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RESEARCH ARTICLE

Inland aquatic bioregions of Mediterranean climate region of Slovenia; biodiversity and possible climate change impacts

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ABSTRACT

1. The relation between biodiversity and climate change trends and other human-induced environmental changes in five bioregions of the Mediterranean climate region of Slovenia were studied.
2. For each bioregion running water ecosystem diversity was defined as number of natural river types. Types of running waters were derived as combination of most important ecological characteristics affecting aquatic organisms. One of the ecological characteristics describing river types was also a periodicity dividing permanent and intermittent streams.
3. In addition to the ecosystem diversity a species diversity of benthic invertebrate communities was defined for the each bioregion.
4. Four species diversity measures were calculated: number of taxa, number of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa, Shannon diversity index (H') and Evenness (Pielou's).
5. A significant statistical difference between permanent and intermittent rivers was observed for three species diversity measures, but not for Shannon diversity index.
6. Based on the observed differences in biodiversity measures, possible impacts for the ecosystem and the benthic invertebrate species diversity are discussed.
7. It seems that in some cases at the bioregional scale climate change and human-induced activities can cause a rise in the ecosystem and species biodiversities.

KEY WORDS: Benthic invertebrates, bioindicator, diversity, drought, ecosystem diversity, river types, species in intermittent streams.

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Slovenya'nın Akdeniz İklim Bölgesindeki içsu sucul biyobölgeleri; biyoçeşitlilik ve muhtemel iklim değişikliği etkileri

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ÖZ

1. Slovenya'nın Akdeniz iklim bölgesinde bulunan beş biyobölgesinde, biyoçeşitlilik ve iklim değişikliğindeki yöneliş ile insan kaynaklı çevresel değişiklikler çalışılmıştır.
2. Her biyobölgedeki akarsu ekosistem çeşitliliği seçilen doğal nehir tiplerinde belirlenmiştir. Akarsu tipleri, sucul organizmaları etkileyen en önemli ekolojik karakterlerin kombinasyonu kullanılarak belirlenmiştir. Ayrıca nehir tiplerini tanımlamada kullanılan ekolojik karakterlerden biri de akarsuların devamlılığı ve aralıklı olarak kurumalarıdır.
3. Ekosistem çeşitliliğine ek olarak bentik omurgasız komünitelerinin tür çeşitliliği her biyobölge için belirlenmiştir.
4. Dört adet tür çeşitlilik indeksi kullanılmıştır: taksa sayısı, EPT (Ephemeroptera, Plecoptera, Trichoptera) sayısı, Shannon Çeşitlilik İndeksi (H') ve Pielou Eşitlik İndeksi.
5. Shannon Çeşitlilik İndeksi hariç diğer üç çeşitlilik indeksi sonuçlarına göre devamlı akan ve aralıklı olarak kuruyan nehirler arasında, belirgin bir istatistiksel fark gözlenmiştir.
6. Biyoçeşitlilik ölçümlerinde gözlenen farklara dayanarak, ekosistem ve bentik omurgasız türleri için iklim değişikliğinin olası etkileri tartışılmıştır.
7. Bazı durumlarda biyobölgesel ölçekte, iklim değişikliği ve insan kaynaklı etkinlikler ekosistem ve tür biyoçeşitliliğinde bir artışa neden olabilmektedir.

KEY WORDS: Aralıklı akarsulardaki türler, bentik omurgasızlar, biyoindikatör, çeşitlilik, ekosistem çeşitliliği, kuraklık, nehir tipleri.

