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Framework for long-term ecological research in alpine river systems

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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). Global climate change scenarios suggest that this decrease will continue. 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). Predictions to 2100 for areas such as the European Alps suggest a continued glacier retreat, more intense/longer droughts, and widespread precipitation shifts from snow to rain. As a consequence, mountain hydrology and geomorphology will alter significantly, leading to substantial change on the water regime of snow- and ice-dominated regions, both on the global scale and on the regional scale (Milner et al. 2009). This will lead to the creation of new habitats for the colonisation and development of plant and animal species during the process of primary succession (e.g. Chapin et al. 1994, Kaufmann 2001).

On the other hand, the fauna of alpine headwater streams is strongly adapted to the environmental conditions and under the scenarios of future alpine meltwater reductions some of these aquatic species are vulnerable to extinction (Jacobsen et al. 2012, Füreder 2012). As aquatic ecosystems also can sustain populations of higher organisms such as fish, amphibians and birds, the potential effects could be felt much more widely than in river systems. However, the potential effects of alterations to alpine river hydrology and biodiversity across other alpine areas can only be speculated at present due to minimal baseline data on alpine basin hydrology, geomorphology effects on basin hydrology, temperature and water chemistry, and linkages between these aspects and river ecology.

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.

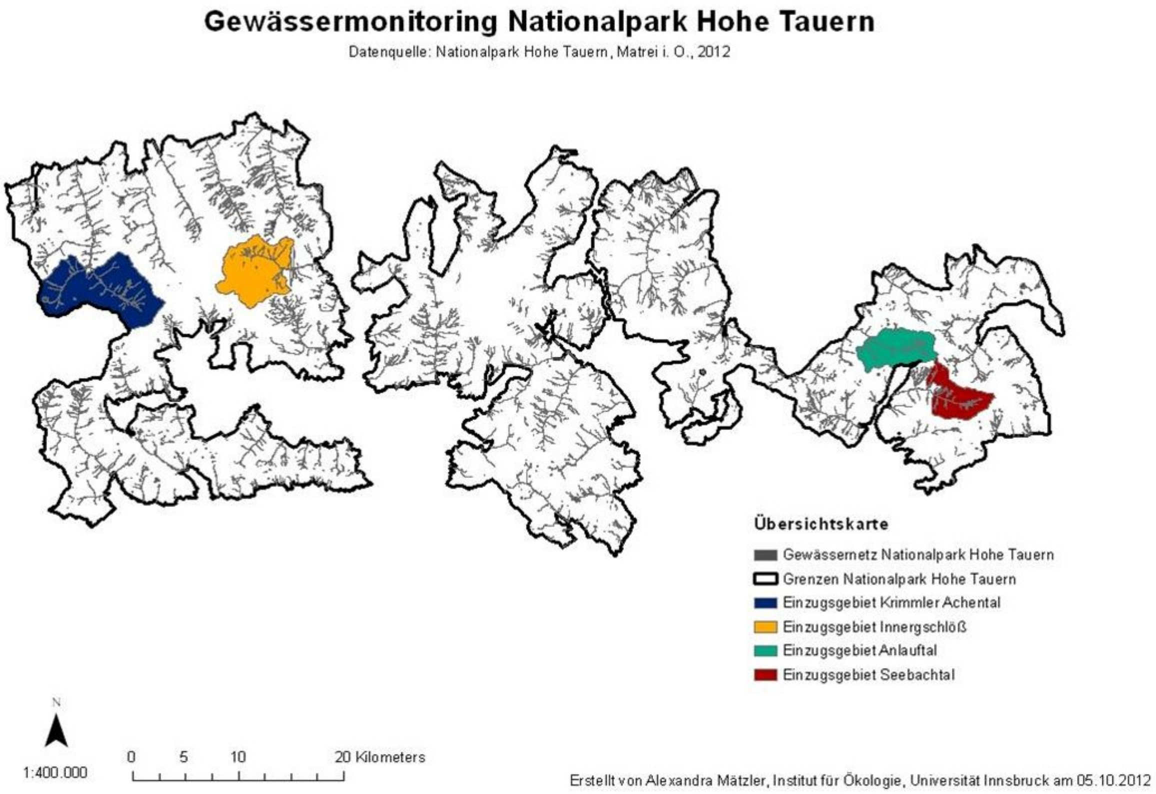

Figure 1: Nationalpark Hohe Tauern in Austria, location of the catchments (Krimmler Achental, Innergschlöß, Seebachtal, Anlauftal), where freshwater monitoring was implemented

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 rivermorphology 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.

