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WORK PACKAGE: 7 (Indicators of ecosystem health)

WP LEADER: Daniel Hering (UDE) and Astrid Schmidt-Kloiber (BOKU)

REPORTING PERIOD: FROM February 2004 TO January 2009

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1. Workpackage objectives and starting point (state-of-the-art) at beginning of the Project

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?
2. Achievements and deviations

A detailed description of the workpackage achievements is given in section 3, broken down by workpackage key questions and by tasks. 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 were already released), 45 reports and 27 journal articles (16 of which have yet appeared).

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

Books
Two books produced by WP7 were released during the lifespan of the project, four more books will appear soon after the project's termination:


Journal articles and book chapters
Published and “in press”:


Submitted and in preparation:
- Barker, T. & Maltby, E.: Climate change and indicators of wetland functioning. In prep.
- Buffagni, A., Armanini, D.G., Cazzola, M., Demartini, D. & Erba, S.: Climate change and habitat of riverine endemic species of a large Mediterranean island (Sardinia): are they vulnerable to extinction? Submitted.

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.
- 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).

Case study 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.
Case study 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. 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 France’s 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.
Spatial distribution of predicted impacts of climate change on fish assemblages under B2 (left-hand 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.)
Case study 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 divided 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 suited to detect 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.

- **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 division 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.
ii) What has been the impact of the research undertaken in the work package, in the research area and beyond?

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.

**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](http://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.

**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.

**Websites**

The main outcome of the central Task 4 of WP7 is the website [www.freshwaterecology.info](http://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](http://www.climate-and-freshwater.info) became very popular. Visitors of [www.climate-and-freshwater.info](http://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 than 27,000. The average number of page visits for the last three month is more than 4,000/month. Google page ranking is currently 5.

**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 publications 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](http://www.freshwaterecology.info) about 9,000 publications have been evaluated.

**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](http://www.freshwaterecology.info)) and by defining criteria and indicators for assessing the impact of climate change on freshwater ecosystems ([www.climate-and-freshwater.info](http://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](http://www.wiser.eu)).
3. Work performed and end results

KEY QUESTIONS

What chemical parameters are best suited as indicators of climate change?
A combination of field studies and modelling, particularly on eutrophication and acidification processes, have been employed to determine the chemical parameters best suited as indicators of climate change (WP7, Task 2). A literature database has also been compiled on the impact of climate change on chemical parameters in rivers, lakes and wetlands, which has been included into the website www.climate-and-freshwater.info. Both literature data and own findings have been used to suggest chemical indicators best suited for assessing the effects of climate change on freshwater ecosystems (see section “Indicators for climate change impacts” on the website). The 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. Information on chemical indicators ("Indicators in current use" and "Indicators for climate change impacts") is given for a range of freshwater types.
Climate change is revealed in values for mean and extreme temperatures and precipitation. These controlling variables have strong influences on hydroperiod, soil moisture, oxygen status and biological processes that depend on them. It is likely that the key nutrients ammonium, nitrate, nitrite and phosphate will react to changes in environmental conditions, and some minerals might be mobilised by changes in pH values. Biologically generated gases that potentially have important effects include oxygen, carbon dioxide, methane, and nitrous oxide. Most of these parameters are easy to measure and so potentially suited as indicators to monitor changes driven by climate change.
Examples of work being carried out within WP7 on different chemical indicators can be found in Deliverables 271, 274 and 280, and in Kroglund et al. (2007, Hydrology and Earth System Sciences Discussions, 4, 3317-3355).

Can functional indicators be identified to address climate change impacts on freshwaters?
Ecosystem functions, such as capacity for water and nutrient retention, nutrient export rates and ecosystem maintenance, may significantly change with the increasing impact of a stressor. Functional characteristics of ecosystems depend on numerous abiotic and biotic components. The concept of functional indicators aims at identifying the most relevant, and the most easily detectable. This key question was addressed in WP7 Task 3. The concept of functional indicators has been proven its applicability for wetlands. The transferability to lakes and rivers, particularly to assess climate change impacts, has been subject to further studies.
Wetland functioning can be influenced by climate change in numerous ways, including direct temperature effects on soil and aquatic processes, indirect effects that come about through melting of ice, changed patterns of rainfall, and species distribution changes. Rates of primary production and respiration are likely to be affected by changes affecting temperature, hydrology, nutrient-flux and species distributions. The prime outcome of this part of the project is the book: “Functional Assessment of Wetlands; towards evaluation of ecosystem services” (Maltby, editor, 2009), Woodhead Publishing, Cambridge. Further results are given in Deliverable 273 (Manuscript on functional indicators in wetlands). As a result, a wetland functional indicator database has been incorporated into
an existing meta database on indicators of ecosystem health in relation to climate change (WP7 Task 1) and eventually in the database www.climate-and-freshwater.info.

