis on data collection for associated catchments. Efforts were especially directed towards the establishment of a combined catchment/lake model system for Loch Lomond by combining the HYDROMOD-1D lake model with the newly established INCA-N model for the two main tributaries (Falloch and Endrick). The latter was prepared in parallel to the WP 6 task 2 activities concerning long-term nutrient loads in the sub-catchments of the Loch Lomond watershed. These values were necessary for subsequent water quality modelling of the lake. Apart from the validation procedures for the establishment of INCA models for the main catchments calculations were been done to look at possible implications of future climate change for the nitrogen budget in the River Endrick catchment.

WORK PACKAGE 4: Climate– acidification interactions

Task 1: Effects on runoff water chemistry of episodic and seasonal variations in climatic factors (IVL)

Task 1.1 Experimental manipulations of snow-cover, freezing-thawing cycles, and soil wetness in mini-catchments (Storgama, Norway) (NIVA)

At one of the sites, Storgama, a series of experiments was conducted in 2003-2007 (**NIVA**) to test the role of snowpack in regulating NO_3 concentrations and fluxes in runoff (Kaste et al. 2008). Here whole-catchment manipulations in mini-catchments included extra insulation of soils in two catchments (by means of rock wool mats) to prevent sub-zero temperatures during winter, and removal of snow in two other catchments to promote soil frost. (See **Deliverables 20 and 103**). The experiments support the statistical analysis of the long-term record from Storgama (de Wit et al. 2008).

Task 1.2 Simulation of hydrological and sea-salt extremes by experimental watering (Gårdsjön, Sweden) (NERC, IVL, NIVA)

To investigate the potential effect of high seasalt episodes on DOC runoff concentrations, a field-scale watering experiment was conducted (**NIVA**, **IVL)** in 2004 at the experimental catchment G1 at Gårdsjön, Sweden (**Deliverable 21**). The catchment slope of 2000 m^2 was brought to a hydrological steady state, i.e. a situation when sprinkling of water from the watering system was approximately equal to discharge rate. After reaching the hydrological steady state the catchment was watered for 4 days with distilled water, after which seasalt was added to the sprinkling solution. Seasalt was added first for two days at level typical for ambient throughfall and then a high level observed during storms and periods of high winds. (See **Deliverables 104 and 352** for results).

Task 2: Analysis of long time-series data to examine episodic, seasonal, and long-term effects (NERC)

Task 2.1 Climate change and acidification recovery (NERC, IVL, NIVA, SLU, SYKE, CNR, HBI-ASCR, HBI-BCASCR TRENTU)

Climate effects on NO_3 concentrations can be elucidated by analysing long data records of climate, N deposition and streamwater NO_3 concentrations. **NIVA** (de Wit et al., 2008) conducted an analysis of 20-year records of NO_3 in four small streams in Norway, three of which (Birkenes, Langtjern, Storgama) have received moderate levels of acid deposition and are highly acidified with pH levels 4.5-5.5. (**Deliverable 174**).

Northern Italy is a hot spot with respect to increasing concentrations of NO_3 in streams and rivers. **CNR** analysed long-term data and highlighted trends indicate increasing degree of N saturation in catchments of small and medium sized rivers south of the Alps (Rogora 2007, Rogora and Mosello 2007). Results are presented in **Deliverable 105**.

HBI-ASCR and **HBI-BCASCR** examined the effects of terrestrial processes affecting freshwater quality in areas burdened with a legacy of heavy acid deposition and N-saturation, such as mountain forests in central Europe by monitoring nitrate and sulphur budgets (**Deliverables 302** and **252**).

SYKE effort here focused on examining patterns of variation in dissolved organic carbon (DOC) in surface waters. Studies were undertaken of seasonal patterns in boreal lakes and streams (**Deliverable 61**). Future climate change effects on the annual mean levels and seasonal patterns of DOC concentrations in surface waters were also assessed (Laudon and Buffam 2008) (**Deliverable 351**). **SYKE** (Vuorenmaa et al., 2006) also studied trends in total organic carbon (TOC) concentrations over the period 1987–2003 in 13 small forest lakes in Finland (**Deliverable 102**). Recovery from acidification (reduced S deposition) and long-term changes in runoff as potential drivers for the trends were examined.

Analyses by **CGS** of the long-term increase of DOC in two geochemically-contrasting forested catchments in the Czech Republic (Hruška et al. In review) are presented in **Deliverable 253**). Work on the potential influence of climate change as a driver of increases in DOCwas undertaken by **MI** (**Deliverable 251**).

NERC undertook field manipulation experiments on podsolic heathland soils in Wales to assess the effects on microbial activity and DOC concentrations of experimental drought (Toberman et al., 2008; Evans et al., 2006). **SYKE** analysed a 35 year Swedish record of DOC, acid deposition and river discharge (Erlandsson et al. 2008) (**Deliverable 350**). **NIVA** completed a statistical analysis of long-term data records from Storgama, Birkenes and Langtjern (Norway) (de Wit et al. 2008).

A survey and re-survey of high-mountain lakes in the Tatras of Slovakia was undertaken by **HBI-ASCR** and **HBI-BCASCR** to assess recovery in response to reduced S and N deposition (**Deliverable 101**).

Long-term records from sites in Europe and North America were studied by **CNR** to identify "breakpoints" in the concentrations of NO_3, DOC and SO_4 to determine whether there are common breakpoints among stations that can be ascribed to unusual climatic conditions (**Deliverable 254**).

Task 2.2 Impact of changing weather patterns on episodic flow in streams and rivers (NERC, IVL, NIVA, SLU, SYKE, CNR, HBI-ASCR, TRENTU)

Superimposed upon chronic acidification of surface waters are acid episodes - temporary decreases of pH and ANC which are frequently triggered by climatic events such as drought, floods, rapid snowmelt, and inputs of wind-borne seasalts. These can cause acute toxicity to aquatic organisms Scenarios of future climate change may entail increased frequency and severity of such climatic extreme events. The implication is that this may delay biological recovery in response to decreased S and N deposition. NERC

(Evans et al., 2008) developed a procedure by which each acid episode could be assigned to one of four main drivers: hydrology (i.e. direct influence of precipitation), summer drought, snowmelt, and seasalt deposition (Deliverable 22). The procedure entails quantifying the relative magnitudes of changes in base cations and the three major strong acid anions SO_4, NO_3 and Cl in explaining the observed decrease in ANC. This was applied to Afon Gwy, a small moorland stream in mid-Wales. NIVA (Wright, 2008) used the same procedure to examine episodes at the Birkenes catchment, southernmost Norway (**Deliverable 175**).

Task 3: Impacts of climate change using space-for-time substitution (UCL, NERC, IVL, NIVA, SLU, SYKE, CNR, HBI-ASCR, TRENTU, MI)

Analogue matching software was produced by **UCL** that allowing these techniques to be applied in a general manner across the project. A major focus of the effort has been the development of a package of code for the R statistical software (Simpson 2007). (**Deliverable 106**). This package is called analogue and has been made freely available under the GNU GPL (Version 2) licence – an open source licence allowing for free and unencumbered use of the software. analogue implements a number of analogue-type methods for palaeoecological analysis, including analogue matching and the MAT transfer function methods for predicting past environmental variables from the k-nearest neighbours in a modern training set. Applications started with development of the statistical method using hydrochemical and physical parameters from MAGIC (Model for Acidification of Groundwater in Catchments) hindcasts and contemporary chemistry. This was done using a modern training data set of acid sensitive sites in Norway, where biological data are available as well as hydrochemical data. A series of MAGIC hindcasts were available for 60 sites in Norway and these have been used as the palaeo-samples in the analogue matching procedure **(Deliverable 62)**. A run of the model was also performed for MAGIC hydrochemical forecasts for 2010 as a proof of concept.

A Scottish data set provided by **MI** was analysed using similar model formulation (**Deliverable 249).** Simulated pre-industrial, current and future estimates of hydrochemical variables were based on high resolution model parameters. Parameterisation was consistent with the 2005 data submission to the Co-ordination Centre for Effects (CCE), except for detailed site specific sequences for discharge, dry deposition, and uptake at the forested sites. These scenarios were calculated for 59 sites in the Galloway region. Hydrochemical variables for each of the Galloway lakes were matched with lakes from a large UK data set of samples on the basis of low dissimilarity (high similarity) using Gower's measure. The results were also used to quantify reference conditions for Scottish lakes (**Deliverable 255**).

Task 4: Using dynamic models to evaluate climate scenarios (NIVA, IVL, SLU, SYKE, CNR, HBI-ASCR, HBI-BCASCR, TRENTU, MI, CGS)

NIVA (Wright et al., 2006) led work on the use of the MAGIC model to examine the relative sensitivity of eight major climate-sensitive processes on the recovery of soil and water from acidification (**Deliverable 63**). This exercise simply tested the relative importance of various processes, and did not involve use of actual climate scenarios in projecting future response in soil and water chemistry. **HCSU** (Hardekopf et al., 2008) took the next step, and used best available information to set the rates and parameter values for several of the key climate-driven processes in MAGIC to project future acidification and recovery at a Litavka, small catchment in the Czech Republic. Their simulation included the temperature dependence of weathering rate, DOC release from soil, net soil N mineralisation, and forest growth. They used several future climate scenarios derived from GCMs and downscaled to the Litavka site.

NERC (Evans, 2005) took another approach and used empirical statistical relationships between climate parameters and observed streamwater chemistry at Afon Gwy, a small stream in Wales, UK, to set parameter values and rates in MAGIC for evaluation of future climate scenarios.

Several other modelling studies have focussed on the role of DOC. **TRENTU** (Aherne et al., 2008a) used MAGIC coupled with INCA-C, a new model that simulates DOC concentrations in runoff from catchments (Futter et al. 2007) to project future recovery from acidification of a small stream to Plastic Lake, Ontario (**Deliverable 256**). Downscaled climate scenarios derived from GCMs were used. As INCA-C does not provide information on soil solution DOC, the MAGIC simulations were run without any future change in soil DOC.

TRENTU (Aherne et al., 2008b; Posch et al., 2008) expanded this type of scenario study to include an entire lake population in Finland. They used the MAGIC model framework and extensive soil, surface water and deposition datasets for 163 Finnish forested catchments to evaluate the water chemistry response to several scenarios for acid deposition, climate change and forest harvesting.

TRENTU evaluated the effects of the use of forest biomass for energy production in particular the expected to shift from stem-only to whole-tree harvesting (WTH), on the base cation budget within catchments and the potential for causing re-acidification at the study catchments (Aherne et al. 2008b).

NIVA de Wit and Wright (2008) used the statistical analyses of de Wit et al. (2008) (as supported by the experiments of Kaste et al. (2008)) to project future NO_3 concentrations and fluxes at Storgama given several future scenarios of N deposition and climate. Two N deposition scenarios were used (current legislation CLE and maximum feasible reduction MFR) together with four climate scenarios (two greenhouse gas emission scenarios A2 and B2 from the UN Intergovernmental Panel on Climate Change (IPCC) report run with two global climate models, HadAM3 of the Hadley centre and ECHAM4/OPYC3 of the Max Planck Institute. The climate scenarios come from regional downscaling provided by the PRUDENCE project (**http://prudence.dmi.dk**).

Process-oriented models offer another tool by which the effect of climate change can be assessed. **NIVA** (Sjøeng et al. In review-b, Sjøeng et al. In review-a) used the MAGIC model to project future NO_3 concentrations in streamwater at Øygard, a small catchment in SW Norway. MAGIC was first calibrated at monthly timesteps to the 12-year data record, and then driven by four climate scenarios from PRUDENCE (A2, B2 with the Hadley and MPI models) under two different "storylines" of assumptions involving future rates of plant processes (**Deliverable 176**).

WORK PACKAGE 5: Climate– toxic substance interactions

Task 1: Transfer from atmosphere to hydrosphere, seasonal deposition patterns (CSIC, CNR, HSCU, UIBK, UCL)

UCL undertook fortnightly sampling for trace metals, persistent organic pollutants (POPs) and spheroidal carbonaceous particles (SCPs) in deposition was undertaken at Lochnagar. For trace metals and SCPs this started from the beginning of the project (a continuation of a previous sampling programme) and continued through to March 2008. For POPs this ran from June 2004 and although originally planned to run for two years was extended through to March 2007. Fortnightly POPs samples from Lochnagar were filtered through GF/C and C_{18} filters and transported frozen to Barcelona for analysis. Metals data from Lochnagar contributed to a manuscript from this Task (Bacardit et al). **UCL** analysed filtered monthly deposition samples (fortnightly at Lochnagar) from all WP5 sampling sites (Lochnagar, Skalnate Pleso, Redo, Gossenkollesee, Robiei, Pallanza, Locarno and Devero) were analysed for SCPs for a two year period. These SCP data were used to compare seasonal, annual and longer-term trends in SCP deposition at these sites. A manuscript has been prepared on these data (Rose and Turner: **Deliverable 354**).

CSIC produced a protocol for the sampling of deposition for metals and POPs analysis which was circulated to all participating laboratories at the beginning of the project. Appropriate filters and sample bags were also sent to each laboratory for the samples. The sampling protocols and analytical methods for heavy metals and POPs in precipitation were tested and validated. Regular monthly sampling of deposition at Estany Redó for major ions, trace element, and POPs analyses (May 2004-May 2006) was carried out by **CSIC** which was also responsible for analyses of trace elements and organic pollutants in deposition samples from Redó (Pyrenees), Ladove (Tatras, provided by HSCU) and GKS (Tyrol Alps, provided by UIBK) and analyses of organochlorine compounds and polybromodiphenyl ethers in Lochnagar atmospheric precipitation. A paper accepted for publication on trace elements deposition values and seasonal variability (**Deliverable 177**): M. Bacardit & L. Camarero - The atmospheric component of the global cycle of trace elements in SW Europe: fluxes of airborne Al, Fe, Ti, Mn, Pb, Cd, Zn, Ni, Cu and As over the Pyrenees. *J. Geophys. Res.* 2009. A manuscript on transport patterns of heavy metal (**Deliverable 355**: M. Bacardit, et al., - Atmospheric metal pollution in European mountain catchments as determined from direct bulk deposition records) was submitted to *Atmos. Chem. Phys. Discuss.* Other manuscripts on POPs in deposition are in preparation.

CNR completed the analysis of POPs and metals in the precipitation samples collected at Robiei, Pallanza, Locarno and Devero.

At Gossenköllesee (2413 m, Tyrol), **UIBK** sampled precipitation for POPs, SCPs and heavy metals at monthly intervals between June 2004 and August 2006. All samples were filtered and pre-treated according to the guidelines. Filters for SCP analysis were transferred to **UCL**, filters for POP and metal analysis were sent to **CSIC**. SCP sampling continued until the end of the project. UIBK has performed meteorological measurements at Gossenköllesee (automatic weather station, totalizing precipitation gauge) to support the data interpretation under Tasks 1 and 2.

The collection of precipitation for analyses of POPs, heavy metals and SCPs in Skalnate pleso (2004 – 2006 (in co-operation with CSIC and UCL) was undertaken by **HCSU.**

Task 2: The redistribution and uptake of POPs and metals as a consequence of temperature change (CSIC)
Task 2.1 Temperature gradients (CSIC, CNR, HSCU, UIBK)

Three main studies were considered in this task: soils, snow and fish.
Soils
An altitudinal transect in the Pyrenees (**CSIC**) encompassing a large temperature gradient was sampled in the Cregüeña valley (Central Pyrenees) in June 2004. Six points in the gradient were sampled, at c. 250 m altitudinal intervals. Soils were sampled using a plastic corer and samples were processed to determine the general pedologic characteristics, and the organic and heavy metal contents. The same localities were used for POP soil sampling in the Pyrenees. In the Tatras (**HCSU**) sampling of soil cores was carried together with fish sampling. Three soil cores were taken in each catchment of the five studied lakes representing the same gradient in altitude and position on the South and the North slope of the mountains as for fish. In addition, two samples in the highest and lowest point of the gradient were taken for PAH's bioavailabillity. Samples represented non-developed skeletal soils and consist usually of two layers: upper organic layer and lower mineral soil. Samples were delivered for analyses to **CSIC** and **CNR**. In the Alps (**UIBK**) analysis of soil samples along a altitudinal gradient from 500 m to 2500 m was performed. A manuscript on metals in soils has been submitted (M.Bacardit & L. Camarero - Pollutant trace elements and lithologic metals in soils along a gradient of altitude in the Central Pyrenees, Spain. Submitted to *Environmental Pollution* **Deliverable 257**).

Snow
Some methodological tests were carried out before the snow surveys. We characterized the major chemical compounds and trace elements in the 2004-05 winter snowpack along the Maladeta valley (42º41'N, 0º38'E, Central Pyrenees, Spain), in an altitude range of 1820 - 3200 m a.s.l. Analyses of trace elements in snow were also inlcuded in Deliverable **257**). Data analyses of POPs in snow have been completed and a manuscript submitted (Grimalt et al. submitted). **UIBK** performed snow sampling in March 2006 at 6 sites along an altitudinal gradient (from about 1100 to 2500 m) in the Tyrolean Alps.

Fish
Six lakes were selected in the Pyrenees among those with fish populations in the southern slope of the Central Pyrenees. It was intended to cover the largest altitudinal gradient (1600 – 2700 m a.s.l.). Fish sampling was carried out in July 2004. Fish were collected with a series of six individual bottom gillnets of different mesh sizes. Only fish larger than 25 cm and captured alive was selected for further processing. All fish were length measured,

weighted, dissected and determined for sex on site. Distinct and appropriate sub-sampling protocols were used for POP, metal, stable isotopes and molecular ecotoxicological assays. Scales and otoliths were collected for age determination and stomach contents for diet evaluation. Measurement of otoliths in the fish collected in the Pyrenees and the Tatra were made for age determination. The composition of organochlorine and organobromine compounds in the fish collected in the Pyrenees, the Tatra and the Alps (Tyrol). And the composition of $\delta^{13}C$ and $\delta^{15}N$ in muscle of the fish collected in the Pyrenees, the Tatra and the Alps (Tyrol) were measured.

