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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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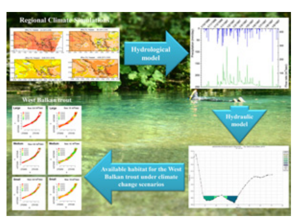
HIGHLIGHTS

- 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.,

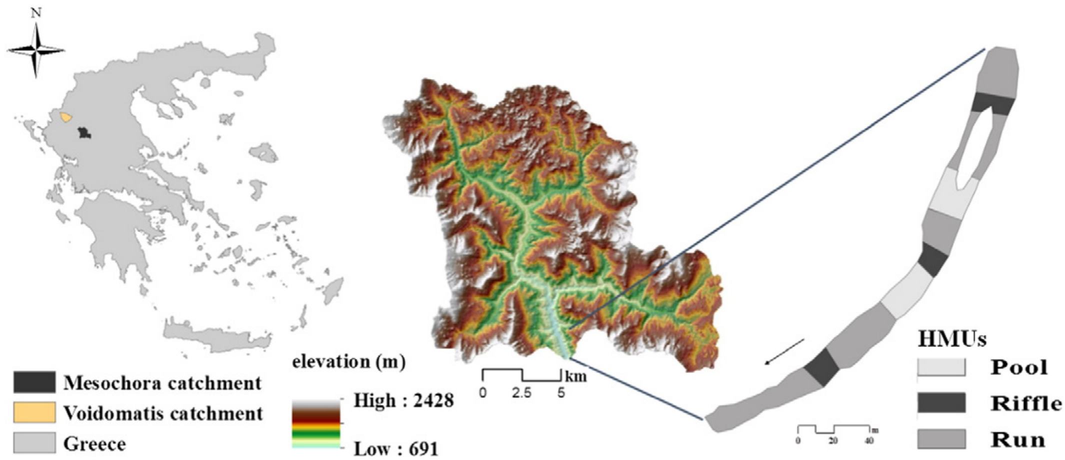

Fig. 1. Location of Mesochora and Voidomatis catchments (left), digital elevation model of Mesochora catchment and distribution of hydromorphological units in the representative reach of the Acheloos River (right).

2014; Kim et al., 2013; Luo et al., 2013; Salmoral et al., 2014). SWAT is a process-based semi-distributed continuous hydrological model. The watershed is subdivided into a set of sub-watersheds connected with the river network. Each sub-watershed is further divided into smaller basic units called Hydrological Response Units (HRUs), which represent a combination of land use, soil and slope. SWAT simulates energy, hydrology, soil temperature, mass transport and land management at HRU level.

2.2.1. Model Setup, calibration and validation

The main required spatial data for the parametrization of SWAT model is the Digital Elevation Model (DEM), the land cover and the soil map of the catchment. In this application, the topography was represented by a 25 m × 25 m DEM while CORINE Land Cover (CLC), 1990 and 2000 databases, were used to represent land cover. The soil information was derived by the European Soil Database (Panagos et al., 2012) and by the geological maps of the National Institution of Geology and Mineral Exploration (NIGME). Due to the data availability limitations both for the model parametrization and the model calibration the results of SWAT application by Panagopoulos et al. (2011) in a nearby medium sized watershed were also taken into account. The meteorological variables used to run the model were precipitation and air temperature on daily time step. The required daily time-series of measured precipitation and air temperature for three weather stations located inside the watershed ("Katafyto", "Pertoulio", and "Theodoriana") and one nearby station ("Ioannina") were provided by the Public Power Company of Greece (PPC) and the Hellenic National Meteorological Service (HNMS) respectively. However, only "Theodoriana" and "Ioannina" stations cover the entire simulated period (1983–2004) and were used to run the model, while the other two stations were used to estimate the precipitation and temperature lapse rates. The first three years of the simulation period were used as a warm up period. Based on the DEM, the positions of the hydrometric stations, and the location of the representative study reach (Mesochora reach), the watershed was divided into 58 subbasins, and consequently into 2094 HRUs.

