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Climate change – Temperature and light: two driving forces for aquatic biology

Figure 2. *„Burning globe". Source: www.linfield.edu*

Editorial

Dear Reader

Politicians still debate what is evidence for most scientists: whether global warming is happening at all and whether it is driven by human activities (i.e. greenhouse gas emissions). However, all measurements and long-term data sets show that global warming is a fact, whether man-made or not. Climate history archived in Greenland ice over millennia by included air bubbles shows that the recent increase in temperature and greenhouse gases during the past 50–100 years exceeds any historical fluctuations. Actually, global warming is clearly evident by excess glacier melt, significant global changes in precipitation patterns and extreme weather events such as more frequent and heavier storms, floods and droughts. Although model predictions and scenarios are coupled with uncertainty, the general trends are uniform and clear *(Figure 1)*. Since temperature increase is coupled with CO_2 increase, human influence is very likely. Human growth and activity after the technical revolution have increased greenhouse gas emissions and outbalanced the global sources and sinks of CO_2. Major consequences are, amongst others, ocean level rise and desertification. It is clear that human society will be largely affected, e.g. by large-scale water shortages, and the big question is how to cope with this problem and how to adapt.

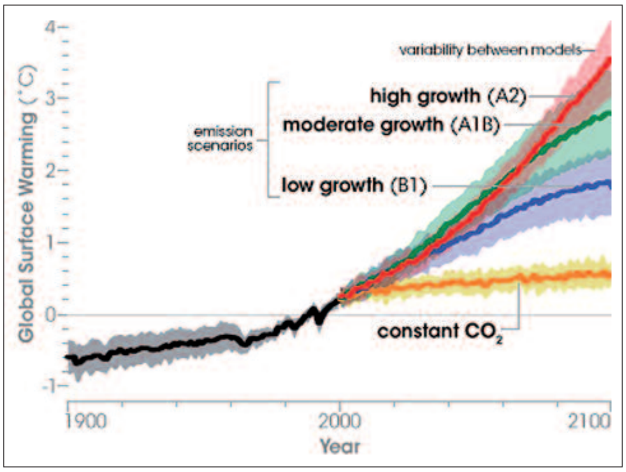

Figure 1. *Temperature projections to the year 2100, based on a range of emission scenarios and global climate models. Scenarios that assume the highest growth in greenhouse gas emissions provide the estimates in the top end of the temperature range. The orange line ("constant CO_2") projects global temperatures with greenhouse gas concentrations stabilized at year 2000 levels. Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S, Qin D, Manning M (eds.)])*

This issue of Danube News treats some selected aspects of global warming in the Danube River Basin (DRB). Two articles demonstrate the physical and hydrological changes in riverine ecosystems and discuss measures how to handle the consequences thereof. Two articles deal with changes in temperature and light as the driving forces for aquatic insect and fish life histories. The objective is to learn and know more about these natural factors that ultimately are the basis of human ecology, economy and welfare. Public awareness and public participation are key issues for an environmental policy that aims to obtain true "sustainable" development in the DRB. This was demonstrated in March 2011 by the ICPDR having initiated a new Expert Group led by Professor Mauser and his GLOWA team from the University of Munich. This team will prepare a study on Climate Change Adaptation Strategies in the DRB as the basis for the development of such a strategy during 2012. May such efforts lead to good solutions and this Danube News help the ongoing and never ending climate debate to be more objective.

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GLOWA-Danube: Integrative techniques, scenarios and strategies for the future of water in the Upper Danube Basin

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Introduction

Global Change will have regional impacts on the water resources in Central Europe and thereby on future human livelihood (IPCC 2007). In order to identify regional effective and efficient adaptation strategies, the interdisciplinary research project GLOWA-Danube (www.glowa-danube.de) focused on the comprehensive analysis of the future water availability of the Upper Danube Basin. This includes the impact of climate, demographic and socio-economic changes on the water resources until 2060 for industry, agriculture, tourism and others. Additionally, key stakeholders from policy, economy and administration were involved in the development of adaptation strategies.

The large-scale, mountainous watershed of the Upper Danube, defined by the outlet gauge Achleiten near Passau after the confluence of the Rivers Inn and Danube *(Figure 1)*, is one of the largest and most important alpine watersheds in Europe with an area of 76 660 km² and more than 10 million inhabitants. It is characterized by heterogeneous natural conditions as well as a complex and intensive use of water resources for e.g. hydropower, farming or tourism. The Upper Danube Basin thus combines many water use challenges of Central Europe and is particularly vulnerable to climate change.

The decision support system DANUBIA

For the analysis of the impacts of Global Change on the water resources and the development of appropriate adaptation strategies, the integrative decision support system DANUBIA (Barth et al. 2004) was developed. It is a coupled simulation model, which includes model components describing natural and socio-economic processes and their interactions (www.glowa-danube.de). DANUBIA was successfully validated with comprehensive data sets of the years 1970–2005 and was then applied under scenario conditions. The results were discussed with key stakeholders from policy, economy and administration within an intensive dialogue to develop appropriate adaptation measures. In the following DANUBIA runs, these measures were taken into account and discussed again to check their efficiency. All results are published in the "Global Change Atlas Obere Donau" (GLOWA-Danube project 2010) as print and online version (http://www.glowa-danube.de/atlas/index.php) to support decisions in relation to Global Change adaptation strategies.

Figure 1. The investigation area of the Upper Danube River Basin. The gauge at Achleiten near Passau measures the discharge of the watershed

The GLOWA-Danube scenarios

The GLOWA-Danube scenarios describe a feasible range of possible climate and social developments for the period from 2011 to 2060. They are all based on the IPCC SRES A1B emission scenario (IPCC 2007). In order to cover a plausible range of uncertainties, the regional trend of various Regional Climate Model (RCM) outputs was reproduced by using the stochastic climate generator KLIMAGEN (Mauser 2010). The social scenarios offer three alternatives, which take into account inter alia new technologies, the globalisation as well as demographic, economic and political decisions. They distinguish between continuing the current status-quo, a society focusing on economic efficiency and a society characterized by returning to the overall social responsibility.

Depending on the chosen scenario, the mean annual air temperature will increase between 3.3 and 5.2°C, continuing the observed increase of 1.6°C since 1960 in the Upper Danube Basin. While in the past precipitation was slightly decreasing during summer, a small increase was observed during winter. In the scenario period, precipitation will decrease during summer by 14–69% and increase in winter by 8–47%, summing up to an annual reduction of 4–16%.

Impact of Global Change on the water balance in the Upper Danube

In the following section, selected results of the impact of Global Change on the water balance in the Upper Danube

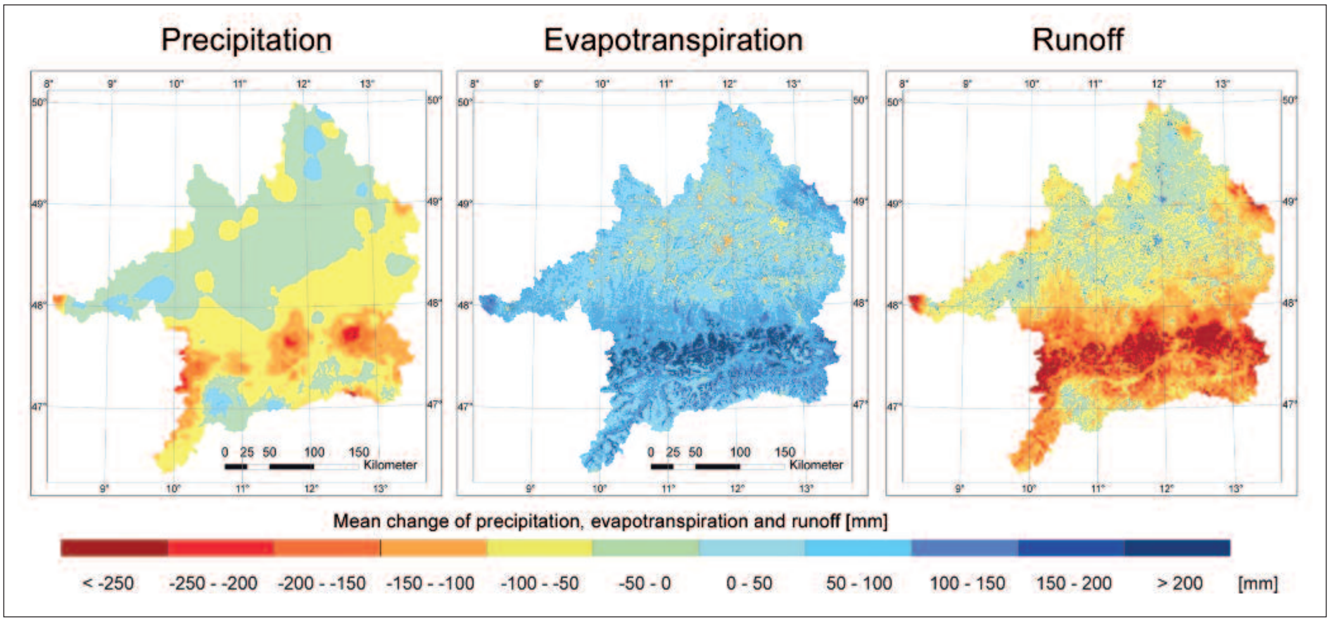

Figure 2. Difference of the water balance between the two periods 2036–2060 and 1971–2000 in the Upper Danube. As an example, this calculation is based on the combined scenario REMO regional (climate trend) and Baseline (climate variant)

are shown. More and detailed results can be found on http://www.glowa-danube.de/atlas/index.php.