For a number of case studies the transferability of the functional indicator concept to other aquatic ecosystem types has been tested (Deliveable 281: Manuscript on how to transfer the functional indicator concept on rivers and lakes). Several functional parameters have been included into the selection of best suited indicators as indicators to monitor climate change shifts (www.climate-and-freshwater.info).

Can biological indicators be identified and used to assess communities' responses to climate change?

Biological indicators (indicator species) are frequently used in European water management to monitor the effects of various stressors such as eutrophication, organic pollution, acidification, intense catchment land use or hydromorphological stress. The generation of an indicator value database for European freshwater species was a central biological component of Euro-limpacs and is described below. The database includes six organism groups (Trichoptera, Plecoptera, Chironomidae, Ephemeroptera, fish and diatoms).

What are biological indicators?

Freshwater species and communities react directly or indirectly to changes in climate, reflecting changes in temperature, season and precipitation. These environmental factors have impacts on ecosystem processes important for functioning, such as deoxygenating of water bodies, uptake rates of mineral resources, rates of primary and secondary production, migration patterns, species distributions, changes to life cycle stage timings, decomposition rates, gaseous emissions, and similar processes that characterise ecosystems and influence ecosystem services. Some species have the genetic or behavioural capacity to adapt to modest changes in their environment, even when permanent. Changes in food resource availability, for example, can sometimes be compensated by adapting life-cycle stages, but there are minimum requirements for some resources, e.g. oxygen, and maximum tolerances for others, e.g. ammonia, beyond which species cannot survive.

Permanent shifts in environmental conditions, or changes in variation of environmental extremes, may result in local extinction of characteristic species and invasions by exotic species. Even without the extinction of species permanent shifts in the biota may occur, e.g. by the decrease of certain feeding types, which may be replaced by others. In more general terms, global warming supports tolerant (generalist) species, while more sensitive species may decrease or disappear.

Generation and evaluation of an indicator value database for European freshwater species

Within Task 4 of WP7 large databases on autecological characteristics and requirements of European freshwater inhabiting taxa have been compiled, covering diatoms, benthic invertebrates and fish (www.freshwaterecology.info). This data collection served as a base for selection of either single species or functional trait indicators for climate change. The original data compiled in the database are presently being published in the book series “Distribution and Ecological Preferences of European Freshwater Organisms”.

The databases was analysed to determine which parameters change along climatic gradients, thus being potentially suited as indicators. Parameters such as stream zonation preference, temperature preference, altitudinal preference, life cycle patterns and distribution patterns seem to be most suited.

The vulnerability of freshwater organisms to direct and indirect effects of climate change can be estimated by the ecological preferences of species. Endemic species, species inhabiting springs and those adapted to low water temperatures are particularly threatened by climate change. Insect species potentially endangered by climate change are unevenly distributed in Europe. A high proportion of species in the Mediterranean ecoregions and in high mountain areas have a high vulnerability to climate change. Most central and northern European species, however, are widely distributed and likely to be less affected by climate change.
Data evaluations can be found in Deliverables 190 (Trichoptera), 192 (fish), 193 (Plecoptera), 194 (diatoms), 278 (Chironomidae) and 282 (Ephemeroptera) and in Hering et al. (2009, Aquatic Sciences, in press, DOI 10.1007/s00027-009-9159-5), Buisson & Grenouillet (2009, Diversity and Distributions, in press.) and Haidekker & Hering (2008, Aquatic Ecology 42: 463-481). The data evaluations suggest that a considerable proportion of European biodiversity is endangered by direct and indirect climate change impacts, although the severity differs greatly between European regions.

