SEVENTH FRAMEWORK PROGRAMME
THEME 6: Environment (including Climate Change)

Adaptive strategies to Mitigate the Impacts of Climate Change on European Freshwater Ecosystems

Collaborative Project (large-scale integrating project)
Grant Agreement 244121
Duration: February 1st, 2010 – January 31st, 2014

Deliverable 3.6: Manuscript on current interactions between temperature, hydrology/water level in European lakes and consequences for lake restoration.

Lead contractor: **Middle East Technical University (METU)**
Other contractors involved: **Aarhus University (AU)**

Due date of deliverable: **36**
Actual submission date: **36**

Work package:**3**
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Estimated person months: 5

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013) Dissemination Level (add X to PU, PP. RE or CO)		
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PP	Restricted to other programme participants (including the Commission Services)	
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Abstract
This deliverable comprises four research papers and one PhD thesis on hydrology and temperature effects on lakes and consequences for restoration. Here we provide the abstracts for these. Copies of the full papers can be obtained by request from the Proejct Web site at http://www.refresh.ucl.ac.uk/contact.

High water-level fluctuations are typical of lakes located in the semi-arid Mediterranean region, which is characterized by warm rainy winters and hot dry summers. Ongoing climate change with severe episodes of drought may lead to lower and more variable water levels, longer hydraulic retention time and eutrophication as nutrient concentrations increase in the remaining water. Higher hydraulic retention time also triggers salinization. In addition, the cascading effect of top-down control by fish as well as the nutrient cycling are sensitive to changes in temperature. Information on the effects of water level and temperature on in-lake trophic dynamics and their interactions is crucial in such regions and may have profound implications for restoration.

It is hypothesized that in the Mediterranean region, major water level decline during summer due to higher evaporation, may potentially help maintain macrophyte growth even in eutrophic shallow lakes and therefore, at least partly, counteract the effect of reduced clarity from climate-driven **enhanced eutrophication. An experiment was conducted at contrasting water levels in a Turkish shallow lake. This showed that lower water levels help maintain macrophyte growth in a Mediterranean eutrophic shallow lake, despite a stronger (negative) cascading effect of fish predation on water clarity confirming the above hypothesis. Laboratory and field studies further showed large-bodied grazer *Daphnia* avoid submerged macrophytes and instead prefer to hide near the sediment when exposed to predation risk, because of high fish densities in the vegetation. These results confirm earlier findings that macrophytes are less efficient refugia for large bodied zooplankton in these lakes compared with northern temperate lakes making them lakes more vulnerable to a shift to a turbid state when the nutrient level increases, due to reduced grazing on phytoplankton.**

In semi-dry Mediterranean climatic regions, excessive water use especially for irrigated crop farming, and global warming also enhances salinization of inland freshwater lakes, whicyh has a major impact on the zooplankton community structure. A study of 31 Turkish lakes showed a shift towards smaller sized classes including rotifers, which are less efficient phytoplankton grazers. Salinity strongly control *Daphnia* populations through increased mortality, decreased reproduction, and reduced growth rate. Global warming-induced increase in salinity may therefore also cascade through the food web and lead to higher risk of having turbid waters in warm and dry region.

Lake restoration may therefore be more difficult in warm regions. Nutrient loading reduction and reduced water abstractions are the first step needed to restore eutrophic lakes. In Mediterranean climatic regions, restrictions on human use of water especially irrigation purposes as well as on nutrient loading to lakes are urgently needed to achieve good ecological status (WFD). To fulfil this objective, adaptation measures are required. In Mediterranean climatic zones the obvious methods are to change agricultural practices for reducing demand for water and the loss of nutrients to surface waters, to improve sewage treatment and to reduce the storm-water nutrient runoff. In warm Mediterranean zones adaptations may also include re-establishment of artificial and natural wetlands, introduction of riparian buffer zones and re-meandering of channelised streams, which may all have a large impact on the N loading in lakes. In-lake measures may increase the rate of recovery after measures to reduce the nutrient loading have been taken. One such method is biomanipulation. The review of biomanipulation methods and results included here indicates that it might be possible to enhance water clarity even in warm freshwater lakes by removing the dominant benthic fish, such as carp, though the long term effects of such measures are unknown. It is suggested that dual treatment including both biomanipulation and chemical treatment of the sediment to immobilise phosphorus might be a way forward to enhance the chance of long-term recovery of lakes in all climate zones.

Deliverable 3.6: Manuscript on current interactions between temperature, hydrology/water level in European lakes and consequences for lake restoration.

(METU and AU) (month 36).

