Conference Volume	5th Symposium for Research in Protected Areas 10 to 12 June 2013, Mittersill	pages 197 - 204

Framework for long-term ecological research in alpine river systems

Leopold Füreder[1] & Wolfgang Schöner[2]

[1] River Ecology and Invertebrate Biology, Institute of Ecology, University of Innsbruck, Austria
[2] ZAMG-Zentralanstalt für Meteorologie und Geodynamik, Abteilung Klimaforschung, Wien, Austria

Abstract

Long-term observations and experiments have never been more important for testing ecological theory and for addressing today's most difficult environmental challenges. Among them, climate change processes pose a considerable threat to global biodiversity and are recognized to particularly affect alpine landscapes. This high climatic sensitivity and lack of significant human impact make alpine river basins important environments for examining hydrological and ecological response to global change. Two interdisciplinary research projects carried out in six glaciated catchments in the Hohe Tauern NP, aimed at defining climate–hydrology–ecology interactions and demonstrating the importance of alpine river systems as indicator environments of hydrological and ecological impacts of climate change and variability. We addressed major research gaps through detailed multidisciplinary field investigations into, (a) alpine river system hydrology, geomorphology and physicochemical habitat, and (b) temporal and spatial patterns in aquatic macroinvertebrates, coupled with, (c) the application and further development of an invertebrate species traits method, and (d) innovative modelling approaches. Based on these results, we propose a framework of integrated, long-term ecological research in alpine headwater systems and its application in other alpine areas. Within this kind of LTER network, interdisciplinary approaches are fundamental for predicting stream hydromorphology and ecology under scenarios of future climate variability, for assessing the utility of alpine river systems as indicators of global change, and for developing conservation strategies for these fragile ecosystems.

Keywords

ecosystem structure and function, climate change, environmental conditions, aquatic conservation, hydrology

Introduction

Climate change and freshwater ecosystems

Alpine and arctic regions including their glaciers and snow fields play a critical role in the water cycle, as they store water mainly during the cold season and release it as meltwater during the warm season. Globally, 50 % of river system receive their discharge from water of snow and ice (BARNETT et al. 2005). Due to global climate change snow and ice cover has decreased strongly within the last century (BATES et al. 2008). During the last three decades this trend has even accelerated (OERLEMANS et al. 2009, BARRY 2006), supporting strongly the actual suggestion of global climate change scenarios of a continued decrease of glaciation. Within the next century, glacier retreat will persist, weather will be characterised by stronger and longer dry periods and precipitation is more pronounced by rain instead by snow (BENISTON 2003). As a consequence of accelerated glacier retreat and an extension of the seasonal melting periods, catchment hydrology and geomorphology will alter significantly. A period with higher melt-water quantities and increased discharge dynamics will be followed by a period of less harsh and moderate environmental conditions. This substantial change on the water regime of snow- and ice-dominated catchments is a process that will take place both on the global scale and on the regional scale (MILNER et al. 2009).

Several research activities have started to concentrate on the potential effects of changing climate and environmental conditions on terrestrial and aquatic ecosystem structure and function in alpine and arctic regions (e.g. CHAPIN et al. 1994, KAUFMANN 2001, BRITTAIN & MILNER 2001). As a consequence of glacier shrinking together with the altered catchment hydrology and geomorphology new habitats for plant and animal species will develop, leading ultimately to a dynamic and complex pattern of environmental conditions, in many cases exhibiting steep gradients within relatively small spatial scales. This has opened an ideal framework to examine important aspects in ecological theory, like the demographic succession theory (e.g. MARCANTE et al. 2009) or the harsh-benign hypothesis (THOMSON et al. 2002).

Current rates of climate change are unprecedented and biological responses to these changes have also been rapid at the levels of ecosystems, communities and species. While most research on climate change effects on biodiversity has concentrated on the terrestrial ecosystems, where considerable changes in terrestrial biodiversity and species' distribution have already been detected, fewer studies are available from the freshwater ecosystems (HEINO et al. 2009). Nevertheless, existing results have shown that freshwater biodiversity is highly vulnerable to climate change, with extinction rates and extirpations of freshwater species matching or exceeding those suggested for better-known terrestrial taxa (SCHINDLER 1997, POFF et al. 2002). The fauna of alpine headwater streams is strongly adapted to the environmental conditions and under the scenarios of future alpine meltwater reductions the aquatic invertebrate assemblages will alter in their composition with even some species going extinct (BROWN et al. 2009a, JACOBSEN et al. 2012, FÜREDER 2012). This may have potential effects on terrestrial and even higher organisms such as fish, amphibians and birds. Nevertheless, while observing changes in glacier coverage, hydrology, geomorphology and biology we experience a general lack of knowledge about these harsh ecosystems, the underlying principles of cause and effect and the potential new linkages that may develop.