Information on biological indicators (indicators in current use, indicators for climate change impacts and species that are endangered by climate change) are given for a range of freshwater types on the website www.climate-and-freshwater.info.

Can different indicator types be linked to give a common framework for rivers, lakes and wetlands?
The impacts of climate change on freshwater ecosystems are manifold and vary between regions and water types. Within Workpackages 1-8 several cause-effect chains leading from changing climate to physico-chemical or biological processes have been investigated, many others are evident from literature. The individual impacts are best reflected by different parameters; in some cases these are physico-chemical values, indicating a key-breakpoint, while in other cases the signal given by the biota is more evident. Therefore, a combination of different indicators will be most reliable.

www.climate-and-freshwater.info
Results from WP7 have been consolidated in a website called "Climate Change and Freshwater", which acts as an indicator selection tool.
The site gives 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 headings of the website are:
- Indicators in current use. This describes 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. This lists specific indicators, which are, according to WP7 results, suited to detect 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. This contains a broad selection of species, which are (potentially) endangered by, or benefit from, climate change. The selection covers a broad range of organism groups and all European ecoregions.
- Case studies. The contents of more than 500 papers are presented, describing individual studies on how climate change is affecting individual sites, organism groups or regions.

Can assessment/prediction methods for freshwaters be modified to address climate change?
Existing assessment and prediction systems are being expanded and modified in the context of global change by integrating the databases generated within WP7. The basis has been laid with Task 5 by compiling information on how existing assessment systems are impacted by climate change effects and which indicators are best suited to reflect the effects of climate change on freshwater ecosystems. Biota of rivers, lakes and wetlands respond directly or indirectly to climate change, e.g. by the disappearance and/or invasion of species. In many cases this may lead to a shift in functional
characteristics of the communities, e.g. alterations in stream zonation preferences or in feeding type composition or in habitat preferences. These shifts could be detected by applying standard assessment procedures, which are based on community composition and ecological traits of the occurring species. Assessment metrics were developed that are sensitive to climate change impacts, based on the indicator value database (WP7 Task 4); a functional design on how to integrate these metrics into existing assessment software has been written for the case of the ASTERICS software, which is used to assess rivers with benthic invertebrates in Europe (for details see Deliverable 276: Indices to include Climate Change impacts into biological assessment programmes).

A set of indices were derived that are suited to assess the impact of climate change on freshwater biota. These include existing indices (such as stream zonation indices, which clearly reflect river water temperature) and indices that are being newly developed (including temperature-sensitive and temperature-tolerant taxa or indices reflecting species life history).
PROGRESS WITH TASKS

Task 1: Generation of a meta-database on indicators of ecosystem health in relation to climate change (UDE, BOKU, ULIV)

Objective(s) of task
- Categorisation of the potential effects of global change on physical, chemical, hydrological, and biological processes and their interactions for different types of freshwaters. Assessment of the relationship between climate change and indicators.
- Literature analysis to categorize to identify possible indicators for the different direct and indirect effects of climate change on aquatic ecosystems.
- Generation of 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).

Summary description of work performed, end results
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 homepage. 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)

Objective(s) of task
The overall objectives of Task 2 were to perform case studies on eutrophication and acification indicators and their interaction with climate change effects and to summarize existing chemical indicators based on a literature evaluation. More specifically, the objectives were:

Eutrophication case study
- To estimate effect of climate change on discharge patterns and nutrient loading from a forested head water catchment by using bottom up approach.
- 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.
- 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.
- To calculate response surfaces of the N/P relationship of the nutrient load from the simulations.
Acidification case study
- 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.
- 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
- To synthesize the outputs of the REBECCA project to select chemical indicators for Climate Change, and to prepare this output for the use in Task 5

Summary description of work performed, end results

Eutrophication case study (SYKE, AERC)
- 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.
- Both total P and N loads from the Mustajoki catchment are clearly more sensitive to precipitation than to temperature. The response surface of nutrient load follows that of mean discharge so that the estimated increase in precipitation will most probably increase nutrient load.
- The combined effect calculated as N/P relationship of the nutrient load entering the Lake Pääjärvi is sensitive to temperature, as total N load is more sensitive to temperature increase than total P load. Increase in temperature with slight increase in precipitation up to 20% will increase N/P relationship. When increase in precipitation is over that temperature increase do not have any influence on N/P ratio any more.
- In future climate the total N and total P load entering the lake increase, but the N/P ratio of the entering load rather increases than decreases. At the current state the chlorophyll growth in the deep Lake Pääjärvi is clearly phosphorus limited, and climate change probably will not change that.