Analysis of biological activities
Fish livers were sampled from two latitude gradients: Pyrenees and Tatras. In total, 120 samples from 10 lakes (five from each district) were collected. Water samples from Lago Maggiorre tributaries were tken for yeast-based bioassays. Snow samples in the Pyrenees for yeast-based bioassays were collected. A procedure for transporting samples without degrading RNA was devised and tested satisfactorily. The design and testing of appropriate primers for quantification of the expression of different genes in Salmonidaewere completed and the corresponding amplification products were afterwards cloned and sequenced. A Yeast based method to detect dioxine-like activities in water and sediment samples was developed and tested. **UIBK** and **CSIC** completed Fish sampling in 4 mountain streams along an altitudinal gradient (˜1100 to 2000 m) in the Tyrolean Alps was carried out in spring 2005. Fish samples were processed on site and at the UIBK laboratory, a detailed analysis was run at the **CSIC** laboratory.

HCSU examined the distribution of fish in the Tatra Mountain lakes (Hořická et al., 2006) and altitudinal gradient of POPs distribution in fish (Gallego et al., 2007). **Deliverable 365** (A Report on Influence of environmental factors and air pollution on age structure and growth of fish in alpine lakes in the Tatra Mts) was produced. Experimental work on behavioural response of freshwater snails to aluminium toxicity ameliorated by silicon and bioavailability of aluminium within different concentration of humic acid was completed.

Task 2.2 Within-lake pollutant transfer: food-web bioaccumulation dependence on climate (CSIC, CNR, HSCU)

Sampling and analyses of trace elements and organic pollutants in the food web of four lakes in an altitudinal gradient (1600, 1900, 2400 and 2700 m a.s.l.) in the Pyrenees, plus three lakes in the Tatra mountains, were carried out by **CSIC**. Samples include: phytoplankton, zooplankton, algal biofilms on rocks and sediments, benthic macroinvertebrates (with distinction of diverse taxa and/or functional groups), macrophytes (distinction of species/genus), fish (sub-samples of different tissues: gills, liver, kidney, and muscle). Results are presented in **Deliverable 258**. Analysis of organochlorine compounds in food-webs has also been completed (**Deliverable 263**). Following on from the study of the POP accumulation in the food web of headwater catchments, the role of insect larvae and pupae as OC and PBDE sources has been investigated. Trichoptera and diptera have been taken as choice organisms because they are common in benthic aquatic habitats and accumulate substantial amounts of these compounds. HCB, HCHs, 4,4'-DDE, 4,4'-DDT, PCBs and PBDEs have been measured. Results are included in the manuscript: Bartrons, M. et al., 2007. Concentration changes of organochlorine compounds and polybromodiphenyl ethers during metamorphosis of aquatic insects. *Environmental Science and Technology*, 41: 6137-6141. CSIC was also responsible for analysis of PBDEs and PCBs compounds in fish from Pyrenean lakes distributed along an altitudinal transect (Gallego, E. et al., 2007. Altitudinal gradients of PBDEs and PCBs in fish from high mountain lakes. *Environmental Science and Technology*, 41: 2196-2202). **CSIC** assessed altitudinal distributions of BDE-209 and other polybromodiphenyl ethers (see **Deliverable 370** for results). Variability in nitrogen stable isotope ratio of dissolved ammonium and nitrate in high mountain lakes was examined by **CSIC**. The results are reported in **Deliverable 368**. Analysis of C and N stable isotope variability in mountain lake food webswas undertaken by **CSIC -** results are reported in **Deliverable 369**. Finally CSIC looked into altitudinal gradients of OCs in high mountain lake invertebrates. Results are reported in **Deliverable 371**.

Regular sampling of the food web structure in the Tatra Mts. lakes was performed every year in September – October by **HCSU** which published several papers analysing various trophic levels of the community (Bitušík et al., 2006, Hořická et al., 2006, Nedbalová et al., 2006, Marková et al., 2006, Sacherová et al., 2006, Tátosová and Stuchlík, 2006).

Task 3: Climate change and mercury mobilisation (IVL, SYKE, UCL)

Monthly sampling of bulk rainfall and lake water for total mercury and methylmercury analysis was undertaken by **UCL** at Lochnagar from the beginning of the project (a continuation of a previous sampling programme) and continued through to March 2008. From November 2005, methylmercury sampling of lake waters was discontinued, after a sampling period of 3 years, as all samples were below detection limit. However, the frequency of sampling of bulk rainfall at Lochnagar for methylmercury was doubled to fortnightly in order to better quantify the intriguing winter peaks in this determinand. A one-off set of inflow samples was also taken in June 2004 for methylmercury and these also all showed low levels (**Deliverable 372**). In order to help explain the winter peaks of methylmercury in deposition a high frequency monitoring programme was conducted at Lochnagar using a snowpack sampler modified to include a heated pad to allow for daily snow sampling over the winter 2007/08. The sampler was deployed in November 2007 and more than 40 daily samples were sent to IVL for analysis (**Deliverable 372**). The extensive Lochnagar Hg dataset was made available to the Inca-Hg modellers (**AERC**; WP6) following a workshop on INCA-Hg in September 2007 hosted by UCL.

IVL led the catchment irrigation experiment at Gårdsjön) which aimed to investigate the impacts of increased precipitation on leaching of total mercury and methylmercury from forest soils. The main irrigation of a small catchment from the Gårdsjön area was performed during May- October 2005. Sampling and measurement of total- and methylmercury (and basic water chemistry parameters) in run-off was conducted at a high frequency during the experimental period and continued at a lower frequency until the end of the project (January

2009). The following deliverables have been pruduced in this Task: **Deliverable 25** (Summary of 9 months of experimental manipulations at Gårdsjon catchments), **Deliverable 67** (Report outlining the experimental design and sampling strategy for study of climate change and mercury mobilisation), **Deliverable 107** (Report on results of experimental manipulations at Gardson catchment), **Deliverable 373** (Presentation of results at European SETAC conference, Warsaw, May 2008 - Platform presentation), **Deliverable 374** (Manuscript to international journal on Hg results in the studied lakes) and **Deliverable 375** (Joint WP5 report on climate change and mercury)

NIVA analysed fish samples from the Norwegian THERMOS lakes (Lake Breisjøen and Lake Store Gryta).

SYKE investigated mercury and methyl mercury mobility and bioaccumulation in lakes affected by temperature changes to assess the effects of climate change on the thermal regime of freshwater lakes. SYKEs mercury work in WP5 was closely connected to WP1 THERMOS experiment (WP1 Task 3.3). There are also close links with the Norwegian THERMOS lake manipulation experiment, where a clear-watered deep mountain lake has been manipulated. The main aims of the experiment were to:

- To quantify the effects of controlled thermocline manipulation on biogeochemical cycles foodweb structure and productivity, and biodiversity in dystrophic systems.
- To quantify the effects of manipulation on mercury (Hg) and methyl mercury (MeHg) cycle
- To estimate the impact of thermocline mixing on MeHg concentration in fish

The study was conducted by manipulating the stratification pattern (thermocline depth) of a small polyhumic boreal lake (Halsjärvi) in southern Finland during 2004-2007 and comparing the results with a reference lake (Valkea-Kotinen). Detailed monitoring of chemical and biological variables (mainly weekly-biweekly sampling) was carried out in both lakes. See **Deliverable 78** (Report on pre-treatment studies for lake manipulation experiment) and **Deliverable 180** (Report on the first results on mercury and methylmercury mobility and bioaccumulation in lakes affected by temperature changes)

Task 4: Climate change and remobilisation of heavy metals and POPs from polluted soils (UCL)

Task 4.1 Remobilisation of metals and POPs from organic soils (UCL, CSIC, CNR, UIBK, HSCU, EAWAG)

UCL assessed the mechanisms by which catchment stored trace metals (and by inference other deposited pollutants such as POPs) are transferred to surface waters. Lakes were sampled in three regions of Scotland to provide both climatological and steep historical pollutant deposition gradients. Within each region, three lakes were selected to include a site with little or no catchment soil (or a very small catchment: lake ratio); a site with good soil coverage but with little or no erosion and a site with good soil coverage, but with high levels of soil erosion, especially close to the loch shore. At each site multiple sediment cores were taken and analysed for trace metals (Hg, Pb, Cd, Ni, Cu and Zn) and spheroidal carbonaceous particles (SCPs) in order to determine the full lake sediment basin fluxes of these atmospherically deposited contaminants. A soil core was also taken from each site. Radiometrically-derived chronologies were used to produce the sediment inventories on a decadal basis. Therefore, by comparing the full sediment basin records of trace metals and SCPs at these different lake types we can establish and test a series of hypotheses:

(i) The sediment records of pollutants (metals and SCPs) at sites with little or no soil cover should not be affected by soil processes and therefore should show the same temporal trends as those of atmospheric deposition.

(ii) If enhanced catchment erosion is the cause of increased toxic pollutant transfer from soils to sediments then sites with good soil coverage but no erosion should not show enhanced catchment inputs but sites with eroded soils will. Both metals and SCPs will be affected. The sediment records of pollutants at sites with little or no soil cover should be unaffected.

(iii) If enhanced leaching from catchment soils, as a result of elevated allochthonous DOC is the cause of increased pollutant transfer then all sites with good soil coverage should show enhanced inputs. The records of trace metals should be enhanced as they bind to DOC. The records of SCPs will not be affected by this mechanism. The sediment records of pollutants at sites with little or no soil cover should be unaffected.

For results and design see **Deliverable 68** (The main transfer mechanisms for POPs and trace metals from soils to sediments: Sites, methodologies and preliminary data), **Deliverable 181** (The main transfer mechanisms for POPs and trace metals from soils to sediments: Data report) and **Deliverable 379** (An assessment of the mechanisms for the transfer of lead and mercury from atmospherically contaminated organic soils to lake sediments with particular reference to Scotland, UK).

Three lakes in an altitudinal gradient in the Pyrenees were studied by **CSIC** in order to obtain the field data needed to apply a model of transport of heavy metals from their catchments. The difference in altitude causes differences in the mean temperature, providing an experimental setting to establish differences in the transport rate of heavy metals caused by temperature changes. At each lake, atmospheric precipitation collectors and sediment traps were deployed in order to measure atmospheric and sedimentary fluxes on a monthly basis. In addition, monthly field trips were carried out to measure the quantity and quality of the suspended particles and the heavy metal load in the lakewater, both in the particulate and dissolved fractions. Soil and air temperature were continuously (30 min intervals) monitored by using miniloggers. Analyses of trace elements in samples were collected monthly including dissolved fraction and suspended particles in lake water, sediments from traps, atmospheric deposition, and soils and sediment cores – see **Deliverable 367** for a fuller description of this work.

UIBK performed soil sampling in collaboration with **CSIC** at 6 sites along an altitudinal gradient (from about 1100 to 2500 m) in the Tyrolean Alps in summer 2005. Samples were analysed by CSIC.

- HSCU completed the soil sampling programme was finished along the altitude gradient in the Tatra Mts during the first period of the project. Information about soil types within studied catchments were published (Kopáček et al., 2004b, 2006) – see **Deliverable 26**

(Report comparing the POP composition in soil and sediment cores in the Pyrenees and the Tatra Mountains).

Task 4.2 Sediment reworking and pollutant transfer in alpine catchments (EAWAG)

CNR completed high-resolution measurements of suspended particles and water temperatures in the polluted Bay of Pallanza, Lago Maggiore, during two hydrological cycles (see details under Task 4.2). Total particle fluxes were quantified from material recovered from open sediment traps and sequencing sediment traps deployed at different water depths and at various temporal resolutions. Trap samples were analysed for their nutrient content (C_{org}, N_{tot}, C/N-ratio, BSi) and particle characteristics. Analyses of POPS in lake Maggiore were also made.

After purchasing the necessary instruments and material (traps, T-loggers, acoustic release etc.) and developing a protocol for the proper handling of mooring instruments and for the sediment trap sampling procedure, an instrumental mooring was deployed by **EAWAG** in October 2004 in 120.5 m water depth in the Bay of Pallanza in Lago Maggiore (194 m a.s.l.). The chosen site is characterized by natural alpine inflow conditions and by severe anthropogenic pollution. The mooring consisted of an anchor weight, 2 sequencing and 4 integrating sediment traps, 4 temperature loggers, and 7 buoys along a 10 mm pre-stretched nylon rope. The sampling intervalsof the 2 sequencing traps ranges from 21 days (Nov.-Feb) to 7 days (March-April). The interval duration was chosen based on seasonal changes and the dynamics of productivity in the lake. The water depths of the individual instruments within the mooring were determined by the known pattern of water circulation within the bay and by the depth of the thermocline. During 2005 the mooring was recovered and redeployed, after resetting the instruments and sampling the trap material. The sampled material was freeze-dried, weighed and used for calculating sediment flux rates. The mooring was recovered in May 2006. Simultaneous high-resolution measurements of suspended particles and water temperatures were conducted in high-altitude Lej da Silvaplauna (1800 m a.s.l.), covering four hydrological cycles. Total particle fluxes were quantified and trap samples were analysed for nutrient content (C_{org}, N_{tot}, C/N-ratio, BSi) and particle characteristics. Sediment and temperature data from the two sites were compared and results presented at the EGU Conference in Vienna (April 2007) and the SIL Conference in Montreal (August 2008); the comparison was published by Kulbe et al. (2008).

Task 4.3 Metals, climate change and river floodplain sediments (UFZ)

UFZ reviewed the 'state-of-the-Art' concerning trace metal mobility in floodplains soils (Deliverable 261). This work was followed up by an attempt to identify indicators from the association between soil characteristics and toxic metal analysis to characterise the degree of actual and potential mobility of trace elements in the system and identify spatial patterns of trace metal mobility grade. This task dealt with the behaviour of trace metals in the soil solution under changing seasonal conditions, particularly under changing river water levels. Within the Middle Elbe region three study sites were investigated, representing the typical geomorphological units of floodplains: levee, depression, and plateau. From July 2005 till August 2008 data were collected regularly using a steady data logger. At all three sites field monitoring stations to investigate soil hydrology were set up. The samples were brought to the laboratory where Organic carbon (DOC), inorganic carbon (IC), sulphate (SO_4^{2-}), nitrate (NO_3), and chloride (Cl^-) concentrations in the pore water were determined on non-acidified samples directly after sampling. The remaining pore water samples were acidified with a few drops of concentrated HNO_3 to keep the metals in solution; in these samples As, Cd, Cr, Cu, Ni, Zn were analysed using ICP-MS, and Fe, Mn, Ca, and Na using ICP-AES (see (**Deliverable 262** for results). **UFZ** used laboratory experiments (incubation tests) to examine variations in the duration of flooding and soil responses, in particular the influence of temperature increase on trace metal mobility. This was undertaken using a microcosm arrangement testing three temperature levels. Within the microcosms sensors that measured soil suspension, temperature, redox potential, and pH-value were installed and samples were analysed for Hg, As, Cd, Cu, Cr, Ni, Pb, and Zn as well as for DOC and salts (see **Deliverable 424**). A final sub-task here was to regionalise the results using geostatistical methods and merge into a GIS. Results from this were included in Bolze, Set al., (submitted) Regionalization of metal concentrations in floodplain soils; Exemplified at the Elbe River, Germany, *Journal of Plant Nutrient and Soil Science* and Schulz-Zunkel, C. and F. Krueger (2009, in press): Trace metal dynamics in floodplain soils of the River Elbe. A review. *Journal of Environmental Quality*

WORK PACKAGE 6: Integrated catchment analysis and modelling

Task 1: Catchment data collation and process analysis (AERC, NERC, SYKE, UIBK, NIVA, NERI, AU, HYDROMOD, CNRS-UPS)
The purpose of this task was to collate historic and new data and ensure that the latest process understanding was incorporated in the modelling approaches used. It was also to ensure that the model applications covered all climates and key pollutant issues in European freshwater ecosystems. Although this task was completed after 2 years, it was decided to continue it to the end of the project since new data were continuously becoming available, the meta-database still needed to be updated, and the new knowledge incorporated in the models. Methodologies and Approaches employed included data collection using manual and automatic methods, meta-database construction and maintenance, GIS analysis using the meta-database, digital terrain modelling and statistical methods for data analysis (e.g. trend analysis using the nonparametric Mann-Kendall rank test).

A substantial meta-database describing the key integrated modelling sites across Europe was created, and subsequently maintained, by **AERC** and **UCL**. Data were measured and collated from a large number of catchments, including the Piburger See (Austria, **UIBK**); the Bjerkreim, Tovdal and Vansjø-Hobøl catchments (Norway, **NIVA**); the Savijoki, Mustajoki/Teuronjoki and Simojoki catchments (Finland, **SYKE**); the Kennet, Lambourn, Test and Tamar (England, **AERC**); the Conwy (Wales, **NERC**); Falloch/Loch Lomond (**HYDROMOD/NERC**); La Tordera (Spain, UB); the Rivers Odense and Gjern (Denmark, **NERI** and **AU**), and the Adour/Garonne Basin (France, CNRS-UPS). These catchments were specifically associated with WP6: the database for the whole of Euro-limpacs contains 113 catchments. The meta-data confirmed the appropriateness of the sites chosen and the data available for each for assessing the effects of climate change on European waters.
A Special Issue of the *Science of the Total Environment* (365, 2006) was produced which described new monitoring and modelling work done in Euro-limpacs (**Deliverable 109**).

Task 2: Component model development and application (AERC, NERC, SYKE, NERI, AU, UIBK, NIVA, IVL, HYDROMOD, CNRS-UPS)
The purpose of this task was to develop and apply component models to assess the likely impacts of global change in European freshwater systems. The techniques used included model development and testing, modelling on a national and large river basin scale, using a GIS based modelling approach, integrated modelling in catchments using dynamic, mechanistic models and modelling using stochastic and statistical models.