The calibration and validation were made at "Mesochora" gauging station for a two-year period (October 1986–September 1988) due to data availability limitations. The first year was used for the calibration and the second year for the validation of the model. Key considerations in the model calibration were the overall water balance and the seasonal variation which were done at a monthly time step, as well as the low flows which were done at a daily time step. Model performance was evaluated statistically based on the Nash–Sutcliffe efficiency (NSE, $-\infty$ to $+1$, values close to $+1$ indicate better model performance) and the percent bias (PBIAS, indicator of under- or over-estimation, values close to 0 indicate better model performance). The performance was considered satisfactory if NSE > 0.5 and PBIAS < ±25% (Moriasi et al., 2007; Rahman et al., 2013). Specifically for the low flows, the model performance was evaluated using the relative NSE (rNSE) and the NSE with logarithmic values (lnNSE) to reduce the problem of the NSE sensitivity to extreme values (Krause et al., 2005).

2.3. Climate change scenarios

The assessment of the potential regional changes in temperature and precipitation patterns, under future emission scenarios (A1B for 2021–2050 and 2071–2100 time periods and A2 for 2071–2100) of Intergovernmental Panel on Climate Change (IPCC), was based on the study of Tolika et al. (2012) who provided the corresponding data for two annually distinguished periods.

Overall, the A2 and A1B are pessimistic scenarios in which the CO_2 concentration will increase up to 815 ppm until the end of the century and on a global scale temperature will rise from 2.5 °C to 4.5 °C. On the other hand the B2 scenario, a more optimistic one, suggests a smaller mean planetary temperature rise ranging from 1.5 °C to 3.0 °C. All the scenarios are described in detail by Nakicenovic et al. (2000).

Tolika et al. (2012), considered twenty-two simulations from various Regional Climate Model (RCMs) in order to assess the future changes in temperature and precipitation with respect to the control period (1961–1990). All the models estimated warmer and dryer conditions over the study area. For reasons of simplicity, in this study the future changes in temperature and precipitation were considered by adjusting the temperature and precipitation data series of the control period (1983–2004) according to the average value of eight RCMs with resolution of 25 km under A1B scenario for both 2021–2050 and 2071–2100 time periods and fourteen simulations with a spatial grid resolution of 50 km for the period 2071–2100 under A2 (9 simulations) and B2 (5 simulations) scenarios (Table 1). A similar approach was also used in previous studies (e.g., Jha et al., 2006; Kalogeropoulos and Chalkias, 2013).

2.4. Indicators of hydrologic alteration (IHA) and Range of Variability Approach (RVA)

A common method to analyze the hydrological changes in a target river is to analyze streamflow time series with the indicators of hydrologic alteration (IHA), which allow the comparison between a baseline period (pre-impact) and another scenario (Richter et al., 1996), in this case climate change scenarios (post-impact). The method relies on 33 parameters (median and coefficient of dispersion) corresponding to five fundamental characteristics of the flow regime (magnitude, frequency, duration, timing and rate of change) which greatly influence the ecological processes in river ecosystems (Poff et al., 1997; Mathews and Richter, 2007).

The changes of the IHA were evaluated through the Range of Variability Approach (RVA) in the IHA software package (version 7.1; The Nature Conservancy, 2009). In a RVA analysis, the pre-impact data for each parameter (20 annual data or more) are divided into three categories of equal size; the *low* category with values lower or equal to the 33rd percentile; the *middle* category between the 34th and 67th percentiles; and the *high* category over the 67th percentile (default setup; The Nature Conservancy, 2009). The program then compares the observed frequency of the values during the post-impact period with the expected frequency (pre-impact) of the IHA parameters within each of the three categories. The degree to which the RVA target category is not attained can be summarized in a hydrologic alteration factor (HAF), which is calculated for each of the IHA parameters as a percentage, that is:

$$\text{HAF\%} = \frac{\text{Observed frequency} - \text{Expected frequency}}{\text{Expected frequency}}. \quad (1)$$

Negative HAF values indicate that the frequency within a category will be decreased in the post-impact scenario. The value HAF = −1 corresponds to the condition when the event is not observed (in the specified category). A HAF is zero when the observed annual values under a scenario fall within the three RVA target ranges with the expected frequency (33% each category).