Meryem Beklioglu, Erik Jeppesen and Martin Søndergaard

This deliverable include three research papers and one PhD thesis on hydrology and temperature effects on lakes and consequences for restoration

1) *Tuba Bucak, Ece Saraoğlu, Eti, E. Levi, Ü. Nihan Tavşanoğlu, A. İdil Çakıroğlu, Erik Jeppesen & Meryem Beklioğlu. 2012. The role of water level for macrophytes growth and trophic interactions in Mediterranean shallow lakes: a mesocosms experiment with and without fish. Freshwater Biology 57(8): 1631-1642 (attached)*

2) *Ü. Nihan Tavsanoğlu, A. Idil Çakıroğlu, Seyda Erdoğan, Mariana Meerhoff, Erik Jeppesen, Meryem Beklioğlu. 2012. Sediment – not plants – is the preferred refuge for Daphnia against fish predation in Mediterranean shallow lakes: an experimental approach. Freshwater Biology- 57(4): 795-802 (attached).*

3) *Gizem Bezirci, Sara B. Akkas, Karsten Rinke, Feriha Yildirim, Zeynep Kalaylioglu, Feride Severcan, Meryem Beklioglu. 2012. Impacts of salinity and fish-exuded kairomone on the survival and macromolecular profile of Daphnia pulex. Ecotoxicology (2012) 21:601–614 DOI 10.1007/s10646-011-0820-0 (attached)*

4) *Ülku Nihan Yazgan Tavşanoğlu.2012 Zooplankton adaptation strategies against fish predation in Turkish shallow lakes. PhD. Thesis, Department of Biology, Middle East Technical University (METU): Supervisor Prof. Dr. Meryem Beklioğlu Yerli, Co-Supervisor: Prof. Dr. Erik Jeppesen, December 2012, 181 pages Ankara, Turkey. (only the abstract attached)*

5) *Jeppesen E., M. Søndergaard, T.L. Lauridsen, T.A. Davidson, Z. Liu, N. Mazzeo, C. Trochine, K. Özkan, H. S. Jensen, D. Trolle, F. Starling, X. Lazzaro, L.S. Johansson, R. Bjerring, L. Liboriussen, S. E. Larsen, F. Landkildehus & M. Meerhoff, 2012. Biomanipulation as a restoration tool to combat eutrophication: recent advances and future challenges - Adv. in Ecol. Res. 47:411-487 (attached)*

Synthesis

High water-level fluctuations are typical of lakes located in the semi-arid Mediterranean region, which is characterized by warm rainy winters and hot dry summers. Ongoing climate change with severe episodes of drought may lead to lower and more variable water levels, longer hydraulic retention time and eutrophication as nutrient concentrations increase in the remaining water. Higher hydraulic retention time also triggers salinization. In addition, the cascading effect of top-down control by fish as well as the nutrient cycling is sensitive to changes in temperature. Information on the effects of water level and temperature on in-lake trophic dynamics and their interactions is crucial in such regions and may have profound implications for restoration.

In Mediterranean region, major water level decline during summer owing to higher evaporation, may potentially help maintaining the growth of macrophytes even in eutrophic shallow lakes and therefore at least partly, counteract the effect of reduced clarity that is expected with global warming as a consequence of enhanced eutrophication. We conducted an experiment at contrasting water level in a Turkish shallow lake. Confirming the above hypothesis, we showed that lower water level help maintaining the growth of macrophytes in a Mediterranean eutrophic shallow lake, despite a stronger (negative) cascading effect of fish predation on water clarity. Laboratory and field studies further showed large-bodied grazer *Daphnia* avoid submerged macrophytes and instead prefer to hide near the sediment when exposed to predation risk, because of high fish densities in the vegetation. These results confirm earlier finding that the macrophytes are less efficient refuge for large bodied zooplankton than in the north temperate lakes making these lakes more vulnerable to a shift to a turbid state when the nutrient level increases, due to reduced grazing on phytoplankton. A multi-lake study of 31 Turkish lakes confirmed this hypothesis.

In semi-dry Mediterranean climatic regions, excessive water use especially for irrigated crop farming and global warming also enhances salinization of inland freshwater lakes, with strong influence on the zooplankton community structure. The 31 lake study showed that a shift towards smaller sized classes including rotifers, which are less efficient of grazers on phytoplankton. Salinity strongly control *Daphnia* populations through increased mortality, decreased reproduction, and reduced growth rate. Global warming-induced increase in salinity may therefore also cascade through the food web and lead to higher risk of having turbid waters in warm and dry region.