Seven WP6 workshops were organised and chaired by **AERC** to facilitate model developments and applications, sometimes as part of the agenda of project meetings, and these were well-attended by partners. During the project **AERC** has led the development of new integrated catchment (INCA) analysis models creating a tool-kit of models applicable at the catchment scale to investigate the impacts of environmental change on flow, nitrogen, phosphorus, sediment, carbon, mercury and other heavy metal dynamics in both the terrestrial and aquatic components of a catchment. The hydrological and landscape representation of these different models has been harmonised so that only the equations describing the biochemical cycling of the determinand simulated vary between the different versions. The phosphorus version of INCA takes the science further and incorporates equations to describe the interactions between macrophytes and epiphytes and the physical and chemical aquatic environment. This work on linking hydrology, water quality and ecology is being further developed through the development of a new model of eutrophication development in rivers. A tool-kit thus now exists to examine the integration factors and processes controlling hydrology and water quality for a range of climate and land-use types across Europe. Progress on the individual models, and partners involved, are detailed below.

INCA–N: Temperature response functions and a snow sub-model were included in INCA-N to make it more suitable for Nordic countries. **Deliverable 27** (**SYKE, AERC** and **NIVA**). A new hydrological calibration and validation has been carried out with the most recent INCA-N model version for period 1985–2004. N processes were also calibrated for the period 2004–2008 based on new, frequently monitored inorganic stream N concentrations (Granlund, 2009). The calibrated model was then used for climate change impact assessment in Task 6 in supprt of a PhD Thesis. (Granlund, 2009) (**SYKE**). INCA-N was calibrated for the period 1995–2004 for the Mustajoki catchment in southern Finland. A final calibration of INCA-N to the Tovdal River basin, S. Norway was accomplished (**NIVA**). Calibration of the INCA-N model to the Piburger See catchment has been improved (see Task 1) (**UIBK**). A new version of the INCA-N model on the River Gjern catchment has been calibrated and validated (**NERI**, **AU**). Data for setting up the INCA-N model on the River Odense catchment was collected. The INCA-N model has been calibrated on the river Odense and finally validated (**NERI**, **AU**). INCA-N was successfully calibrated to the catchment of Loch Lomond (**HYDROMOD**). INCA-N was been applied to the Gårdsjön catchment in Sweden (Futter et al. in press) (**AERC/IVL**). INCA-N was tested in the River Strymon catchment in Greece (**EKBY**). INCA-N was applied to the La Tordera catchment in Spain. Development is continuing (**UB**)

INCA-P **SYKE** organised an expert workshop in Helsinki to aid the development of the INCA-P model (**Deliverable 186**). A considerably revised structure of the INCA-P model, to include both particulate and soluble P in soil and streamwater, was created as a product of the workshop (**Deliverable 185**). The workshop had 21 participants from 8 institutions representing 5 countries, both within and outside of Euro-limpacs. (**AERC/SYKE**).

INCA-Sed The original INCA-Sed was further developed and applied to various UK catchments (**Deliverable 70, AERC**). A successful application of “prototype” INCA-Sed to Gjern, Odense and Savijoki was completed (**Deliverable 183, SYKE/NERI/AU**). A miniworkshop for the INCA-Sed model development was organised in Helsinki (**SYKE**). INCA-Sed was further developed and integrated into a new version of INCA-P (**AERC**). The revised INCA-Sed model was applied to four small research catchments in southern Finland (**SYKE**). The new version of INCA-Sed was applied to the Lugg catchment. (**AERC**).

INCA-C A new catchment-scale model of organic carbon dynamics, INCA-C, has been developed with input from various partners (**AERC, SYKE**). INCA-C was developed and tested with data from the Plastic and Harp Lake catchments, Canada (**Deliverable 105, AERC**). INCA-C was developed in a series of mini-workshops and applied to a long-term dataset at Valkea-Kotinen, Finland (**SYKE**). INCA-C was applied to assess carbon dynamics in north European catchments (**AERC**).

INCA-Hg A new model to assess mercury dynamics (INCA-Hg) was developed, and applied to Gårdsjön and Lochnagar in Scotland - **Deliverable 182** (**AERC**).

INCA-Tox A new integrated catchment (INCA) model for simulating metals and mine discharges in river basins (INCA-Tox) has been developed (**AERC**).

Acidification models PEARLS was been extended to include a routing component to account for long residence times in lakes. Transformation processes based on residence times are incorporated in the routing component. This allows realistic modelling of non-conservative constituents. This extended model has been applied to the Bjerkreim and Conwy (**NERC**). Catchment maps of acidification have been generated for the Bjerkreim and Conwy using PEARLS. (**NERC**). PEARLS was extended to allow simulation of chemical constituents other than ANC. A novel approach to time stepping has been implemented, allowing time steps longer than typical residence time in the river. This was required to allow for modelling of lake/river systems such as the Bjerkreim with very mixed residence times. (**NERC**). The MAGIC-lite / PEARLS linked model set has been developed further – see Task 5 (**NERC**).

Biological models The impact of land cover on fish species distribution in the Garonne has been modelled using artificial neural networks (**Deliverable 114** - **CNRS-UPS**). The self-organising map algorithm of the artificial neural network technique was used to model macro-invertebrate distribution in the Lambourn. (**CNRS-UPS**). A statistical modelling study of the potential impact of climate change on fish assemblages in French streams was carried out (**CNRS-UPS: Deliverable 266**). This used an ensemble forecasting approach with 7 species distribution models, 3 GCMs and 4 greenhouse gas emission scenarios applied in factorial combination to give 84 model combinations for each of 35 fish species in French rivers. This work has been submitted for publication as book chapters in Community Ecology of Stream Fishes (American Fisheries Society) and Changement climatique et biodiversité (Association Française pour l'Avancée des Sciences) (**CNRS-UPS**). **AERC** generated a flow/P response surface for Ranunculus in the Kennet using Monte Carlo version of the original INCA-P (**Deliverable 115, AERC**). A new dynamic model of macrophyte-epiphyte-algal dynamics has been developed to investigate theories of eutrophication development in rivers (**AERC**).

Other Models Data from the River Odense catchment (Task 1) were used to model the deposition of sediment and P on inundated lowland floodplains for inclusion in other models like MIKE11-TRANS (**NERI**, **AU**). The steady-state, conceptual but empirical model of nitrogen and phosphorus fluxes MONERIS was successfully calibrated to the La Tordera catchment in Spain (**UB**). The self-organising map algorithm of the artificial neural network technique was used to model chemistry in the Adour-Garonne hydrographic network during the last three decades. (**CNRS-UPS**).

National-Scale GIS-based Modelling The GIS-Based N_EXRET model was applied to the whole of Finland to assess N sources and retention in surface waters, and to identify N loading hot-spots. See highlight (**SYKE**).

Task 3: Model uncertainty (AERC, NERC, NIVA, NERI, AU)
The purpose of this task was to investigate model parameter, structural, input-data and calibration-period uncertainty as an aid to model development and to estimate the uncertainty in the model predictions of the impacts of global change. In modelling complex environmental systems including material fluxes, sources of uncertainty are due to errors in:

1. Boundary conditions (driving variables)
2. Initial conditions
3. Model structure (including computational representation)
4. Parameter values

These sources result in inaccurate prediction, and we commonly wish to give some limits on the expected true value of a variable at a point in space and time, given the model-simulated value. This requires estimates of the statistical distribution of all the sources of uncertainty influencing the model simulations. To generate model output uncertainty, a common technique is to use Monte Carlo realisations of the sources of uncertainty in repeated model applications to generate statistical distributions of outputs. Various variants of these techniques have been used in WP6. In addition, techniques such as application of different models to the same datasets have been employed.

An uncertainty and sensitivity analysis toolkit for INCA-N was developed (see Task 5) (**AERC**). The WP6 workshop at the Final Project Meeting in Blanes (2008) discussed uncertainty, and presentations by **SYKE** and **CNRS-UPS** demonstrated how they had applied uncertainty analysis to INCA-N. A standardised procedure for partners was suggested. (**AERC, SYKE, CNRS-UPS, NIVA**). A sensitivity analysis based on Kolmogorov-Smirnov statistics was used in two applications of INCA-N model, in the Mustajoki and Savijoki catchments, Finland (**SYKE**). Sensitivity analysis data from two research sites in Finland was provided as a contribution to a forthcoming manuscript about sensitivity analysis by the INCA-N model (**SYKE**). The new sensitivity analysis tool for INCA-N was successfully applied to one sub-catchment of the Tovdal river (**NIVA**). An uncertainty analysis of the original version of INCA-P was performed (**AERC**). The model uncertainty for components of the TRANS model has been analysed for the model set up on the River Gjern, Denmark (**NERI**, **AU**). A preliminary uncertainty analysis was applied to the original versions of INCA-Sed and INCA-P as part of a larger study on model uncertainty (**AERC** - **Deliverable 69**). n uncertainty analysis of the original version of INCA-P was done (**AERC**). Markov-Chain Monte-Carlo (MCMC) was explored by **NERC** and **AERC** as a tool for analysing parameter sensitivity in INCA-N. This was applied to the PEARLS Model (**NERC/AERC**). GLUE uncertainty analysis was applied to an INCA-N application at the Simojoki site (**Deliverable 109**)

(**SYKE/AERC**). **NIVA** contributed with uncertainty analysis work related to MAGIC model applications to **Deliverable 69** "Report summarising the preliminary investigation of model uncertainty". Parts of this work have been published. In the reporting period 2008-2009 application of MAGIC-lite/PEARLS/routing models on the Conwy has used stochastic realisations of scenario rainfalls under climate change 2002-2100 derived from the ECHAM4 model run by SMHI (Sweden) for the SRES scenarios A2 and B2. Atmospheric inputs were generated using Poisson distributions of marine and pollutant components to generate uncertainty in deposition consistent with variability measured in field data (NERC). A special issue on "Uncertainty in ecological models" was edited for the journal *Ecological Modelling* (Sovan Lek, 2007) Uncertainty in Ecological models. Ecological Modelling, 207:1-2) (**CNRS-UPS**). An extended uncertainty and sensitivity analysis was applied to the INCA-N application on the Garonne catchment using the Monte Carlo sensitivity tool (**CNRS-UPS**)

Task 4: Integration of component models and socio-economics (AERC, IVL)
Objectives:
The purpose of this task was to integrate the latest socio-economic scenarios into the modelling assessments of global change. Socio-economic models were run in addition to the hydrochemical models in order to estimate the effects of socio-economic change and socio-economic policies on water quality in rivers.

AERC explored the consequences of predicted agricultural and climate changes for flow and nitrate and ammonium concentrations in the River Kennet in southern England - **Deliverable 113**. **AERC** led the integration of an economic model and a catchment nitrogen model to determine the effects of nitrogen taxation on water quality. Additional work of a socio-economic nature is reported in Work package 9.

Task 5: Integrated model tool-kit development (AERC, NERC, SYKE, UR1, NIVA, NERI, HYDROMOD)
The purpose of this task is to chain component models to allow assessment of coupled wetland-lake-river systems and to improve the modelling representation of the spatial and temporal variation in the factors and processes controlling pollutant behaviour. Many specialised ecosystem models are available which give robust and detailed predictions in a limited scientific field. With climate change, the possible environmental impacts are diverse and inter-connected and involve the responses of a myriad of processes in whole catchments. Integrated management strategies will be needed to tackle the problems, and to model responses on a catchment scale, individual models also need to be integrated. WP6 contains a number of examples of this. It was an aim of WP6 to produce a model-based assessment of the changes in the hydrology and water quality at sites across Europe representative of different climate and land-use types. As a step towards this, **AERC** led the development of a modelling methodology that could be applied consistently across sites in Europe to provide a comparable assessment of the hydrology and water quality at different sites. This methodology now consists of steps to: down-scale climate data for use in hydrology and water quality impacts models, perform a sensitivity analysis and then a

subsequent uncertainty analysis. As part of this process a range of down-scaling methods were explored.

Chained HBV-INCA-N models were applied to the Garonne, a large (60,000 km^2) river system in France (Tisseuil et al, 2008) (**CNRS-UPS/AERC**). Tools for smooth data transfer between the HBV model, the INCA-N/INCA-P model and the MyLake model were established. (**NIVA**). A paper describing model chaining (HBV-MAGIC-INCA-N-FJORD) in the Bjerkreim catchment was published and produced as **Deliverable 111** (**NIVA**). PEARLS has been applied to the Conwy catchment, North Wales, providing ANC threshold exceedence probabilities for the stream network. In conjunction with the MAGIC soil acidification model, PEARLS has been used to estimate changes in ANC over the coming 50 years under standard emission scenarios. Additional sampling was undertaken on the Conwy, in collaboration with CEH Bangor. This has generated data designed to test the mixing assumption and to provide better probability distributions of ANC from landscapes which were poorly represented in previous surveys. (**NERC**). The MAGIC-lite model was further developed and linked within a single program with the PEARLS model to provide seamless simulation of changes in stream water acidity in response to daily climate scenarios and atmospheric deposition trends (NERC).

AERC organised and chaired WP6 workshop held in Reading on down-scaling of GCM data for use in catchment models. The Statistical Downscaling Method as a common tool for all partners to use to down scale GCM outputs to the catchment was explored (and ultimately rejected) (**AERC**). Detailed standardised methodology for downscaling PRUDENCE data for use in the effects models was circulated (**Deliverable 433** - **AERC**). An attempt was made to reduce the length of model chains by downscaling river flows directly from GCM outputs. This was applied to the Garonne and shows promise (**Deliverable 382** - **CNRS-UPS/AERC**). The Monte-Carlo based Sensitivity and Uncertainty Analysis Toolkit for the INCA models was developed and tested. This together with the standardised method for downscaling PRUDENCE data provides a methodology that can be applied across all sites in WP6 to provide a consistent and comparable assessment of the response of catchment nitrogen dynamics to environmental change. (**AERC**). The journal article on the 'best use of catchment scale water quality models' was completed (**AERC**).

SYKE/NIVA finalised the linking of INCA-MyLake models. The effects of climate change scenarios on surface temperature and ice cover on Lake Pääjärvi were studied. These analyses were done in the connection of developing the FINESSI web tool (http://www.finessi.info/finessi/index.php?=&lang=en) which allows the user to explore the possible impacts of climate change in Finland on chosen impact areas and at different time periods up to the end of the 21st century. The tool is intended for planners and researchers, but it may also be of interest to students and to members of the public (**SYKE**).

The WSFS hydrological model, in combination with the INCA-N and INCA-SED models, was applied to simulate discharge and inorganic N and suspended sediments load from the Mustajoki catchment to Lake Pääjärvi (see also WP7). (**SYKE**).

The MAGIC-lite daily time step soil acidification model was extended to include additional organic aluminium processes and improved integration of with the surface water flow model PEARLS/routing. The models were run for the Conwy catchment using daily climate change scenario data from 2002-2100 derived from the ECHAM4 model run by SMHI (Sweden) for the SRES scenarios A2 and B2. The MAGIC-lite/PEARLS/routing models now form an integrated catchment-scale model in a framework which is applicable to a range of water quality variables. A major achievement under this Euro-limpacs task has been the completion of the MAGIC-lite model to provide a causal link to the pre-existing PEARLS/routing model, allowing stream water quality to respond directly to atmospheric deposition drivers, while accounting for key soil processes.

Task 6: Integrated modelling for impact assessment (AERC, NERC, SYKE, UR1, NERI, UIBK, NIVA, IVL, HYDROMOD)
Objectives:
The purpose of this task was to apply the component and chained models to assess the impacts of global change on European freshwater systems. The task was intended to integrate the work done in Tasks 1-5. Generally, climate change scenarios combined with effects models were run to predict a range of future events in the target aquatic ecosystems.

Climate scenario data from the regional climate model RCAO for the scenario period 2071-2100 and the emission scenarios A2 and B2 have been applied to a hydrological model in order to estimate changes in discharge under future climate conditions at the Piburger See, Austria (**UIBK**). INCA-N model simulations were run for two catchments, Savijoki and Mustajoki, for a baseline situation and for four climate change scenarios (assuming no changes in cultivation techniques (**SYKE**). The calibrated INCA-N model was applied at the Tovdal catchment to assess possible impacts of various climate scenarios. The results were presented at the final Eurolimpacs meeting in Blanes (**NIVA**). A paper projecting nitrate fluxes from the Tovdal River using the mass transport model TEOTIL run on four scenarios of climate change was published (**NIVA**). INCA-N was applied to the Lambourn catchment, SE England, from 1920-2003, over a change in land use. The results were discussed in terms of model use and testing (**Deliverable 303**: **AERC**). **AERC** edited a special issue of *Hydrology Research* on modelling the impacts of climate change (with WPs 1 and 4). (**Deliverable 380**: **AERC**). INCA-C was applied to Plastic Lake in Canada to assess changes in DOC under future climate scenarios (**AERC**). The application of an in-stream oxygen model to the River Thames to assess the impacts of climate change was evaluated (**AERC**).

Four miscellaneous publications on climate change modelling were produced by **AERC**: Modelling nitrogen dynamics in montane catchments ; modelling the impact of European emission and climate change scenarios on dissolved organic carbon concentrations the surface waters of a boreal catchment ; the effects of changing climate and deposition on long-term nitrogen dynamics of a montane lake; and modelling stream and soil water nitrate dynamics during experimentally increased nitrogen deposition in a coniferous forest catchment at Gårdsjön, Sweden using INCA-N. Additional modelling was conducted for Lago Maggiore, Italy. Using temperature profiles simulated for future climate conditions by the Hydromod partners, the PROTECH model was used to model the predicted phytoplankton changes for the lake (**NERC**). Possible climate change impacts on runoff in smaller Danish streams were analysed using the NAM-model and were subsequently calibrated and validated on 11 catchments (**NERI**, **AU**). Possible climate change impacts on diffuse nutrient losses to Danish freshwater were analysed utilising a combination of the NAM-model and statistical nutrient models (**NERI**, **AU**).The first climate change scenarios on runoff, nutrient loss and nitrogen retention have been conducted for the River Gjern catchment using ECHAM4/OPYC General Circulation Model (IPCC A2 scenario) dynamically downscaled by the Danish HIRHAM regional climate model (25 km grid) for two time slices: 1961-1990 (control) and 2071-2100 (scenario). GCM data for use in impact assessments for the Danish catchments was downloaded and statistically downscaled at a workshop in Reading, UK, using the SDSM software. Land-use (agriculture and forestry) scenarios have been run for the Simojoki site, based on INCA-N application (**SYKE**). A study of nitrogen leaching patterns and adaptation to climate change in two Finnish river basins was studied and a journal paper published (**SYKE**).