2.5. Assessment of the available habitat for the West Balkan trout

The flow requirements of three size classes of the W. B. trout have been assessed through the physical habitat simulation approach (Bovee et al., 1998), in terms of depth and velocity, by combining Habitat Suitability Curves (HSC) and hydraulic simulation. During summer 2014 snorkeling was performed following international standards (Heggenes and Saltveit, 1990; Martínez-Capel et al., 2009) in the Voidomatis river to collect data on microhabitat-use by West Balkan trout; visual data were gathered for 103 large sized (>20 cm), 87 medium sized (10–20 cm) and 94 small sized (<10 cm), individuals of W. B. trout. The HSC were developed following Bovee (1986); these curves relate the hydraulic or habitat variables with a suitability index (SI), ranging from 0 (unsuitable for the aquatic species) to 1 (excellent).

HEC-RAS (Version 4.1) was used to perform a pseudo-2D hydraulic simulation to estimate the changes in the depth and velocities for 30 stream flows, covering a wide range of possible summer flows under all the examined scenarios, ranging from 0.5 to 40 $m^3\ s^{-1}$ in the Mesochora reach. A topographic survey encompassing the main channel and banks was carried out with a GPS/GNSS Geomax — Zenith 20 using geodesic references (i.e. GGRS '87 — Greek Geodetic Reference System) to generate digital elevation models as the base for the model. Simulations were performed at 27 cross-sections along the river reach. Every cross-section was subdivided in 12 cells both in the main channel and the overbank area and velocities calculated separately for each cell for the simulated water stage. In the physical habitat simulation, the hydraulic results were translated into the corresponding values of SI, through the use of the HSC, for each of the three size classes of fish independently. The geometric mean of the two SI for the hydraulic variables (i.e., the *combined* SI) was used to calculate the Weighted Usable Area (WUA) for every simulated flow. WUA is the sum of the *combined* SI weighted by area, over all the points of the hydraulic model in the Mesochora study site; this index was used as the general indicator of habitat quality and quantity for each of the three sizes of W. B. trout, and the WUA-flow curves were generated. In order to study only the suitable conditions for the target species, WUA was estimated considering the cells with *combined* SI higher than 0.5 only (hereafter $WUA_{0.5}$). The whole procedure was carried out in R software (R Development Core Team, 2012 R: A language and environment for statistical computing). Moreover, habitat duration curves were constructed following the procedures described within the IFIM methodology for environmental flow studies (Bovee et al., 1998) indicating the exceedance probability for the potential habitat area in the corresponding climate change scenarios with *combined* SI higher than 0.5.

Table 1
Rate of change in average precipitation (P) and temperature (T) projections based on RCMs (Tolika et al., 2012).

Scenarios	A2		B2		A1B 2050		A1B 2100	
	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)
Winter	−11.3	3.6	1.8	2.5	−3.7	1.4	−15.1	3.2
Summer	−53	4.8	−27.9	3.6	−19	1.9	−36.9	4.3

3. Results

Due to data scarcity, the calibration in SWAT was based mainly on the curve number (CN) parameter, while; specific attention was given to the calibration of the base flow parameters alpha factor (ALPHA BF = 0.35) and lag (GW DELAY = 31) due to their importance during habitat-limiting low flow periods and for environmental flow regimes. The calibration of the base flow parameters was done graphically at daily time step. The final step consisted of ensuring that the seasonal flow balances were acceptable by slightly adjusting the estimated temperature lapse rate (TLAPS) that significantly impacts the timing of snowmelt (TLAPS = 3.05 °C/km). Concerning the water balance and the seasonal variation (monthly time step), the performance indicators in calibration were NSE = 0.69, PBIAS = 5.6%; and in validation NSE = 0.51, PBIAS = 22.2%. Concerning the low flows prediction (daily time step) the performance indicators in calibration were rNSE = 0.89, lnNSE = 0.85; and in validation rNSE = 0.59, lnNSE = 0.96. The comparison between the simulated and the observed hydrographs for both the calibration and validation periods is illustrated in Fig. 2.