Acidification case study (NIVA)
- Results from 347 short-term (<14 days) exposures of salmon parr and smolt performed between 1990 and 2003 in Norway were summarized. 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. In addition to exposure intensity and timing, exposure duration is important for the setting of critical limits.
- Data from Norwegian national monitoring program undertaken in 1995 was 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. Distinct water types differences with respect to pH and ANC were apparent. The clear correlation between total Al and TOC suggests that Al in affected regions is transport from the edaphic to the aquatic environment with organic matter. Relative to the “unaffected” regions, total Al in affected regions was on the average increased by 50 µg Al/l. This increase can be related to the pH decrease alone and represents an average increase related to acid rain. TOC had no major
effect on pH in this dataset. Based on lake survey data from 1995, an increase in TOC is not expected to decrease pH by more than 0.2 pH units, but is expected to increase total Al. Based on this, the observed increase in TOC observed over the last 2 decades has most likely no or only minor effect on cationic Al but will have an effect on total and PCV reactive Al. The increase in TOC is not expected to result in any need for any major change in liming strategies in Norway. Changes in seasonal temperature and hydrology can affect the seasonal cost. Current liming strategies are on the whole robust enough to cope with this.

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 summarized 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)

Objective(s) of task
- To produce a conceptual study on wetland “functional indicators” and to specify wetland functional indicators for a wide range of wetland types.
- To develop a concept on how to transfer the functional indicators idea to rivers and lakes.

Summary description of work performed, end results
- Literature search for physical, chemical and biological effects of climate-related influences on wetland functioning. Compilation of relevant study conclusions for inclusion in the ‘meta-database’ under Task 1. The results have been summarized further in a brief report (Deliverable 122) (ULIV).
- Transformation of the preliminary literature review produced by ULIV on wetland functional indicators into the web database (see Task 1) (UDE).
- Identification of links among wetland processes and functions, and environmental variables (ULIV)
- Determination of effects on wetland ecosystem services of changes in key environmental variables. (ULIV)
- Refinement of functional assessment of wetlands to incorporate changes expected under climate change. (ULIV)
- Elaboration of core underlying principles of functional analysis in wetlands, indentifying parallels with processes and functions in lake and river ecosystems. Analysis of core principles in decision-tree development for lakes and rivers and derivation of meaningful conclusions for use in the field.
- Preparation and submission of Deliverable 273 (Manuscript on functional indicators in wetlands).
- Preparation and submission of 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)

Objective(s) of task
- To summarize existing information on distribution and ecological preferences of European freshwater biota
- To present the results in an online database
- To evaluate the data according to the sensitivity of species for climate change effects

Summary description of work performed, end results

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.

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.

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-IRSA, UGR, CEH, 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.
- Finalization of the autecocial data (CNR).
- Integration of the Ephemeroptera data into www.freshwaterecology.info (BOKU).

Plecoptera database (BOKU, UDE, UnivGR, 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 (UGranada).
- Compilation of the databases from the different regions (BOKU, UDE).
- Integration of the Plecoptera data into www.freshwaterecology.info (BOKU).

Trichoptera database (BOKU, UnivGR, 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 (UGranada); 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.

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).

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).

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.
- Continuous updates whenever new data were available.

Preparation the book series “Distribution and Ecological Preferences of European Freshwater Organisms”
- 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).
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.
- For all insect groups the sensitivity of species for climate change differs strongly with ecoregion. As an example the results for Trichoptera are as follows: Of the European Trichoptera species and subspecies, 47.9% are endemic, 23.1% have a strong preference for springs, 21.9% are cold stenothermic, 35.5% have a short emergence period, and 43.7% are feeding type specialists. The fraction of endemic species meeting at least one of the four other sensitivity criteria mentioned above is highest in the Iberic-Macaronesian Region (30.2% of all species), about 20% in several other south European ecoregions and about 10% in high mountain ranges, while in 15 out of 23 ecoregions (including all northern European and lowland ecoregions) the proportion is less than 3%.