Task 7: Integrated modelling for impact management (AERC, NERC, SYKE, UR1 NERI, UIBK, NIVA, IVL, HYDROMOD)

Objectives:

The purpose of this task was to apply the component and chained models to evaluate the management options for mitigating or minimising the impacts of global change. Models were applied as in the tasks above, and the models re-run to include the effects of effects of land use changes or other mitigation treatments.

UIBK prepared an impact management plan for the Piburger See (cf. Tasks 1, 2 and 6). An estimate of the effects of three land use treatments on nitrate concentrations in the River Kennet was carried out using INCA-N and a variety of climate change scenarios (**AERC**). INCA-N and P modelling of the Rivers Lugg, Tamar, Tame, Lambourn, Kennet and Tweed has been carried out (**Deliverable 381**: **AERC**).A model-based assessment of the long-term changes in streamwater nitrate concentrations in a permeable catchment due to climate and agricultural changes and an assessment of the consequences for management of long residence times of pollutants in permeable catchments was carried out (**AERC**). A review of the potential impacts of climate change on surface water quality has been published (**AERC**). A new integrated catchment model for simulating metals and mine discharges in river basins has been applied to assess pollution impacts and restoration strategies in the Aries-Mures River System in Transylvania, Romania (**AERC**).

WORK PACKAGE 7: Indicators of ecosystem health

Task 1: Generation of a meta-database on indicators of ecosystem health in relation to climate change (UDE, BOKU, ULIV)
The objectives of Task 1 were to: i) categorise the potential effects of global change on physical, chemical, hydrological, and biological processes and their interactions for different types of freshwaters and undertake an assessment of the relationship between climate change and indicators; ii) undertake a literature analysis to categorise to identify possible indicators for the different direct and indirect effects of climate change on aquatic ecosystems; and iii) generate a web database as a basis for the experimental and analytical work in Tasks 2-4 and in particular for the indicator selection tool (Task 5).

The principle of the Task was based on a network of Cause-Effect-Chains, which simplify the complex interactions of Climate Change and communities/processes in aquatic ecosystems and provide the framework for the database. The following steps were performed:

- Generation of draft Cause-Effect-Chains (**UDE**)
- Discussion of the draft with project partners and subsequent improvement (contributions by **SYKE**, **MasUniv**, **UU-Bio**, **NERC** and **BOKU**)
- Compilation of data on the individual steps of the Cause-Effect-Chains (literature references), on potential indicators and on data available on these indicators (**UDE**)
- Discussion of the draft compilation with project partners and further improvement (contributions by **SYKE**, **MasUniv**, **UU-Bio**, **NERC**, **NIVA** and **BOKU**)
- Building a draft for a web-based database and pre-defined queries (**UDE**)
- Feeding the data into the database and launching the web-version (**UDE** and **BOKU**)

Overall, more than 1,000 references were analyzed, about 500 of which were finally included into different versions of the database. The database was continuously updated throughout the project's lifespan and first hosted under the Euro-limpacs hompage. Finally, it was simplified and included into the product of Task 5 (www.climate-and-freshwater.info).

Task 2: Compilation and analysis of data on the response of chemical parameters to climate change through various drivers (SYKE, NIVA, UCL, AERC)
The overall objectives of Task 2 were to perform case studies on eutrophication and acificifation indicators and their interaction with climate change effects and to summarise existing chemical indicators based on a literature evalution. More specifically, the objectives were:

i) Eutrophication case study

i. To estimate effect of climate change on discharge patterns and nutrient loading from a forested head water catchment by using bottom up approach.
ii. To simulate total N and total P loads from the Mustajoki catchment to the Lake Pääjärvi in southern Finland by the INCA family models INCA N and INCA SED.
iii. To model the effect of climate change on discharges with the hydrological model Watershed Simulation and Forecasting System (WSFS), which is used to produce the input data for the nutrient model.

iv. To calculate response surfaces of the N/P relationship of the nutrient load from the simulations.

Acidification case study

i. To identify empirical relationships between water quality components and their possible effects on salmon populations. Focus is on exposure intensity, duration and timing. The results are interpreted as a simulation of an episode.
ii. To explore relationships between pH/TOC/ANC in relation to total Al and various forms of Al. To understand how these relationships are interrelated and affect Al concentration and speciation can aid in understanding how climate can affect water quality, thereby affecting current liming strategies.

Summary of chemical indicators

i. To synthezise the outputs of the REBECCA project to select chemical indicators for Climate Change, and to prepare this output for the use in Task 5

i) Eutrophication case study (**SYKE, AERC**) The following work was performed:

- Calibration of the Watershed Simulation and Forecasting System (WSFS) for the study catchment; generation of response surfaces
- Calibration of the INCA models for the study catchment using Geographical Information System (GIS) and water quality monitoring data. Generation of response surfaces.

ii) Acidification case study (**NIVA**) The following work was performed:

- Results from 347 short-term (<14 days) exposures of salmon parr and smolt performed between 1990 and 2003 in Norway were summarised. The results from the various bioassays were compared to water quality limits proposed on basis of the relationship between water quality and population status/health in Norwegian rivers. Focus was on chemical-biological interactions that can be drawn across experiments and exposure protocols. Dose-response relationships were suggested for acid neutralizing capacity (ANC), pH, cationic Al and gill accumulated Al, versus mortality in freshwater, effects on hypo-osmoregulatory capacity in seawater challenge tests and on smolt to adult survival in release experiments.
- Data from Norwegian national monitoring program undertaken in 1995 were used to establish relationships between Al species and other water chemical constituents. This dataset contains data from 1500 lakes, where the lakes to be sampled were chosen randomly.

iii) *Summary of chemical indicators* (**SYKE**) The major results of selected REBECCA deliverables related to chemical pressures and biological (ecological) status of lakes (and partly rivers) were summarised and included into a database used for the indicator selection tool (Task 5).

Task 3: Development of "functional indicators" for wetlands and extension to rivers and lakes (ULIV, NERI, UU-BIO)

The objective(s) of Task 3 were to: i) produce a conceptual study on wetland "functional indicators" and to specify wetland functional indiactors for a wide range of wetland types; and ii) to develop a concept on how to transfer the functional indicators idea to rivers and lakes.

A literature search for physical, chemical and biological effects of climate-related influences on wetland functioning was undertaken and relevant study conclusions were compiled for inclusion in the 'meta-database' under Task 1. The results have been summarized further in a brief report (**Deliverable 122**) (**ULIV**). The preliminary literature review produced by **ULIV** on wetland functional indicators was uploaded into the web database (see Task 1) (**UDE**). **ULIV** identified links among wetland processes and functions, and environmental variables and determined the effects on wetland ecosystem services of changes in key environmental variables. **ULIV** refined the functional assessment of wetlands to incorporate changes expected under climate change and completeda book on "Functional Assessment of Wetlands; towards evaluation of ecosystem services" (Maltby, editor, 2009). Further, **ULIV** completed an elaboration of core underlying principles of functional analysis in wetlands, indentifying parallels with processes and functions in lake and river ecosystems and an analysis of core principles in decision-tree development for lakes and rivers and derivation of meaningful conclusions for use in the field. This work resulted in **Deliverable 273** (Manuscript on functios work nal indicators in wetlands) and **Deliverable 281** (Manuscript on how to transfer the functional indicator concept on rivers and lakes).

Task 4: Generation of an indicator value database for European freshwater species (UDE, BOKU, ALTERRA, NERC, CNR, MasUniv, NERI, SLU, UGR, CNRS-UPS)
The objectives of Task 4 were: i) to summarise existing information on distribution and ecological preferences of European freshwater biota; ii) to present the results in an online database; and iii) to evaluate the data according to the sensitivity of species for climate change effects

This work had a number of key components and the main activities are presented below

i) *Preparation* (**BOKU**, **UDE**, **all partners**)

- Selection of specifically targeted organism groups representing different ecosystem types, ecoregions, and taxonomic groups. The following groups were selected: Diatoms, mayflies (Ephemeroptera), stoneflies (Plecoptera), caddisflies (Trichoptera), non-biting midges (Chironomidae), fish (Pisces).
- Compilation of existing data for diatoms (mainly from OMNIDIA), macro-invertebrates (mainly from AQEM and STAR projects) and fish (mainly from the FAME project).
- Distribution of a questionnaire asking for possible autecological parameters and categories (for these parameters), which could indicate the effects of climate change (macroinvertebrates only). Selection of parameters separately for diatoms, benthic invertebrates and fish.
- Generation of a database structure.

ii) *Diatom database* (**Alterra**)

- Start of compilation of autecological characteristics of diatoms by combining existing Alterra information with existing information from larger European databases such as OMNIDIA. The resulting diatom database comprises 15 categories and 66 autecology columns, and includes 12,375 taxa codes (including synonyms).
- Integration of the diatom data into www.freshwaterecology.info (**BOKU**).
- Meeting with Michael Coste (CEMAGREF) to clarify a large number of synonym-questions and the composition of certain parameters.
- Several updates of the diatom database were made and implemented on the website.

iii) *Ephemeroptera database* (**CNR**, **UGR**)
- Compilation of an autecological data input table (**BOKU**).
- Distribution of this input table (including existing data) among the experts within the consortium.
- Literature compilation (about 2,800 references).
- Development of a scheme for compiling the ecological data from these references.
- The final autoecological matrix on European Ephemeroptera species was compiled merging contributions from the different project partners (**CNR**, **UGR**, **NERC**, **SLU** and **UDE**). Out of the compiled literature, more than 1,400 references were available and were thus reviewed. Finally, more than 670 papers revealed to contain useful information.
- Finalisation of the autecolocial data (**CNR**).
- Integration of the Ephemeroptera data into www.freshwaterecology.info (**BOKU**).

iv) *Plecoptera database* (**BOKU**, **UDE**, **UGR**, **SLU**)
- Design and distribution of data input table (**BOKU**, **UDE**).
- Preparation of literature database using the input of all WP7 partners (collation of more than 1,400 references) (**UDE**, **BOKU**).
- Intensive literature review and data entry (classification of species according to the different ecological parameters) for the Alps and South-Eastern Europe (**BOKU**), Central Europe (**UDE**), Northern Europe (**SLU**), Southern Europe (**UGR**).
- Compilation of the databases from the different regions (**BOKU**, **UDE**).
- Integration of the Plecoptera data into www.freshwaterecology.info (**BOKU**).

v) *Trichoptera database* (**BOKU**, **UGR**, **SLU**)
- Design and distribution of data input table (**BOKU**)
- Intensive literature review and data entry (classification of species according to the different ecological parameters) for Central Europe (**BOKU**), Northern Europe (**NERC**), Southern Europe (**UGR**); evaluation of more than 1,400 literature references.
- Compilation of the databases from Central, Northern and Southern Europe, including identification of double/differing entries (**BOKU**).
- Integration of the Trichoptera data into www.freshwaterecology.info (**BOKU**).
- Further improvement and completion by the involvement of external experts.

vi) *Chironomidae database* (**BOKU**, **MasUniv**)
- Design and distribution of data input table (**BOKU**, **MasUniv**)

- Preparation of literature database using the input of all WP7 partners (collation of more than 3,387 references) (**MasUniv**, **BOKU**).
- Agreement on the nomenclatoric approach applied in Fauna Europea (**MasUniv**, **BOKU**).
- Intensive literature review and data entry (classification of species according to the different ecological parameters) (**MasUniv**, **BOKU**).
- Integration of the Chironomidae data into www.freshwaterecology.info (**BOKU**).

vii) *Fish database* (**CNRS-UPS**)

- Compilation FAME autecological data covering 9 ecological parameters for all European species.
- Extension of the information by other data sources: 21 traits were used to describe the fish autecological characteristics. These 21 biological traits were specified as 72 trait modalities (**CNRS-UPS**).
- Integration of the fish data into www.freshwaterecology.info (**BOKU**).

viii) *Building the online database* (**BOKU**)

- Structural design of a MS Access database for the gathered autecological data.
- Design and technical realisation of www.freshwaterecology.info (mySQL database with a PHP-interface).
- Presentation of all compiled data on macroinvertebrates, fish and diatoms (including taxonomy and distribution, where available).
- Establishing of access rights for internal and external users (UDE, BOKU).
- Integration of distribution maps for benthic invertebrate taxa (BOKU, UDE).
- Implementation of a quick search function for all taxagroups.
- Inclusion of extensive help sections.
- Inclusion of a literature query.
- Continous updates whenever new data were available.

ix) *Preparation the book series "Distribution and Ecological Preferences of European Freshwater Organisms"*

- Agreement with Pensoft Publishers on the book series.
- Preparation and release of Volume 1 (Trichoptera).
- Submission and proof correction of Volume 2 (Plecoptera).
- Preparation of Volume 3 (Ephemeroptera), Volume 4 (fish) and Volume 5 (diatoms).

x) *Data evaluation*

For each organism group one to four manuscripts evaluating the database www.freshwaterecology.info were prepared. As a general approach criteria for the sensitivity of taxa for climate change effects were defined and analysed per ecoregion.

Task 5: Linking different indicator types (SLU, UDE)

The key objectives here were to link the different types of indicators for climate change impact on freshwater ecosytems developed in WP7 and indicators developed by other research teams into an indicator selection tool and to produce a website (www.climate-and-freshwater.info) to support this tool.

It was decided that the indicator selection should be a website, which includes information on current monitoring programmes and indicators suited to extend them to better reflect Climate Change impacts. During a joint WP7/WP9 meeting in 2007 it was decided to link this tool to the vulnerability analysis under WP9.

Four databases were built as background information for the indicator selection tool:
i) Indicators in current use: For selected regions and water types all indicator schemes currently being used or under development (mainly for the purpose of the Water Framework Directive) are listed and described – including the potential impact of Climate Change on the indicators in question (**UDE**, **SYKE**, **SLU**).
ii) Indicators for climate change impacts: These sites list specific indicators, which are, according to WP7 results, suited to detect the impact of Climate Change on freshwater ecosystems (**UDE**: rivers; **SLU**: lakes; still awaited **ULIV**: wetlands)
iii) Species affected by climate change: These sites contain a broad selection of species, which are (potentially) endangered by Climate Change or are benefiting from Climate Change (**UDE**, **SLU**, **UGR**, **CNR**, **CNRS-UPS**).
iv) Case studies: The contents of more than 500 papers are being presented, describing individual studies on how Climate Change is affecting individual sites, organism groups or regions.

An indicator selection tool in the form of a website (www.climate-and-freshwater.info) was developed, which combines the different types of indicators for climate change impact on freshwater ecosytems developed in WP7 and indicators developed by other research teams. It includes the above mentioned databases. Several updates of the database and website were performed to include current literature references and indicators types.

Task 6: Assessment and spatial extrapolation (UDE, BOKU, SLU, ULIV, SYKE)
The objectives of Task 7 were to produce case studies on how to include climate change indicators into existing assessment programmes and to summarise the results of WP7 in a book chapter for the Euro-limpacs book (Kernan, M. et al.: Changing climate and changing freshwaters: a European perspective. Blackwell Publishers).

Case studies on how to include climate change indicators into existing assessment programmes were completed, including the development of new indices reflecting climate change impacts on freshwater biota and a functional design in how to include these into existing assessment software. Decisions were taken on which assessment methods should be extended and on the nature of the extension. The selection of assessment formulas to be used for the extension of the assessment systems was made. The functional design for the extension of the ASTERICS assessment system was completed and new indices to be included into the ASTERICS assessment software (**UDE**, **BOKU**) were developed. The functional design for the inclusion of indices related to the indicator value database into the ASTERICS assessment software was completed. This included updates of already established indices such as current preferences, feeding types and habitat preferencestogether with some newly designed indices, e.g. on temperature preference, dispersal capacity or stream zonation preference (**UDE**, **BOKU**). **Deliverable 386** (Key indicator species of climate change impacts) and **Deliverable 276** (Indices to include Climate Change impacts into biological assessment programmes) were completed.

WORK PACKAGE 8: Reference conditions and restoration strategies

Task 1: Establishing and validating reference conditions for different ecosystem types across Europe (SLU)

Task 1.1 Establishing a reference condition database for key sites across Europe (SLU, UCL, NIVA, CNR, BOKU, WRI-RAS)

The two main objectives of task 1.1 are (i) to identify reference conditions of a number of key (data rich) sites across Europe and (ii) to establish a meta-database for selected key sites across Europe by collating information from past and ongoing monitoring programs.

CNR has focused much of their work on Lake Maggiore (Italy) as well as two other sites: Piburger See and Alserio. Both Lake Maggiore, a large and deep water body (max depth, 370 m), and Piburgersee (Austria) were selected as flagship sites in WP3. Lacustrine sediment cores, newly or previously collected, were analysed or re-analysed at high temporal resolution (sub-decadal or annual) focusing on the last 150-200 years. A meta-database of palaeolimnological data for Italian lakes was prepared, containing information on core stratigraphy and chronology, on the chemical and biological descriptor analysed and on lake water chemical data. These palaeolimnological analyses contributed to other WPs (WP3, WP4) to assess historical development of eutrophication, acidification and the impact of environmental changes on plankton communities in the lake. Sediment samples were also be used to investigate mercury and xenobiotic substances in Lake Maggiore (WP5).

Taking a different approach, **WPI-RAS** have focused their effort on determining reference conditions for metals and metalloids in different climatic regions across the European part of Russia. This work has established baseline conditions for a number of variables in a wide range of lentic ecosystems types. Reference conditions were also established for of three large lakes (Imandra, Ladoga and Onega) in the north-western part of Russia by **WPI-RAS** using retrospective analysis of analytical reviews of published studies and time-space analysis of dominant characteristics of ecosystem condition during the pre-industrial period.