The increasing temperatures in the scenarios result in a continued decrease of the snowfall fraction which on average will amount to 18 % until 2050. In comparison to the past, this equals a reduction of 7 % and leads to a reduced snow coverage of 30 to 60 days throughout all altitudes in the Upper Danube Basin. Present snow conditions of 1000 m a.s.l. will be found at 2000 m a.s.l. in 2060. Additionally, temperature increase causes a rising evapotranspiration of 10 to 25 %. Together with the changes in precipitation, future water availability will be reduced particularly along the northern rim of the Alps, where precipitation will decrease and evapotranspiration increase because of a longer growing season *(Figure 2)*. In contrast, in the northern part of the watershed a slight increase of water availability is partly modelled, which is due to small changes in the amount of precipitation and a reduction of evapotranspiration because of drought stress.

The seasonal course of runoff at the outlet gauge Achleiten shows a shift of the maximum from summer to spring from 1961 to 2060. This shift is attributed to the reduction of snow storage and the increasing evapotranspiration during summer, because the seasonal course of precipitation with its maximum during summer will not change *(Figure 3)*.

The impact of Global Change on extreme runoff events was also analysed. The low flow will decrease between 25

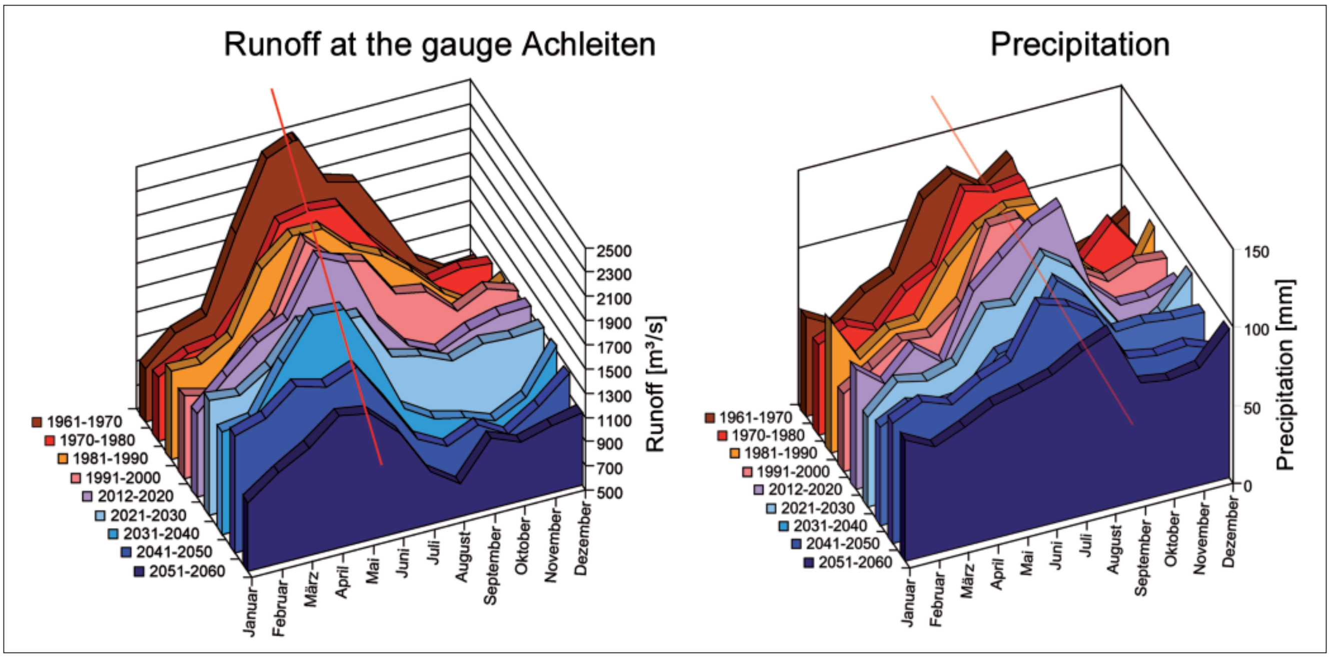

Figure 3. Decadal course of monthly precipitation in the Upper Danube watershed and discharge from 1961 to 2060 at the outlet gauge of Achleiten

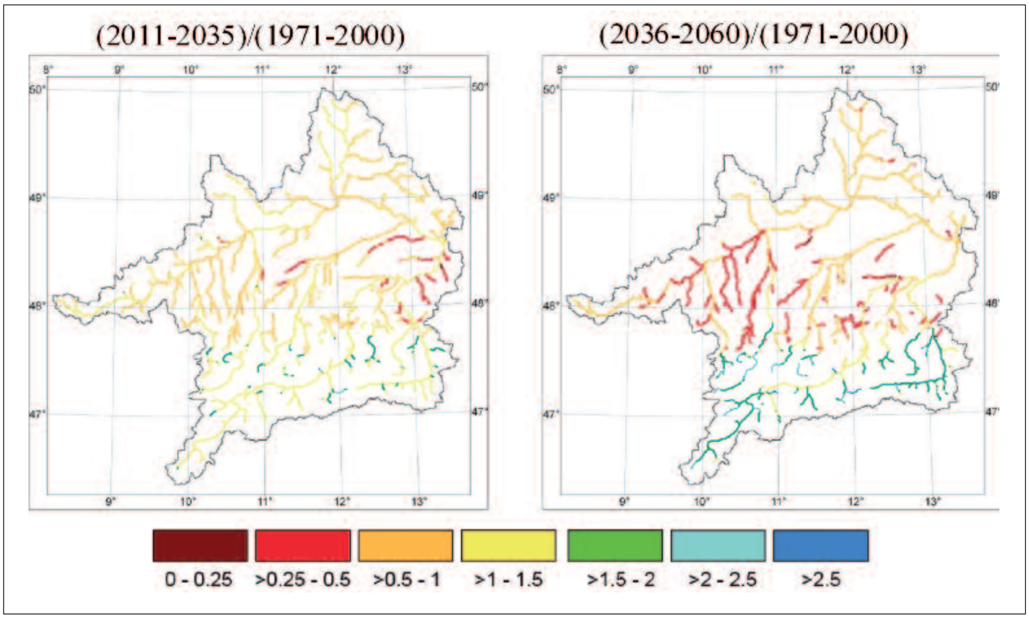

Figure 4. Ratio of $NM7Q_{50}$ between the future periods (2011–2035 and 2036–2060) and the past period (1971–2000).
As an example, this calculation is based on the combined scenario REMO regional (climate trend) and Baseline (climate variant)

to 52 % in Achleiten. In contrast to this sharp reduction along the Upper Danube River, an increase of low flow is modelled under scenario conditions in the alpine valleys. Reasons are transformation of snowfall into rainfall and melting glaciers. The changes of low flow in the river network of the Upper Danube watershed are illustrated for one scenario in *Figure 4* showing the ratio of $NM7Q_{50}$ (7-day minimum flow with recurrence period of 50 years) between the future periods (2011–2035 and 2036–2060) and the past period (1971–2000).

The ratio of the flood occurring statistically every 100 years (HQ_{100}), analysed in accordance to the $NM7Q_{50}$ ratio, as average over all 16 climate scenarios is shown in *Figure 5*. The results indicate an increase of flood peaks in the alpine valleys and headwatersheds (green, yellow, red). In the other parts of the watershed the flood peaks stay almost stable (blue). This again can be explained by changes of the snow-rainfall fraction.

Conclusion and outlook

The analysis of the scenario model runs shows a reduction of the water availability in the range of 5 to 35 % depending on the scenario at Achleiten, but indicates no water scarcity in the Upper Danube Basin. Besides several other consequences, a reduction of hydropower production is modelled. The worsening of the low flow situation together with increasing water temperatures causes a reduced amount of cooling water, e.g. for thermal power stations during summer. Additionally, navigation will be limited during low flow situations. The reduced snow storage at lower elevations intensifies winter tourism at higher elevations. Accordingly, 20 to 50 % of today's ski areas will no longer be able to secure their existence through ski tourism. In farming, the harvest of crops will be advanced by three weeks, but planning reliability is assumed to decline due to larger inter-annual variability of weather conditions.

