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Diversity measures indicating environmental change in alpine river ecosystems

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Abstract

Environmental conditions under change strongly affect alpine streams and their benthic communities by altering ecosystem structure and function. Adequate methods for the evaluation of these cause-effect relationships have rarely been developed. Biological indices are known as reliable tools for ecosystem characterization but hardly any experiences have been gained for their application in the alpine zone. We selected 69 established biological indices, grouped them into five categories according to their expressiveness and verified 43 of them as theoretical suitable for alpine stream assessment. Using invertebrate assemblages from 159 quantitative benthic samples from 18 alpine stream sites, at three sampling occasions, the validation and suitability of each individual index was tested. Our analyses suggest best index performances when evaluating: i) alpha diversity (Q Statistic), ii) evenness (Smith & Wilson B), iii) disparity (Harrison 2) and iv) assemblage changes (Harrison 2) in alpine streams. We also identified and depicted potential for development of common index models for the evaluation of the v) ecological function of alpine aquatic ecosystem, which are based on species level classifications. Our results demonstrate that theoretical preparatory work regarding the methodology of alpine freshwater studies is inevitable in order to reveal expressive results.

Keywords

alpine stream diversity, biological index, benthic invertebrates, monitoring

Introduction

Environmental changes due to anthropogenic or climatic influences are the main driving forces for worldwide ecological modifications (LENTO et al. 2013). Especially alpine streams and the inhabiting benthic communities will be affected by climate change effects like accelerated glacial retreat, oscillating discharges, reduced habitat stability, altered water chemistry, decreasing nutrient availability, and finally, increasing water temperatures (JACOBSEN et al. 2012, KHAMIS et al. 2014). These environmental modifications will affect the diversity of benthic communities in alpine freshwater ecosystems, dominated by Chironomidae, Ephemeroptera, Plecoptera, Trichoptera and some infrequent other Diptera species (LODS-CROZET et al. 2001). The larvae of these insects are relatively immobile and therefore directly exposed to the environmental conditions (FÜREDER 2007). Former studies revealed narrow species-specific range of occurrences of these highly adapted benthic insects, qualifying them as suitable base for alpine freshwater ecosystem and community diversity characterization (FÜREDER 1999, ROBINSON et al. 2010).

Biological indices are most appropriate for depicting general community conditions and changes in a simplified and comparable way (CARLO et al. 1998). However, most common indices were published for low land ecosystems (CARLO et al. 1998) and hardly any of these mathematical models proved to fit the demands of alpine streams. BROWN et al. (2009) already pointed out these failings and demonstrated the possibilities biological indices burrow as early warning signals for environmental change and for long-term monitoring programs. The search for adequate indices, evaluating the holistic alpine freshwater diversity is inevitable and overdue.

In this study, we critically examined the most common used biological index models regarding their applicability for alpine freshwater ecosystems in three steps: 1) Index collection: collection and grouping of indices according to their prediction by analyzing relevant literature. 2) Theoretical index validation: preselection of index models from step 1 regarding their theoretical applicability for alpine benthic communities and 3) index computation and statistical verification. For the last step, three major abiotic driving forces on benthic species (water temperature, distance from the glacier snout and percentage of glaciation of catchment) were used to evaluate the best indices.