CNR developed a new method for establishing reference condition of lakes using sediment pigment concentration. **Deliverable 294** "Use of sedimentary pigments to infer past phosphorus concentration in lakes", by Guilizzoni et al. demonstrated a new palaeolimnological method to infer past total phosphorus (TP) concentrations in lake water from spectrophotometrically-measured sedimentary pigments, particularly total carotenoids.

UCL using the sediment accumulation rate (SAR) database developed in WP2 defined reference conditions for various lake types (see WP2 Task 1.2). Reference SARs for different lake types were estimated and reported in **Deliverable 89**, at the 10th International Paleolimnology Symposium in Duluth, USA (June 2006) and as manuscripts (**Deliverable 226** and **Deliverable 329**). Reference conditions for toxic metals and persistent organic pollutants were also considered.

UCL developed a palaeolimnological meta-database ("LakeCores") and analysed the data to determine the timing and extent of acidification and eutrophication of lakes across Europe, and to define the period that best represents reference conditions (see **Deliverable 241**, Battarbee et al., accepted).

The contribution of SLU to Task 1 has mostly focused on clarifying the methods and terminology frequently used in defining and establishing reference conditions. This work has resulted in a number of peer-reviewed papers, book chapters and reports. Two papers, Stoddard et al. (2006) and Bishop et al. (in press) have focused on clarifying terminology commonly used in working with reference conditions, such as the use of pristine, minimally disturbed or best available. Bishop et al. (in press) addresses confusion that commonly occurs when different stakeholders try to discuss the concept of the reference condition or naturalness.

UCL produced **Deliverable 72** a report summarising how reference conditions are established for key sites: Johnson R.K. and R. Battarbee. 2006. Manuscripts have been prepared for a Journal of Paleolimnology Special Issue "Reference states and lake restoration: the role of palaeolimnology" guest edited by UCL, Bennion, H. & Battarbee, R.W. (see **Deliverable 126,** Battarbee et al., 2007). To date, eight papers have been submitted, five of which have been accepted, two are in revision and one is in review. Two further papers will be submitted shortly. It is envisaged that all accepted papers will be forwarded to the journal in spring 2009. The papers encompass **Deliverables 242, 294**, **295**, **and 329:** Rose, N.L., Morley, D., Appleby, P.G., Battarbee, R.W., Alliksaar, T. Guilizzoni, P., Jeppesen, E., Korhola, A. and Punning, J-M. 2009. Sediment accumulation rates in European lakes since AD 1850: Trends, reference conditions and exceedence. (Journal of Paleolimnology special issue). Completed manuscript accepted for publication.

In conjunction with WP3 Task 3.1, existing palaeolimnological datasets for UK lakes have been explored by UCL to determine reference conditions for lakes impacted by eutrophication (see Deliverable 72, Johnson et al., 2005) based on diatoms (see **Deliverable 242**, Bennion & Simpson, accepted) and other fossil remains in the sediment record (see Johnson et al., in review).

UCL developed a methodology for site-specific retrodiction of climate (temperature and precipitation).

Task 1.2 Error estimation and reference conditions (SLU, UCL, CNR)
Given the pivotal role that a reference value has in determining anthropogenic stress in the WFD there is an urgent need to better understand the errors associated with different methods. For example, although a number of methods are commonly used to describe reference conditions, surprisingly little is known of the inherent strengths and weaknesses of the various approaches or the potential problems associated with using different methods within or across regions. Different methods used to establish reference values may result in substantially different values of reference condition (see **Deliverable 72**

this project degradation, resulting in false negative error and also affect our ability to detect ecosystem recovery, despite potentially considerable social and economic investments. The main objective of Task 1.2 is to better our understanding of the variance or uncertainty associated with methods commonly used to establish the reference condition.

CNR has compared the use of different modelling approaches for establishing reference conditions for phosphorus in Italian lakes. This work was also used to validate a spatial (typology) approach for inferring P concentrations (**Deliverable 295**). Regarding acidification, **UCL** has recently characterised the biological reference conditions for a set of 120+ acid-sensitive lakes in the UK using palaeoecological data. Use of modern statistical data mining techniques to fit palaeoecological transfer functions were found to provide better model fits and reconstructions in circumstances where current techniques have trouble. This work "Assessing the accuracy of diatom-based transfer functions in defining reference pH conditions for acidified lakes in the UK", was published a paper in The Holocene by Battarbee et al. (2008).

SLU compared the use of spatial and model-based approaches for detecting change. Comparisons of the precision and sensitivity of two different modelling approaches using phytoplankton assemblages to detect human-induced change to nutrients, acidification and urbanization by **SLU** were undertakenThis work is being summarized in a paper (Comparison of RIVPACS community models and decision tree species-by-species models for detecting human-induced change) as part of the special issue being put together under task 3 (**Deliverable 396**).

Task 2: Use of reference conditions to establish restoration targets (SLU, UCL, Alterra, UU-BIO, UDE, NERI, BOKU, MasUniv)

1. Workpackage objectives

Reference conditions are often used either directly or indirectly to establish restoration targets. However, in areas where land use has substantially altered the landscape finding adequate numbers of contemporary reference sites can be difficult. The main objective of this task is to identify many of drivers of assemblage composition. This information is then used in WP8 Task 3 to better understand the effects that global change, in particular climate change, will have on establishing reference conditions and restoration targets.

Work here has focused on the use of different methods, such as palaeoreconstruction, analogue matching and modelling, to establish reference condition in areas where contemporary sites are poorly represented or lacking. **UCL** has continued with their work on the extension of the analogue matching approach to different sites and lake types across Europe using diatom and environmental data in the EDDI combined total phosphorus dataset. The analogue matching approach is being evaluated for a selection of key European lakes both acidified (from WP4) and enriched (WP3). The errors associated with using hindcasting methods, namely export coefficient models and diatom phosphorus transfer functions, to determine reference conditions for lakes were assessed using a dataset of UK lakes (Bennion et al., 2005). **UCL** also evaluated the use of palaeolimnological techniques to establish reference conditions for acidified lakes and the use of reference conditions as restoration targets has also been thoroughly assessed during the course of the project.

Using contemporary data, **SLU** has recently calibrated models to predict the probable taxon occurrence of phytoplankton assemblages. SLU used these models to predict the effects that global change will have on boreal lake ecosystems. **Alterra** has studied the usefulness of borrowing sites from other areas to establish reference conditions in heavily managed landscapes. **UDE** has performed comparative analyses of different taxonomic groups and their response to spatial and other environmental drivers of community structure.

This task has produced **Deliverable 291** (Paper on "Ecological relationships between stream communities and spatial scale"), **Deliverable 404** (Manuscript on "The effect of organic enrichment on the relative contribution of macroinvertebrates and fungi to litter breakdown in boreal streams"), **Deliverable 405** (Manuscript on "Habitat-specific stability and persistence of benthic invertebrate communities in boreal lakes")and **Deliverable 406** (Manuscript on "Ecological relationships between stream communities and spatial scale: implications for designing catchment level monitoring programmes").

Task 3: Evaluation of current restoration strategies and determination of the extent that climate change may influence recovery (UU-BIO, UDE, SLU, UCL, ALTERRA, NERI, NIVA, BOKU, MasUniv, WRI-RAS, UR1)

Task 3 objectives were to understand better the role of natural recovery and the efficacy of restoration efforts for lake, stream and wetland ecosystems, and to examine the role that climate change and climate variability play in current and future recovery and restoration success. Specifically, this task addressed (i) the role of ecosystem and landscape connectivity in restoring freshwater ecosystems in a climate-proof way, (ii) assessment of the success of common restoration methods under current conditions and in a world of projected climate change, and (iii) analysis of time-series data to identify effects of climate change on recovery and restoration successes.

The role of ecosystem and landscape connectivity in restoring freshwater ecosystems in a climate-proof way has been discussed in an overview paper on the 'Operational Landscape Unit' (OLU) concept by **UU-Bio** and **IVM** (An Operational Landscape Unit approach for identifying key landscape connections in wetland restoration. ***Journal of Applied Ecology*** Scientific understanding on the strength and functioning of ecosystem connections via dispersal of plants has been deepened, with results being made available to the wider scientific community through 4 publications by **UU-Bio** (see WP8 achievements) and through presentations at numerous international scientific meetings.

The success of common restoration methods under current conditions and in a world of projected climate change, and the use of time-series data to identify effects of climate change on recovery and restoration successes have been addressed in several studies carried out by **UU-Bio**, **UDE**, **SLU**, **UCL**, **Alterra**, **NERI**, **AU**, **BOKU**, **UR1** and **WRI-RAS**.

To assess restoration of streams, two measures in particular were investigated: restoration of in-stream woody debris in mountain and lowland streams and re-meandering of mountain and lowland streams (**Alterra**, **UDE** and **BOKU**).

To assess recovery of lakes following acidification, eutrophication and pollution, time series were analysed by **UCL** (palaeo data) and **SLU** (contemporary data). **UCL** applied the technique of analogue matching to nine enriched lakes across Europe using the EDDI diatom total phosphorus training set to assess the potential of the methods for identifying reference conditions for lakes subject to eutrophication (**Deliverable 34**). For acidified lakes, UCL have analysed data from the UK Acid Waters Monitoring Network and other sites to assess the response of the diatom flora to the marked reduction in sulphur deposition that has taken place in the UK since 1990 (**Deliverable 394**). Sediment core data (from 1800 to 1990 AD) and sediment trap data (from 1990 to the present day) have been combined to show a continuous trajectory for each site from the pre-acidification reference state to the point of maximum acid deposition through to the present day. Studies from Swedish boreal lakes by **SLU** have focused on whether interpretation of recovery is confounded by putative climate-induced changes in water chemistry (increased water colour). **WRI-RAS** assessed recovery of actic lakes from pollution.

Task 4: Effects of climate change on restoration targets (UCL, SLU, UU-BIO, UDE, ALTERRA, NERI, BOKU, MasUniv, NIVA, CNRS-UPS)

The objective of Task 4 was to to assess how restoration targets for different driver-response systems may need modification to accommodate the future impact of climate change. Several approaches were considered: (i) space-for-time substitution modelling*;* (ii) climate change and connectivity; (iii) modelling expected effects of climate change*;* and (iv) multivariate analyses of biology-environment data

Alterra performed collection and collation of data on restoration of lowland streams in the Netherlands (see Task 3). The effects of climate change on restoration success were explored. Attempts were made to pursue Water Authorities to cooperate in a further data collection and collation of restoration of lowland streams in the Netherlands. In 2008 a new questionnaire was produced that can be used to amongst others assess the effects of climate change on restoration success.

SLU calibrated a model (RIVPACS-type) to predict phytoplankton assemblages and then used this model to hindcast assemblages. The model was then use to forecast future changes in phytoplankton assemblages using expected changes in climate (precipitation and temperature). A manuscript was submitted: “Are reference state phytoplankton assemblages changing with climate? – hindcasting and forecasting species composition in boreal reference lakes” as part of the Task 3 special issue of Journal of Applied Ecology.

UCL focused on method development using existing data sets. Data from the EU FP5 project EMERGE was analysed using multivariate regression trees (MRT). A report outlining the work-plan and rationale for this Task was produced as **Deliverable 74**. Work on harmonising the European Diatom Database Initiative (EDDI) diatom data sets for TP and pH was undertaken. New methods for reconstructing past environments from sub-fossil species assemblages were developed. These techniques may allow more rigorous prediction of reference conditions than current techniques. Ensemble methods such as bagging and random forests and modern statistical techniques such as multivariate adaptive regression splines have been assessed initially. Further investigation and evaluation of techniques for analysis of space-time patterns were undertaken. A cross comparison of techniques between research groups in the project using a Danish phytoplankton data set was undertaken under the auspices of the Space-for-time Cross Cutting theme. Several other avenues were investigated as part of this task, such as an analysis of range expansion of dragonfly species in relation water temperature changes observed during the period of record collection. Three species - the Banded Demoiselle (*Calopteryx splendens*), the Scarce Chaser (*Libellula fulva*) and the Golden-ringed dragonfly (*Codulegaster boltonii*) – were investigated in relation to observed water temperature changes post 1990. The results were consistent with those of other published studies on dragonflies, though this work focused on riverine species whereas other studies have investigated standing waters. Additionally, **UCL** investigated several indicators for salmon survival (e.g. limits on spawning, optimal temperature for growth, and thermal barriers to upstream migration) and how these indicators have changed in frequency of occurrence over the period 1990-2006. **UCL** continued to investigate the roles of climatic variables and other drivers on the acidity of waters in lakes in Galloway, including the application of the models to new GCM scenarios. **UCL** developed techniques to predict water temperatures from air temperatures thus allowing application of down-scaled GCM scenarios for predicting future changes in water temperatures from climate change scenarios. This modelling work is currently being written-up as a manuscript for submission to Ecological Modelling

UDE published several manuscripts in River Research and Applications, Journal of Applied Ecology and Landscape Ecology 20: 755-772.

UU-BIO sought to quantify the effects of climate change on the connectivity of wetlands. The key questions addressed was *To what extent is climate change already affecting restoration success? How might climate change affect both natural and human-induced ecosystem recovery*? To meet the objective we investigated how plant species disperse through landscapes, to understand the mechanisms and quantify dispersal flows between sites. This was done by collecting experimental data on the mechanisms of transport of plant seeds by wind, water, waterfowl and humans using field data collection and lab and greenhouse measurements. Seed falling times and seed release functions were measured under various conditions in the lab and in a wind tunnel (dispersal capacity by wind), seed floating times in lab experiments (dispersal capacity by water), seed ingestion by mallards and survival of ingestion by mallards in feeding experiments (dispersal capacity by waterfowl), and seed adherence to muddy boots in field experiments (dispersal capacity by humans). Seed germination experiments were carried out in the greenhouse to test the viability of dispersed seeds and competition experiments between young plants to estimate chances of survival after transport. This work resulted in **Deliverable** 289 (Manuscript on greenhouse experiments on seed dispersal) and **Deliverable 290** (Manuscript on dispersal of plant seeds by ducks) and five other manuscripts published or in press.

WORK PACKAGE 9: Tools for catchment management and decision support

Task 1: Socio-economic pressures and global change (AERC)

Task 1.1 Relationships between future climate policies and emissions of atmospheric pollutants (IVL)

The objective of Task 1.1 was to refineme scales of SOx and NOx deposition scenarios for use in modelling activities at individual sites. This sub-task aimed to identify links between current strategies to reduce CO2 emissions and atmospheric pollutant emissions (e.g. SO2 and NOx), and the influence of CO2 emission control strategies on European emissions and estimate deposition of atmospheric pollutants. The purpose of this work was to inform the scenarios incorporated within the DSS and other modelling activities in the project.

Emissions of SOx and NOx for the A2 and B2 scenarios and a "reduced emission scenario" were prepared. This was based on application of the Integrated Model to Assess the Global Environment (IMAGE), Framework to Assess International Regimes for differentiation of future commitments (FAIR) and the GET model. Based on source-receptor matrices obtained from EMEP Meteorological Synthesizing Center-West at the Norwegian Meteorological Institute, deposition of SOx and NOx in European countries was calculated. Country-level deposition scenarios were then refined in scale to provide projected deposition rates (mgN/m^2 and mgS/m^2) for Euro-limpacs sites.

Task 1.2 Impacts of economic drivers on agricultural practices under climate change (AERC)

Task 1.2 sought to identify global pressures likely to affect land use decisions such as future climate change and socio-economic developments (e.g. developments in trade policies, economic and population growth) and to translate these into land-use changes at the catchment level.

To achieve this, information (climatic, demographic, economic etc) derived from modelling exercises based at the global level is filtered down through regional models to a national level model of England and Wales agriculture i.e. the Reading Climate and Land Use Allocation Model (CLUAM), to provide estimates of land use change down to the river catchment level. The A2 and B2 SRES scenarios were used to drive the climate change scenarios. The climate change scenarios were generated using the Hadley Centre's third generation coupled Atmosphere-Ocean Global Circulation Model (HadCM3) to produce annual climate change projections for two time slices, the mid 2020s and mid 2050s. The HadCM3 climate scenarios have been used in a suite of crop models, produced by IBSNAT/ICASA and IGER to generate changes in future yields for all global regions. These yield changes, together with socio-economic data from the two SRES scenarios, were then fed into the BLS Global Food Model developed by the International Institute for Applied Systems Analysis, Vienna. The BLS Food Model is a suite of interlinked territorially-based models forming one General Equilibrium model, used for analysing the world food trade system, in terms of (1) production volumes; (2) market prices; and (3) technology change (physical yields). The BLS Food Model was deployed to add sufficient detail to the largely qualitative SRES and global/regional yield change data to make them suitable for the UK-based CLUAM.

All the models, global, regional and national are kept internally consistent by using a suite of scenarios. The CLUAM model has been adapted for use in this project by the inclusion and delineation of four UK river catchments i.e. Conwy, Kennet, Tamar and Wye. The CLUAM is a linear programming model of agriculture in England and Wales, which seeks to maximize total economic margin using various production activities to produce a range of agricultural outputs using different inputs and resources, on different types of land. The CLUAM generated the following outputs, at the Land Class, regional and national levels and downscaled for the four catchments given above:

- Changes in livestock numbers and crop and grassland areas;
- Area of land under different land types and the area falling out of agriculture;
- Areas of land transfers (between land cover types and reflecting land improvement);
- Change in the use of inputs, including fertilizer and chemical use per hectare and in aggregate.

These results are presented in **Deliverable 133**.

Task 1.3 Contingent valuation of the impacts of climate change, land management and atmospheric deposition on lakes, rivers and marginal wetlands (AERC)
The objective of Task 1.3 was to evaluate the contingent valuation of impacts of climate change for the Lake Cheimaditida catchment and feed into the development of DSS.