Protected areas – an optimal arena for long-term ecological research

The rapidity at which global landscapes are being transformed by environmental change has revived the importance of biological monitoring (ROBINSON et al. 2011). There are several reasons for conducting (long-term) ecological research in protected areas: i) The specific regions where designated as protected areas since they harbour some of the most characteristic and/or biodiverse habitats including best adapted and endemic assemblages on the planet. ii) They typically show the least historical impacts from humans and likely represent areas showing natural patterns, process dynamics and fluctuations that can be compared with areas more directly impacted by humans, especially as the human population grows. iii) These conditions may carry for the generation of data from biomonitoring programmes which are essential to be used for understanding eco-evolutionary and ecosystem processes better in the face of rapid landscape transformation.

Aims of research

For the framework of the long-term ecological research in alpine river systems we addressed these major research gaps through detailed multidisciplinary field investigations into: (a) alpine river system hydrology, (b) proglacial and alpine river geomorphology and physicochemical habitat, and (c) aquatic macroinvertebrates, coupled with (d) the application and further development of an invertebrate species traits method to be used with results from PROSECCO.ALPS for (e) various modelling approaches, combining data from a, b, c, and d, to predict hydroecological dynamics and change under various climate scenarios (these are still under evaluation). It was the aim to undertake intense biological field work within a three-years period to elaborate and define adequate methodologies for long-term research and to gain a comprehensive set of basic data for the future monitoring.

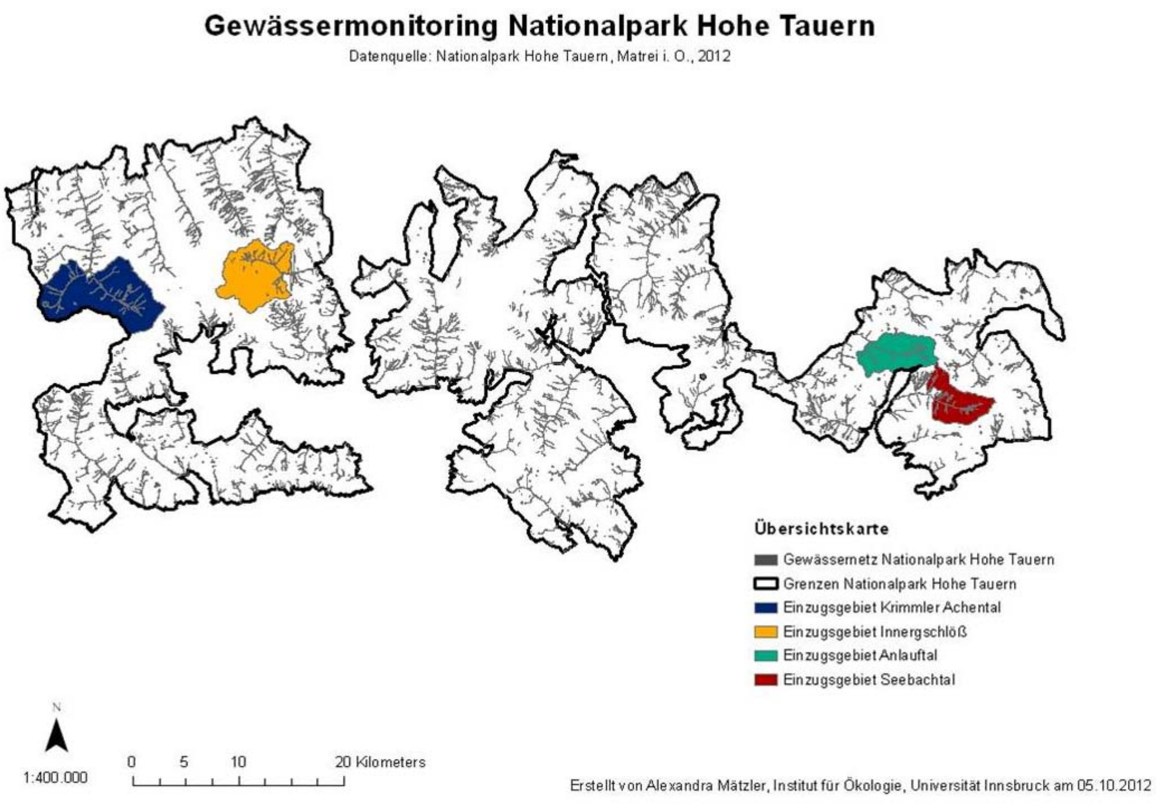

Figure 1: Nationalpark Hohe Tauern in Austria, location of the catchments (Krimmler Achental, Innergschlöß, Seebachtal, Anlauftal), where freshwater monitoring was implemented