The distribution of median monthly flows for the scenarios B2 and A1B-2050 presented low hydrological alteration (Fig. 3). Conversely the A2 and A1B-2100 produced lower stream flow in comparison with the middle category, especially during May (Table 2). However, to a certain degree, in the period from March to October all the projected scenarios presented lower monthly median flows than the pre-impact (baseline) period (Fig. 3). Specifically, the positive values of the Hydrologic Alteration Factors (HAF) in the *low* category (i.e. below the 33th percentile) for the months May to September corroborate this observation (Fig. 4).

The HAF related with minimum flows also showed a relevant increase in the low RVA category in all the scenarios, meaning that the minimum flows (several N-day minima) will be exacerbated (Fig. 4); thereafter a high risk of droughts and limitation on water supply and suitable habitat is likely to occur. In addition, the low pulse duration was also increased (positive values in the high category) in all the scenarios. Regarding the maximum flows, in the A1B 2050 scenario (Fig. 4a) they will be slightly reduced (1-day, 3-day, 30-day, and 90-day maximum flow) but the scenario B2 lacks of a clear trend. The effects on high and low flows are more profound in the A1B 2100 and A2 Scenarios (Fig. 4c, 4d, respectively), as it is explained herein.

The scenarios A1B 2100 and A2 (period 2071–2100) presented high hydrologic alteration. Regarding A1B 2100 (Fig. 4c) the positive values of the parameters related to drought (1-day, 3-day, 7-day, 30-day, 90-day minimum) in the *low* category indicated that droughts would occur more frequently. This fact is highlighted by the −1 values in the *high* category indicating the absence of the high flows events. Regarding the parameters related to flood (1-day, 3-day, 7-day, 30-day, 90-day maximum) negative values in the *middle* and *high* category indicate that in terms of magnitude, the flood regime will be totally altered. On

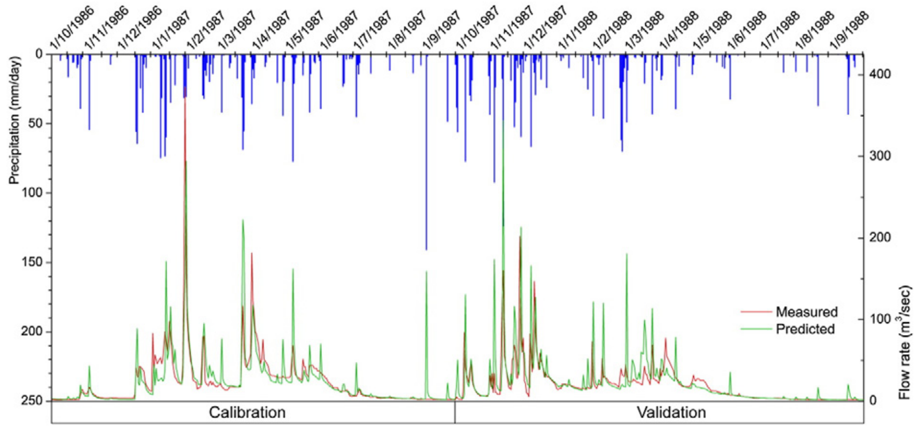

Fig. 2. Simulated and observed hydrographs for both the calibration and the validation periods.

the other hand, the timing of the extreme flow conditions, either low or high (group 3), will be only slightly affected.

The A2 Scenario (Fig. 4d) was considered as the most altered because the *low* category values were higher, for almost all the HAF, than in any other scenario in this study. The HAF for monthly flows in the *middle* and *high* category were reduced from April to November, expanding the dry conditions. This effect was also observed in the reduction of HAF related to drought (1-day, 3-day, 7-day, 30-day, 90-day minimum) where there is a complete absence of the *high* category values (−1), showing the highest alteration from all the examined scenarios. A detailed comparison between the simulated natural flow (pre-impact) and the worst case scenario (A2) with the median, coefficient of dispersion and the HAF (version 7.1; The Nature Conservancy, 2009) is presented in Table 2.