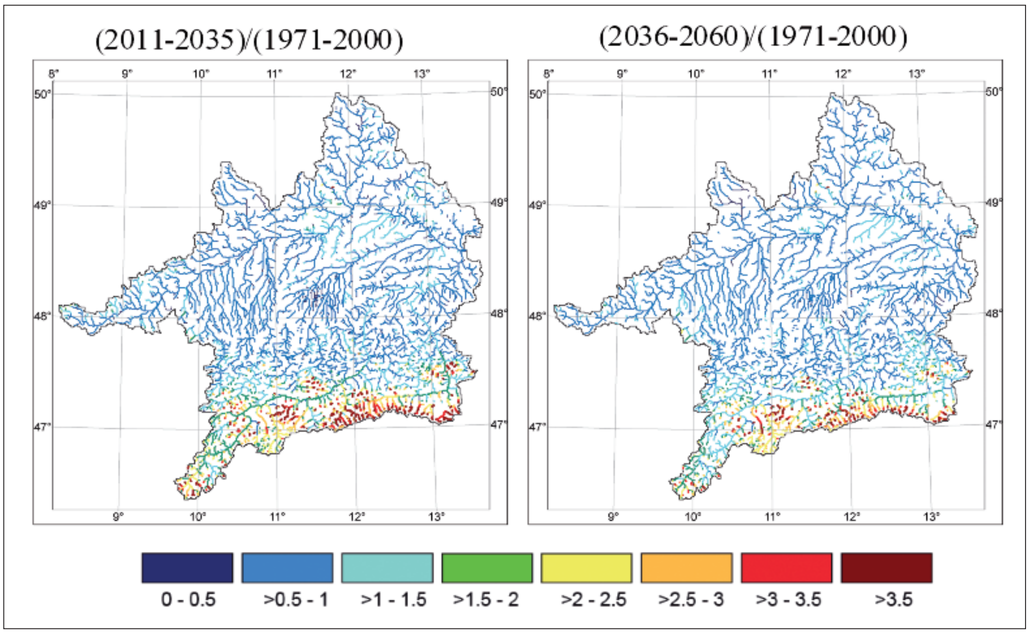

Figure 5. Ratio of average HQ_{100} over all 16 climate scenarios between the future periods (2011–2035 and 2036–2060) and the past period (1971–2000)

These consequences, particularly the reduced amount of water released, are not only of importance in the Upper Danube Basin but also impact the downstream countries. In order to provide foundations for a common, Danube Basin-wide understanding for the development of adaptation strategies to climate change in water related issues, a study was launched in December 2010 by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). In close collaboration with the ICPDR and a team of experts, ongoing adaptation activities in the Danube watershed are being analysed until the end of 2011. The outcomes of this study will be the main basis for the development of the Climate Change Adaptation Strategy of the ICPDR in 2012 (see logo).

Acknowledgements

All project partners are gratefully acknowledged for their collaboration. We also would like to thank the German Federal Ministry for Education and Research (BMBF), the State of Bavaria and the Ludwig-Maximilians-Universität Munich for funding the GLOWA initiative. We acknowledge the Germany's National Meteorological Service (DWD), the Central Institute for Meteorology and Geodynamics (ZAMG) and the Bavarian Environment Agency (LfU) for providing data.

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Melting glaciers: Is there an impact on the Danube hydrology?

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Glaciers and runoff

Mountains are often regarded as ''water towers'' providing vital amounts of water to large rivers (Viviroli et al. 2007). Glaciers are the topmost element of the headwaters in many watersheds. They are important water storage components in the hydrological cycle and act as water reservoirs at the seasonal, but also at the multi-decadal time scale. It is evident that the water contribution from glaciers is negatively correlated to water stress in dry alpine valleys and in the lowlands: In summer, glaciers release the water that was added to intermediate storage during winter in the form of snow. At longer time scales, glaciers increase their water storage in cold and wet years, and contribute importantly to runoff in hot and dry years when there is the greatest water need, e.g. for agriculture. Hence, the role of glaciers in moderating low flow in the summer months is considerable. With the expected retreat of alpine glaciers in the next decades there is an increasing concern about water supply security in the European Alps and the adjacent plains. Future changes in hydrology are likely to have strong socio-economic impacts at a regional and a global scale (Kaser et al. 2010; Weber et al. 2010).

The Danube is the largest river originating in the European Alps. In many parts of its headwaters glaciers are present. In total, there are about 1100 glaciers in the hydrological basin of the Danube currently covering an area of roughly 470 km^2. Most of them are located in Austria and some in Switzerland. Many glaciers in the Danube Basin are relatively small. The largest glaciers (e.g. Pasterze, Vadret da Morteratsch, Gepatschferner) form impressive glacier tongues that reach far down into the valleys. The glacierization of the Danube headwaters is considerable: 4.5 % of the drainage basin of the Inn at Innsbruck is covered with glacier ice. When moving downstream, however, the glacierization drops to insignificant values. The Danube catchment with a size of more than 800 000 km^2 at the Black Sea is only glacierized by 0.06 %, a fraction which might seem negligible. Thus, the question arises: Does glacial melt water in the Danube headwaters has a supra-regional impact? Are glaciers important to the hydrology of the entire Danube or only in the mountainous regions?

Retreating glaciers in the Alps

Glaciers are excellent indicators of climate change. Their retreat is an obvious signal of climate warming, which is easily understandable also for the non-scientist. Glaciers in the European Alps have reached a last maximum extent in the so-called Little Ice Age around 1850. Large moraines still indicate the glacier size at that time. A strong loss of glacier ice volume has been observed over the last century. The termini of large glaciers, such as Vadret da Morteratsch and Vadret da Roseg in the Upper Engadine (Switzerland) have retreated by almost 3 km *(Figure 1).*

The response of glaciers to variations in climate is most directly revealed by their mass balance. In years with a cold summer and important snowfalls in wintertime the mass balance is positive; glaciers increase their volume and take

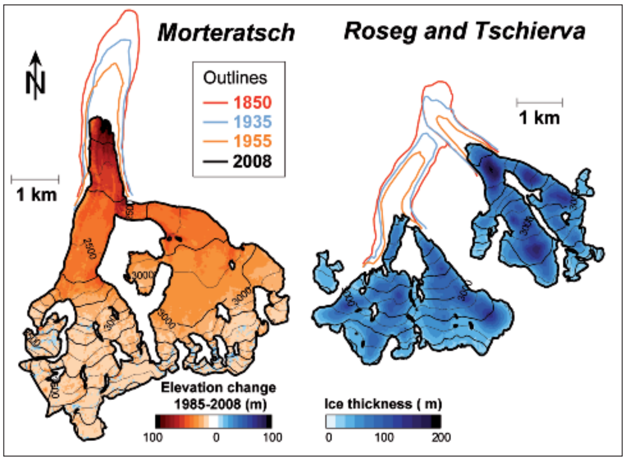


Figure 1. Retreat of two large glaciers in the Danube catchment in response to atmospheric warming since the end of the Little Ice Age. Lines indicate the size of the glacier in 1850, 1935 and 1955. The glaciers have retreated by up to 3 km. For Vadret da Morteratsch (left, current size: 15 km²) the change in ice surface elevation over the last two decades is displayed. A decrease in surface elevation is evident all over the glacier with a maximum of up 4 metres per year near the glacier terminus. For Vadret da Roseg and Vadret da Tschierva (right), two valley glaciers that were still connected 100 years ago, the current ice thickness is displayed, which reaches a bit less than 200 metres at maximum. Since 1900 the two glaciers have lost about 60% of their ice volume and are expected to have disappeared completely by around 2080 (Figure from Huss et al. 2010b)

water out of the hydrological cycle. Warm and dry years, however, lead to a negative mass balance, as more ice is melted than is added to glacial storage by precipitation in the form of snow.

For 50 glaciers in Switzerland long-term mass balance series with a monthly resolution were compiled (Huss et al. 2010a, b). These series originate from a comprehensive set of field measurements performed on the glaciers covering almost the entire 20th century. The field data were evaluated using a detailed numerical model for snow accumulation and melt over the glaciers. Thus, for each month in the period 1908 – 2008 the quantity of water provided by the investigated glaciers is known, and is extrapolated to all glaciers in the Danube Basin.