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

Objective(s) of task
- To link the different types of indicators for climate change impact on freshwater ecosystems developed in WP7 and indicators developed by other research teams into an indicator selection tool. To produce a website (www.climate-and-freshwater.info) on this tool.

Summary description of work performed, end results
- On the general project meeting in Leipzig (April 2007) it was decided that the indicator selection tool will be a website, which includes information on current monitoring programmes and indicators suited to extend them to better reflect Climate Change impacts. On a meeting in Liverpool in July 2007 it was decided to link this tool to the vulnerability analysis under WP9.
- Four databases were build as background information for the indicator selection tool:
  - **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).
  - **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).
  - **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).
  - **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 ecosystems 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)

Objective(s) of task
- To produce case studies on how to include climate change indicators into existing assessment programmes.

Summary description of work performed, end results
- 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.
- Decision on which assessment methods should be extended and on the nature of the extension.
- Selection of assessment formulas to be used for the extension of the assessment systems.
- Functional design for the extension of the ASTERICS assessment system.
- Development of new indices to be included into the ASTERICS assessment software (UDE, BOKU).
- Functional design for the inclusion of indices related to the indicator value database into the ASTERICS assessment software. This will include updates of already established indices (such as current preferences, feeding types and habitat preferences) together with some newly designed indices, e.g. on temperature preference, dispersal capacity or stream zonation preference (UDE, BOKU).
- Preparation and submission of Deliverable 386 (Key indicator species of climate change impacts).
- Preparation and submission of Deliverable 276 (Indices to include Climate Change impacts into biological assessment programmes).
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<td>Task 4 Compilation of Chironomidae data</td>
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<td>Task 4 Compilation of Fish data</td>
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<td>Task 3 Start of functional assessment indicator work</td>
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<td>Task 2 Data based catchment-lake interaction in Finland</td>
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<td>Task 2 Complete data-set required by the MyLake model</td>
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<td>Task 4 Compilation and web-presentation of Plecoptera data</td>
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<td>Task 4 Compilation of diatom data</td>
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<td>Task 4 Start of compilation of Ephemeroperta data</td>
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<td>Task 4 Experimental design for selected indicator species (North-South gradient)</td>
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<td>Task 4 Compilation of Chironomidae data</td>
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<td>Task 2 Set-up of the MyLake model for lake Pajajarvi</td>
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<td>Task 2 Set-up of INCA-SED/P and evaluation of INCA-N use in climate change context in Finland</td>
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<td>Task 4 Compilation of Ephemeroperta data</td>
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<td>Task 4 Evaluation of Trichoptera data in relation to climatic gradients</td>
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<td>Task 5 Start of work on linking different indicator types</td>
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<td>Task 6 Start of work on assessment and spatial extrapolation</td>
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<td>Task 5 Start of work on linking different indicator types (SLU, UDE, Month 37)</td>
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<td>Task 6 Start of work on assessment and spatial extrapolation (UDE, Month 37)</td>
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<td>Task 4 Evaluation of fish data in relation to climatic gradients (CNRS, Month 42)</td>
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<td>Task 4 Evaluation of Plecoptera data in relation to climatic gradients (UDE, BOKU, Month 42)</td>
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<td>Task 5 Conceptual framework on the extension of the meta-database (WP7, Task 1) into an indicator selection tool (SLU, UDE, Month 42)</td>
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<td>Task 5 Workshop with WP8 to plan links between indicator selection tool and DSS (Month 42)</td>
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<td>Task 4 Update of diatom database (Alterra, Month 42) and presentation on the web (BOKU, Month 46)</td>
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<td>Task 4 - Update of Chironomidae database (MasUniv, BOKU, Month 42) and presentation on the web (BOKU, Month 48)</td>
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<td>Task 2 Suitable chemical indicators and links to biological indicators (SYKE, NIVA, Month 44)</td>