INTRODUCTION

Biodiversity has been defined by many scientists and politicians (e.g. McNeely *et al.* 1990, Wilson 1992). Ecologists usually identify biodiversity at three levels: within species (genetic diversity), between species (species diversity) and of ecosystems (ecosystem diversity) (Heywood and Watson 1995). Climate change leads to loss of biodiversity at all three levels, but assessing the impact of climate change on biodiversity is difficult, because effects of climate change interact with other stress factors (Kappelle *et al.* 1999). Moreover, in inland aquatic environments climate change will also influence human-induced environmental changes (e.g. water abstraction) that will alter benthic communities and biodiversity (Urbanic 2006a). In the Mediterranean an increase of floods, lower levels of precipitation, and a rise in temperature are the three main climate change impacts (IUCN 2003). Giannakopoulos *et al.* (2005) found that in the Mediterranean at the global temperature rise of 2°C mean summer temperature increase will be up to 4°C, whereas the increase in maximum temperature will be up to 5°C.

In the present study, we discuss the relation between biodiversity and climate change trends and other human-induced environmental changes as well as their possible impacts on ecosystem diversity and benthic invertebrate species diversity.

Study Site

Mediterranean geographic region comprises the south-western part of Slovenia (Fig.1). It includes areas which differ in geology, altitude, precipitation and temperature regime characteristics. In the Mediterranean climate region of Slovenia five bioregions were defined as a combination of biogeographical and ecological characteristics of the area (Urbanic 2005, 2006b, 2008a, Table 1).

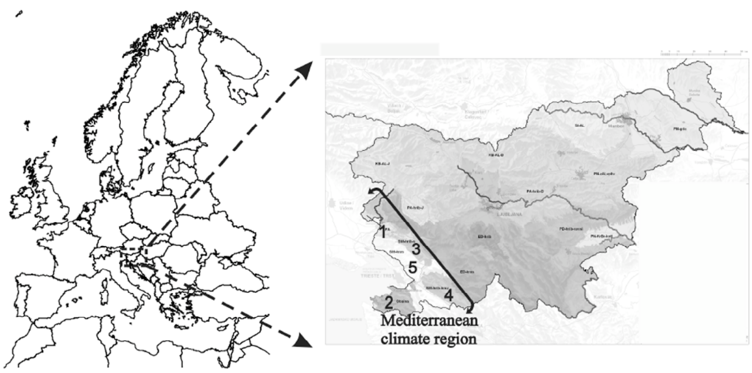

Figure 1. The study area and Inland aquatic Bioregions of Slovenia (Urbanic 2006, 2008a). Bioregions in Mediterranean climate region are marked with numbers (1 – Lower Vipava valley and Brda hills; 2 – Coastal hills; 3 – Sub-Mediterranean hills with surface outflow; 4 – Sub-Mediterrannean hills without surface outflow; 5 – Sub-Mediterranean Karst).

Table 1. Inland aquatic Bioregions of Mediterranean climate region of Slovenia and their main characteristics.

Bioregion	Ecoregion (Urbanic, 2005, 2008b)	Altitude range (m)	Dominant geology	No. of river types
1. Lower Vipava valley and Brda hills	Po lowland	0 - 200	Flysch	2
2. Coastal hills	Dinarids	0 - 400	Flysch	1
3. Sub-Mediterranean hills with surface outflow	Dinarids	100 - 600	Carbonate (and Flysch)	3
4. Sub-Mediterranean hills without surface outflow	Dinarids	400 - 700	Flysch	4
5. Sub-Mediterranean Karst	Dinarids	200 - 800	Carbonate	0

MATERIAL AND METHODS

River types

Biodiversity of bioregions was defined as ecosystem diversity and species diversity. Ecosystem diversity was defined as a number of natural river types. River types were defined according to the system B of the European Water Framework directive (EU 2000). Only rivers with catchment area larger than 10 km^2 were regarded. Types of running waters were described as a combination of bioregion, river size, periodicity (distinguishing between permanent and intermittent rivers) and influence of the karst spring.