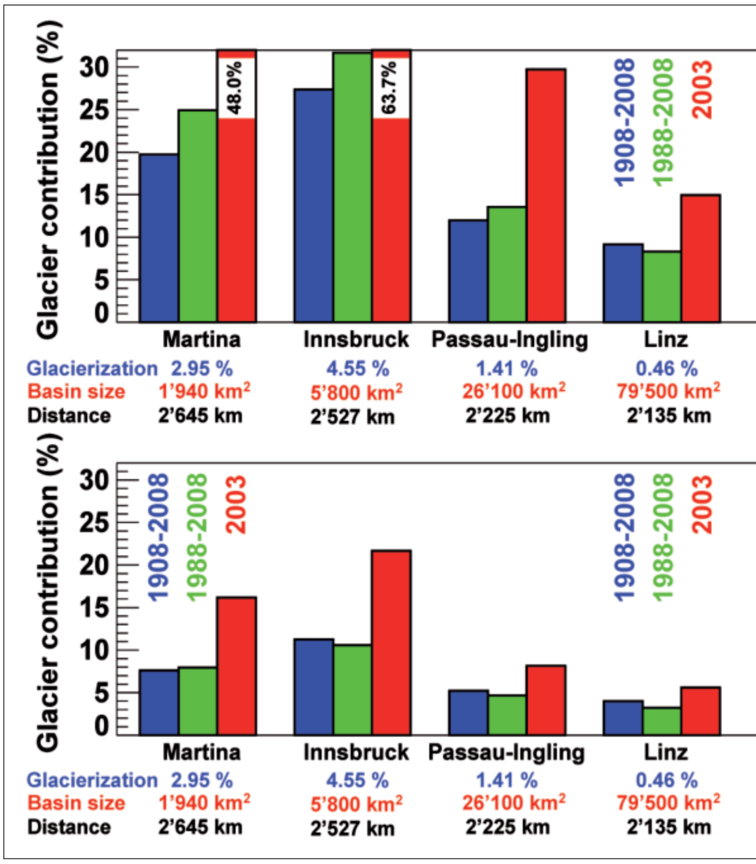
The decrease in ice volume of glaciers in the European Alps over the last century is considerable. Glaciers have lost more than half of their volume since the Little Ice Age, and some of them have already completely disappeared. Large valley glaciers are out of equilibrium with climate. Even with a stabilization of temperatures at the current level, they would continue to retreat considerably. Consequently, large quantities of water are released from long-term glacial storage by a reduction of the glacier ice volume.

The decrease in ice volume in the Alps was not linear over the last century: Glaciers even showed slight mass gains in the 1910s and 1970s resulting in short periods of re-advance of many glaciers. At that time some newspapers were even speculating about the onset of a new ice age – which was not the case as we now know. The 1940s and the last two decades were characterized by a particularly fast glacier mass loss. The most extreme years were 1947 and 2003. The latter is well remembered for the strong heat waves affecting large parts of the European continent. Glacier ice melt in that year was almost three times larger than on the long-term average.

Past and present contribution of glaciers to Danube runoff

Estimating the contribution of glacier melt water to the runoff from large-scale drainage basins, such as the middle and lower reaches of the Danube is not trivial. The effective runoff is determined by a number of complex natural interaction processes as well as human water use. Therefore, a simple approach was adopted: Monthly water input into the hydrological system provided by glacierized surfaces is compared to discharge measured at seven gauges along the Danube. Changes in water storage in the glaciers for each month are given by the comprehensive data set of glacier mass balance. The time glacial melt water needs to reach the gauges is accounted for (some days to almost two months). Thus, the percentage of total discharge that is provided by glaciers can be evaluated. The analysis is performed for the summer months August and September, when glaciers are most important to discharge as snow melt runoff from non-glacierized regions is then close to zero.

For a catchment in the mountainous headwaters of the Danube (Inn at Innsbruck), in August glaciers contributed to runoff by 27 % on average over the last century (blue bars in *Figure 2).* In September, glacier contributions in the headwaters are smaller, but still significant. Glacial melt water importantly determines the runoff regime in the headwaters of



the Danube and provides large water volumes in summer. Without the water supply from glaciers in the late summer months, runoff would be strongly reduced with consequences on ecology and human activities.

Along the course of the Danube, the relative contribution of glaciers to observed runoff at the selected gauges only decreases slowly, and in September it even remains at an almost constant level in the Middle and Lower Danube. Also with a very small glacierization of the basin (less than 0.1 %) the contribution of glaciers to runoff was around 4 % on average over the last century in the late summer months *(Figure 2).* Hence, glaciers have a recognizable impact on the runoff regime even in the Lower Danube.

The impact of glacial melt water on Danube discharge is even more pronounced in periods of glacier retreat. If the ice volume decreases, large quantities of water are released from long-term storage. The last two decades were characterized by particularly fast ice loss. This has caused an increase in the contribution of glaciers to Danube runoff (green bars in *Figure 2).* The increase in glacier runoff since the 1980s is, however, limited as the glacier area that yields melt water in summer is significantly smaller than 100 years ago. In fact, the contribution of glaciers to runoff in the last five years was below the century average. This indicates that glaciers have already started losing their contribution potential because of their continuously reducing size – a process that will increase in importance over the next decades.

The extreme heat waves of the year 2003 have caused severe droughts in many parts of Europe. The runoff of the Danube was significantly lower in the summer months due to very dry weather conditions. But glaciers provided quantities of melt water that were much higher than in normal years. This results in highly important glacier contributions to runoff in the Danube. At Innsbruck, for example, 64 % of the observed runoff originated from glacier melt in August 2003, and at Bogojewo, with a fraction of ice-covered areas of only 0.19 %, melt water still accounts for 18 % (red bars in *Figure 2).* This illustrates the importance of glaciers in moderating low flow conditions due to droughts in the summer months, and shows the supra-regional impact of glacier melt. Runoff in the Lower Danube can be significantly affected by the presence of distant and, compared to the total basin size, small glaciers.

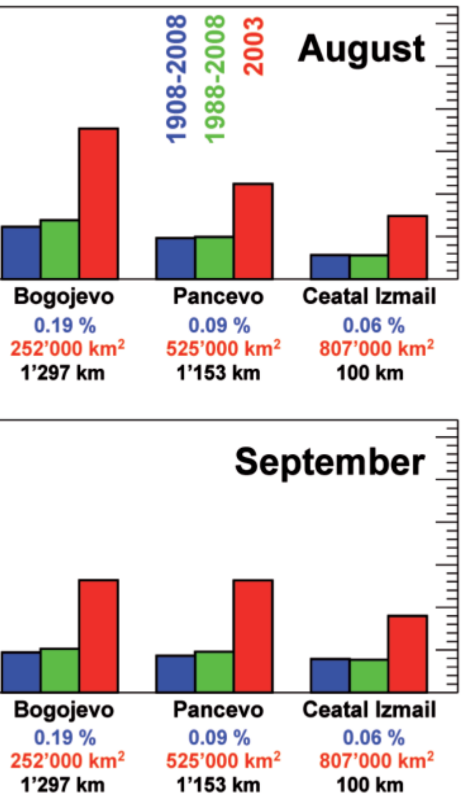


Figure 2. Contribution of glaciers to runoff along the Danube in August and September. The percent of runoff originating from glaciers is given for three periods: the entire 20th century (1908–2008), the last two decades (1988–2008), and the extreme year 2003 (Figure from Huss, submitted)

But why does the minor fraction of glacierized surfaces so significantly contribute to runoff far downstream of the Danube? A glacier area of less than 500 km² seems to be negligible compared to the total Danube Basin with 800 000 km² at the Black Sea. Nevertheless, the glacier contribution was 9 % in September 2003 at Ceatal Izmail close to the Danube Delta! The explanation lies in the strong seasonality of glacier storage change. Annual precipitation over glaciers can be higher by a factor of more than five compared to the lowlands. In addition, this water is accumulated over almost the entire year and is mainly released in only two months (July and August). This large quantity of water input into the tributaries of the Danube enhances runoff in a period of the year, when very little discharge is generated in the lowland areas: In summer precipitation is generally small and losses by evapotranspiration are high. For these reasons, glaciers importantly contribute to summer runoff also in the middle and the lower reaches of the Danube.

Perspectives for the future

Until the end of the 21st century a significant warming of between 2.1°C and 7.8°C is expected for the European Alps according to climate simulations (Christensen & Christensen 2007). The retreat of 50 glaciers in the Alps was calculated using a numerical glacier model for mass balance and ice flow. *Figure 3* illustrates the calculated retreat of the largest glacier in the European Alps, Great Aletschgletscher. Whereas smaller glaciers are expected to disappear within the next decades according to the most likely future climate change, the largest glaciers in the drainage basin of the Danube might still be present by 2100, however, in strongly reduced size. Overall, the model results indicate a loss of 96% of the area of glaciers feeding their melt water into the Danube by the end of this century.