The HSCs from the Voidomatis river indicated that large W. B. trout actively selected deep microhabitats (optimum; 1.4–1.8 m) with low velocities (optimum; 0.15–0.30 m s^{-1}), whereas medium W. B. trout occupied medium-depth habitats (optimum; 0.60–0.95 m) and low velocity (optimum; 0.00–0.33 m s^{-1}). The small W. B. trout actively selected medium-depth habitats (optimum; 0.75–1.05 m) and low velocities (optimum; 0.00–0.30 m s^{-1}). The suitable areas summarized in the $WUA_{0.5}$-flow curves indicated low habitat availability for the large W. B. trout in comparison with the other two life stages; this observation applies to every simulated flow corresponding to the summer conditions under pre-impact and climate change scenarios, as shown in Fig. 5. To show the spatial arrangement of the suitable habitat, the maps for three representative summer flow values (0.8, 2.3 and 5 m^3 s^{-1}) are depicted in Fig. 6.

Based on applied scenarios, the study streams are sensitive to climate fluctuations. The habitat analysis presented a similar pattern to the hydrological analysis via the RVA method. Therefore, the scenario corresponding to the lowest alteration was the A1B 2050, whereas the worst scenario was A2. The most affected size class would be the medium W. B. trout, both regarding the magnitude and frequency followed by the small W. B. trout (Fig. 7). Finally the size class which will be less affected would be the large W. B. trout since it presented a small suitable area for any analyzed flow (Fig. 7).

The differences in habitat projected for the summer period were mainly caused by reductions in water depth. These reductions were especially important under the A2 and A1B 2100 scenarios (Fig. 8). Consequently, the habitat duration curves are much lower than in the other two scenarios, thus suggesting a significant degradation of the suitable habitat area for the W. B. trout. However none of them were low enough to suggest the extirpation of the species of the study site because the minimum $WUA_{0.5}$ was in any case larger than zero. The general reduction in water resources is translated to river habitats where the reduction was observed in events of any frequency and magnitude.

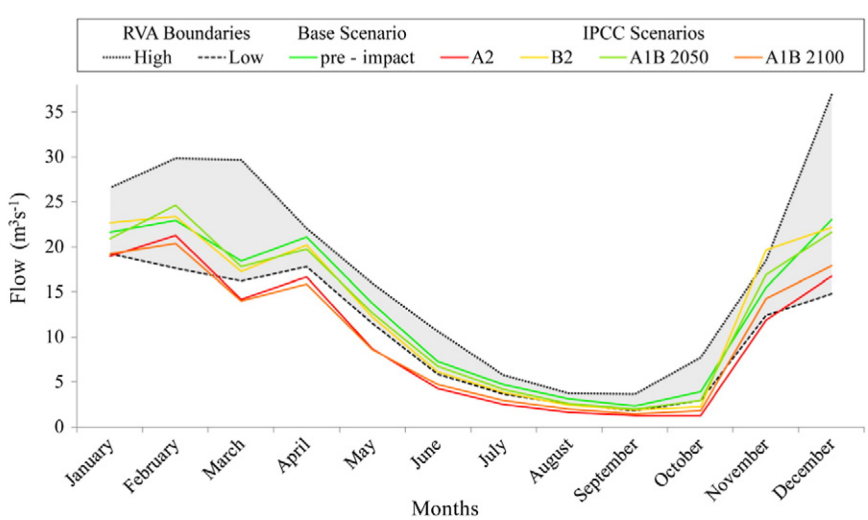

Fig. 3. Comparison of monthly median values of the projected scenarios with the middle category of the Range of Variability Approach — RVA (gray area within RVA boundaries).

Table 2
Hydrologic alteration analysis comparing Natural flow (pre-impact) with the A2 (2071–2100) Scenario.