A choice experiment and a contingent valuation survey were carried out in Lake Cheimaditida in order to estimate the economic value of the benefits this lake generates (e.g., biodiversity, water quality, quantity, agricultural employment provided) and how its economic value changes 1) when levels of its ecological functions change with changing local and global conditions (e.g., land use change, climate change) 2) across different stakeholders of the public (e.g., those located in urban and rural areas). The choice experiment methodology was used to estimate the economic value of changes in ecological, social and economic functions of the Cheimaditida wetland. Pair-wise comparisons of alternative wetland management scenarios and the costs necessary to implement those management options were presented to a number of stakeholders to elicit preferences. By integrating the choices of many stakeholders an average stakeholder valuation can be calculated for each different management options. These surveys resulted have been published in Birol et al. (2005) *Water Science and Technology: Water Supply Journal*, Birol et al. (2008) *Science of The Total Environment* and Birol et al. (2006) *Ecological Economics.*

Task 2: Analysis of policies influencing catchment management (NERI)

Task 2.1 European level analysis (NERI, ULIV)
This task sought to provide European level policy reports for inclusion in the DSS

The main output from this task has been a report on European Policies and International agreements affecting Catchment Management (**Deliverable 36**). This report examined agreements, which have affected and could be expected to affect, the implementation of catchment management practices. The review concentrates at the European level. The overarching piece of legislation in this area is the European Water Framework Directive (WFD), which is the focus of this report. The WFD has several characteristics, which breaks with traditional Water Policies in Europe, and at the same time it forms part of a general development in environmental regulation. The report examines this overarching development of policy into which the WFD sits. Some of the key attributes of the WFD were found to be. The report outlines the main European and international policies according to their framework and their relation to catchment management.

Task 2.2 Member state level analysis (NERI, ULIV)
Task 2.2 aimed to produce member state reports on catchment management

A template for member state policy analyses was developed and agreed between all the project partners involved in this activity; this was used for all countries so that the format was consistent and in an appropriate format for inclusion within the DSS. The policy analyses identify and describe the transposition of EU policies into national legislation and, if relevant, specifically national legislation relevant for catchment management. The members state level policy analysis also includes descriptions of policy measures considered or implemented in the member states and reports their effects, either measured ex post or analysed ex ante. When available the descriptions also include information about cost effectiveness of measures. The policy considerations of greatest relevance to the DSS received particular attention as these reflect the issues that have been identified by the Euro-limpacs project as being the key drivers of change on freshwater systems in the DSS case study catchments.

Separate reports have been prepared for Denmark (**NERI**), Norway (**NERI**), Germany (**Entera**), Netherlands (**Entera**), UK (**UCL**) and Greece (**EKBY**) and have been compiled as a single written output (**Deliverable 299**) as well as being integrated within the DSS.

Task 2.3 Policy considerations for the DSS (NERI, ULIV)
The objective of Task 2.3 was the identification of policy considerations for the DSS and integration within the DSS.

Important catchment management problems were identified through other work being carried out as part of the workpackage (Entera). These were prioritised and issue summaries were produced of relevant policies and catchment management measures as input to the DSS and member state level policy analyses. The format of these summaries was agreed and set out in a template to ensure it was suitable for inclusion in the DSS. For each issue, the summary lists all relevant legislation at the EU level and at member state level. For each policy, the policy objectives are identified and where possible, quantified targets are listed. These targets could be converted into systematic and comparable scores in the generation of value functions in the DSS. Hence, the summaries provide guidance to users of the DSS in setting values of decision criteria and in defining realistic scenarios. The summaries also provide examples of policy measures, drawing on case studies from all member states. The summaries describe measures as well as their effect and any other lessons drawn through evaluations. They consist of text files to be included in the DSS in order to guide users of the DSS to select reasonable scenarios of management options.

Task 3: Stakeholder engagement (ENTERA)

Task 3.1 Production of guidelines for stakeholder engagement and management of engagement process (ENTERA)
Task 3.1 aimed to produce guidelines for those applying the DSS on stakeholder engagement and management of the engagement process.

The first output from this work was the production of report providing guidelines and an outline methodology for involving stakeholders and end-users in the DSS development and application (**Deliverable 37**). This included a questionnaire for project partners to elicit feedback on the role of climate change issues in the implementation of the WFD, particular problems faced by decision makers, models and tools currently used by decision makers and requirements for a DSS. The results from each of the DSS case study catchments were complied and analysed (**Deliverable 132**).

Task 3.2 Engagement at European level (ULIV, UNIBUC-ECO, NIVA, NERI, ENTERA, UU-BIO, IVM, EKBY, UB)
The main aim of Task 3.2 was to engage policy makers at a European level

A European DSS end user meeting was organised as a workshop integrated into a conference of the FP5 project Harmoni-CA (Osnabrueck April 5-7.2006). A summary of the discussion and key points emerging is presented in the report on first European DSS end user meeting (**Deliverable No. 131**).

Task 3.3 Engagement at catchment level (ULIV, UNIBUC-ECO, NIVA, NERI, ENTERA, UU-BIO, IVM, EKBY, UB)
The purpose of Task 3.3 was to engage users at a catchment level with the development and implementation of the DSS

Methodology and results
Within each of the DSS case study catchments, project partners applying the DSS have engaged potential-end users of the DSS through meetings, questionnaires and workshops. These have followed the common guidelines set out by **Entera** (**Deliverable 37**). Each of the applications has, however, concentrated on different aspects of the DSS application. For instance, some have concentrated on socio-economic modelling (e.g. the effects of landuse change and management responses to climate change in the Tamar application), while others have focussed on water quality modelling (e.g. Bjerkreim application). The Dinkel and Tordera case studies have focussed on the engagement of stakeholders and the relevance of the DSS applications to different stakeholder groups.

Within the Dinkel, **IVM** have developed a stakeholder workshop methodology to apply the DSS and other novel tools to a specific problem within the catchment where there is a conflict between three different sets of stakeholders (water managers, farmers and nature conservationists). The methodology is based around developing three extreme scenarios that optimise the management of water for each of the three different stakeholder groups. These three extreme scenarios are then presented to the stakeholder groups and, using novel mapping and socio-economic tools, the stakeholders added their own ideas and preferences to the maps and assessed the management alternatives using a semi-quantitative MCA. The novel tools (touch table and web mapping application) have been developed further by **IVM** through workshops and a full description is presented in **Deliverables 414** and **415**.

As part of an integrated assessment of nutrient fluxes in *La Tordera* catchment **UB** have developed socio-economic scenarios for La Tordera through a participatory process involving representatives of key stakeholder groups. The results have been published in Caille *et al.* (2007) and the stakeholders have been involved in translating their narrative socio-economic scenarios into quantitative scenarios that can be used with a catchment model (MONERIS) to explore the impact of each scenario on nitrogen and phosphorus fluxes. These quantitative modelling results have been integrated within the DSS application.

Task 4: Development of the DSS (ULIV)

Task 4.1 Development of a GIS based planning tool (ULIV, AERC, EKBY, UU-BIO, IVM)
The key objective of Task 4.1 was to develop a GIS based decision support system for use at the catchment scale that allows assessment of catchment management strategies under climate change.

A Decision Support System (DSS) was developed that acts as a framework for integrating data from diverse sources including environmental, social and economic data into a decision support framework based around Multi-criteria Analysis (MCA). The structure of the DSS is flexible and generic so that it can be applied to any catchment in Europe and can incorporate already existing data into the analysis. The approach of the DSS is 'broad but shallow', integrating a wide range of environmental, social and economic variables but not requiring users to apply complex models to all of these variables as a prerequisite for application. However, outputs from models that users already apply within their own catchments, or existing monitoring data, can be incorporated into the analysis for increased accuracy. The DSS is intended to assess specific catchment management problems but to place them in the context of the wider range of social, environmental and economic factors that are affected by, and affect, that specific problem.

The purpose of the DSS is to provide catchment managers and stakeholders involved in the catchment management process with tools for assessing the likely changes to the status of freshwater ecosystems under different catchment management strategies, in the context of climate change. The DSS is based on a GIS platform (ArcGIS) so that it allows users to compare alternative catchment management strategies using a spatially explicit MCA. This allows users to spatially target management interventions by identifying key geographical areas within catchments where action is needed or where management interventions will be most effective. The flexibility offered by integrating the DSS within a GIS environment also allows users to incorporate outputs from the DSS with other GIS data that may already be used for catchment management. Typical problems that the DSS is designed to address are, for example, to identify the areas of a catchment where resources should be targeted or to identify which measures most effectively tackle particular catchment management problems.

Task 4.2 Development of socio-economic valuation tools and integration into the DSS (UU-BIO, IVM)
The main aim of Task 4.2 was to develop socio-economic tools to facilitate stakeholders to evaluate alternative management strategies.

IVM and **UU-BIO** have developed novel socio-economic tools to aid decisions making that expand the current range of tools available to catchment managers. These comprise:

- a web mapping application to communicate digital maps and proposed management plans to stakeholders (**Deliverable 298**);
- an interactive approach to generate management plans based on digital maps within a stakeholder workshop using a 'touch table' mapping tool, with integrated socio-economic tools.

These tools have been tested with stakeholders and end-users in a workshop within the Dinkel catchment (**Deliverables 414** and **415**) and have provided inputs to the DSS case study for the Dinkel. Consultation with the stakeholders following the workshop enabled refinement and improvement of these tools.

IVM have also supported the integration of socio-economic tools into the DSS through the production of specifications for MCA tools.

Task 4.3 Application and testing of tools in study catchments (ULIV, UNIBUC-ECO, NIVA, NERI, UIBK, UU-BIO, IVM, EKBY, UB)
Task 4.3 overwas the application of the DSS at a number of case-study catchments.

In order to test the DSS developed as part of the Euro-limpacs project it has been applied in a number of catchments around Europe. These catchments are:

- Tamar, UK (ULIV – **Deliverable 408**)
- Neajlov, Romania (**UNIBUC-ECO – Deliverable 410**)
- Bjerkreim, Norway (**NIVA – Deliverable 411**)
- Dinkel, Netherlands (**IVM/UU- BIO – Deliverable 414**)
- Cheimaditida, Greece (**EKBY – Deliverable 413**)
- Tordera, Spain (**UB – Deliverable 419**)

The catchments have a range of management problems, which has allowed the DSS to be tested in different contexts. The catchment management problems examined include diffuse pollution, flooding, acidification, hydromorphology, floodplain connectivity, drought and point source pollution. The case-study applications have taken a range of approaches with some concentrating on the stakeholder engagement aspects of the applications, generating semi-quantitative inputs for the DSS based on information elicited from stakeholders in workshops (e.g. Dinkel application). Others have focused on generating quantitative inputs to the DSS based on modelling of hydrological, water quality, ecological and economic variables (e.g. Bjerkreim, Tamar), using expert judgement to define the parameters of the MCA. The applications of the DSS have also been used to integrate the outputs from across the Euro-limpacs project in the case-study catchments, particularly modelling outputs from workpackage 6. The Figures below illustrate the types of results generated from the applications of the DSS for the Bjerkreim catchment (upper figure) and the Tamar catchment (lower figure).

WORK PACKAGE 10: Dissemination and training

Task 1: Project reporting (UCL with all participants)
UCL collated, compiled and delivered annual reports to the Commission (Years 1- 5) and interim reports (Months 6 and 18) including preparation of reporting templates, processing of Project deliverables and providing a summary of reporting activities (with links to the reports) on the Project Web site. All project activities relating to exploitation, dissemination and use of results are included together with contacts with potential end users and all publications and conference presentations resulting from the work undertaken during the reporting periodic have been collated. The Euro-limpacs End-User Strategy was produced **(Deliverable 136)** by the co-ordinator and this was followed towards the end of the Project by a Report on end user / stakeholder engagement across the Project (**Deliverable 305**). **UCL** also collated updated, detailed 'Implementation Plans for the 18 month period following each annual report.

UCL arranged (with the EU Project manager), organised and participated in four annual review meetings (in Brussels (twice), London and Leipzig) and delivered a consolidated response to the external reviewers and the Commission following recommendations.

An internal mid-term review of the Project was undertaken (**Deliverable 300**). The review had three components: i) a review of Partner performance including contribution to WP objectives, deliverables etc.; ii) a review of each WP to assess whether the integration between WPs / cross cutting themes / other Projects specified in the original proposal has been achieved as planned; and iii) a review of Project Management An Executive Committee meeting was held in December to discuss the outcome and decide on any actions that need to be taken. A summary of this was posted on the Project Output section of the Project Web site at
http://www.eurolimpacs.ucl.ac.uk/userarea/output/reporting/midterm_review.php?menu=output.

A Targeted Third Countries proposal was submitted to the EC to extend the Euro-limpacs project to include four new partners, two from China one from Uruguay and one from Argentina to expand the geographical scope and lengthen the environmental gradients being studies in WP3 and WP8. This proposal, submitted with help from NERI, was not successful.

A proposal for a Marie Curie Initial training Network (ITN) was submitted under The Seventh Framework Programme for research and technological development under the call FP7-PEOPLE-2007-1-1-ITN (**Deliverable 138**). This involved a number of Euro-limpacs partners (including the co-ordinator, **UCL**) as well as participants from outside the consortium. The primary objective of the proposal "BIO-INFORM" (Informing Biodiversity Management with Long-Term and Multi-scale Environmental Data) was to educate a new generation of scientists uniquely qualified to fill a number of key gaps in scientific knowledge that constrain decision making in terms of comprehensively appraising the current state of ecosystems. This was not successful.

UCL submitted a proposal for a Euro-limpacs Information System as part of the WATAPT Framework 7 proposal (**Deliverable 202**). This proposal was not successful.

UCL submitted a co-ordination action under Framework 7 for a Freshwater Information System (FRISYS), bringing together output from all previous EU projects on aquatic ecosystems, underpinned by Euro-limpacs (**Deliverable 416**). This proposal was not successful

Contributed to a proposal for a web-based Information System to be included in the IMPEATUSS SSA led by **ULIV (Deliverable 146).** This proposal was not successful.

Monthly newsletters were circulated to all Project participants.

Task 2: Project web-site and bibliography (UCL, UDE)
The original Euro-limpacs web-site, fully operational since the start of the project in February 2004, was divided into two main parts, one accessible to the public and a private partner area (intranet) which was only accessible to authorised users (**Deliverable 2**). On the public side there was a summary of the project with information on participating institutions, the work programme, some scientific background to the project and funding sources.

As the project developed it was decided that the public area of the web-site should be redesigned using a user-friendly contents management system (details given in **Deliverable 205**). During Year 3 the public part of the web-site was expanded to provide a more detailed picture of the science being undertaken in Euro-limpacs, the key questions, the methods being used and the sites where these are being applied. A glossary of scientific terms relevant to climate change impacts on freshwaters was also added (**Deliverable 304**).

The site (http://www.eurolimpacs.ucl.ac.uk/) is easy to navigate and now holds a large amount of information that can be easily accessed by project participants, end-users and members of the general public. The revamped public part of the web-site was launched in March 2007. A menu option headed ‘Intranet’ allows Euro-limpacs partners to move between the public part of the website and the project intranet.

Project output has been organised within the ‘Results’ section of the web-site. Key Questions arising from project activities have been identified (also listed in a flier available from the Document Store on the Euro-limpacs website at http://www.eurolimpacs.ucl.ac.uk/oldsite/docstore/eurolimpacs_50q.pdf) where results are discussed and links made to relevant project deliverables and publications. The project bibliography is also accessible from the ‘Results’ section of the web-site and this is updated from the bibliography database held within the intranet. The bibliography database contains publications that are in press, in review or have been published since the start of the project. DOI links are provided where possible to facilitate quick access to journal articles. **UCL** compiled and has continually updated the Project bibliography.

Project database links were added making it possible to browse, edit and query a project bibliography, site data, site metadata (WP6), meetings diary, document store, meeting minutes, contact details for all partners and web stats.

Publicity materials developed in the first year of the Project **(Deliverables 1 and 2)** were updated regularly (**Deliverable 142**) to reflect progress being made in the work programme. Numerous generic Powerpoint presentations were developed and given to national and international audiences. Some material expanded beyond generic Project designs to include work package specific material (e.g. a WP4 poster was presented at the Acid Rain 2005 conference in Prague) and output targeting more specialised interests (e.g. a flier describing Euro-limpacs activities in mountain areas was distributed at the Global Change in Mountain Regions conference in Scotland). The publicity materials were uploaded onto the Project Web site for use by partners whenever required. In this way a 'library' of materials was available to meet the specific dissemination needs of the Project.

UCL reached an agreement with Blackwell publishers to publish a Euro-limpacs book entitled 'Climate Change Impacts on Freshwater Ecosystems: direct effects and interactions with other stresses' (**Deliverables 203 and 204**). **UCL** and **ULIV** are acting as editors for the book. Full drafts of all chapters have been received **(Deliverable 418)** and reviewed by members of the consortium. The reviews were passed back to the chapter authors along with editorial advice. Revised chapters are now being returned and it is anticipated that final chapters will be with the publishers by April 2009 (**Deliverable 419**).

UCL led a Euro-limpacs chapter in the Wiley book 'The Water Framework Directive - Ecological and Chemical Status Monitoring', published in 2008 (**Deliverable 144**). This replaced the original Deliverable 144 which was to be 'Submission of articles to Commission for use in RTD series' as it was felt that the book would have a greater circulation. The chapter is entitled 'Freshwater ecosystem responses to climate change: the Euro-limpacs project.' By Battarbee et al. Details can be found in the Bibliography at (http://www.eurolimpacs.ucl.ac.uk/cms/component/option,com_content/task,view/Itemid,46/id,176/view,inbook/refid,29).

UCL produced a Euro-limpacs position paper (i.e. the output from the integration workshops held in Leipzig) (**Deliverable 301**). This paper aims to summarise current understanding of the impact of climate change on freshwater ecosystems in Europe based principally on the outputs of Euro-limpacs. It also draws upon the results of related international and national projects. It describes the key changes to the climate system that are expected to occur in Europe over the next 100 years.