Benthic invertebrates

In addition to ecosystem diversity the species diversity of benthic invertebrate communities was defined. Data of 96 samples were collected from 10 river types. Benthic invertebrates were sampled using modified multihabitat sampling (Urbanic *et al.* 2005a) and underwent a subsampling procedure according to Urbanic *et al.* (2005b). In the laboratory only $^1/_4$ of the whole field sample underwent the whole identification and enumeration procedure. All benthic invertebrates were determined to the required taxonomic level used for assessing ecological status of rivers in Slovenia (Urbanic *et al.* 2005b). Most taxa were determined to species and genus levels, and rarely to family (families of Brachycera).

Data analyses

For comparison of naturally permanent and intermittent rivers, only high and good ecological status samples were used, whereas all samples were used for testing the impact of the human-induced environmental changes. Four species diversity measures were calculated: number of taxa, number of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa, Shannon diversity index (H') and Evenness (Pielou's) (Krebs 1989). Student t-test was used to determine statistically significant differences in diversity measures between permanent and intermittent streams.

RESULTS

Ecosystem diversity

Ten river types were defined in five bioregions (Table 2). The most diverse bioregion is the "Sub-Mediterranean hills without surface outflow" where four river types were defined, whereas no river types were defined in the bioregion "Sub-Mediterranean Karst". Six river types were characterised by permanent water flow and four by intermittent.

Table 2. River types of the Mediterranean climate region of Slovenia.

River type/*Bioregion*	Size class (km^2)	Additional attribute
1.1 Small rivers/*Lower Vipava valley and Brda hills*	10-100	
1.2 Medium sized rivers/*Lower Vipava valley and Brda hills*	100-1000	
2.1 Small intermittent rivers/*Coastal hills*	10-100	Periodicity
3.1 Small rivers/*Sub-Mediterranean hills with surface outflow*	10-100	
3.2 Small intermittent rivers/*Sub-Mediterranean hills with surface outflow*	10-100	Periodicity
3.3 Medium sized rivers with karst spring influence/*Sub-Mediterranean hills with surface outflow*	100-1000	Karst spring influence
4.1 Small rivers/*Sub-Mediterranean hills without surface outflow*	10-100	
4.2 Small intermittent rivers/*Sub-Mediterranean hills without surface outflow*	10-100	Periodicity
4.3 Medium sized rivers/*Sub-Mediterranean hills without surface outflow*	100-1000	
4.4 Medium sized intermittent rivers/*Sub-Mediterranean hills without surface outflow*	100-1000	Periodicity

Species diversity

Number of taxa and number of EPT taxa were significantly ($p < 0.0001$) higher in permanent streams in comparison to intermittent streams (Fig. 2) For Shannon diversity index no difference was found ($p > 0.05$), whereas evenness was significantly higher in intermittent rivers ($p < 0.01$). In dried out rivers in the Bioregion "Lower Vipava valley and Brda hills" a decline in the number of taxa was observed in comparison to permanent streams (Fig. 3). On the other hand, impounding a river in a "Coastal hills" bioregion caused permanent water flow and higher taxa diversity than in a naturally intermittent river.