Methods

Sampling took place within the project PROSECCO.Alps (Proglacial stream ecohydrology and climate change over the Alps) in two catchments located in the Großglockner and Goldberg regions, Hohe Tauern NP, Austria. 18 sites along an environmental harshness gradient, nine in each region, were sampled in July, August and September 2011. Four sites were solely spring fed, the other 14 sites were glacially influenced. At each site and sampling, three replicate Surber Samples (100µm mesh size, 0.09m², immediately preserved in 75% Ethanol) were taken and water temperature was measured. Benthic insects of all 159 samples (one stream ran dry in September) were determined to the lowest possible level using adequate determination keys (e.g. JANECEK 1998, LUBINI et al. 2000, BAUERNFEIND & HUMPESCH 2001, WARINGER & GRAF 2004). Water temperature was measured with a WTW multi parameter measurement. Distance from the glacier (G_{Dist} [m]) and percentage of glaciation of catchments (%GC) was measured using the online geographic services of the states Carinthia (http://www.kagis.ktn.gv.at) and Salzburg (www.salzburg.gv.at/sagis). In the first two working steps, commonly used indices were gathered by analyzing relevant literature (69 indices found) and grouped according to their definitions: group i) habitat diversity/alpha diversity (16 indices); group ii) evenness (16 indices); group iii) beta diversity: (17 indices); group iv) assemblage changes along a stream/beta diversity (20 indices) and group v) ecological function & nutrient content (17 indices). In a second step, the 69 indices were theoretically validated by analyzing their mathematical background whether they are suitable for the evaluation of alpine freshwaters. In the third working step the remaining indices from step 2 were computed for all sampling sites in both regions and their performance statistically checked. Linear regression analyses were used to evaluate the index performance of group i), ii) and v). Index values of group iii) and v) were directly evaluated and discussed. For the calculation the three parallel samples of each site and sampling season were added. The two regions and the three tested abiotic conditions were treated separately to double check the performance of the tested indices. An adequate measure has to perform superior in both of our sampling regions and for all three abiotic factors in order to be suitable for all alpine freshwaters around the world.

Extracted results – group i) alpha diversity

In step 1, 16 commonly used alpha indices were gathered. Working step 2 showed, that only 12 measurements are theoretically suitable to assess the alpine freshwater diversity due to their mathematical background. As with decreasing environmental harshness the diversity should be linearly increasing, suitable alpha diversity indices must show this pattern. The index with the highest R^2 value performs best in our study and is therefore the best measurement for alpine stream diversity (Tab. 1).

Index	Großglockner-region			Goldberg-region		
	T [°C]	G_{Dist}	%GC	T [°C]	G_{Dist}	%GC
Brillouin D	0.29	0.77	0.57	0.44	0.29	0.57
Fisher`s Alpha	0.05	0.11	0.14	0.75	0.94	0.72
Margalef D	0.23	0.45	0.34	0.77	0.94	0.72
McIntosh D	0.04	0.00	0.01	0.25	0.07	0.38
Menhinick D	0.07	0.05	0.05	0.55	0.75	0.64
Q Statisitc	0.27	0.67	0.62	0.76	0.90	0.58
Shannon Wiener	0.20	0.66	0.47	0.44	0.29	0.57
Simpson	0.02	0.20	0.13	0.39	0.19	0.43
Species Number	0.43	0.67	0.54	0.79	0.91	0.68
%Chironomidae	0.22	0.23	0.55	0.45	0.53	0.43
%Diamesinae	0.00	0.09	0.02	0.46	0.60	0.53
%EPT	0.05	0.04	0.00	0.42	0.51	0.38

Table 1: R^2 values of the 12 theoretically suited alpha diversity indices for both regions and all three abiotic conditions (water temperature T [°C], G_{Dist} and %GC).

Some indices, e.g. Menhinick D and Fisher`s Alpha, reached very low R^2 values in the Großglockner-region but high coefficients of determination in the Goldberg-region. Simpson and Shannon Wiener index – the two most often used alpha diversity indices in modern ecology - have quite low R^2 values in both regions. The Q Statistic index has the highest R^2 values for all three abiotic conditions and in both sampling regions and seems to fit the alpine conditions best.

Discussion & Conclusion

Statistical analyses showed that not all 12 theoretically suited indices from working step 2 were able to successfully measure the occurring diversity pattern in the sampled alpine streams. The two most often used indices in ecological surveys, Simpson and Shannon Wiener, showed inhomogeneous, low R^2 values. Therefore, we cannot recommend to use these indices for assessing the diversity in alpine freshwater ecosystems. The best alpha diversity index in our study is Q Statistic (KEMPTON & TAYLOR 1976) with the highest R^2 values across all abiotic drivers and in both regions. Our study brought up suitable indices of all five investigated measure groups (Tab. 2).