Study Area and methodology for long-term ecological monitoring

The study area comprises the largest protected region in Central Europe, the Hohe Tauern National Park (NPHT; Fig. 1), which is situated in the Austrian Central Alps with an area of 1800 km². For the realization of a future freshwater monitoring, an inventory of existing freshwaters was already established for the national park (FÜREDER et al. 2002), including 279 streams (981 km stream/river length, catchment area >1 km²) and 136 lakes and alpine ponds. Based on habitat assessments, including catchment and river morphology characteristics, the stream and river types present were defined. A combination of selected methods and the results of habitat assessments (38 out of 61 assessment categories) enabled a comprehensive characterization of alpine stream and river systems to be developed (FÜREDER 2007). For the definition of stream/river types, 161 stream sections that reached natural or semi-natural habitat quality were selected and classified according to three main criteria: a) origin (glacial vs. spring-fed), b) position within the stream network (headwater, middle and lower reaches; following principally the biocoenotic concept of ILLIES & BOTOSANEANU 1963), but also including knowledge from recent literature on alpine and arctic streams, and c) channel morphology, i.e., meandering, braided, sinuous, constrained. From the existing data sets, stream reaches of known natural or semi-natural conditions were selected. Altitude and glaciation of the catchment were the environmental data used for the analysis of geomorphology and provided the baseline dataset in the selected catchments.

For the future long-term freshwater monitoring, four catchments in a well-balanced spatial distribution, i.e. Innergschlöß in SW, Krimmler Achental in NW, Seebachtal in SE, and Anlauftal in NE (Fig. 1, Fig. 2). We collected information on catchment properties and river morphology at various scales (catchment – reach – site). Several physico-chemical parameters were shown to affect ecosystem structure and function of running waters at higher elevations or latitudes. Cold temperature, strong annual and diurnal discharge fluctuations, channel instability and low nutrient levels, together with limited food availability, are among the most important limiting factors in glacial rivers. For the herein presented analyses, the degree of glaciation was set as a surrogate factor, on the assumption that, with increasing glaciation, water flow dynamics and channel instability increase and water temperature generally decreases. Consequently, with increasing glaciation, fewer species occur and at lower densities. Along the gradient of increasing glaciation, general decreases in diversity, richness and abundance were evident.

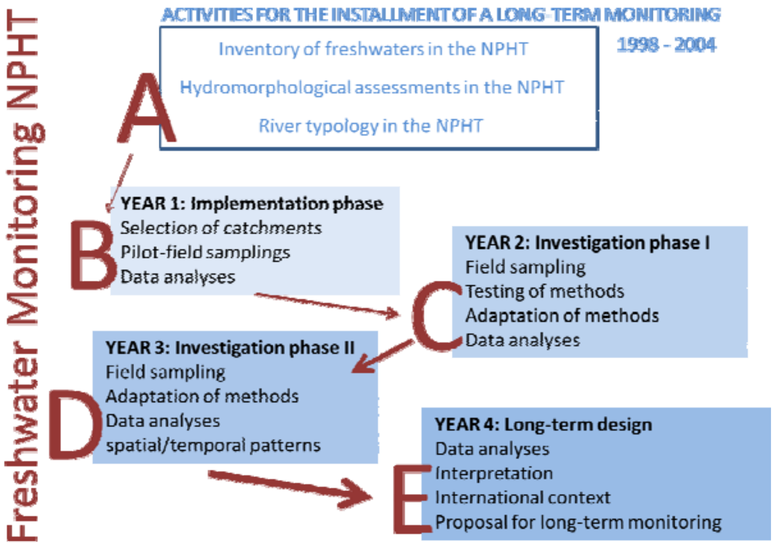

Figure 2: Project phases for the implementation of the freshwater monitoring in the NPHT

The search for an adequate tool-box to monitor the structure and functioning of aquatic ecosystems

The understanding and interpretation of ecosystem dynamics induced by environmental change requires a special set of indicators and their relevant and adequate application. Patterns and processes of ecological systems including their spatial and temporal scales are ideally studied in long-term research activities. Beyond a detailed and continuous monitoring of cause and effect patterns, long-term studies generate important data for the understanding and interpretation of complex abiotic and biotic interactions, interannual variation and cycles, and natural and anthropogenic disturbance and recovery (*sensu* JACKSON & FÜREDER 2006). Especially in the complex interaction of hydrological, thermal and water quality shifts, long-term observations will help to provide clear evidence about the magnitude of natural spatial and temporal variation and the affected physical and biological characteristics by climate change. Our framework for long-term ecological research from a variety of river ecosystems in the NPHT will help to uncover general patterns and location-specific responses in order to better understand climate change driven effects.