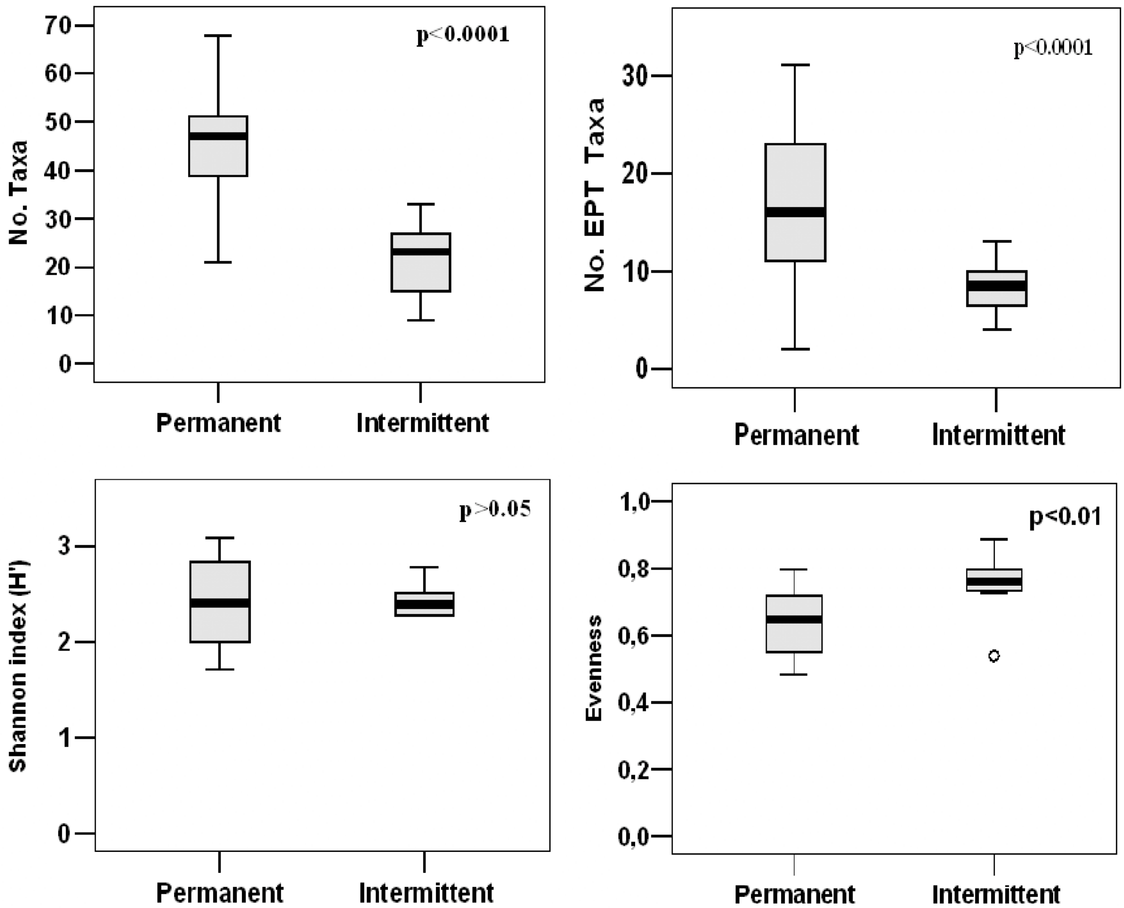

Figure 2. Species diversity measures for permanent and intermittent rivers and statistically significant difference (p). Range bars show maximum and minimum of non-outliers; boxes are interquartile ranges (25 percentile to 75 percentile); bars in boxes are median; open circles are outliers.