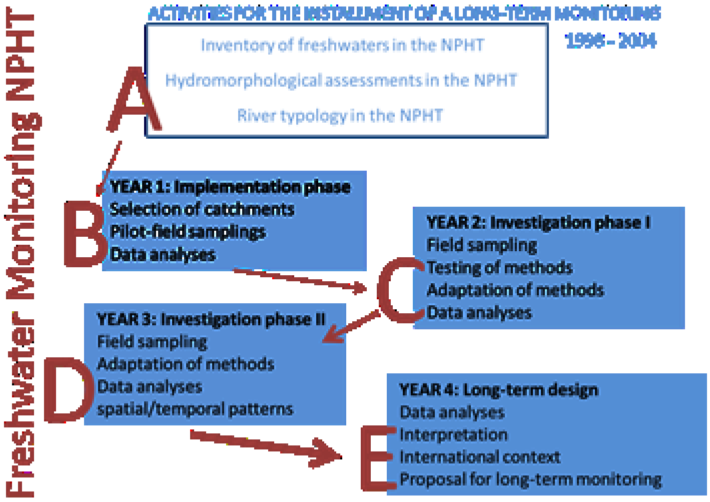

Figure 2: Project phases for the implementation of the freshwater monitoring in the NPHT

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. Long-term research is considered fundamental for studying the effect of environmental change on ecosystem structure and function. It offers opportunities to observe and document slow, rare, subtle or complex changes frequently missed by shorter studies (LIKENS 1989, JACKSON & FÜREDER 2006). Whilst the importance of long-term ecological records is well documented, the availability of year-on-year records spanning more than two decades is currently low for river ecosystems (e.g. OBACH et al. 2001, DURANCE & ORMEROD 2007, MILNER et al. 2009). There is a complex interaction of hydrological, thermal and water quality regime shifts, changes to the energy base of aquatic food webs, and dispersal constraints of individual species. All these constraints respond to environmental change and influence riverine communities (e.g. WOODWARD et al., in press). 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.

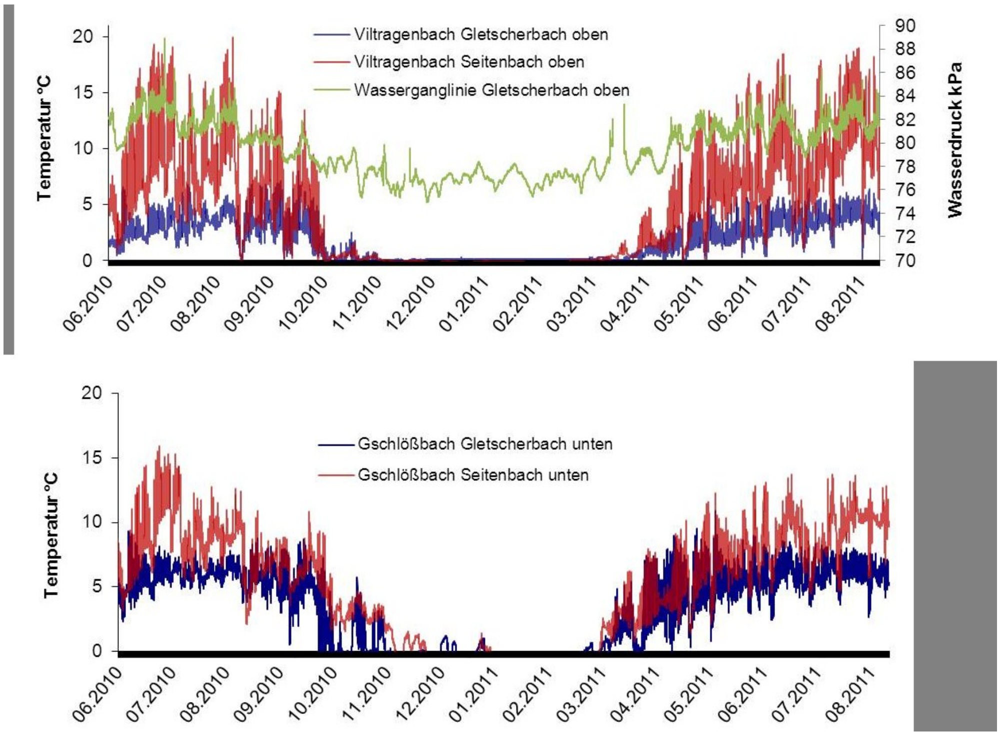

Figure 3: Example of temperature and discharge fluctuation patterns in Viltragenbach (Innerglösch)