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<td>Task 5 - Compilation of biological indicators (SLU, UDE, Month 45)</td>
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<td>Task 5 - Completion of climate change indicators questionnaire by WP leaders (Month 45)</td>
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<td>Task 5 - Start building an indicator selection tool (SLU, UDE, Month 49; achieved at Month 45)</td>
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<td>Task 3 Literature review on functional assessment indicators (ULIV, Month 48)</td>
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<td>Task 2 - Finalization of the work on Al/pH/DOC relationships (NIVA, Month 48)</td>
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<td>Task 4 - Update of Ephemeroperta database (CNR, UGranada, Month 42) and presentation on the web (UDE, BOKU, Month 48)</td>
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<td>Task 4 - Evaluation I of diatom database (Alterra, Month 48)</td>
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<td>Task 4 - Evaluation of Chironomidae database (MasUniv, BOKU, Month 48) and presentation on the web (BOKU, Month 48)</td>
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<td>Task 4 - Compilation of indicator types from project results and literature (SLU, UDE, Month 48)</td>
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<td>Task 6 - First set of indices to assess the impact of Climate Change on biological elements (UDE, BOKU, Month 48)</td>
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<td>Task 5 - Start building an indicator selection tool (SLU, UDE, Month 49)</td>
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<td>Task 4 - Evaluation of Chironomidae database (MasUniv, Month 50)</td>
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<td>Task 2 - Response surface between climate variables and nutrient loading/nutrient concentration (SYKE, Month 52)</td>
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<td>Task 2 - Finalization of the work on Al/pH/DOC relationships (NIVA, Month 48; new deadline: Month 52)</td>
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<td>Task 4 - Submission of the book manuscript on the autecology of Trichoptera. First book in a series on the organism groups evaluated in the project. (BOKU, Month 52)</td>
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<td>Task 3 - Transfer of the functional indicator concept to rivers and lakes (ULIV, Month 54)</td>
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<td>Date due (Month)</td>
<td>Actual/Forecast completion date</td>
<td>Lead contractor</td>
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<td>Task 4 - Concept for the integration of selected results of WP2 into the <a href="http://www.freshwaterecology.info">www.freshwaterecology.info</a> database (BOKU, UDE, ALTERRA, Month 54)</td>
<td>7</td>
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<td>Task 4 - Evaluation of Ephemeroptera database (CNR, Month 54)</td>
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<td>Task 4 – Start of comparative analysis of the individual organism groups (UDE, BOKU, Month 54)</td>
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<tr>
<td>Task 4 – Preparation of the book manuscript on the autecology of Plecoptera. Second book in a series on the organism groups evaluated in the project. (BOKU, UDE, Month 54)</td>
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<td>Task 5 – Delivery of the databases of indicators to WP 9 for the decision support system. (UDE, Month 54)</td>
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<td>Task 4 – Evaluation I of diatom database (Alterra, Month 48; new deadline: Month 55)</td>
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<td>Task 6 – First set of indices to assess the impact of Climate Change on biological elements (UDE, BOKU, Month 48)</td>
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<td>Task 2 – Finalization of manuscript on eutrophication case study (SYKE, Month 56)</td>
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<tr>
<td>Task 3 – Finalization of manuscript on functional indicators (ULIV, Month 56)</td>
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<td>Task 4 – Submission of the book on the autecology of Plecoptera. Second book in a series on the organism groups evaluated in the project (BOKU, UDE, Month 56)</td>
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<td>Task 6 – Analysis of indices suitable to detect climate change in aquatic communities (UDE, BOKU, Month 56)</td>
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<td>Task 4 – Preparation of the book manuscript on the autecology of Ephemeroptera. Third book in a series on the organism groups evaluated in the project (BOKU, CNR, Month 58)</td>
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<td>15,16</td>
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<tr>
<td>Task 4 – Preparation of the book on the autecology of Chironomidae. Fourth book in a series on the organism groups evaluated in the project. (BOKU, MasUniv, Month 58) – instead, two book manuscripts on fish and diatoms were prepared</td>
<td>7</td>
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<td>60</td>
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<td>Task 5 – Finalisation of the indicator selection tool (<a href="http://www.climate-and-freshwater.info">www.climate-and-freshwater.info</a>) (UDE, Month 58)</td>
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<td>Task 4 – Work on a manuscript entitled “Comparison of benthic macroinvertebrate species traits along a north-south gradient in Sweden and New Zealand” (SLU, Month 60)</td>
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