Lake restoration may therefore be more difficult in warm regions. Nutrient loading reduction and reduced water abstractions are the first step needed to restore eutrophic lakes. In Mediterranean climatic regions, restrictions on human use of water especially irrigation purposes as well as on nutrient loading to lakes are urgently needed to restricted to achieve good ecological status (WFD). To fulfil this objective, adaptation measures are required. In Mediterranean climatic zones the obvious methods are to change agricultural practices for reducing demand for water and the loss of nutrients to surface waters, to improve sewage treatment and to reduce the storm-water nutrient runoff. In warm Mediterranean zone adaptations may also include re-establishment of artificial and natural wetlands, introduction of riparian buffer zones and re-meandering of channelised streams, which may all have a large impact on, not least, the N loading of lakes. In-lake measures may, however, help speeding up the recovery after such measures to redeuce the nutrient loading have been taken. One such method is biomanipulation. A review of biomanipulation methods and results, included in this study, indicate that it might be possible to enhance water clarity even in warm freshwater lakes by removing the dominating benthic fish, such as carp, though the long term effects of such measures are lacking. It is suggested that dual treatment including both biomanipulation and chemical treatment of the sediment to immobilise phosphorus might be a way forward to enhance the chance of long-term effects of in-lake restoration of lakes in all climate zones.

The 4 papers and a PhD thesis are summeried by their abstracts as follows:

1) The influence of water level on macrophyte growth and trophic interactions in eutrophic Mediterranean shallow lakes: a mesocosm experiment with and without fish.

1. Water-level fluctuations are typical of lakes located in the semi-arid Mediterranean region, which is characterized by warm rainy winters and hot dry summers. Ongoing climate change may exacerbate fluctuations and lead to more severe episodes of drought, so information on the effects of water level on the functioning of lake ecosystems in such regions is crucial.
2. In eutrophic Lake Eymir, Turkey, we conducted a 4-month (summer) field experiment using cylindrical 0.8-m- (low-water-level) and 1.6-m-deep (high-water-level) mesocosms (kept open to the sediment and atmosphere). Fish (tench, Tinca tinca, and bleak, Alburnus escherichii) were added to half of the mesocosms, while the rest were kept fishless. Ten shoots of Potamogeton pectinatus were transplanted to each mesocosm.
3. Sampling for physicochemical variables, chlorophyll a (chl-a), zooplankton and per cent plant volume inhabited (PVI%) by macrophytes was conducted weekly during the first 5 weeks, and subsequently biweekly. Macrophytes were harvested on the last sampling date. During the course of the experiment, the water level decreased by 0.41 ± 0.06 m.
4. Throughout the experiment, fish affected zooplankton abundance (-), nutrient concentrations (+), chl-a (+) and water clarity (-) most strongly in the low-water-level mesocosms and the zooplankton community shifted towards dominance of small-sized forms. The fishless mesocosms had a higher zooplankton/phytoplankton ratio, suggesting higher grazing.
5. Greatest macrophyte growth was observed in the low-water-level fishless mesocosms. However, despite high nutrient concentrations and low water clarity, macrophytes were also abundant in the fish mesocosms and particularly increased following a water-level decrease from midsummer onwards. Macrophyte growth was poor in the high-water-level mesocosms, even in the fishless ones with high water clarity. This was ascribed to extensive periphyton development reducing light availability for the macrophytes.
6. Our results indicate that a reduction in water level during summer may help maintain the growth of macrophytes in Mediterranean eutrophic shallow lakes, despite a strong negative effect of fish predation on water clarity. It is therefore probable that an expected negative effect of global climate change on water clarity because of eutrophication and enhanced top-down control of fish may be, at least partly, counteracted by reduced water level, provided that physical disturbance is not severe.

2) Sediments, not plants, offer the preferred refuge for Daphnia against fish predation in Mediterranean shallow lakes: an experimental demonstration

1. Different behavioural responses of planktonic animals to their main predators, fish, have been reported from shallow lakes. In north temperate lakes, large-bodied zooplankton may seek refuge from predation among macrophytes, whereas in subtropical lakes, avoidance of macrophytes has been observed. The prevalent behavior probably depends on the characteristics of the fish community, which in Mediterranean lakes is typically dispersed in both the open water zone and in the littoral, as in temperate lakes, and is dominated by small size classes, as in subtropical lakes. 2. We performed ‘habitat choice’ experiments to test the response of Daphnia magna to predation cues at both the horizontal and vertical level by mimicking a ‘shallow littoral’ zone with plants and a ‘deeper pelagic’ zone with sediments.
3. Initial separate response experiments showed that natural plants, artificial plants and predation cues all repelled D. magna in the absence of other stimuli, while sediments alone did not trigger any significant response by D. magna.
4. The habitat choice experiments showed that, in the presence of predation cues and absence of plants, Daphnia moved towards areas with sediment. In the presence of both

plants and sediments, Daphnia moved away from the plants towards the sediments under both shallow and deep water treatment conditions.
5. Based on these results, we suggest that Daphnia in Mediterranean shallow lakes avoid submerged macrophytes and instead prefer to hide near the sediment when exposed to predation risk, as also observed in subtropical shallow lakes. This pattern is not likely to change with water level alterations, a common feature of lakes in the region, even if the effectiveness of the refuge may be reduced.

