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Species traits in the alpine stream fauna: a promising tool for freshwater monitoring

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Summary

Alpine river ecosystems above the treeline are generally fed by glacial icemelt, snowmelt, and groundwater, share common features (e.g. steep gradients, high flow velocities and dynamics) and support a unique flora and fauna, including endemic and threatened species adapted to harsh environmental conditions. Alpine river ecosystems are under major pressure from climate change, altered hydrology with retreating glaciers and shrinking snow cover, and increasingly from a variety of anthropogenic influences including hydroelectric power, water abstraction and tourism that are expected to change biodiversity and ecosystem structure and function. Although various attempts have been made to characterise diversity in alpine streams, little is known about the relationships between catchment characteristics, diversity and ecosystem function at higher altitudes. In preliminary investigations for a river monitoring in the Hohe Tauern Nationalpark, we found that glaciation in the catchment turned out to be a major factor for defining the hydromorphological conditions, the degree of harshness to influence taxa richness and diversity of the aquatic fauna. Subsequently, we tested the effect of glaciation on the bottom fauna in applying a set of species traits, indicating strategies and adaptations of resilience and resistance as well as to face environmental harshness. We extended the application of species traits to a larger variety of river systems. As current climate change scenarios propose major impacts at high altitudes considerable changes within the faunal assemblages including their functional organisations are to be expected. In this respect, the application of species traits in combination with traditional indices will build a useful methodology in environmental monitoring.

Keywords

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

Background and Aim of the Investigation

River systems in alpine and arctic environments are a dominant feature of the landscape, receiving and distributing water, solid substances, nutrients and other material. They are responsible for landscape alterations and a dynamic change of riverine and adjacent environments. The dimensions of change strongly depend on river size, discharge and flow dynamics as well as the water-source contributions. Between the permanent snowline and the treeline, streams may be either glacier-melt dominated, seasonal snowmelt-dominated or spring-fed, often alpine and arctic stream networks comprise a complex mosaic of these stream types (Ward, 1994; McGregor et al., 1995; Füreder, 1999). Each differs in environmental conditions and is known to support a somewhat different assemblage of organisms (Brown et al. 2003). These differences among assemblages reflect the distinct environmental conditions that are characteristic of the individual stream types, such as degree of glacial influence, geology of the watershed and disturbance timing and intensity (e.g., seasonal floods from snow-melt versus more stable flow from groundwater inputs: e.g. Milner & Petts, 1994).

The environmental conditions in alpine glacial streams and rivers exert a severe constraint on the successful colonization and persistence of aquatic macroinvertebrate species. Therefore, the occurrence of a particular species is a direct expression of this species' ability to tolerate or adapt to the existing conditions (Füreder, 1999). Although the stream fauna of glacier-fed streams is greatly reduced, downstream faunal changes are distinct and predictable (Milner & Petts, 1994; Ward, 1994). The differences among assemblages may reflect the high degree of specialization of species in alpine streams – many of these species have a narrow tolerance range for a number of environmental variables (e.g., temperature, current, nutrient concentrations) relative to related species in other types of streams. Survival under the harsh environmental conditions in alpine streams requires physiological and/or life cycle adaptations. As a result, the duration of life cycles, larval growth and egg/larval development is to be expected to be different compared to less extreme environments. These adaptations have hardly been studied in ecological investigations in alpine freshwater habitats.

In order to define a comprehensive monitoring tool for the identification of climate-change effects on alpine riverine ecosystems (including geomorphology, ecology, biology and species-adaptation characteristics) we primarily focused on potential effects of glaciation on habitat characteristics and faunal assemblages using various datasets (details in Füreder et al., 2002; Füreder, 2007). Considering the paucity of information on trait-related studies for glacier-fed rivers and the variety of these running waters (Brown et al., 2003), the goals were (1) to provide information on the variability of alpine stream types in terms of hydromorphological and type-specific characteristics, (2) to assess the glacial influence on habitat characteristics and the faunal assemblages, (3) to specifically concentrate on species traits along a gradient of glacial influence and (4) to present a conceptual model for alpine and arctic river ecosystems under environmental and climate change.