UDE prepared a web-based meta-database under WP7, Task 1; link to the project website. The database built under WP7, Task 1 will be used to store future publications resulting from Euro-Limpacs. A close link between this database and the project bibliography will be built.

Within WP7 Task 5 a website on the effects of climate change on freshwater ecosystems was produced by **UCL** and launched under the name: www.climate-and-freshwater.info The web site http://www.eurolimpacs.ucl.ac.uk/userarea/database/wp7.1/search.php is been updated.

Task 3: Meetings and conferences (UCL with all participants)

Project meetings

1st Project Meeting (Project Start-Up meeting): Innsbruck, 7th-12th March 2004. **UIBK** and **UCL** organised the start up Project meeting in Innsbruck.Workshops were organised for each work package, chaired by the work package leader. The leaders and co-leaders were tasked with using these to finalise detailed work programmes for the first 18 months and allocate responsibilities for activities throughout this period across the work-package. Details of the meeting can be found at http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/output/meetings/innsbruck.php

2nd Project Meeting: Athens, 5th-12th September 2005. **UCL** organised the second Project meeting including logistics (liaising with local partner **EKBY**), structure and agenda in Athens. The meeting primarily focused on presentation of scientific progress and discussion. Details of the meeting can be found at http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/output/meetings/athens.php

3rd Project Meeting: Leipzig, 16th-20th April 2007. **UFZ** and **UCL** organised the third Project meeting in Leipzig. It provided an opportunity to get a clear picture of the achievements during the first three years as well as highlighting what remained to be done to ensure all Project objectives were met. A meeting report can be found at http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/output/meetings/leipzig.php.

4th (Final) Project Meeting: Blanes, 13th -17th October 2008. The fourth and final Euro-limpacs Project meeting was held with just over three months of the Project remaining (organised by **CSIC** and **UCL**) and focused on dissemination of results obtained across the Project. Details of the meeting are located at http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/output/meetings/blanes.php.

Executive Committee Meetings

Executive Committee Meetings were held regularly throughout the duration of the project. These are listed below, together with links to minutes from the meetings.

London, 12th February 2004
http://www.eurolimpacs.ucl.ac.uk/oldsite/docstore/ExC%20Meeting_24Feb04_Minutes.doc

Silkeborg, 14th January 2005
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=28

Santiago de Compostela, 24th June 2005
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=29

Athens, 5th September 2005
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=30

London, 20th January 2006
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=32

Liverpool, 19th July 2007
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=35

Brussels, 4th April 2008
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=36

Blanes, 13th October 2008
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=37

Steering Group Meetings

Steering Group meetings were held at key stages during the project. These are listed below with links to meeting minutes.

Innsbruck 7th and 12th March 2004
http://www.eurolimpacs.ucl.ac.uk/oldsite/docstore/SG_Meeting_07Mar04_Minutes.doc
http://www.eurolimpacs.ucl.ac.uk/oldsite/docstore/SG_Meeting_12Mar04_Minutes.doc

Essen 30th June 2004
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=25

Silkeborg, 13th January 2005
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=27

Athens, 6th September 2005
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=31

London, 23rd March 2006
http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/minutes.php?view=TRUE&itemid=34

Other internal project meetings

- Work Packages 4 & 6 joint meeting, Abingdon, UK, September 2004
- Work Package 5 meeting, Barcelona, Spain, November 2004
- Work Packages 2, 7, & 8 joint meeting, Wageningen. The Netherlands, November 2004,
- Work Packages 4 & 6 workshop, Alicante, Spain, March 2005
- Work Package 9 meeting, Barcelona, Spain, March 2005
- Work Package 3 workshop, Silkeborg, Denmark, April 2005
- Work Package 6 mini workshop, Oslo, Norway, May 2005
- Work Packages 6 & 9 workshop, Reading, UK, May 2005

- Work Package 4 workshop, Bergen, Norway, October 2006
- Work Packages 2, 7 & 8 Meeting, Silkeborg, Denmark, April 2006
- Work Package 6 workshop, Reading, UK, April 2006
- Work Package 9 workshop, Osnabrueck, Germany, April 2006
- Work Package 5 workshop, Gothenburg, Sweden, April 2006
- Work Package 9 DSS workshop, University of Liverpool, UK, October 2007
- Work Package1 meeting, Pallanza, Italy, November 2007
- Work Package5 workshop, Warsaw, Ploand, 26-29 May 2008
- Work Package2 synthesis meeting, Uppsala, Sweden, 25-27 August 2008
- Work Package 6 workshop, 16 October 2008

- Deep Lakes meeting, Pallanza, Italy, November 2004, cross-cutting theme
- Deep Lakes workshop, L. Hornindalsvatn, Norway, June 2005, cross-cutting theme
- Deep Lakes meeting, Edinburgh, UK, May 2006, cross-cutting theme
- INCA/mercury workshop, University College London, UK, September 2007, Organised by AERC and UCL

External Meetings

A 3-day training course entitled 'Bio-indication and bio-assessment in rivers under the constraints of the Water Framework Directive and Climate Change' was held by **UDE** in Essen, Germany in June 2005. The training course was aimed at German water managers and stakeholders. Participants included 22 members of regional and national water boards and consultancies from all over Germany. Topics covered included: the theoretical background of macroinvertebrate sampling in streams and rivers; sorting methods; necessities and demands for species-based identification; assessment software; practical training in sampling and sorting; interpretation and analysis of assessment. The training course was successful and there were requests from the participants to hold the course again in other regions of Germany.

UCL organised a special session at the ASLO 2005 summer meeting in Santiago de Compostela, Spain (entitled "The interaction between global change and other key drivers of change – effects on European freshwater ecosystems") at which a number of Euro-limpacs presentations were given. A similar session was organised at the ASLO 2006 Summer Meeting in Victoria, Canada entitled "Integrated approaches to assessing the effects of global change and other drivers of change on freshwater ecosystems" at which a number or presentations highlighted work being undertaken across the Project. **UCL** also organised a special session at the SIL 2007 Meeting in Montreal on "Assessing water quality and ecological status: - issues of scale, the role of monitoring and establishing reference conditions in a changing climate" – at which a number or presentations highlighted work being undertaken in WP8 were presented

CNR organised a SE_RHS Course (Ivrea, Italy, 5-8 July 2005) to teach how the expanded version of the RHS should be applied.

SYKE organised an expert workshop in Helsinki, Finland 28th-30th September 2005 to aid the development of the INCA-P model. The workshop included presentation of the status quo of INCA-P, other phosphorus modelling approaches and a series of presentations of processes affecting P transport and transformations in soils, on field scale and in catchments. A considerably revised structure of INCA-P model was created as a product of the workshop and later commented on by participants. The workshop had 21 participants from 8 institutions representing 5 countries, both within and outside of Eurolimpacs.

A Euro-limpacs session at International Scientific Conference on Environment and Climate Change Influence on Freshwater Ecosystems (Moscow, October 2005) was organised by **UCL** and **WPI-RAS.**

UCL participated in the conference "Communicating European Research" CER2005, Brussels 14-15 November 2005. A stall was manned for the duration of the conference and several contacts with related projects were established.

UCL attended the CLIME Project closure meeting to strengthen links between this and Euro-limpacs and to discuss how CLIME output might feed into the Euro-limpacs work programme. **UCL** and **ENTERA** established a collaborative link with the Harmoni-CA project Contract N. EVK1-2001-00192. A presentation and poster were given at the Harmoni-CA Conference in Osnabrueck 4-7 April 2006. A link was established with the IWRM-Net Project. **UCL** participated in the Project's workshop on 11th January 2007.

UCL provided an invited keynote speaker and discussant at the Climate and Water meeting held by the Commission in Sept 2006. Rick Battarbee from UCL was invited to become a member of the EEA Advisory Committee on Climate Change, and attended a two-day meeting on Indicators of Climate Change in Copenhagen in January 2007. In addition, he was invited to become a member of the Royal Society advisory committee on Climate Change.

UCL organised and chaired the Euro-limpacs UK end user meeting "Climate Change and Aquatic Ecosystems in Britain: Science Policy and Management" held at UCL in May 2007. This was co-sponsored by the UK Environment Agency, The Freshwater Biology Association and the EC. The purpose of the meeting was to (i) Review progress in modelling climate change and freshwater ecosystems in the UK; (ii) Present the interim results of current UK and EU-funded research on climate change, especially from the EU-Euro-limpacs, EU_CLIME and EU-PRINCE projects; (iii) Discuss the implications for the implementation in the UK of current EU policies on water quality and aquatic biodiversity (principally the Water Framework Directive and the Habitats Directive) and (iv) to identify gaps in our understanding and assess priorities for future research. Presentations were given by scientists summarising work to date on climate change projections, impacts and modelling and management strategies. Additionally, representatives from key conservation and regulatory agencies as well as the water industry, highlighted key issues and concerns in the UK from an ecological and policy perspective. The proceedings from this meeting have been published and can be viewed at

http://www.ecrc.ucl.ac.uk/component/option,com_docman/task,doc_download/gid,504/Itemid,59/.

UCL attended a workshop in Copenhagen (October 2007) and advised the EEA on climate change, freshwater quality and biodiversity for forthcoming EEA report on Indicators of Climate Change.

UCL also represented Euro-limpacs at the "FUTURE CLIMATE, IMPACTS & RESPONSES" Symposium on IPCC and EC research on 19th and 20th November 2007 and the EEA / EIONET workshop on climate change vulnerability, impacts and adaptation, 27-28 November 2007 in Copenhagen and provided a presentation summarising Euro-limpacs objectives and activities.
Submitted a proposal for the participation of the Euro-limpacs Project to the Conference "Communicating European Research" CER2005, Brussels 14-15 November 2005.

Task 4: Key methodological approaches (UCL, NERI, AERC, CNRS-UPS)

1st Time Series Analysis Workshop (UCL, London), 8-10 July 2004
A panel of external speakers gave presentations on the kinds of data analysis that can be applied to environmental time-series and were on hand to provide expert knowledge and advice during the workshop. A report from this workshop is provided in **Deliverable 6.**

2nd Time Series Analysis Workshop (UCL, London), 5-7 November 2007
The aim of the workshop was to introduce and review a variety of statistical techniques that could be of use to Euro-limpacs investigators in the analysis of their data. For the most part, the focus was on techniques for which user-friendly implementations are freely available in the R programming environment. A report from this workshop is provided in **Deliverable 207.**

1st Palaeolimnology and Decadal Trends Workshop (UCL, London), 23-25 May 2005
This workshop was hosted by **UCL** and attended by numerous partners (**UCL, CNR, NERI, UICE, ULIV, NIVA)** to review progress in all palaeolimnological tasks across the project, discuss how palaeolimnology can be used to assess reference conditions for lakes and how palaeolimnology can contribute to an understanding of climate impacts on lakes. A report from this workshop is provided in **Deliverable 137.**

2nd Palaeolimnology and Decadal Trends Workshop (UCL, London) 7-9 November 2007
This workshop addressed the key question "to what extent and how can we identify the influence of climate in our data-sets on inter-annual to decadal time-scales?" The workshop aimed to review progress on this theme and plan the publication of two special

issues, one on "decadal-scale trends", and the second on "reference conditions". Details are given in **Deliverable 206.**

1st Space For Times Substitution (SFTS) Workshop (CNRS-UPS, Toulouse) 16-17 September 2004

The first meeting was in Toulouse in September 2004. It covered the context and potential applications of space-for -time substitution techniques. Participants presented their existing datasets (including national and pan-European fish, phytoplankton, diatom and cladocera datasets) and highlighted the key questions to be addressed using the space-for-time substitution approach. Several different techniques were introduced and different methods were discussed.

2nd Space For Times Substitution (SFTS) Workshop (CNRS-UPS, Toulouse) 29-30 September 2005

The second workshop focused on a single Swedish-Danish dataset and during the meeting the data were discussed, arranged and preliminary analysed. During the second and the third meeting, the database dealing with several Sweden lakes and macrophyte data had been checked carefully by the person responsible of these data. Once the data available, the analyses had started. The analyses have been divided between them according to their possibilities.

3rd Space For Times Substitution (SFTS) Workshop (Leipzig) 18 April 2007

The third and last meeting was in Leipzig during the Eurolimpacs annual meeting (May 2007). The SFST had to conclude during the meeting that the data available were not enough adapted to the subject for good results.

Task 5: Project database (UCL, UDE)

Since the start of the project, basic site data has been collated for wetland, lake, river and terrestrial sites. These data are stored in a database and may be edited and queried on the Euro-limpacs web-site. So far there are site data for 113 sites, an example is shown in **Deliverable 38**. For each site there is a list of associated work package sub-tasks. Detailed metadata forms have been prepared for WP6 and examples are shown in **Deliverable 38**. The data can be subsequently edited by the originator and viewed by all partners. Metadata entry for other work packages is under discussion. Two other meta-databases have been assembled as part of work in WP7; **Deliverable 30** (Meta-database on Indicators for Climate Change impacts on freshwater ecosystems) and **Deliverable 31** (Macro-invertebrate Taxa and Autecology Database). The former are fully integrated into the Euro-limpacs web-site. The latter meta-database is hosted externally and is accessible from the Euro-limpacs web-site. A palaeoecological meta-database 'LAKECORES' has also been developed bringing together information about lake sediment cores. Over the last three years of Euro-limpacs an attempt has been made to identify all published information about lake sediment cores that have been used to reconstruct the recent ecological history of lakes in Europe. **BOKU** prepared and maintained a web-based database under WP 7, Task 4 (www.freshwaterecology.info) with a link form and to the project's website. It was decided not to develop a Project meta-database encompassing the entire scope of Euro-limpacs activities. This would have been a severe drain on resources given wide ranging scope of research undertaken and the disparate nature of data employed. More resources were subsequently devoted to ensuring that the Public part of the Project Web site provided easily navigable access to Project output and therefore, to information about sources and types of data used.

UDE generated the website www.climate-and-freshwater.info. **BOKU** developed and mainatined the web-based database under WP7, Task 4 (www.freshwaterecology.info) with a link form and to the project's website and compiled literature for different WPs (WP2 task 2, WP7 task 4). **UDE** also contributed to the database and website www.freshwaterecology.info

Task 6: Training

Task 6.1 Internal training
Two Time Series Analysis Workshops and two Palaeolimnology and Decadal Trends Workshops have been hosted by **UCL** during the Project. Three Space-for-Time Workshops organised by **CNRS-UPS** have been held Details are given under Task 4.

Task 6.2 Specialist external workshops
Alterra and **CNRS-UPS** organised a WP2 summer school in Moulis (France), 24th to 28th October 2005. Courses and training subjects were: Habitat preference analysis (Karel Brabec), ANN modelling (Sovan Lek & Muriel Gevrey), the use of tracer analyses (Francesc Sabater), RHS Habitat surveys (David Armanini), Diatoms; methods and autecology in current and paleo studies (Anna Besse).

UCL produced **Deliverable 7:** Report highlighting outcomes of first specialist workshop on "ecological indictors" identifying methodologies and data sets to be used (WP 10 T 6.2)

Over the course of Year 3 there were 6 training workshops on ecological indicators and stream assessment held in Germany, Hungary, Romania and Slovakia involving a total of 74 participants arranged and run by **UDE**.

Task 6.3 Postgraduate and post-doctoral training
Opportunities to involve postgraduates in the Project have been actively encouraged, with 20 partners being involved with postgraduate or postdoctoral research that feeds directly into Euro-limpacs. These are detailed in Table 3.

A short course compendium (**Deliverable 141**) was prepared by **UCL**. The availability of training for project end-users was investigated by compiling information on short courses that cover a range of Euro-limpacs research activities. This short course compendium provides information on courses of up to a month's duration that are provided by European institutes, both internal and external to the project.