For the next decades, glaciers are expected to show strong melting, thus providing quantities of water that are comparable to the past. In high-mountain catchments with large glaciers, runoff might even show an increase due to the release of water from glacial storage. The runoff regime in the headwaters will, however, soon shift from a glacial to

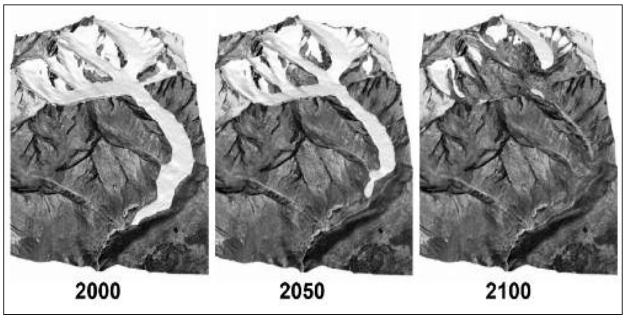


Figure 3. Modelled future glacier retreat of Great Aletschgletscher, the largest glacier in the European Alps (drainage basin of the Rhone). The numerical glacier model was forced with the most likely changes in temperature and precipitation given by climate simulations. Until the mid-21st century a strong thinning of the glacier tongue is expected, but the change in glacier length is still limited. By 2100, the glacier will probably have split up into individual branches and the 14 km long glacier tongue might have completely disappeared (Figure from Jouvet et al., submitted)

nival type due to the fast shrinkage of ice-covered areas. Especially in basins that currently show a high portion of glacier melt water in August and September, the lacking glacier contribution could result in a water shortage and might entail serious economic consequences. For example, irrigation for agriculture might be at risk, groundwater levels could be lowered, shipping traffic might be affected, and important ecological impacts on habitats along the Danube are expected. The consequences of future glacier retreat on the hydrology of large rivers might be more severe than previously assumed. Glaciers significantly contribute to run-off from macroscale watersheds. It is thus important to account for the impact of glaciers and their future changes on the hydrological regime – also in poorly glacierized drainage basins.

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The influence of temperature and light on aquatic insects

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Temperature has a primary role in the ecology of aquatic insects. Apart from springs where constant water temperatures prevail, thermal heterogeneity is a characteristic feature for both lotic and lentic habitats with aquatic insects responding to absolute levels as well as seasonal and diurnal ranges, rate functions and the timing of thermal events (Ward 1992). Strictly contrasting to this multitude of thermal triggers and their subsequent ecological response patterns, there are only two basic key functions of temperature at a biochemical level: effects on chemical reaction velocity and effects on molecular structure. Light and photoperiod, on the other hand, act primarily in an indirect way, mostly as a tool for the synchronisation of life cycles and some basic activities.

Influence of water temperature and day length on embryonic and larval development

Absolute levels of water temperature play a major role in embryonic and larval development of aquatic biota. There are clear relationships between hatching success and water temperature with a hatching climax at an optimum temperature and distinctly reduced hatching rates at suboptimum temperatures *(Figure 1).* In mayflies (Ephemeroptera), for example, most species hatch in the temperature range from 3 to 25°C (Bauernfeind & Humpesch 2002), in the damselfly *Coenagrion puella* from 12 to 28°C *(Figure 1;* Waringer & Humpesch 1984). Besides hatching success, water temperature greatly influences the duration of embryonic development, which, in the case of *C. puella,* took 73–88 days at a constant temperature of 12°C but only 11–13 days at 28°C.

As in embryonic development, there are clear lower and upper thresholds for growth (= moulting frequency and size increment per moult). For example, in *C. puella,* no growth was observed when larvae are subject to water temperatures <12°C. In the range 12–28°C, however, all larvae moulted at regular intervals with moulting intervals of instars 1–7 strictly increasing with decreasing water temperature (12°C: 26–32 days; 28°C: 6–8 days) whereas moulting intervals in instars 8–11 were relatively temperature independent at 37–48 days. In mayflies, growth rates range from nearly zero in winter to 3.3% per day in summer (Bauernfeind & Humpesch 2002); in dragonflies (Odonata), mean growth rates over the whole larval period range from 0.4% in *Calopteryx virgo* to 3.9% per day in *Lestes sponsa* (Waringer & Humpesch 1984). Although most studies were performed at constant temperatures in the lab, control

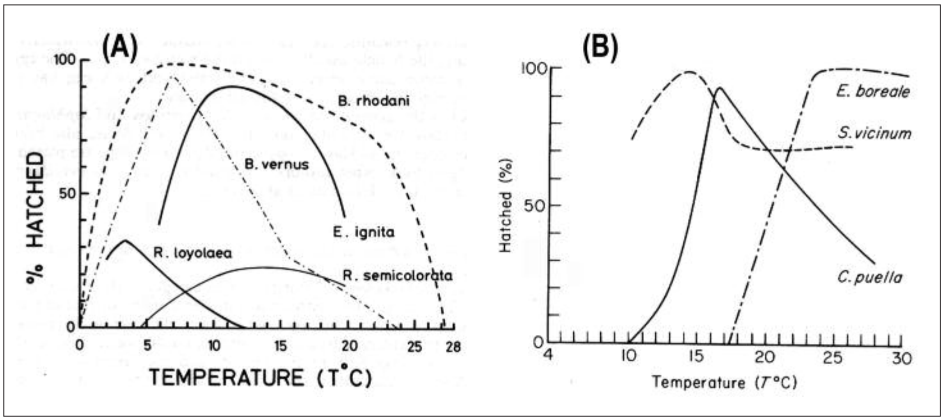


Figure 1. Percentage of eggs hatching as function of water temperature. (A): Baetis, Ephemerella, Rhithrogena (Ephemeroptera; taken from Elliott & Humpesch 1980); (B): Coenagrion, Enallagma, Sympetrum (Odonata; taken from Waringer & Humpesch 1984)

experiments in the field have very frequently proven their applicability for fluctuating, natural temperatures.

Besides direct egg development, many insects show delayed egg development. For example, the dragonflies *Sympetrum depressiusculum* and *S. danae* spend winter in the egg stage. In *S. sanguineum* both direct and delayed development may occur. Although the water temperature in autumn may be favourable for development, the embryos of species with overwintering eggs stop the differentiation processes and enter a stage of delayed development where only physiological processes take place (= prospective dormancy or diapause). In *S. danae* the onset of egg diapause occurs at photoperiods at the autumnal equinox (12 hours day) which induces diapause development *(Figure 2).* Temperature and photoperiod interact: pre-diapause development is accelerated by higher temperatures and by a long day photoperiod. The diapause stage is initiated immediately prior to blasokinesis by a short day photoperiod (less than 12 hours) and is terminated most rapidly at lower temperatures; post-diapause development is often induced by long day photoperiods and has a positive temperature coefficient. The evolutionary benefit of delayed development lies in the well-synchronised hatching of the adults: in *S. danae* 50 % of the eggs hatch within the first three days (Waringer 1983). This, in turn, quickly builds up stable populations and maximizes mating encounters and reproductive success. Resting stages, triggered by defined photoperiods, are also reported for larvae (e.g. *Anax imperator;* Corbet 1957, 1999) and adults: in the caddisfly genus *Limnephilus,* emergence takes place in May-June, accounting for a first period of flight activity. The summer, however, is spent in a resting stage (parapause) where the activity of both sexes is greatly reduced and the ovaries of the females ripen until mating activity fully develops in autumn. This timing of oviposition perfectly fits the hydrology of breeding habitats, e.g. termporary waters which dry up in summer and are refilled in autumn (Malicky 1973; Waringer 1991).

Influence of water temperature on aquatic insect community structure and voltinism

Based on the metabolic temperature dependence of growth and development, water temperature is one of the major determinants for longitudinal zonation patterns of aquatic insects (e.g. Illies 1961; Moog & Wimmer 1994), resulting in distinct species sets within crenal, rhithral and potamal stream sections (Moog 2002; Graf et al. 2008, 2009). An extremely well-studied example of a downstream series of species along a gradient of progressively increasing water temperatures is the caddisfly (Trichoptera) triplett *Diplectrona felix* (immediate headwaters), *Hydropsyche instabilis* (tributaries) and *H. pellucidula* (main course of river) in a Welsh stream (Hildrew & Edington 1979). In the laboratory, the authors revealed marked, temperature-dependent differences in oxygen uptake which can be seen as a surrogate for metabolic rate responses in the three species. The data suggest that differential adaptations to water temperature enable each species to colonize a stream section where it is competitively superior. The correlation between ambient temperature and species inventory along a stream continuum