Group	Best Index	Author(s)
Group i) alpha diversity	Q Statistic	Kempton & Taylor 1976
Group ii) evenness	Smith & Wilson B	Smith & Wilson 1996
Group iii) beta diversity	Harrison 2	Harrison et al. 1992
Group iv) regional beta diversity	LZI (LängsZonalerIndex)	Zelinka & Marvan 1961
Group v) ecological function & nutrition content	BMWP/(M)BMWP	BMWP 1987

Table 2: The best diversity measures of all five index groups

This set of indices is best suited to evaluate the diversity of alpine freshwater ecosystems. In times of environmental change, measures with the highest sensitivity are needed to detect even the smallest alterations. For reliable results in studies and long term monitoring projects, the selection of analysis tools is at least as important as the sampling itself. Only by thoroughly picking the most suitable analysis tools, the full potential of a data set is exploited. Therefore, we suggest to use our recommended indices for alpine stream diversity assessment in order to ensure reliable and comparable results.

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References

BAUERNFEIND, E. & U.H. HUMPESCH 2001. Die Eintagsfliegen Zentraleuropas (Insecta: Ephemeroptera): Bestimmung und Ökologie. Verlag des Naturhistorischen Museums Wien.

BMWP (BIOLOGICAL MONITORING WORKING PARTY), 1978. Final Report: Assessment and Presentation of the Biological Quality of Rivers in Great Britain, Unpublished Report, Department of Environment., Water Data Unit.

BROWN, L.E., HANNAH, D.M. & A.M. MILNER 2009. ARISE: a classification tool for Alpine RIver and Stream Ecosystems. Freshwater Biology 54: 1357–1369.

CARLO, H R, HERMAN, P.M.J. & K. SOETAERT 1998. Indices of diversity and evenness. Oceanis 24 (4): 61–87.

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

FÜREDER, L. 2007. Life at the Edge: Habitat Condition and Bottom Fauna of Alpine Running Waters. International Review of Hydrobiology 92: 491-513.

HARRISON, S., S.J. ROSS & J.H. LAWTON, 1992. Beta diversity on geographic gradients in Britain. Journal of Animal Ecology 61: 151–158.

JACOBSEN, D. & O. DANGLES 2012. Environmental harshness and global richness patterns in glacier-fed streams. Global Ecology and Biogeography 21: 647-656.

JANECEK, F. R. 1998. FAUNA AQUATICA AUSTRIACA, Taxonomie und Ökologie aquatischer wirbelloser Organismen, Diptera: Chironomidae (Zuckmücken), Universität für Bodenkultur, Abteilung Hydrobiologie, Wien.

KEMPTON, R.A. & I.R. TAYLOR, 1976. Models and statistics for species diversity. Nature 262: 818-820.

KHAMIS, K., HANNAH, D.M., BROWN, L.E., TIBERTI, R. & A.M. MILNER 2014. The use of invertebrates as indicators of environmental change in alpine rivers and lakes. Science of the Total Environment 493: 1242-1254.

LODS-CROZET, B., CASTELLA, E., CAMBIN, D., ILG, C., KNISPEL, S. & H. MAYOR-SIMEANT 2001. Macroinvertebrate community structure in relation to environmental variables in a Swiss glacial stream. Freshwater Biol 46(12): 1641–1661.

LUBINI, V., KNISPEL, S. & G. VINCON 2000. Plecoptera Bestimmungsschlüssel Schweiz, Neuauflage von J. Aubert (1959): Plecoptera. Insecta Helvatica BD. 1.

LENTO, J., MONK, W. A., CULP, J. M., CURRY, R. A., COTE, D. & E. LUIKER 2013. Responses of Low Arctic Stream Benthic Macroinvertebrate Communities to Environmental Drivers at Nested Spatial Scales. Arctic, Antarctic, and Alpine Research 45(4): 538–551.

ROBINSON, C.T., KAWECKA B., FÜREDER, L. & A. PETER 2010. Biodiversity of Flora and Fauna in Alpine Waters. Alpine Waters 6: 193-223.

SMITH, B. & B. WILSON, 1996. A consumer`s guide to evenness indices. Oikos 76(1): 70-82.

WARINGER, J. & W. GRAF 2004. Atlas der österreichischen Köcherfliegenlarven – unter Einschluss der angrenzenden Gebiete. Facultas Universitätsverlag, Wien.

ZELINKA, M. & P. MARVAN, 1961. Zur Präzisierung der biologischen Klassifikation der Reinheit fließender Gewässer. Archiv für Hydrobiologie 57(3): 389-407.

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