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Potential impacts of climate change on flow regime and fish habitat in mountain rivers of the south-western Balkans

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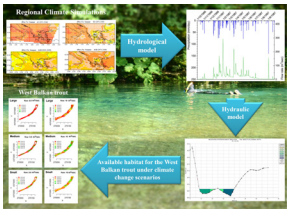
HIGHLIGHTS

- South-western Balkan mountain streams were found sensitive to climate fluctuations
- Climate fluctuations will seriously affect mountainous stream habitat diversity
- Climate fluctuations will affect West Balkan trout, but also other biota
- Medium sized West Balkan trout will be mostly affected by climate fluctuations
- The results obtain could be applied to similar mountainous regions communities of Balkan

GRAPHICAL ABSTRACT



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ABSTRACT

The climate change in the Mediterranean area is expected to have significant impacts on the aquatic ecosystems and particular in the mountain rivers and streams that often host important species such as the *Salmo farioides*, Karaman 1938. These impacts will most possibly affect the habitat availability for various aquatic species resulting to an essential alteration of the water requirements, either for dams or other water abstractions, in order to maintain the essential levels of ecological flow for the rivers. The main scope of this study was to assess potential climate change impacts on the hydrological patterns and typical biota for a south-western Balkan mountain river, the Acheloos. The altered flow regimes under different emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) were estimated using a hydrological model and based on regional climate simulations over the study area. The Indicators of Hydrologic Alteration (IHA) methodology was then used to assess the potential streamflow alterations in the studied river due to predicted climate change conditions. A fish habitat simulation method integrating univariate habitat suitability curves and hydraulic modeling techniques were used to assess the impacts on the relationships between the aquatic biota and hydrological status utilizing a sentinel species, the West Balkan trout. The most prominent effects of the climate change scenarios depict severe flow reductions that are likely to occur especially during the summer flows, changing the duration and depressing the magnitude of the natural low flow conditions. Weighted Usable Area-flow curves indicated the limitation of suitable habitat for the native trout. Finally, this preliminary application highlighted the potential of science-based hydrological and habitat simulation approaches that are relevant to both biological quality elements (fish) and current EU Water policy to serve as efficient tools for the estimation of possible climate change impacts on the south-western Balkan river ecosystems.

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1. Introduction

Several studies based on observations and modeling have pointed out that hydrological systems and their biota are threatened from the indisputable fact of climate change (Gedney et al., 2006; Hauer et al., 2013; Wu et al., 2012; Zhou et al., 2011). Still, the potential influence of recent climate fluctuations on the hydrological balance of mountain riverine ecosystems has not been adequately studied. Mountain rivers and streams are ecosystems with distinctive aquatic biota; these are of outstanding value both for mountainous landscapes and for human activities and economic development. Most mountain rivers are often located in poorly accessible areas and are typically of small catchment dimensions, steep relief and high gradients slopes. As a result of these characteristics, many mountain rivers have enjoyed the environmental benefits of low or near-absent human impacts (Vezza et al., 2014), although this is changing in the last few decades. Potential climate changes, altering temperature and precipitation patterns may influence the hydrological balance of the mountain riverine ecosystems leading to the limitation of available water resources for all water users. In the Mediterranean basin for example, this water scarcity may be especially acute during low-flow periods in summer. Vulnerable and habitat specialized aquatic species such as salmonids may not be able to adapt to these changes resulting in the degradation of ecological integrity of such rivers (Isaak et al., 2010). Although several researchers have focused on the investigation of climate-change effects on hydrological processes (Gibson et al., 2005; Kim et al., 2013; Luo et al., 2013), only recent studies have focused on researching the case of mountain rivers (Beniston and Stoffel, 2014; López-Moreno et al., 2013).

The mountain rivers of the south-western part of the Balkan Peninsula are characterized by habitat heterogeneity which supports high species richness and provide an area of international interest (Banarescu, 2004). Many of these upland rivers maintain areas with natural and near-natural flow regimes and long-term biogeographical isolation creates varied aquatic species assemblages (Skoulikidis et al., 2009; Zogaris et al., 2009). Climate change impact studies for the mountain waters of this region are poorly developed, although the importance of changes to river flow regimes has been recently stressed (Angelini et al., 2012; ENVSEC, 2012).