The recently (2013) launched long-term monitoring is built on a comprehensive set of hydrophysical and chemical as well as biological data, which were used to define adequate field methodologies, sample analyses and indicators and serve as an excellent basis for the future explanation of environmental/climate change. From 18 sites in four glaciated catchments the following data are available:

- Discharge and temperature recording from installed loggers (Fig. 3)
- Water chemical analysis
- Benthic macroinvertebrates (Fig. 4) - taxa lists, spatial and temporal distribution of communities

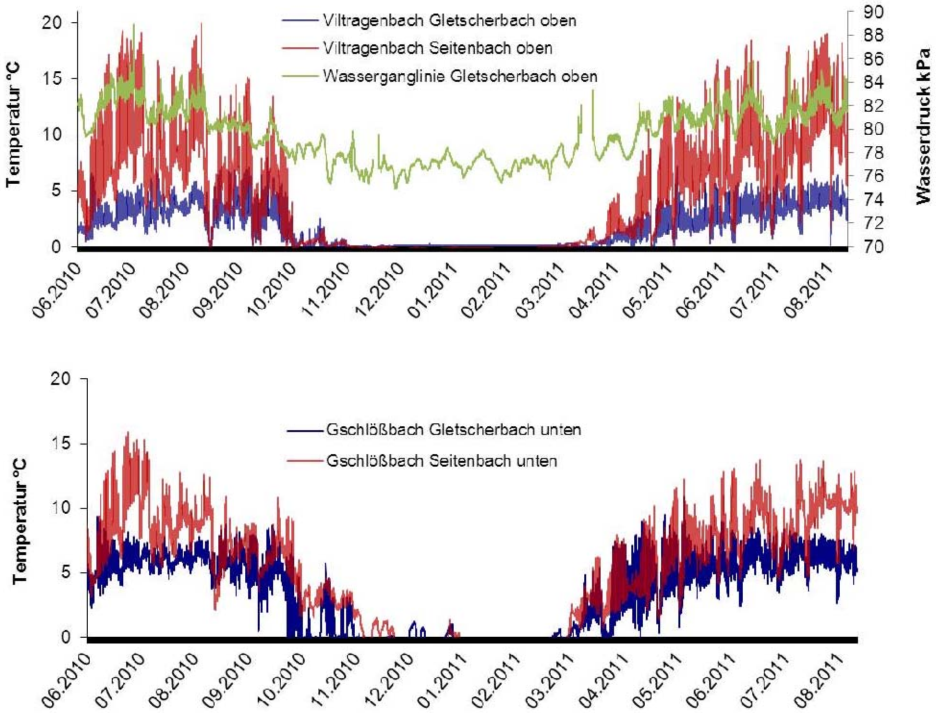

Figure 3: Example of temperature and discharge fluctuation patterns in Viltragenbach (Innerglösch)

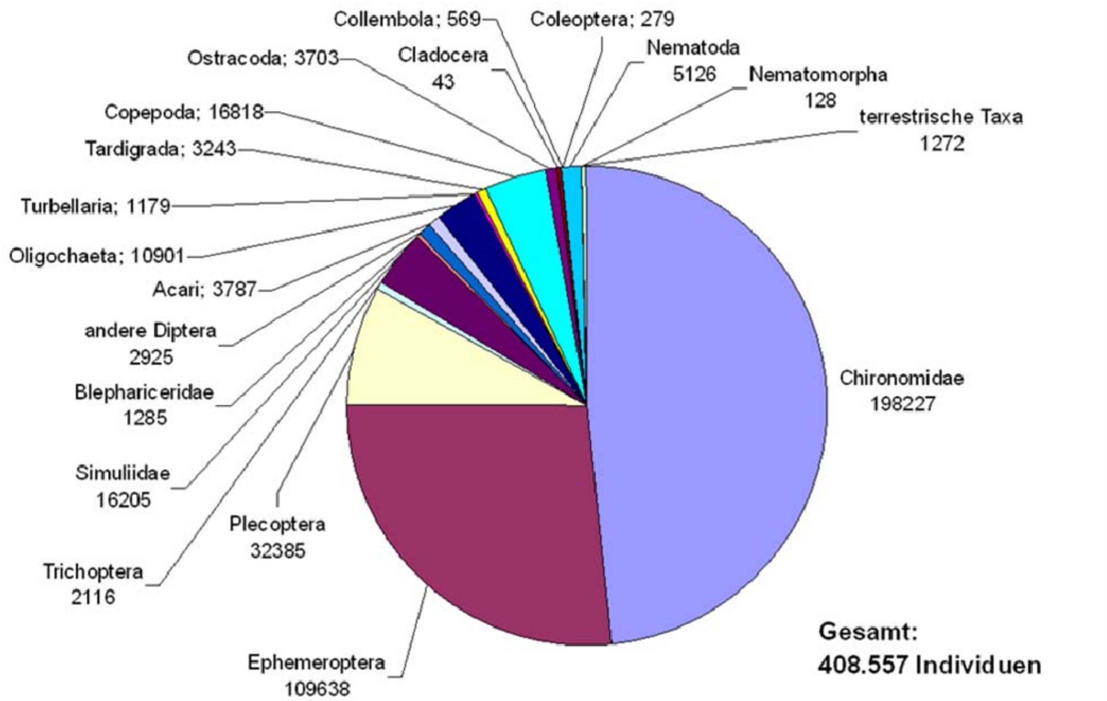

Figure 4: More than 400.000 invertebrates were collected during the research period 2009 – 2011 belonging to 18 higher taxonomic groups