For the intended long-term monitoring a comprehensive set of hydrophyscial and chemical as well as biological data now exist, which were used to define adequate field methodologies, sample analyses and indicators and serve as an excellent basis for the future explaination of environmental/climate change. In particular we have

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

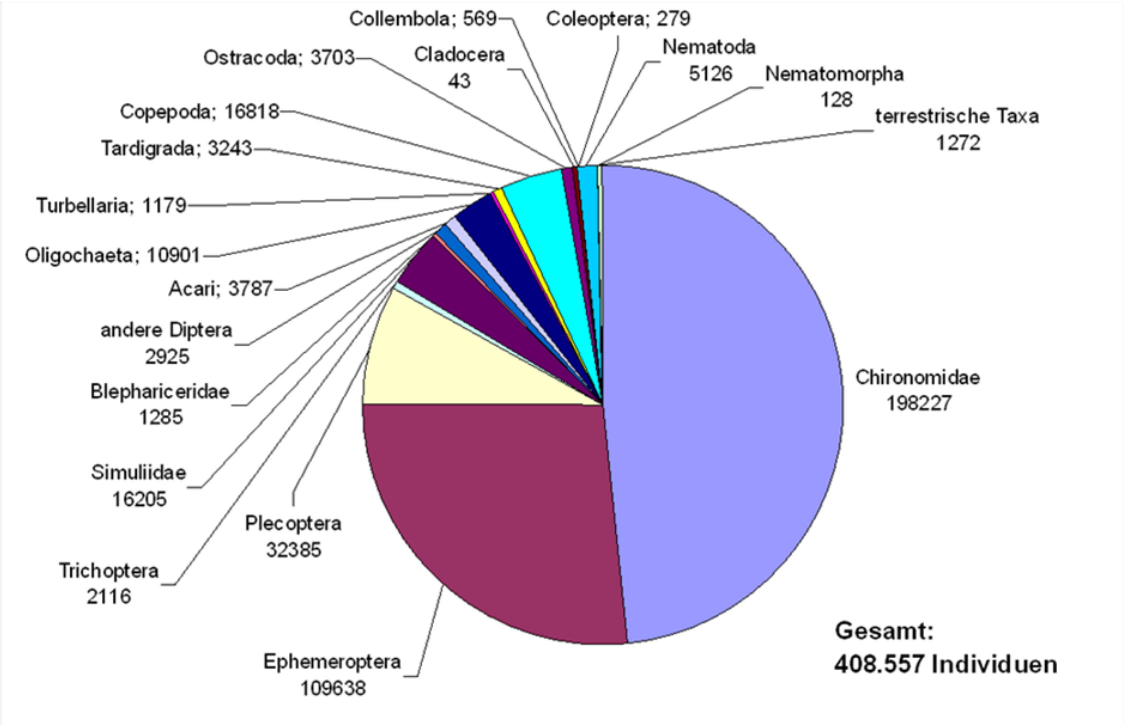

Figure 4: More than 400.000 invertebrates were collected during the research period 2009 – 2011 belonging to 18 higher taxonomic groups

In high altitude and latitude regions glaciers contribute significantly to river flow (e.g. FÜREDER 2007). Interpretation of climate-change scenarios propose marked shifts in the floral and faunal composition of rivers over coming decades due to projected decreases in suspended sediment load, higher water temperature and increases channel stability as catchment glacier cover decreases (e.g. ILG & CASTELLA 2006, BROWN et al. 2007, MILNER et al. 2009). Most regions of the world have seen decreases in glacial mass over the last 50-60 years (ZEMP et al. 2009), extensive and rapid retreat has been observed for many of the Alpine glaciers (e.g. FISCHER 2010). Here, glacial retreat has been occurring rapidly since around 1850 (end of the Little Ice Age), opening up vast areas of deglaciated terrain, and creating hundreds of meters of new rivers that subsequently undergo colonization and primary succession by biotic communities (FINN et al. 2010).