3) Impacts of salinity and fish-exuded kairomone on the survival and macromolecular profile of *Daphnia pulex*.

Global warming is already causing salinization of freshwater ecosystems located in semi-arid regions, including Turkey. Daphnids, which are important grazers on phytoplankton and a major food source for fish and invertebrates, are sensitive to not only changes in salinity levels, but also presence of predators. In this study, the interactive effect of salinity toxicity (abiotic factor) with predation pressure mimicked by the fish-exuded kairomone (biotic factor) and the effect of salt acclimation on daphnids were investigated. Impacts of these stressors on daphnid survival, life history and molecular profile were observed. The presence of the kairomone antagonistically alters the effect of salinity, as observed from the 24- and 48-h values and survival results. Molecular findings provided solid evidence to this antagonism at even lower salt concentrations, for which antagonism was not evident with organismal data. Fish predation counterbalances the negative effect of salinity in terms of reserve energy den- sity. Therefore, it is important to investigate multiple stressor effects in ecotoxicological bioassays complemented with molecular techniques. The single effect of increasing salinity resulted in increased mortality, decreased fecundity, and slower somatic growth in Daphnia, despite their acclimation to salinity. This insignificance of acclimation indicates that Daphnia do not have any physiological mechanisms to buffer the adverse effects of salinity, making it a very crucial factor. Salinity-induced reduction in population growth rate of freshwater keystone species Daphnia—despite acclimation—indicates that global warming-induced salinity may cascade through the food web and lead to dramatic environmental conse- quences in the structure of lake ecosystems.

4) Zooplankton adaptation strategies against fish predation in Turkish shallow lakes.

In this PhD study, the factors influencing zooplankton community structure in Turkish shallow lakes were elucidated with four main approaches: (i) space-for-time substitution for shallow lakes using snap-shot sampling in 31 lakes along a latitudinal gradient; (ii) *in-situ* mesocosm experiments in eleven lakes along a latitudinal gradient using three sets of artificial plants systems; (iii)'Habitat Choice' laboratory experiments mimicking a 'shallow littoral' zone with plants and a 'deeper pelagic' zone with sediments testing the response of *Daphnia magna* to predation cues; and (iv) long-term monitoring data (1997-2011) from two interconnected lakes. Snap-shot and long-term monitoring showed that eutrophication has a strong influence on the zooplankton community via increased fish predation, nutrient loading and salinization. Here too the zooplankton community shifted towards a smaller sized profile, especially in lakes located at lower latitudes. Moreover, The laboratory and *in-situ* mesocosm experiments revealed that under predation risk *Daphnia* preferred to hide near sediment instead of using submerged plants as a refuge. Accordingly, *in-situ* mesocosm experiments revealed a predation pressure induced size structure shift towards small-medium sized zooplankton and calanoid copepods. The long-term monitored lakes experienced (i) drought-induced water level drop, leading to increased salinity and eutrophication, and consequent anoxic conditions and fish kill; as well as (ii) biomanipulation in the downstream lake. Both conditions resulted in major reduction in the top-down control of fish and ultimate predomination by large sized Daphnia spp. Nevertheless, the excessive exploitation of lakes and ongoing warming entail Turkish shallow lakes to become more eutrophic, making this study indicative for the Mediterranean region.

5) Biomanipulation as a restoration tool to combat eutrophication: recent advances and future challenges

Eutrophication resulting from high nutrient loading has been the paramount environmental problem for lakes world-wide for the past four decades. Efforts are being made in many parts of the world to reduce external nutrient loading via improved wastewater treatment or diversion of nutrient-rich inflows. However, even after a reduction of the external phosphorus loading, the effects obtained may be unsatisfactory. This may reflect an insufficient reduction in the external nutrient loading to effectively limit phytoplankton growth. However, the lack of success may also be due to chemical or biological within-lake inertia preventing or delaying improvements. To overcome the resilience and thereby reinforce recovery, a number of physico-chemical and biological restoration methods have been developed. In this chapter, we describe recent developments of biological restoration methods related to eutrophication, their short-term and long-term effects, and discuss the possibility of using combined physico-chemical and biological methods to improve the long-term stability of restoration and to reduce restoration costs. As comprehensive reviews of the effect of fish manipulation in cold temperate lakes are numerous, for these waterbodies, we highlight recent results, including effects on biodiversity and metabolism, and present new approaches of biomanipulation. Our particular focus is, however, directed at biomanipulation in warm lakes and on combined treatments which are far less well described in the literature.