Innovative element of the long-term monitoring is the recording, analysis and interpretation of causal connections between glaciology, hydrology, geomorphology and ecosystem structure and function in the face of a changing climate. Based on the results of the implementation and investigation phase (Fig. 2) and to give consideration to the scientific requirements of a long-term monitoring, but also for cost-efficiency reasons, the operative implementation will be conducted in two work packages:

1. *Abiotic monitoring* – The basic facilities include a continuous observation and high-frequency measure of abiotic/hydrological parameters. The fundamental investigations in the selected catchments consider the hydrology and geomorphology with a continuous recording of discharge and temperature, together with the analysis of water chemistry and turbidity.
2. *Biology and indication of change* – The ultimate and specific tool of the long-term monitoring is the aquatic invertebrate community. The outstanding role of benthic invertebrates as indicators for environmental conditions (ROSENBERG & RESH 1993) is utilized based on the available results on species distribution, diversity and other faunistic properties in the four catchments/river systems. Besides traditional assessment methodologies, a recently developed approach (BROWN et al. 2009b) is used to better understand how contributions of water sources (glacial meltwater, groundwater) and its change interact temporally and spatially with the biota. As another promising approach, in order to emphasise the importance of understanding climate change effects on ecosystem structure and function, we employ analysis of diversity and functional compositions (e.g. feeding types and other biological species traits) of stream invertebrate communities. Although the use of multiple biological traits to characterize the functional component of diversity in river ecology is well established (POFF 1997, TOWNSEND et al. 1997, USSEGLIO-POLATERA et al. 2000, FÜREDER 2007, STATZNER & BÊCHE 2010), we still have fragmented information on species-specific traits especially from the headwater streams at higher elevation (FÜREDER 2007). Ongoing work is dedicated to this research gap. Nevertheless, from our investigations in alpine river ecosystems (FÜREDER 2007) also from applications in other mountain regions and continents (e.g. BROWN & MILNER 2012), we can conclude that the species-trait approach is a promising tool to detect and interpret spatial and temporal patterns in the structure and function of aquatic communities and potential climate change effects.

Under exploitation of the three-years baseline data, these analysis are now being performed and various hypothesis tested. These measures and analysis also have been expanded to two additional catchments, the Goldberg and Pasterze catchments (investigated within the project PROSECCO.ALPS). This allows us to consider in particular the role of hydrology and geomorphology in six catchments. We model the scenario of environmental and climate change effects on key environmental conditions and the structure and function of the invertebrate fauna in alpine streams according the harsh-benign concept (*sensu* Peckarski 1983). We consider alpine streams being positioned along the right slope of a harshness-ecosystem-structure-and-function curve (Fig. 5A), where environmental harshness is moderate to extreme, depending on the degree of glacial influence. With less harsh environmental conditions affected parameters (diversity, richness, species traits) are higher or more variable (in “glacio-rhithral” and “krenal, rhithral” stream types). Environmental and climate change effects (Fig. 5B) would alter the situation and consequently stream sections would move along the curve to the right.

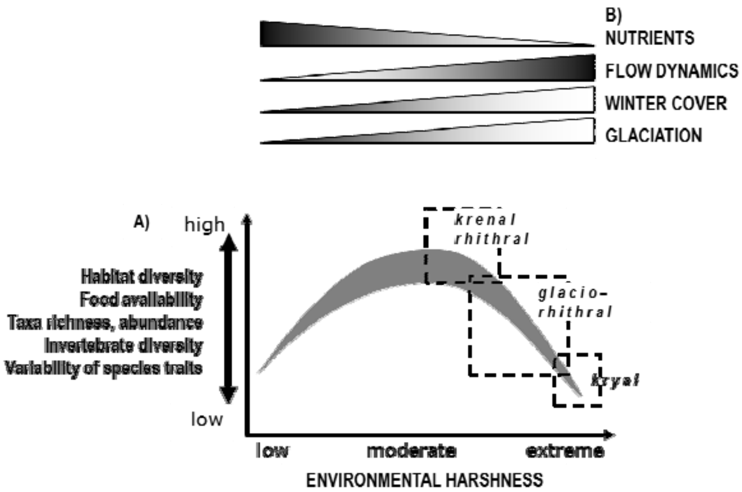

Figure 5: Scenario of environmental and climate change effects on key environmental conditions and consequently on the structure and function of the invertebrate fauna in alpine streams (from: Füreder, 2007; modified).