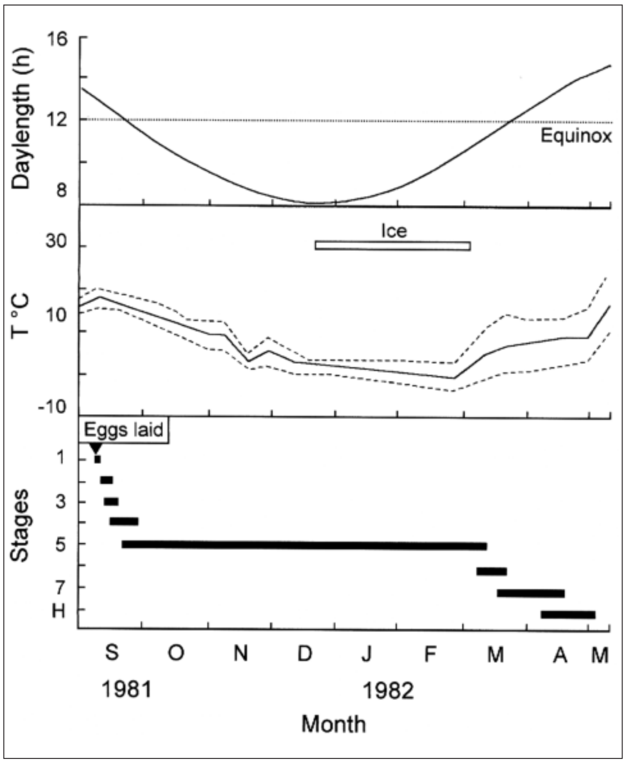


Figure 2. Temporal distribution of the seven stages of embryonic development (stages 1–7) of Sympetrum danae (Odonata) in the field; H= hatching time. Values of mean water temperature (with range) are given every 10 days at the center, and day length (hours) are shown at the top (taken from Waringer 1983)

can be also well illustrated by non-intended large-scale experiments, with the Thaya watershed being a fine example. The Thaya River has been dammed at Vranov back in 1934, creating a thermally stratified reservoir. The hypolimnetic water release used by a powerplant changed annual ranges of water temperature downstream at Hardegg from 0.0–23.1°C before damming to 4.0–14.5°C nowadays, shifting the aquatic biocoenosis from epipotamal to meta/hyporhithral. Today, due to this thermal rhithralisation, 80.4 % of the caddisfly species inventory classifies the Hardegg site as rhithral and only 17.3 % as potamal, with the remaining 2.7 % consisting of crenal and littoral species (Waringer 2003).

Temperature also strongly affects voltinism (= number of generations per year). Based on ambient temperature, the caddisfly *Rhyacophila evoluta* may have a one-, two- or three-year life cycle, depending on altitude (Décamps 1967). This illustrates a temperature-dependent shift of multi-, tri- or bivoltine life cycles at low altitudes/latitudes to univoltine and, finally, semivoltine and partivoltine life cycles at high altitudes/latitudes. For example, the damselfly *Ischnura elegans* is mainly trivoltine at a latitude of 43–44°N, univoltine at 53–54°N, and semivoltine at 57–58°N (Corbet 1980, 1999). Therefore, it is possible to establish statistically strong, negative correlations between voltinism and latitude of a study site, as it has been successfully demonstrated by Corbet et al. (2006) for 275 species and subspecies of Odonata.

Influence of temperature and light on flight activity

Among meteorological parameters, air temperature has been identified as a major factor influencing flight activity of aquatic insects. In this context, the use of light traps provided many useful data for Trichoptera, Chironomidae, Ephemeroptera and Lepidoptera species mostly active during the night (Waringer 1989, 1991; Waringer & Graf 2006). Maximum night air temperatures are the key parameter for flight activity in caddisflies: most were caught in the first third of the night with the catching success increasing almost exponentially as maximum night air temperatures increased. At the March, for example, all caddisflies were captured when sunset air temperatures exceeded the 7.6–13.8°C range and minimum night air temperatures were higher than the 5.0–10.8°C range.

In aquatic insects which are active mostly during the day, light intensity may play a key role. In Austrian populations of the damselfly *Coenagrion puella*, for example, a minimum light intensity of 60×10^3 lux is necessary to initiate flight activity in the morning. When light intensity falls below this threshold in the evening, mating behaviour and oviposition significantly decrease, and the insects fly to their resting sites. This is the typical pattern on windless, clear summer days. No flight activity is observed, however, on cloudy days with light intensity below the threshold of 60×10^3 lux or at days with wind intensities > 8 m per second (Waringer 1982).

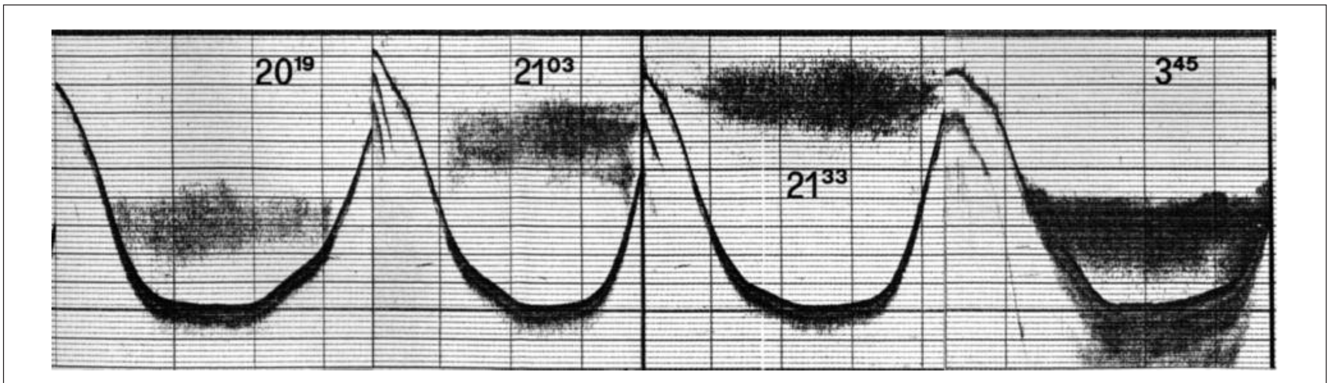
Diurnal periodicity of the drift of aquatic invertebrates

Within a given stream section, aquatic insect activity is characterised by diurnal patterns which are triggered by day-night periodicity. When exposing drift nets over a stream cross-section and taking continuous drift samples over a 24 h period, it becomes obvious that drift periodicity is strongly influenced by diel activity patterns of aquatic biota. Such influences can be observed in benthic species during periods of enhanced activity associated with mating, emergence, or predator activity. Some invertebrates are most active and consequently drift more frequently at night, when the risks from visually foraging predators such as fish are lowest. In European streams, fire salamander larvae *(Salamandra salamandra)* are important because they occur further upstream than do trout. In this "salamander region" upstream of the "salmonid region" the basic day-night drift pattern is modified by presence (April to August) or absence (September to March) of salamander larvae releasing chemical cues (kairomones) detected by their invertebrate prey (Oberrisser & Waringer 2011).

Diurnal vertical migration patterns

Light is also a well-known trigger for vertical migration periodicity in standing water bodies. As in many zooplankton species, vertical migration is performed by the aquatic dipteran *Chaoborus (Figure 3).* All four instars migrate to the

Figure 3. Echogram of nightly migration patterns of Chaoborus flavicans (Diptera) in the Hafnersee, Carinthia. Times of the day when profiles were taken are indicated at each frame (taken from Schiemer et al. 1982)



water surface during the night and return to the hypolimnion (first and second instar) or the lake sediments (third and fourth instars) shortly before sunrise (LaRow 1969). This persistent diurnal rhythmicity can be detected by echography *(Figure 3).* The emergence of larvae from the sediments is triggered by a light stimulus from the setting sun. Migration in the planctivorous larvae of *Chaoborus* is a fine example of benthic-pelagic coupling and, in combination with nocturnal immigration of fishes from the littoral, ensures that trophic interactions between zooplankton and its vertebrate and invertebrate predators are strongest during the night. In the Hafnersee, the typical diet of *Chaoborus flavicans* consists of *Bosmina longirostris* (76 %) and rotifers (20 %) (Schiemer et al. 1982). In the night, this typical diet of *Chaoborus* is well-fed with phytoplankton, significantly enhancing its nutritional value. On the other hand, reactive distances of the fish predators of *Chaoborus* are greatly reduced at night, illustrating the ecological benefits of diurnal vertical migration.

The impact of global warming

In the context of global warming, some aquatic insect species are favoured by the fact that higher water temperature regimes accelerate pre-adult development, thereby possibly shifting voltinism, e.g. from univoltine to bi- or multivoltine. Rising water temperatures might also enlarge distributional ranges, thereby enabling mediterranean species to spread over large areas which have been previously uncolonized. The dragonfly *Crocothemis erythraea* is a well-known example of a rapidly expanding species (Raab et al. 2007). On the other hand, stenotopic, cold-adapted insects such as the caddisfly subfamily Drusinae, where the distributional range is composed of fragmented montane sky-island populations, are severely threatened by global warming. Because water temperature of springs and headwaters is closely correlated with mean annual air temperature of the location, global warming will strongly affect their persistence and compromise large parts of their range. Among these cold-adapted species, micro-endemics of the Alps (e.g. *Drusus franzi, D. noricus)* which inhabit the peaks of isolated mountain areas (e.g. Klugveitl, Kaltenbachalm, Saualpe) are particularly threatened (Graf et al. 2008). For these species, high altitudes may act as summit traps as vertical and/or horizontal migrations to colder climate zones in response to global warming will not be feasible for such species, possibly leading to their extinction (Malicky 2000; Pauls 2004). Such species are primary candidates for an early warning system (Hering et al. 2009). As global warming will continue to influence species distribution, changes in the species-specific ranges may foster management steps that can be used to prioritize conservation efforts for cold-adapted freshwater biota. Species distribution models, combined with climatic data, will assist in determining high quality sites under present and future climate conditions, thereby providing an important tool to conservation biologists.