Study Areas, Datasets and the Selection of Species Traits

The study areas comprise the Hohe Tauern National Park (NPHT), which is situated in the Austrian Central Alps with an area of 1800 km^2, and other non-impacted areas near and above the tree-line. For the realization of a freshwater monitoring, an inventory of existing freshwaters was already established for the NPHT (Füreder et al., 2002), including 279 streams (981 km stream/river length, catchment area >1 km^2) and 136 lakes and alpine ponds. Based on habitat assessments, including catchment and river-morphology characteristics, stream and river types were defined. For the definition of stream/river types in the alpine region, 161 stream sections that reached natural or near-natural habitat quality were selected and classified. For the characterization of alpine stream invertebrate assemblages the data used were drawn exclusively from non-impacted, natural or near-natural stream sections. Using our own data and that from various other sources we assembled information on 60 sites from 37 different rivers. For this presentation, a major focus was on the importance of glacial influence on stream insect assemblages, taxa richness, abundances, diversity and evenness, as well as resistance, resilience and environmental harshness traits within the assemblages. A total of 297 aquatic invertebrate taxa had been identified in earlier studies and were compiled into the data set. Species traits from published data, unpublished theses and personal communications from experts were available to characterize life-history traits for each of these species. The definition of species traits is outlined in Füreder (2007).

Environmental Conditions and the Invertebrate Fauna of Alpine Streams

The dataset of the freshwater inventory of NPHT provided 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 present 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 observed.

Traits of Resilience, Resistance and Environmental Harshness

The invertebrate taxa of glacier-fed rivers were shown to be equipped with several physiological and biological attributes that enable them to survive and successfully complete their life-cycles in the harsh environment. With increasing glaciation, these specific abilities within the invertebrate assemblage are increased in their relative proportions. As hypothesized, where environmental harshness reaches its highest levels, most taxa are very specifically and well adapted to these conditions.

A Conceptual Model for Alpine River Ecosystems Faced with Environmental and Climate Change

Results of our investigations, as well as from other groups working in similar systems, demonstrate how alpine running water systems and their biota can be regarded as catchment-scale integrative monitors for a set of hydrological, thermal and biotic variables – variables that are expected to be modified by climate change. Since current climate change scenarios indicate proportionally more detectable impacts at both high altitude and latitudes, alpine running waters can be regarded as research foci in the context of climate change and their communities considered to be as much under change as other biological communities.

Alpine streams may play a specific role within the scenario of environmental and climate change effects on the abiotic factors and, consequently, on the structure and function of aquatic biocenoses (Fig. 1). Alpine streams are positioned along the right slope of a harshness-ecosystem-structure-and-function curve (Fig. 1A), where environmental harshness is moderate to extreme, depending on the glacial influence. In glacial streams ("kryal" river reaches) environmental factors, such as flow dynamics, temperature and nutrient/food levels, reach their most extreme levels and therefore only a few but highly adapted species are found. Recent investigations and results presented here indicate that habitat diversity, food availability, taxon richness, invertebrate diversity and abundance follow the gradient of decreasing glaciation ("glacio-rhithral"). The variability of species traits is also affected, being low where the environmental harshness is extreme but higher when harshness is moderate. In spring-fed streams ("krenal") and in snowmelt and rainfall induced systems ("rhithral"), more species can co-exist because of moderate and more favourable environmental conditions. Only when the environmental harshness is low freshwaters can get very productive. Then single species are promoted, resulting in lower species numbers but usually with high abundances. Environmental and climate change effects (Fig. 1B) would alter the situation: glacial retreat would reduce the glaciation of the catchment and diurnal and annual dynamics of flow would decline. The duration of snow cover is expected to be reduced. As a consequence, production would increase in both the stream and in the catchment and, consequently, favour nutrient and food availability for the aquatic fauna. The same would be true for other environmental change effects that result from water diversion for artificial snow generation and hydropower. Decreasing environmental harshness (e.g., due increasing groundwater influence, decreasing glaciation, reduction of environmental extremes in temperature and flow dynamics) will favour overall biodiversity, as a potential effect of climate change. The relative contribution of the channel types that provide numerous refugia for the aquatic fauna will increase with the continued glacial retreat.