Paving the way for a long-term monitoring

Early ecologists recognised that environmental conditions were temporally dynamic (MCINTOSH 1985) and that the temporal length of a study contributed significantly to its conclusions, generalisations and/or predictions. For example, observations distributed across several days or months may differ from those that span years or decades because longer studies have a greater probability of observing or helping to explain slow, rare, subtle or complex changes in natural environments – see references in JACKSON & FÜREDER (2006). Although the value of long-term ecological perspectives is well documented, the collection of long-term data is still limited by funding constraints, personal or institutional changes in research directions, research careers that last a maximum of 30–40 years and the absence or inaccessibility of comparable data. In their review paper, JACKSON & FÜREDER (2006) already illustrated the value of long-term ecological studies of freshwater macroinvertebrates by examining the availability and characteristics of long-term data and describing recent contributions such long-term studies have made to lotic and lentic ecology.

The intention to install a long-term hydrobiological monitoring program has been in place in the Hohe Tauern Nationalpark since 1998, however mostly in a preparatory face. In its first stage, an inventory of all freshwater ecosystems was developed, followed by a hydromorphological characterisation and assessment. Now the results of the first implementation phase exist, providing all prerequisites for a long-term monitoring. One of the main problems counteracting a realisation was the establishment of the infrastructure to carry out the monitoring longer than the financial and temporal frame of single project. Therefore, we defined a project structure that guarantees the generation of observation data, recordings and measurements on a continuous and/or regular basis, together with a regular sampling of biotic elements. This minimum data set is comprehensive on its own, however because of the high value of continuous background data will attract synergistic research projects as well as PhD and Master students to carry out their thesis within a larger framework (Fig. 6). With its interdisciplinary and integrative approach, the long-term monitoring has pilot character and offers substantial synergies for relevant research activities.

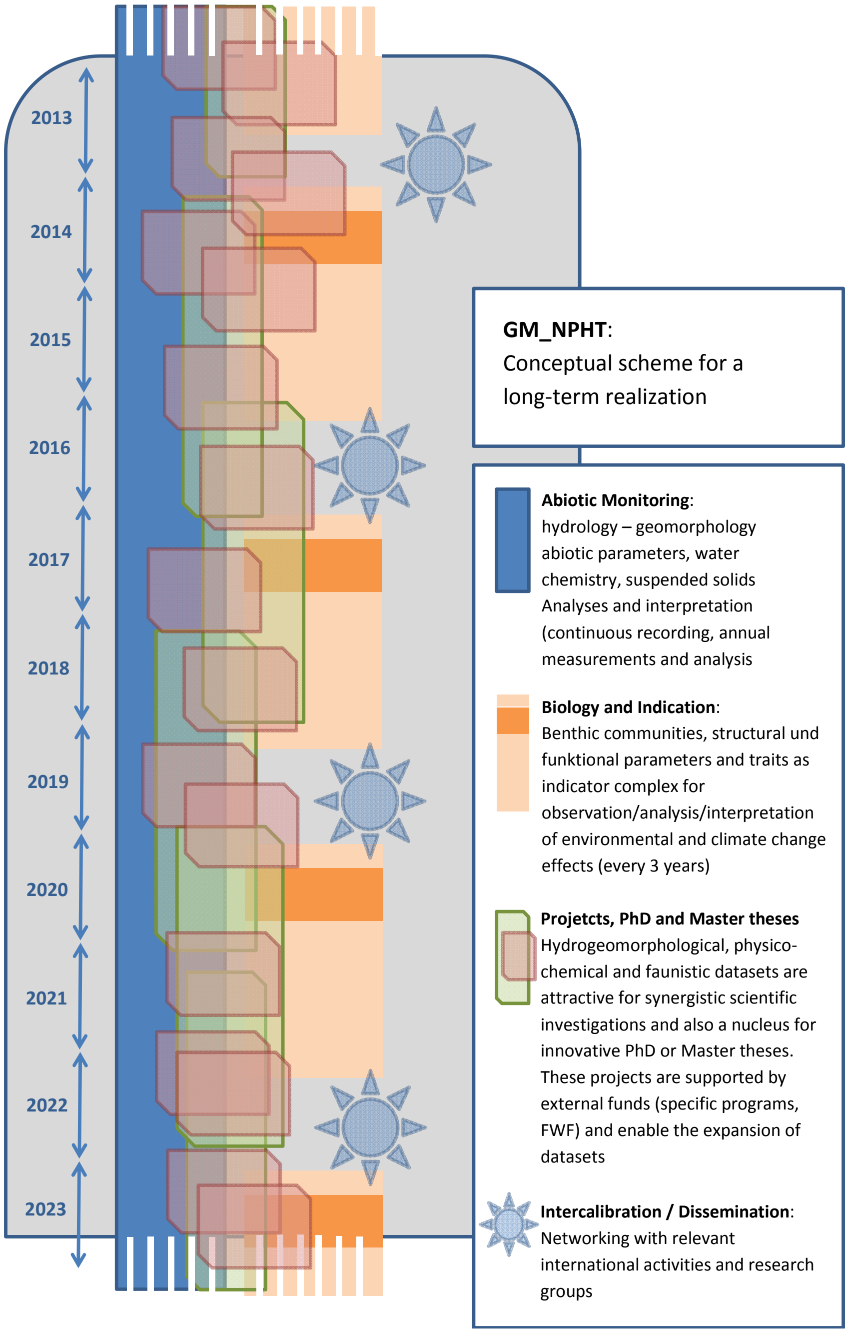

Figure 6: Conceptual scheme for the realization of a long-term monitoring on glacial rivers in the Hohe Tauern Nationalpark.