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Global warming affecting fish in the Danube River Basin

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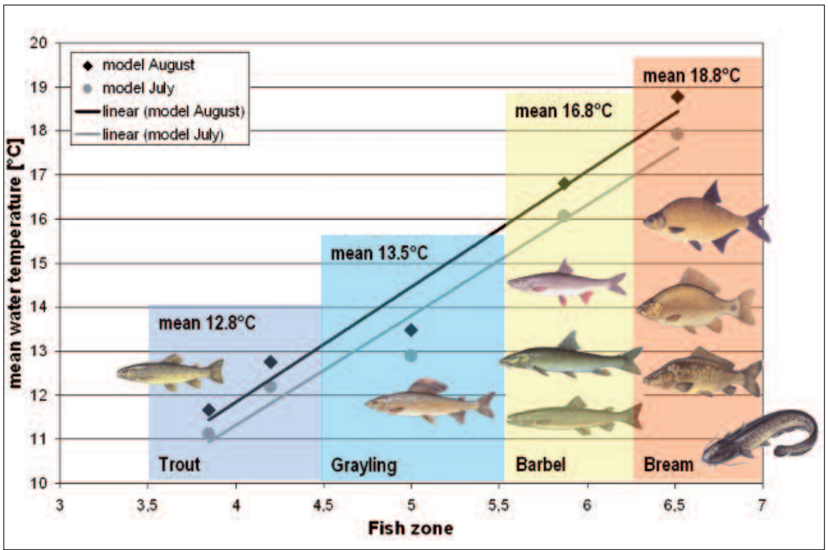
Temperature and fish

Riverine ecosystems are affected by different anthropogenic pressures. Besides water pollution, hydromorphological alterations, connectivity disruptions and direct interferences with the fish community (e.g. fishing, stocking), climate change jeopardizes the integrity of river ecosystems. Fish are influenced by climate change in multiple ways. The most significant effects result from increased water temperatures, however, altered hydrological regime as well as interactions between water temperature and water quality might additionally affect sensitive species and life stages. Water temperature plays a major role in the distribution of fish species. Therefore, an increase in water temperature reduces suitable habitat for coldwater species.

Fish are poikilothermic, i.e. their metabolism (and thus respiration, digestion, growth, activity, reproduction) strongly depends on water temperatures. Fish may react very sensitive even to slight temperature changes (Schmutz & Jungwirth 2003). While some species can exist over a wide temperature range (eurythermic species) others show a narrow (mostly low) temperature optimum (stenothermic). At higher temperatures reduced oxygen saturation and lower oxygen supply coincide critically with higher oxygen demand of fish.

The water temperature of a river depends on altitude and monthly discharge, amongst other. Air temperature is a good predictor of water temperature, which in general increases with distance from the source (i.e. decrease in altitude) (Melcher et al. 2009). The different temperature regimes along a river continuum in combination with the temperatures preferred by fish species cause a typical distribution of fish communities which can be classified into different fish zones (Huet 1949). While the upper fish zones (i.e. trout and grayling zone) accommodate mostly oligo-stenothermic fish species (e.g. salmonids), lower fish zones (i.e. barbel and bream zone) show higher percentages of mesothermic species (e.g. cyprinids) (Jungwirth et al. 2003). *Figure 1* shows the fish zones and the increasing mean summer water temperatures along the longitudinal gradient. The preference of a species for a certain fish zone is expressed by a species-specific fish index, allowing the calculation of the actual fish community index at any site within the catchment. A shift of the fish zone index compared to natural conditions is an indication of human perturbation (Schmutz et al. 2000). Increased water temperatures due to climate change cause an upwards shift of the fish zone index (Matulla et al. 2007).

Figure 1. Fish zones and their mean water temperature (July and August) in Austrian rivers (Melcher et al. 2009)



Climate change

The global mean air temperature increased by 0.6°C during the last century (IPCC 2001). The rise in Europe was even stronger (+0.8°C) and reached up to 1.8°C in Austria (Böhm et al. 2001). This development also induced a rise in water temperature which can be observed in several rivers including the Danube. Zweimüller et al. (2008) state an increase of 0.2°C in air temperature and 0.1°C in water temperature per decade since 1950 (measured at the Danube station Hainburg). Especially January, August and October seemed to show a stronger temperature increase (>0.2°C per decade). A further increase of 0.8 to 1.6°C for most months compared to 1951–1960 is expected until 2024 (Zweimüller et al. 2008). *Figure 2* shows a temperature increase of 1.7°C (from 9.3°C to 11°C) since 1901, with a stronger increase since 1970 for Hainburg.

Investigations of tributaries of the Danube (e.g. Mur, Traun, Ybbs) support these findings. A study on the Mur predicts a summer temperature increase of 0.7°C near the river head and 1°C at lower reaches for the period 2027 to 2049 compared to current conditions. This would result in a shift of fish community/zone up to 70 meters in altitude (Matulla et al. 2007). Another survey predicts a temperature increase for the Mur and Ybbs of up to 2°C in lower reaches between 2001 and 2049 (compared to 1976–1998) with a shift of 40 to 50 km of all fish zones along the river network (Schmutz et al. 2004). The temperature increase might also lead to changes in hydrology induced by early snow melt and a higher proportion of rain-based precipitation. A further temperature increase might cause discharge redistributions from summer to winter (Godina 2010).

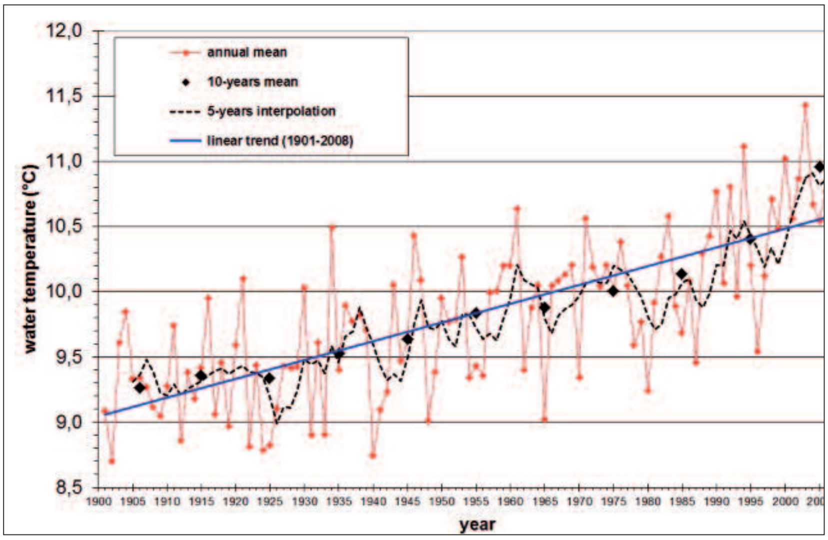


Figure 2. Change in Danube's water temperature during the last century (data from HZB, BMLFUW 1991–2008)

Climate change and its effects on fish

Even a small increase in water temperature can alter the fish community composition. While too low temperatures cause lethargy (reduced digestion, low reaction time), temperatures above optimum increase metabolism (e.g. digestion) to a degree, where fish cannot find enough food for compensation thereby exhausting their fat reserves. Eurythermic species prefer and tolerate significantly higher temperature during summer, while temperature conditions in rivers are very similar during winter for steno- and mesothermic species (Jungwirth et al. 2003). Hence, a temperature increase during summer pushes stenothermic fishes to the limits of their existence. To overcome this stress, they are forced to evade to higher altitudes or latitudes, if possible (Schmutz & Jungwirth 2003). This effect can be measured by an upward shift of the fish zone (see above).

Optimum and lethal temperatures vary within life history, whereby eggs mostly show narrower limits than adults (Küttel et al. 2002). Hence, even slight temperature increases may induce a reduced reproduction success of temperature sensitive species. The brown trout *(Salmo trutta* L.) is a typical representative of the oligo-stenothermic guild. As key species of the trout zone it is not only present in high altitude rivers but also in larger tributaries of the Danube. Limiting factors of its distribution are mostly water temperature, oxygen saturation and the presence of reproduction habitats (Jungwirth et al. 2003). Egg development requires temperatures between 0 to 13°C, whereby mortality increases above 12°C and below 7°C. At temperatures above 15°C all eggs die. Maximum temperatures are 23°C for larvae and 28°C for juveniles, while adults show a critical maximum at 25°C but prefer habitats with 14 to 17°C (Küttel et al. 2002). Another coldwater species is the European grayling *(Thymallus thymallus).* Reproduction is performed between 6 to 10°C. Egg development takes place between 6 to 13°C (optimum 9°C), whereby at 16°C all eggs die. Adults prefer habitats between 4 and 18°C and tolerate temperatures up to 25°C (Küttel et al. 2002). Since this stenothermic species prefers larger rivers, its upstream migration is limited (Jungwirth et al. 2003). Appropriate habitats of species like Danube salmon *(Hucho hucho)* are already strongly reduced due to hydromorphological alterations. A shift of fish zone would lead to further reductions and might even result in its extinction (Schmutz et al. 2004).