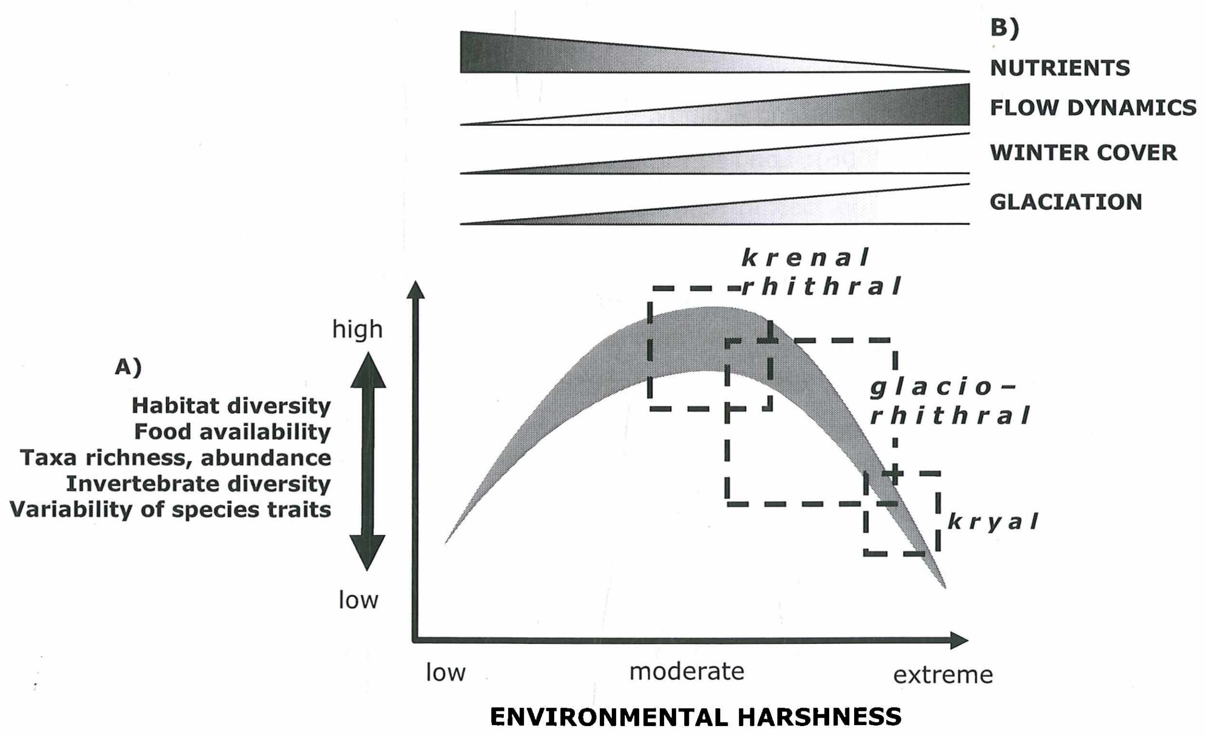

Figure 1: Scenario of environmental and climate change effects on key environmental conditions and consequently on the structure and function of the invertebrate fauna in alpine streams (from: Füreder, 2007; modified).

Climate change is expected to influence the hydrological regime of arctic, alpine and mountain streams in a variety of ways but the influence on glacier meltwater may be particularly significant (McGregor et al., 1995; Füreder, 2007; Milner et al., 2009). Changes in the magnitude and variability of a range of climate determinants of glacier behaviour, as a result of an enhanced greenhouse effect, will have important implications for the future hydrogeomorphological, runoff dynamics and temperature regimes of glacial streams. Water resources developments, such as water diversions for hydro-electric power, water abstraction and land-use changes, will also have marked impacts upon these stream ecosystems, particularly on benthic communities. Stream macroinvertebrate communities are widely used to monitor these changes in water quality as a result of human impact, notably with regard to organic pollution and acidification (Jackson & Füreder, 2006). As has been outlined in several other studies in rivers from other climate and geographical regions, the herein presented application of species-traits methodology, with detailed knowledge of environmental templates determining macroinvertebrate distribution, is a promising technique for using benthic invertebrates as bioindicators of environmental change in arctic and alpine running waters. Among the potentially sensitive ecological systems, alpine and arctic running waters may serve as models to examine the consequences of climate changes, regarding them and their biota as catchment-scale integrative monitors for a set of hydrological, thermal and biotic variables that might be modified by environmental and climate change.

Given the enormous amount of natural and near-natural riverine systems in protected areas in the Alps, the application of herein presented methodologies will provide an outstanding opportunity for freshwater monitoring. Similar research activities in alpine running water ecosystems would add important knowledge for the assessment of biodiversity in mountain areas. With proposed methodologies, the information about diversity, abundance, rarity and endemism of invertebrate taxa would be complemented with functional attributes which all together build essential information for the understanding and interpretation of climate and environmental change effects on aquatic ecosystems.

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