Table 3: Postgraduate and post-doctoral training undertaken during the Project

Type	Name	Partner	Work Package
PhD	Rebecca Moran	ULIV	WP3
Post-doc	Heidrun Feuchtmayr	ULIV	WP3
PhD	Anne Merete Sjøeng	NIVA	WP4
PhD	Jiri Kana	HBI-BCASCR	WP4
Master	Marie Maresova	HBI-BCASCR	WP1
PhD	Jan Turek	HBI-BCASCR	
Master	Michael Jobst	BOKU	WP2
Master	Stefan Donner	BOKU	WP2
PhD	Patrick Leitner	BOKU	WP2
PhD	Xuhui Dong	UCL	WP3
PhD	Patrik Bexell	UCL	WP2
Post-doc	Gavin Simpson	UCL	WP1, 4, 8, 10
Master	Iva Martincova	MasUniv	WP7
Master	Jana Dvorakova	MasUniv	WP2
Master	Katerina Heczkova	MasUniv	WP2
Master	Stepanka Dvorakova	MasUniv	WP2
PhD	Vit Syrovatka	MasUniv	WP2, WP7
PhD	Karla Petrivalska	MasUniv	WP2
Master	Ben Warren	NERC	WP2
PhD	Claire Ferguson	NERC	WP3
Post-doc	Sonja Jähnig	UDE	WP2
Post-doc	Jochem Kail	UDE	WP8
Post-doc	Alexandra Haidekker	UDE	WP7
Post-doc	Peter Rolauffs	UDE	WP7
PhD	Jörg Strackbein	UDE	WP7
Post-doc	Armin Lorenz	UDE	WP7
Master	D.Wittrin,	UDE	WP7
Master	Tuszewski, A.	UDE	WP7
Master	Sager, K.	UDE	WP7
Master	Farrenschohn, D.	UDE	WP7
Post-doc	Merel Soons	UU-BIO	WP8
Master	Irma Bakkers	UU-BIO	WP3
Master	Arjen de Groot	UU-BIO	WP8
Master	Joost Keuskamp	UU-BIO	WP1, WP3
Master	Daan Blok	UU-BIO	WP3
Master	Heleen Bos	UU-BIO	WP3
Master	Daan Asscheman	UU-BIO	WP3
Master	Lotte Huibers	UU-BIO	WP3
Master	Bob Brederveld	UU-BIO	WP8
Master	Jose Maria Martinez	UU-BIO	WP3
Master	Marcus van Loon	UU-BIO	WP3
Master	Kees van der Vlugt	UU-BIO	WP8
PhD	Thora Hrafnsdottir	UICE	WP3
Master	Rakel Julia Bergsteinsdottir	UICE	WP3
Master	Erlin E. Johannsdottir	UICE	WP3
PhD	Ulf Hauptfleisch	UICE	WP3
PhD	Rakel Gudmundsdottir	UICE	WP3
PhD	Elisabet R. Hannesdottir	UICE	WP3
Master	Olafur Patrick Olafsson	UICE	WP3
Master	Paula Fonollà	UB	WP1

PhD	Alba Argerich	UB	WP2
PhD	Frederique Caille	UB	WP6-9
PhD	Paul Franklin	AERC	WP6
PhD	Attila Lazar	AERC	WP6
Master	Carl Pelling	AERC	WP6, WP7
PhD	Jennifer Lannon	AERC	WP6
PhD	Manuel Jesús López Rodriguez	UGR	WP7, WP3
PhD	Martin Erlandsson	SLU	WP4
PhD	Simon Hallstan	SLU	WP8
Master	Nicholas Casajus	CNRS-UPS	WP6
Master	Frédéric Sans Piche	CNRS-UPS	WP2
PhD	Laetitia Buisson	CNRS-UPS	WP6, WP2, WP7
PhD	Clement Tisseuil	CNRS-UPS	WP6
Post-doc	Muriel Gevrey	CNRS-UPS	WP2, WP6, WP7
Master	Stéphane Chantepie	CNRS-UPS	
Master	Paul Carayon	CNRS-UPS	WP2
PhD	Johannes Rempfer	EAWAG	WP3
PhD	Sabine Flury	EAWAG	WP3
PhD	Manuela Filippini	EAWAG	WP3
PhD	Arne Hammrich	EAWAG	WP3
PhD	Montserrat Bacardit	CSIC	WP5
PhD	Daniel von Schiller	CSIC	WP1
PhD	Mireia Bartrons	CSIC	WP5
Master, PhD	Lourdes Arellano	CSIC	WP5
Master, PhD	Roberto Quiroz	CSIC	WP5
Master, PhD	Roger Fonts	CSIC	WP5
Master, PhD	Eva Gallego	CSIC	WP5
Master	Andreas Meingaßner	UIBK	WP1
Master	Michael Bacher	UIBK	WP1
Master	Lukas Rastner	UIBK	WP1
Master	Eleonore Wieser	UIBK	WP1
PhD	Martyn Futter	TRENTU/AERC	WP6/WP4
PhD	Rankinen, K.	SYKE	WP6
PhD	Vuorenmaa, J.	SYKE	WP4
PhD	Granlund, K.	SYKE	WP6
Master	John Bøhme Christensen	NERI	
PhD	David Hardekopf	HSCU	WP1, 4, 5
PhD	Jolana Tatosova	HSCU	WP1, 5

Contractors Involved

Partic. no.	Participant name	Participant short name	Country
1	University College London, Environmental Change Research Centre (ECRC)	UCL	UK
2	National Environmental Research Institute, Department of Freshwater Ecology	NERI	DK
3	Royal Holloway and Bedford New College	RHBNC	UK
4	University of Duisburg-Essen, Centre for Microscale Ecosystem, Institute of Hydrobiology, Essen	UDE	D
5	University of Reading, Aquatic Environments Research Centre (AERC)	AERC	UK
6	ALTERRA Green World Research, Team of Freshwater Ecology, Wageningen	ALTERRA	NL
7	Centre for Ecology and Hydrology: NERC Wallingford, NERC Edinburgh, NERC Dorset, NERC Windermere, NERC Bangor	NERC	UK
8	Spanish Council for Scientific Research: Centre for Advance Studies (CEAB, Blanes) Institute of Chemical and Environmental Research (IIQAB, Barcelona), Institute of Molecular Biology (IBMB, Barcelona)	CSIC	E
9	Swedish Environment Research Institute	IVL	S
10	Norwegian Institute for Water Research, Oslo	NIVA	N
11	Swedish University of Agricultural Sciences, Department of Environmental Assessment	SLU	S
12	Finnish Environment Institute	SYKE	FIN
13	University of Innsbruck, Institute of Meteorology and Geophysics, Institute of Zoology and Limnology	UIBK	A
14	University of Liverpool	ULIV	UK
15	University of Natural Resources and Applied Life Sciences, Institute of Water Provision, Water Ecology and Waste Management, Department of Hydrobiology, Vienna	BOKU	A
16	Consiglio Nazionale delle Ricerche: Water Research Institute (IRSA) – Institute for Ecosystem Studies (ISE)	CNR	I
17	Centre National de la Recherche Scientifique and Université of Toulouse, "Laboratoire Dynamique de la Biodiversité"	CNRS-UPS	F
18	Swiss Federal Institute of Environmental Science and Technology, Departments of Water Resources, Drinking Water, Limnology, Surface Waters	EAWAG	CH
19	Greek Biotope/Wetland Centre Soil and Water Resources Department	EKBY	GR
20	ENTERA, Hanover	ENTERA	D
21	Czech Academy of Sciences, Hydrobiological Institute, České Budějovice	HBI-ASCR	CZ
22	Charles University, Prague; Hydrobiological station, Blatna	HSCU	CZ
23	HYDROMOD Scientific Consulting	HYDROMOD	D
24	Institute for Environmental Studies	IVM	NL
25	University of Leuven, Department of Biology, Laboratory of Aquatic Ecology	KULeuven	B
26	Masaryk University Brno, Faculty of Science, Department of Zoology & Ecology	MasUniv	CZ
27	University of Barcelona, Department of Ecology	UB	E
28	Centre for Environmental Research Leipzig-Halle, Department of Conservation Biology and Natural Resources (CNBR)	UFZ	D
29	University of Granada, Department of Animal Biology	UGR	E
30	University of Iceland, Institute of Biology	UICE	IS
31	University of Bucharest, Department of Systems Ecology and Sustainable Development	UNIBUC-ECO	RO
32	University of Rennes, Research Unit 'Ecosystem Functioning and Biological Conservation'	UR1	F
33	Utrecht University, Institute of Biology, Landscape Ecology Group	UU-BIO	NL
34	Russian Academy of Sciences, Water Problems Institute	WRI-RAS	RUS
35	Trent University (Ontario, Canada), Environmental and Resource Studies	*TRENTU*	CAN
36	Czech Geological Society	*CGS*	CZ
37	Macaulay Land User Research Institute	*MI*	UK
38	Hydrobiological Institute, Academy of Sciences of the Czech Republic	HBI-BCASCR	CZ
39	Aarhus University	AU	DK

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http://www.eurolimpacs.ucl.ac.uk/

Project logo

Euro-limpacs

2. DISSEMINATION AND USE

Publishable results of the Final plan for using and disseminating the knowledge

The main product of Euro-limpacs is knowledge.

The Project with more than 50 sites across Europe has collected a large amount of data on freshwater systems and the stressors affecting them, in particular those related to climate change.

The knowledge is developed by individual partners into databases, papers, books and tests results which feed databases and metadatabases available on the project website towards the end of the project.

The data are organised into a set of tools that can be used to assist in the assessment of ecosystem health, and the management and restoration of European freshwater ecosystems.

In particular, the main "products" developed consist of:

- an expert Decision Support System (DSS) for stakeholders and a wide range of end-users which incorporates global change scenarios and which will be promoted through web portals and the incorporation into the implementation strategy of relevant European and international policy instruments including the WFD, CAP, Kyoto, UNECE, Ramsar, CBD, CSD and WSSD.
- Databases
- A bibliography of all the scientific publications, popular science, and media releases generated by the Euro-limpacs Project
- The Euro-limpacs web-site

The consortium has identified knowledge that has potential for exploitation both as "stand alone results" or as part of a more complex information network (associated websites, end-users networks)

There are no commercially exploitable results identified within the limits of the project duration and the results are either published, available on the public domain or used for further research.

The table below provides an overview of expolotable knowledge produced by Euro-limpacs and its use. Comprehesive details of the dissemination of this knowledge via peer review scientific publications, presentations at international and national conferences and meetings and direct engagement with the end user community are provided by the final Plan for Using and Disseminating Knowledge.

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s) of application**	**Timetable for commercial use**	**Patents or other IPR protection**	**Owner & Other Partner(s) involved**
1) INCA-N, INCA-P, INCA-Sed, INCA- C and INCA-Tox models	INCA - Water quality models	-Water management -Further research	N.a.	Copyright	**AERC** TRENTU SYKE AU NIVA

					HYDROMOD CNRS-UPS IVL UIBK
2) MAGIC model	"Magic" Modelling tool	-air pollution abatement -soil and water management -Further research	From 1990	Copyright	**NIVA**
3) A knowledge tool on discharge dynamics-habitat instability-ecosystem effect	Knowledge database	Ecological water management	Beyond 2009	Copyright/ know-how	**ALTERRA** Partners of WP2
4) Macro-invertebrate Taxa and Autecology Database	On-line database	-Water management, -Further research	To be included into assessment software in year 5 of the project	Copyright	**BOKU, UDE** & ALTERRA, NERC, CNR, MasUniv, AU, SLU, UGR, CNRS-UPS
5)Scientific results which can be used for water and forest management	Database of future scenarios of soil and water development	-Water and forest management -Further research	No commercial use for that research	Copyright/ know-how	**CGS**
6) Analytical methodologies for POP determination	Measures of organic pollutants in soils, sediments and rain-waters	-Water management -Further research	Possibly 2006	Copyright/ know-how	**CNR**
7) Analytical methodologies for trace metal determination	Measures of trace metals in soils, sediments and rainwaters	-Water management -Further research	Possibly 2006	Copyright/ know-how	**CNR**
8) Identification of restoration target	Reference condition database	-Water management -Further research	Possibly 2008	Copyright	**CNR**
9) South European macro-invertebrates taxa autoecology	Autoecological archive on South European aquatic invertebrates	-Water quality and biodiversity management -Further research	Possibly 2007	Copyright/ know-how	**CNR** WP2 and WP7 partners
10) Modelling biota response to climatic/antropogenic changes	Model to predict the biotic changes in response to climatic/ antropogenic change	-Water management -Further research	Possibly 2008	Copyright/ know-how	**CNR** NIVA
11) Lake level	Lake level forecast	-Water	Possibly	Copyright/	**CNR**

modelling		management -Further research	2008	know-how	SYKE, HYDROMOD
12) Garonne database	Garrone Database	-Water management -Further research	No commercial use	Copyright	**CNRS-UPS** AERC, UCL, NERC, AU,SLU, ALTERRA,
13) Ecological modelling	ECOMODEL Modelling tool	-Further research	(2006) Published book	Copyright	**CNRS-UPS** AERC, NERI, AU, UCL, SLU
14) Decision Support System	Generic GIS-based DSS	-Catchment management -Further research	Possibly 2009	Copyright protection	DSS framework - **ULIV** Integration methodology – ULIV & **AERC** Knowledge base - All partners
15) Sediment-water interactions	Models	-Modelling, water management, lake restorations -Further research	At present, unknown	Copyright/ know-how	**HBI-ASCR**
16) Climatic and atmospheric deposition data	Databases, papers	National and international hydro-meteorological databases	At present, unknown	Copyright/ know-how	**HBI-BCASCR**
17) Emission/deposition scenarios for SOx and NOx in 2100.	Database	Science, research, policy development	At present, unknown	Copyright protection	**IVL**
18) Response of acidified soils to climate change	Databases, assessments, reports	Science, research, policy development	At present, unknown	Copyright protection	**IVL**, NIVA, NERC
19) Behaviour of mercury in the environment under influence of climate change	Databases, assessments, reports	Science, research, policy development	At present, unknown	Copyright protection	**IVL**, SYKE, NIVA, UCL
20) Database	Database	Water management	No	Copyright	**UB**

Tordera catchment (Mediterranean stream)			commercial use planned	protection	
21) Database Pyrenean streams	Database	Water management	No commercial use planned	Copyright protection	**UB**
22) Galloway Database	Database	Soil and water management	2007	Copyright protection	**MI**
23) Database on Indicators of Ecosystem Health	online database	research, water management	No commercial use planned	N.A.	**UDE & BOKU**, ULIV
24) For use in: EIA for proposed geothermal power plants. Predicting impact of eutrophication in global warming scenario	Expecting to publishing in international journals Plan for scientific papers in international journals	Environmental and Food Agency and Reykjavik Energy	N.A.	N.A.	**UICE**
25) Knowledge on climate change effects on wetland eutrophication	Knowledge (papers)	Science, water management, landscape planning	N.A.	Copyright	UU-Bio
26) Knowledge on dispersal processes in wetlands	Knowledge (papers)	Science, water management, landscape planning	N.A.	Copyright	UU-Bio
27) Knowledge on wetland connectivity	Knowledge (papers)	Science, water management, landscape planning	N.A.	Copyright	UU-Bio
28) Knowledge on climate change effects on wetland restoration	Knowledge (papers)	Science, water management, landscape planning	N.A.	Copyright	UU-Bio
29) Knowledge on DSS required input	Knowledge (DSS)	Water management, landscape planning	2006-2009		UU-Bio, IVM
30) Euro-limpacs Network of end-users	**Knowledge, data**	**Science, water management, landscape planning**	**Subject to further research**	**Copyright**	**All partners**
31) “Analogue”	**Software**	**Further research Analogue**	**2008**	**Copyright**	**UCL Gavin**

		matching of data sets			**Simpson**
32) Climate Change Impacts on Freshwater Ecosystems	**Book**	**Training**	**2008**	**Copyright**	**UCL** **All Partners** **Publisher**

Description of result: **Decision Support System (DSS)**
The Decision support system (DSS) is a practical, operational advice, using geographical information systems (GIS) that can be incorporated for managers in competent authorities for use in restoring habitats to good ecological status.

Partners involved in exploitation
UCL, ULIV, all partners

How the result will be exploited
There are no commercial values to be expected from the DSS and it will be made available to end-users upon request via the project website.

Technical and market considerations:
The DSS has been demonstrated at workshops and in the field throughout Europe

Possible obstacles to commercialisation:
The DSS has been developed in consultation with end-users. No relevant obstacles are foreseen.

Exploitation other than commercialisation:
It will be a useful tool for research purposes as well as for water management.

Further research required:
Further research in the field of indicators for ecosystem health.

IPR protection measures (Copyright):
Copyright

Commercial contacts already made:
Not applicable

Socio-economic impact:
Indirect, through water management and application on environmental issues

Description of result: **Euro-limpacs Network of End-users**
The Euro-limpacs Network of End-users is the result of five years of engagement of end-users and involvement of key players in water management and climate change across the globe.
The list of end-users is collected in a database available upon request.

Partners involved in exploitation
UCL, all partners

How the result will be exploited
There are no commercial values to be expected from the **Euro-limpacs Network of End-users** and the end-users database will be only made available to project partners.

Technical and market considerations:
N.A.

Possible obstacles to commercialisation:
N.A.

Exploitation other than commercialisation:
It will be a useful tool for research purposes as well as for further engaging water managers and policy makers

Further research required:
N.A.

IPR protection measures (Copyright):
Copyright

Commercial contacts already made:
Not applicable

Socio-economic impact:
Indirect, through water management and application on environmental issues

Description of result: **Analogue Matching Software "Analogue"**
The analogue package is an application of analogue matching of data sets developed using R statistical software.

The analogue package contains functions to perform modern analogue technique (MAT) transfer functions, which can be used to predict past changes in the environment, such as climate or lake-water pH from species data.

Partners involved in exploitation
UCL, Gavin Simpson

How the result will be exploited
Like R, analogue is also made available under the GNU GPL and as such is freely available and the source code can be consulted to understand how the package works and to modify it if the user so wishes to added new functionality or modify the implementation.

Technical and market considerations:
The main reason for choosing to write the analogue package for R is that R is open source, released under the GNU General Public Licence (GNU GPL), and available freely to anyone who wants to use it. R also provides a rich source of programming tools that allow high quality output and graphical displays to be produced at relatively little effort.

Analogue has been submitted to the Comprehensive R Archive Network (CRAN), an on line repository for R packages. By making analogue available via CRAN, anyone who has R installed on their computer can install analogue with minimal effort using the package management tools built into R.

Analogue implements novel and cutting edge topics in the use of modern analogues for environmental modelling, that are not available in any other computer package or application. By drawing together current research tools into a software package for end users we gain the input of many users in how these functions perform. This input will also feedback into the development of the techniques that is ongoing as part of research within Euro-limpacs and beyond.

Possible obstacles to commercialisation:
No direct commercilisation is foreseen for this result.

Exploitation other than commercialisation:
It will be a useful tool for research purposes as well as for water management.

Further research required:
N.A

IPR protection measures (Copyright):
Copyright

Commercial contacts already made:
Not applicable

Socio-economic impact:
Indirect, through water management and application on environmental issues

Description of result: **Climate Change Impacts on Freshwater Ecosystems (Provisional title)**
This book focuses on the key drivers of aquatic ecosystem change (land-use, nutrients, acid deposition and toxic substances) and examines their interactions with global, especially climate, change using time-series analysis, space-for-time substitution, palaeolimnology, experiments and process modelling.

Partners involved in exploitation
UCL, all partners

How the result will be exploited
The book will be sold by the Blackwell Publishers

Technical and market considerations:
The book has the potential to become a major milestone in the field of Climate Change and Fresh Water Ecosystems

Possible obstacles to commercialisation:
No relevant obstacles are foreseen.

Exploitation other than commercialisation:
It will be a used for training and further research

Further research required:
The book is a stand alone product but updates will be produced and negotiated with the Publisher

IPR protection measures (Copyright):
Copyright will be assigned to the Publisher

Commercial contacts already made:
Blackwell Publishers

Socio-economic impact:
Indirect, through training of scientist and water managers

Note: a more comprehensive and structured list of activities can be found in Deliverable 305