While stenothermic species are mainly negatively influenced by increasing temperatures, eurythermic species might be favored. Besides extended habitat availability, these species may benefit from increased growth at higher temperatures (Wolter 2007). If floods during winter become more frequent, fry of autumn-spawning species like the brown trout are at higher risk. On the other hand, a reduction in summer floods might reduce reproduction success of cyprinids. Alterations in discharge can also increase erosion, which might favor clogging of the river bed and, hence, reduce spawning grounds.

Also competition with invasive species plays an important role. An example is the rainbow trout *(Oncorhynchus mykiss)* which is more tolerant to anthropogenic alterations and better adapted to higher temperatures than the native brown trout. A temperature increase might favor exotic species which can outcompete more sensitive, native species (Schmutz et al. 2004).

Besides climate change, other factors can influence the temperature regime of a river. These are mainly thermal effluents, discharge reductions due to water abstraction and water releases from reservoirs. While the first two factors enhance the increase in water temperature, the effect of the latter depends on the processed water (Cassie 2006). The release of bottom (hypolimnetic) cold water via hydropower turbines can lead to a strong temperature decrease in downstream river segments during summer or increase in winter. Similar effects can occur due to groundwater exfiltration (Zweimüller et al. 2008). Furthermore, upstream glaciers or lakes influence the temperature and discharge regime. Small streams exhibit stronger daily and annual temperature fluctuations and shadowing by riparian trees and shrubs is crucial for light and temperature regulation.

Adaptation measures

It is obvious that the most important measure is combating climate change, thereby mitigating negative influences to riverine ecosystems. Since this needs time, and water temperatures are already rising, additive measures need to be considered. To evaluate the influence of climate change on a river and its biocenoses, a catchment perspective is necessary. In particular, hydromorphological alterations jeopardizing fish species are in focus. Reducing anthropogenic impacts is strengthening ecosystem resilience. Restoration of the riparian buffer is important since it reduces solar radiation input (especially for small streams). Restoration of instream conditions (structures, woody debris, and irregular cross sections) favors habitat conditions and makes fish populations more robust against temperature change and other stressors. Furthermore, lateral and longitudinal connectivity needs to be re-established, allowing fish to migrate to more suitable areas. Since less discharge may reinforce a temperature increase, this has to be considered by the determination of ecologically sound residual flows.

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In Memoriam Peter Kothé (1928-2010)

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Dr Peter Kothé, the IAD Country Representative of Germany from 1973 to 1992, passed away on 2 March 2010 at the age of 81 in Koblenz, where he had been working for the German Federal Institute of Hydrology (BfG) since 1958. We will keep him in our memory for his valuable contributions to IAD, especially the two international conferences at Regensburg in 1975 and at Passau in 1987 under his excellent organization.

Peter Kothé was born in Schwerin/Mecklenburg on 3 June 1928. He attended the humanistic high school in his home town and studied biology and hydrobiology at the Universities of Greifswald and Hamburg. Forced by political circumstances he moved from the German Democratic Republic to the Federal Republic of Germany in 1951. His scientific work focused on the assessment of the ecological status of running waters by means of benthological evaluation methods.

Dr Peter Kothé realized that the deficit of species caused by hostile conditions in rivers is a powerful tool of biocoenotic structural analysis of benthic communities. The method of the "deficit of species" *(Artenfehlbetrag)* developed by Kothé provided a realistic indicator to express the degree of biocoenotic changes due to domestic and industrial pollution (Kothé 1962, 1966; German Test Guideline DEV M 7, 1971). This method can also be applied to evaluate the impact of river morphology (sediment transport) and stream flow on benthic communities. For instance, the *„Artenfehlbetrag according to Kothé"* was incorporated into the German Test Guideline on salt pollution of waters DIN 19570 (1973) and is mentioned in almost all limnological textbooks. The concept was slightly changed and included into the European Water Framework Directive (WFD) in the form of the *Ecological Quality Ratio* (EQR). Thus, Dr Kothé's work exemplified how theoretical knowledge and intensive research are applied in water-resources management and contribute to national as well as international legislation.

Without doubt, side by side with Dr Herbert Knöpp, Peter Kothé ranks among the German pioneers in water protection. For students, his work remains a source of understanding the biological assessment of polluted rivers.

In Memoriam Nicolae Bacalbaşa-Dobrovici (1916-2010)

Radu Suciu, Danube Delta National Institute, Tulcea, Romania

Nicolae Bacalbaşa-Dobrovici, an internationally renowned Danube River fishery scientist died in Galatz on July 11, 2010 at the age of 94. He served for 58 years at the "Lower Danube" University of Galatz (Fishery and Aquaculture Faculty) and made significant research contributions in fishery of the Niger and Danube Rivers. He is survived by his wife Veronica, former head of the contagious diseases department of the municipal hospital of Galatz, and twin sons Nicolae and Gheorghe (born 1944), well known physicians and medical professors in Galatz and Bucharest.

Bacalbaşa-Dobrovici graduated agriculture at the Bucharest Polytechnics (1941) with a thesis on conditions for reproduction, nutrition and development of fishes in the Danube floodplain lakes at Feteşti. He was head of the fish pond service of Bessarabia (1942), founder of the discipline "fishery technique" and for 33 years lecturer (1948) and later professor (1975) of the fishery and fish culture faculty in Constantza and Galatz. Bacalbaşa-Dobrovici having published more than 130 scholarly publications and six books is best known as the author of the first Romanian manual/treatise on Fishing Technique (first edition 1953, revised and republished in 1965) and as the first Romanian fishery expert working for FAO. His report to FAO on the development of fishery in the Niger River, written after a two year expeditionary survey of about 600 km of this major African river (1969–1970), was also the subject of his PhD in fishery, earned from the University Alexandru Ioan Cuza of Iassy (1972).

He was member of the IAD from 1967, were he acted also as head of the Fishery Expert Group (until 2004). Fellow IAD colleagues remember Nicolae as a most active member, true opinion leader in fishery and head of the fishery team during the Danube River expedition between Bratislava and Vilcovo organized by IAD (1988). His international activity was eased by the fact that he was fluent in Russian, German and French. Retiring in 1981 as an acting professor he continued serving as a consultant professor and supervised during the next years 10 PhD students with successful careers in academia, research and industry. His last 15 years of activity were devoted almost entirely to rising awareness and field research on endangered species of sturgeons of the Lower Danube River/Romania (18 scientific papers, some presented at the International Symposiums on Sturgeons of Bordeaux (1991), Piacenza (1997) and Oshkosh (2001)). Therefore, he was invited to represent the Danube River as member of the Sturgeon Specialists Group/Species Survival Commission of IUCN in 1992. His name will be forever linked to saving sturgeons of the Danube River.

In Memoriam Antal Schmidt (1944-2010)

Keve T. Kiss, Institute of Ecology and Botany, Hungarian Danube Research Station of the Hungarian Academy of Sciences, H-2131 Göd, Hungary

Antal Schmidt, the well-known Hungarian algologist and hydrobiologist, died on July 8, 2010. He was born in Gara (near Baja, the town he loved) on April 11, 1944. He studied at the University of Szeged on the Faculty of Biology and Chemistry during 1962–67. Then he started to work at the hydrobiological laboratory of the Lower Danube Valley Authority of the Environment, Nature and Water, Control and Monitoring Centre. This had been his first and last workplace until his retirement. For a few years he dealt with the chemistry of the River Danube and other surface waters of the Baja region, then his interest turned to algae and he became a specialist of phytoplankton. He was the leader of the Phytoplankton/Phytobenthos Expert Group of IAD during 1968–2007.

He was an excellent taxonomist and published hundreds of detailed descriptions of phytoplankton species of Hungarian waters. He described many species considered to be new for science. He was co-author of some books about identification of Chlorococcales, Xanthophyceae and *Scenedesmus* species. His activity was focused on the phytoplankton of the River Danube, mainly the South Hungarian stretch, and small rivers as well as of soda lakes situated in the middle of Hungary. He published many important diagnoses based on long-term investigations about the taxonomic composition and the trophic- and saprobic state of waters to propose measures for environmental protection and mitigation of human impact.

Antal Schmidt was probably the last member of his generation, which represented the golden age of the classical algology, who was open to modern methods like electron microscopy and molecular biology. He investigated field samples with light microscope, studied all groups of planktonic algae of fresh waters and always illustrated his papers with his own beautiful drawings.

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Hydrological catchment of the River Danube

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