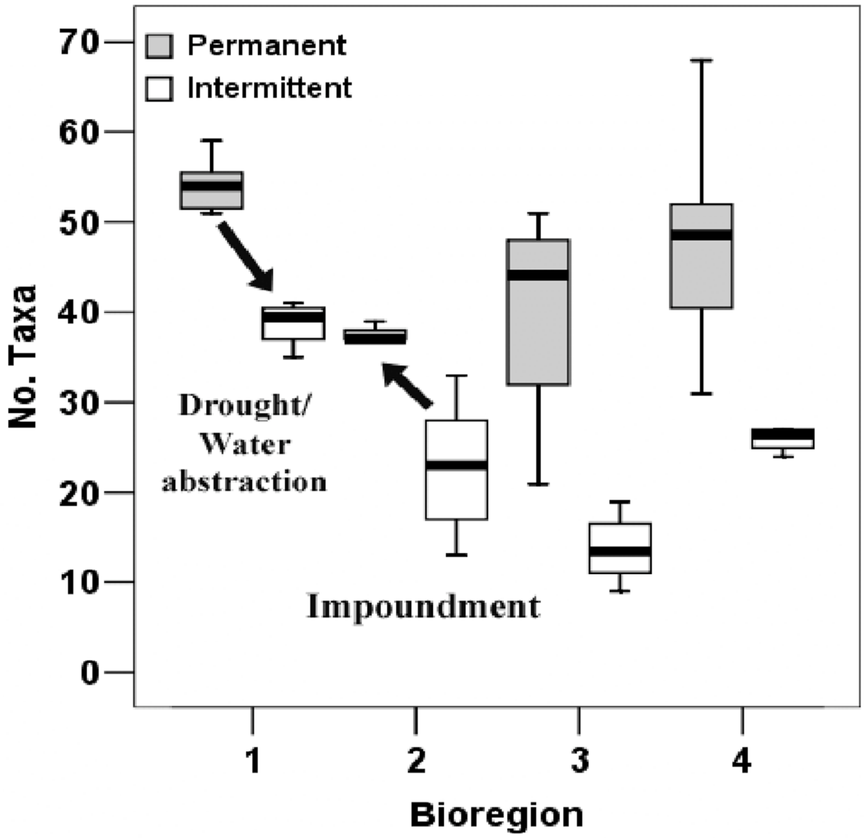

Figure 3. Number of taxa of permanent and intermittent rivers of four Bioregions. Changes due to drought/water abstraction (1) and impoundment (2) are marked with arrows. For boxplot legend see Fig. 2. For bioregion codes see Table 1.

DISCUSSION

Permanent and intermittent rivers were in the reference status in the Mediterranean bioregions of Slovenia. However, in the Lower Vipava valley and Brda hills bioregion only permanent rivers were originally present and in the bioregion Coastal hill there were only intermittent rivers. Climate change scenarios in the Mediterranean (IUCN 2003, Giannakopoulos *et al.* 2005) will have direct effects (raised water temperature and drought) and indirect effects (human activities, e.g. water abstraction, impoundments) on the running water ecosystem biodiversity (Fig. 4). Kappelle *et al.* (1999) argued that assessing the impact of climate change on biodiversity is difficult, because effects of climate change interact with other stress factors. However, we think that human-induced environmental changes can be results of climate change as well. It is probably not reasonable to separate direct and indirect effects of climate change. In the past water abstraction and impounding of rivers were present in the Mediterranean due to warm and dry climate and in the future we can expect them more often also due to climate change. Testing the effects of the water abstraction and impoundments on running water biodiversity we have found that in bioregions where either only permanent or only intermittent rivers were present, human-induced effects increased inland water ecosystem diversity (Fig. 3). Moreover, also species diversity (number of taxa) of the impounded river was higher, due to the change from intermittent to permanent flow. On the other hand, water abstraction in the opposite direction (permanent to intermittent flow) lowered the number of taxa. It seems that at the bioregional scale in some cases climate change and human-induced activities can cause a rise in the ecosystem and species biodiversities (Fig. 5). This is in contradiction to the globally accepted hypothesis that climate change leads to loss of biodiversity at all three biodiversity levels (Kappelle *et al.* 1999). However, a comparison of permanent and intermittent rivers using various diversity measures gave different results (Fig. 2). This may imply that at least at the species level the selection of the diversity measure can influence the interpretation of the climate change impacts.