Already JACKSON & FÜREDER (2006) emphasised the need of long-term monitoring in science and provided three suggestions (*in italic below*) that should help expand and secure the temporal scale in studies of freshwater macroinvertebrates. These intentions were certainly fulfilled with our planned long-term freshwater monitoring program in the Nationalpark Hohe Tauern, because:

1. *Researchers need to look to both continuous and discontinuous approaches to generate long-term studies.* Both can measure change over time, but in different ways and with different investments. The involvement of the University of Innsbruck would guarantee the synergy of larger and smaller research projects, like PhD and Master theses, where both institutions would benefit from long-term data and specific research questions.
2. *Ongoing studies with long-term potential need to be transferred to colleagues dedicated to continuing the effort*. The existence of a long-term data set would attract other colleagues more easily to continue.
3. *After papers are published and researchers retire or move to new projects, options are needed to archive raw data with essential annotation and in some cases voucher specimens so they can be retrieved later. Peer-reviewed publications are valuable sources of information and insight, but they are often not a good source of data for generating a long-term perspective because the data are generally not presented with that purpose in mind.* Also in this respect, the Nationalpark Hohe Tauern with its infrastructure offers excellent possibilities by the Biodiversity Databank to archive data to be available for various specific analyses, also other than climate and environmental change questions.

In conclusion, protected areas in general are under pressures from multiple stressors, but they also carry the legacies of past landscapes and climates, and the burden of future large-scale changes (ROBINSON et al. 2011). They are an ideal arena for long-term biomonitoring, as they feature past and future ecological knowledge for the benefit of scientists, resource managers, and the public. With our framework and already existing comprehensive set of data we are ready to generate important information for which to test scientific principles, to define potential climate change effects and to learn from management actions. This long-term biomonitoring program would provide connections between the Nationalpark Hohe Tauern to a planned worldwide network for monitoring glacial rivers. The therein produced biological information and the expected interpretation and better understanding of changes makes protected areas ever more important.

Acknowledgements

We thank several colleagues and collaborators who helped in fieldwork and laboratory analysis. In particular we thank Alexandra Mätzler, Gerald Andre, Georg Niedrist, Sabrina Schönenberger, Ursula Winder, Stefanie Aumayr, Astrid Tischler, Julia Krug, Felix Lassacher and Stefan Schütz - their relevant research and contribution to this projects is either presented here in the symposium proceeding as an oral or poster presentation or is subject to future publication. We are also grateful to the colleagues and rangers of the Hohe Tauern Nationalpark who enormously helped in assistance and logistics. We further appreciate the financial support of the Nationalpark Hohe Tauern, the Lebensministerium, the Land Salzburg und the European Union (Europäischer Landwirtschaftsfond für die Entwicklung des ländlichen Raumes), who financed the Freshwater Monitoring Nationalpark Hohe Tauern as well as the Austrian Academy of Sciences, who financed the project PROSECCO.ALPS.

References

BARNETT, T. P., ADAM, J. C. & D. P. LETTENMAIER 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438: 303-309.

BARRY, R.G. 2006. The status of research on glaciers and global glacier recession: a review. – Progress in Physical Geography 30: 285-306.

BATES, B.C., KUNDZEWICZ, Z.W., WU, S. & J.P. PALUTIKOF (eds.) 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

BENISTON, M. 2003. Climate change in mountain regions: A review of possible impacts. – Climate Change 59: 5-31.

BRITTAIN, JE. & A.M. MILNER 2001. Ecology of glacier-fed rivers: current status and concepts. Freshwater Biology 46: 1571-1578.

BROWN, L. E. & A. M. MILNER 2012. Rapid loss of glacial ice reveals stream community assembly processes. – Global Change Biology 18: 2195-2204.

BROWN L. E., CÉRÉGHINO R. & A. COMPIN 2009a. Endemic freshwater invertebrates from southern France: diversity, distribution and conservation implications. - Biological Conservation 142: 2613–2619.

BROWN, L. E., HANNAH, D. M. & A. M. MILNER 2009b. ARISE: a classification tool for Alpine River and Stream Ecosystem management. Freshwater Biology 54: 1357-1369.

CHAPIN, F.S. III, WALKER, L.R., FASTIE, C.L. & LC. SHARMAN 1994. Mechanisms of primary succession following deglaciation at Glacier Bay, Alaska. Ecological Monographs 64: 149–175.

FÜREDER, L. 2012. Freshwater Ecology: Melting Biodiversity. In: Nature Climate Change 2: 318-319.