The use of multiple biological traits to characterize the functional composition and diversity of stream invertebrate communities (cf. typical focus on structure/biodiversity) is now well established in the ecological literature (POFF 1997; TOWNSEND et al. 1997; USSEGLIO-POLATERA et al. 2000; FÜREDER 2007, STATZNER & BÊCHE 2010) although few long-term studies exist (but see: BÊCHE et al. 2006, BÊCHE & RESH 2007). Functional classifications group species with similar biological and ecological traits (e.g. life-history, mobility, morphological, and ecological), attributes that have been shaped by natural selection over evolutionary time scales (POFF et al. 2006) and which influence how species respond to contemporary environmental change.

Whilst there are no published studies of how stream macroinvertebrate biological trait composition changes over time as glaciers retreat and disappear, several studies have used a space-for-time substitution to infer trait responses to glacial influence (SNOOK & MILNER 2002, ILG & CASTELLA 2006, FÜREDER 2007). These studies indicate that where glacierization is high, macroinvertebrates are typically cold stenotherms, with small sized streamlined/flattened bodies, possessing clinging habits and displaying omnivorous feeding.

Change in the species trait composition of Alpine river ecosystems over time should theoretically be similar to findings across European rivers if variables such as increased disturbance, and low water temperature and food supply associated with high glacierisation act as environmental drivers, or 'filters' (sensu SOUTHWOOD 1988, POFF 1997, STATZNER et al. 2001, 2004, 2008), to colonization. We can expect that glacial river macroinvertebrate community would show the following changes over time as glacial ice cover in the catchment decreased - see Fig. 5 and FÜREDER (2007) for more details:

(i) increased functional diversity, associated with higher taxonomic richness and habitat changes,

(ii) a shift towards short life cycles as stream temperature increased (ILG & CASTELLA 2006),

(iii) increased aerial mobility of invertebrate taxa as early colonizers (typically weak flying Chironomidae with long-range dispersal capabilities: MILNER 1994) were replaced by stronger flying insects;

(iv) shifts in macroinvertebrate morphology, in particular larger organisms colonizing as glacial influence (and thus disturbance) decreased;

(v) a loss of cold-stenotherms as stream temperature increased (BROWN et al. 2007, FÜREDER 2007), and

(vi) to the relative abundance of functional feeding groups, in particular more shredders linked to the establishment and increased development of riparian vegetation, and predators being the last trophic group to colonise (see MÄTZLER & FÜREDER, this issue).

Under exploitation of the three-years baseline data, these hypothesis are now being tested and expended 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.

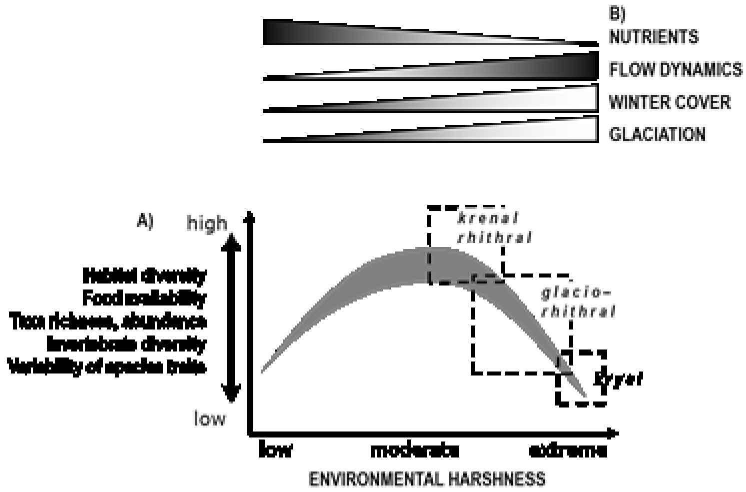

Figure 5: Scenario of environmental and climate change effects on key environmental conditions and consequently on the structure and function of the invertebrate fauna in alpine streams (from: Füreder, 2007; modified).

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). WEATHERHEAD (1986) observed that authors noted unusual events less frequently in longer studies, presumably because the longer temporal perspective modified the definition of an unusual event. Although the value of long-term ecological perspectives is well documented – references in JACKSON & FÜREDER (2006), 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 from older research (e.g. STATZNER et al. 1994). In a 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. Now all prerequisites for a long-term monitoring are available, ready for a program that would link the Nationalpark Hohe Tauern research activities with freshwater research worldwide.

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.

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