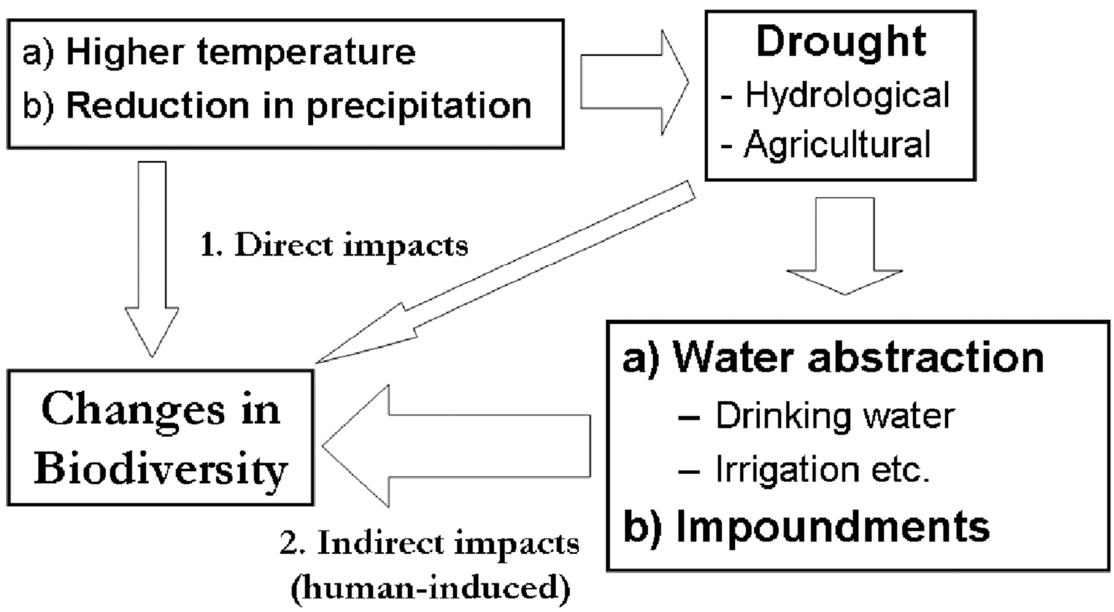

Figure 4. A schematic diagram of direct and indirect climate change impacts on aquatic biodiversity.

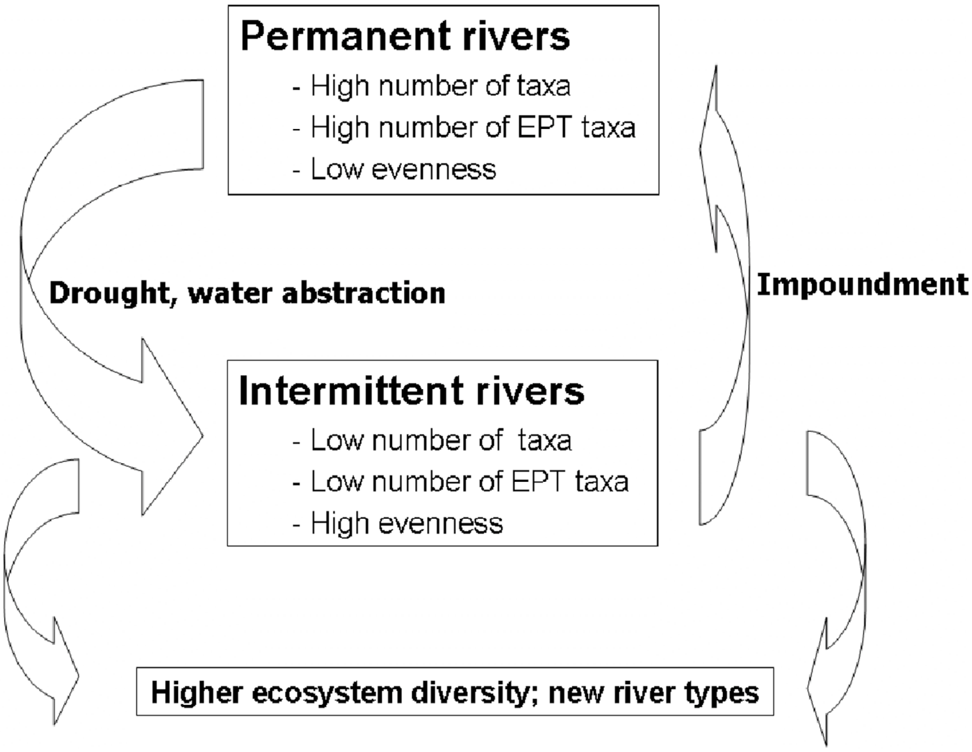

Figure 5. Possible impacts of climate change on biodiversity at the site and bioregional scale.

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