The main objective of this study was to assess potential climate change impacts on the generic hydrological patterns and constituent fish habitats in a typical mountain river system of the south-western Balkans focusing on a case-study in the upper part of Acheloos River, Northwestern Greece. The actual near-natural status of the river habitats for the West Balkan trout (*Salmo farioides*, Karaman 1938) in a representative reach and the potential effects of climate change on the habitats of the West Balkan trout (hereafter W. B. trout) were studied following the general principles of the Ecological Limits of Hydrologic Alteration (ELOHA) framework (Poff et al., 2010). In any similar study of potential changes in hydrology it is important to have empirical evidence of the relationships between fish populations and their aquatic habitats (Hauer et al., 2013). W. B. trout was selected as a target species for several reasons; it is an important indicator of high quality upland rivers, it dominates upland cold-water streams (Economou et al., 2007); it has a restricted distribution in upland streams of the south-western Balkans, ranging from Montenegro to south-western Greece (Kottelat and Freyhof, 2007); and it is assessed as a vulnerable species in a state-wide species threat assessment (Zogaris et al., 2009). Furthermore, salmonids play a crucial role in cold-water food webs and in the generation of ecosystem services (Schindler et al., 2010) and potential effects of climate change both in terms of hydrological alteration and temperature may affect their habitats (Almodóvar et al., 2012).

To achieve the main objective, the following procedure was applied; i) different emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) obtained from regional climate models (RCMs) simulations were used to estimate potential climate change impacts on flow regime using a hydrological model; ii) following the streamflow alterations due to the changing climate conditions for the different scenarios were assessed using the Range of Variability Approach (RVA), in comparison with the simulated natural flow; iii) the physical habitat simulation method integrating univariate habitat suitability curves and hydraulic modeling was used to evaluate the plausible impacts on the relationships between hydrology and biota using West Balkan trout as an indicator of biotic integrity.

2. Materials and methods

2.1. Study area

For this study, work was conducted in two river catchments in northwestern Greece that show typical Mediterranean mountainous conditions widespread in the south-western Balkans.; the Mesochora catchment in the upper Acheloos river, one of the largest rivers in the Pindos Mountains; and the spring-fed section of the Voidomatis tributary of the trans-boundary Aoos/Vjose river, near Greece's frontier with Albania. The Acheloos' Mesochora catchment (632.8 km^2) lies in the central western mountainous region of Greece with mean elevation of 1390 m (Fig. 1). The mean annual runoff of the catchment is 23.5 $m^3\ s^{-1}$ (Panagoulia, 1992). The mean annual precipitation (weighted average over elevation bands) is 1898 mm. Most of the precipitation falls between October and April (wet period) whereas at the higher elevations the greatest amount of the precipitation falls as snow. The hydrology of the Mesochora catchment is controlled by snowfall and snowmelt, with peak and low flow occurring during May and September respectively. The water temperature in summer ranges from 13.7 to 19 °C based on monthly measurements during June to October 2013.

The particular catchments have been selected because they were relatively pristine (close to reference conditions) since no significant water abstraction schemes and/or pollution sources exist in the area. This was necessary in order to study the habitat suitability and the impacts from hydrologic alterations for one of the most important fish species (Western Balkan trout) of the area.

Habitat mapping of a 1.5 km river stretch of the upper Acheloos River (at 670 m A.S.L., 39.479443°, 21.326510°, WGS 84) was carried out during low flow conditions in the beginning of October 2013, in order to delineate the main features of the physical habitat, based on field observations (Bisson et al., 1982). More specifically, identification of several types of HydroMorphological Units, hereafter HMUs (i.e. pools, runs, riffles, glides, rapids), was made according to published methods (Dolloff et al., 1993), measuring their extent and physical attributes. Finally, a 390 m representative river reach (Fig. 1), encompassing similar percentages and dimensions of the surveyed HMUs, was selected as the representative reach (Mesochora reach). The fish microhabitat-use survey, as part of the habitat simulation method was conducted during summer 2014 in the Voidomatis River (39.948815°N, 20.693940°E, WGS84). Voidomatis is a reference river with near-natural conditions within Greece's Northern Pindos National Park. The catchment's mean annual precipitation typically ranges between 1100 and 1700 mm, yielding a mean daily flow of 13 $m^3\ s^{-1}$ (Woodward et al., 2008). Water temperatures in this karstic spring-fed stretch of the river range from 10 to 12.5 °C based on field measurements during mid-summer 2014.

2.2. Hydrological model

In this study, the Soil and Water Assessment Tool (SWAT, Arnold et al., 1998), a process-based semi-distributed continuous hydrological model, was used for simulating streamflow in the study area. SWAT has been successfully applied in mountainous regions solving various environmental issues and exploring hydrological fluxes (Abbaspour et al., 2007; Debele et al., 2010; Panagopoulos et al., 2011). Furthermore, SWAT has been used in many studies investigating climate and land use change impacts on the water cycle and water quality (e.g. Ertürk et al.,

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