FÜREDER, L. 2007. Life at the edge: habitat condition and bottom fauna of Alpine running waters. International Review of Hydrobiology 92: 492–513.

FÜREDER, L. 1999. High Alpine Streams: Cold Habitat for Insect Larvae. – In: Margesin, R., Schinner, F. (eds.): Cold Adapted Organisms. Ecology, Physiology, Enzymology and Molecular Biology. – Springer Verlag, Berlin.

FÜREDER, L., VACHA, C., AMPROSI, K., BÜHLER, S., HANSEN, C.M.E. & C. MORITZ 2002. Reference conditions of alpine streams: Physical habitat and ecology. – Water, Air and Soil Pollution: Focus 2: 275–294.

HEINO, J., ILMONEN, J., KOTANEN, J., MYKRA, H., PAASIVIRTA, L., SOININEN, J. & R. VIRTANEN 2009. Surveying biodiversity in protected and managed areas: algae, macrophytes and macroinvertebrates in boreal forest streams. Ecological Indicators 9: 1179–1187.

ILLIES, J. & L. BOTOSANEANU 1963. Problemes et methodes de la classification et de la zonation ecologique des eaux courantes, considerees surtout du point de vue faunistique. Mitteilungen Internationale Vereiningung fuer Theoretische und Angewandte Limnologie, 12: 1–57.

JACKSON, J.K. & L. FÜREDER 2006. Long-term studies of freshwater macroinvertebrates: a review of the frequency, duration and ecological significance. – Freshwater Biology 51: 591–603.

JACOBSEN, D., MILNER, A.M., BROWN, L.E. & O. DANGLES 2012. Biodiversity under threat in glacier-fed river systems. Nature Climate Change 2: 361-364.

KAUFMANN, R. 2001. Invertebrate succession on an Alpine glacier foreland. Ecology 82: 2261-2278.

MARCANTE, S., WINKLER, E. & B. ERSCHBAMER 2009. Population dynamics along a primary succession gradient: do alpine species fit into demographic succession theory? Annals of Botany 103: 1129-1143.

MCINTOSH, R.P. 1985. The Background of Ecology. Cambridge University Press, Cambridge.

MILNER, A. M., BROWN, L. E. & D. M. HANNAH 2009. Hydroecological effects of shrinking glaciers. Hydrological Processes 23: 62–77.

OERLEMANS J., GIESEN R. H. & M.R. VAN DEN BROEKE 2009. Retreating alpine glaciers: increased melt rates due to accumulation of dust (Vadret da Morteratsch, Switzerland). - Journal of Glaciology 55: 729–36.

PECKARSKY, B.L. 1983. Biotic interactions or abiotic limitations? A model of community structure. - In: Dynamics of Lotic Ecosystems (Fontaine T.D. & S.M. Bartell Eds.). Pages 303 - 324. Ann Arbor Science Publishers, Ann Arbor, MI, U.S.A.

POFF, N. L. 1997. Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. Journal of the North American Benthological Society 16:391–409.

POFF, N.L., BRINSON, M. & J.B. DAY 2002. Freshwater and coastal ecosystems and global climate change: a review of projected impacts for the United States. Pew Center on Global Climate Change, Arlington, VA.

ROBINSON, C.T., DOERING, M. & L. SEELEN 2011. Use of protected areas for freshwater biomonitoring – case studies in Switzerland. eco.mont 3: 13-22.

ROSENBERG D.M. & V. H. RESH 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman & Hall, New York.

SCHINDLER, D.W. 1997. Widespread effects of climatic warming on freshwater ecosystems. - Hydrological Processes. 11: 1043-1067.

STATZNER, B. & L.A. BÊCHE 2010. Can biological invertebrate traits resolve effects of multiple stressors on running water ecosystems? Freshwater Biology 55: 80–119.

THOMSON, J. R., LAKE, P.S. & B. J. DOWNES 2002. The effect of hydrological disturbance on the impact of a benthic invertebrate predator. – Ecology 83: 628-642.

TOWNSEND, C.R., SCARSBROOK, M.R. & S. DOLÉDEC 1997. The intermediate disturbance hypothesis, refugia and biodiversity in streams. Limnology and Oceanography 42: 938-949.

USSEGLIO-POLATERA, P., BOURNAUD, M., RICHOUX, P. & H. TACHET 2000. Biological and ecological traits of benthic freshwater macroinvertebrates: relationships and definition of groups with similar traits. Freshwater Biology 43: 175–205.

Contact

Leopold Füreder
leopold.fuereder@uibk.ac.at

River Ecology and Invertebrate Biology
Institute of Ecology
University of Innsbruck
Technikerstraße 25
6020 Innsbruck
Austria

Wolfgang Schöner
w.schoener@zamg.ac.at

ZAMG-Zentralanstalt für Meteorologie und Geodynamik
Abteilung Klimaforschung
Hohe Warte 38
1190 Wien
Austria