	Pre-impact		A2 scenario		HAF		
	Medians	CD	Medians	CD	*High*	*Middle*	*Low*
Parameter group 1 flows ($m^3\ s^{-1}$)							
January	21.6	0.6	19.0	1.0	−0.2	−0.4	0.7
February	22.9	0.7	21.3	0.9	−0.5	0.0	0.5
March	18.4	1.1	14.2	0.9	−0.7	−0.1	0.8
April	21.1	0.4	16.6	0.5	−0.8	−0.6	1.5
May	13.7	0.5	8.7	0.5	−1.0	−0.9	2.0
June	7.3	0.9	4.3	0.5	−1.0	−0.6	1.7
July	4.7	0.5	2.5	0.5	−1.0	−0.6	1.7
August	3.1	0.7	1.7	0.5	−1.0	−0.7	1.8
September	2.3	1.2	1.3	0.7	−0.8	−0.7	1.7
October	3.9	1.9	1.3	1.8	−0.7	−0.6	1.3
November	15.6	0.8	11.9	0.8	−0.5	−0.4	1.0
December	23.0	1.3	16.8	1.6	−0.2	0.1	0.0
Parameter group 2: flow ($m^3\ s^{-1}$)							
1-Day minimum	1.2	1.2	0.8	0.5	−1.0	−0.6	2.2
3-Day minimum	1.3	1.3	0.8	0.5	−1.0	−0.6	1.7
7-Day minimum	1.3	1.3	0.9	0.5	−1.0	−0.4	1.5
30-Day minimum	2.1	1.2	1.0	0.8	−1.0	−0.3	1.3
90-Day minimum	4.4	0.9	2.0	0.7	−1.0	−0.9	2.0
1-Day maximum	547.7	0.7	413.8	0.6	−0.7	−0.3	1.0
3-Day maximum	260.5	0.7	220.1	0.7	−0.7	0.3	0.3
7-Day maximum	157.3	0.5	135.5	0.5	−0.3	−0.1	0.5
30-Day maximum	77.8	0.5	64.1	0.4	−0.5	−0.3	0.8
90-Day maximum	48.0	0.3	37.7	0.4	−0.8	−0.1	1.0
Number of zero days							
Base flow index	0.0	0.6	0.0	0.4	−1.0	−0.3	1.3
Parameter group 3: timing of extreme water conditions							
Date of minimum	283.00	0.09	293.00	0.08	0.7	0.0	−0.7
Date of maximum	344.00	0.14	359.00	0.09	0.2	−0.3	0.2
Parameter group 4: frequency and duration of high/low pulses							
Low pulse count	7.0	0.6	9.0	0.3	0.0	0.3	−0.4
Low pulse duration	7.0	0.6	8.0	1.1	0.8	−0.4	−0.2
High pulse count	21.0	0.3	16.0	0.3	−0.6	−0.8	1.5
High pulse duration	2.0	0.5	2.0	0.5	−0.5	0.0	0.2
Parameter group 5: rate/frequency of water conditions changes							
Rise rate	13.55	0.5	10.61	0.8	−0.2	−0.6	0.8
Fall rate	−0.61	−0.9	−0.34	−0.8	1.0	0.0	−1.0
Number of reversals	93	0.2	89	0.2	−0.7	0.1	0.5

4. Discussion

4.1. Hydrologic modeling

Streamflow simulation is often challenging in mountain river catchments because of high relief topography and complex hydrological processes. Rates of change in precipitation and temperature with respect to elevation and strong spatial variability of meteorological conditions often limit the ability to accurately reproduce stream runoff by hydrological models (Rahman et al., 2013; Soulis and Dercas, 2007). Furthermore, in many cases, especially in the less developed regions, the meteorological information available is scarce and confined to lower altitudes or coastal locations (Brito et al., 1999; Soulis, 2015). This problem is further exacerbated by limited site-based hydrological and environmental data availability, which is especially the case in the Balkan countries (Skoulikidis et al., 2009). Nevertheless, despite the data limitations, the model performance was considered acceptable according to the criteria posed (Moriasi et al., 2007; Rahman et al., 2013), and presented similar values in comparison with previous studies performed in Greek river basins (Gamvroudis et al., 2015) thus highlighting the validity of any further analysis. Especially for the case of low flows, which are of particular importance for the scope of this study, the model performance was much better and it was considered satisfactory as well. Therefore, even if the remaining uncertainty is an important constrain, the overall model performance was considered adequate for the purposes of a comparative analysis given the data scarcity that characterizes the study area.

4.2. Potential climate change impact on freshwater mountain river systems

Results gained in this study show that the A1B 2050 and B2 scenarios have limited impact in comparison with the other two scenarios (A1B 2100 and A2) where reductions in the precipitation during winter period and temperature increments during summer period affect streamflow, especially by reducing the magnitude and increasing duration of low flows. Our results corroborate a broad scale analysis on the expected impacts of the different climate change scenarios that already suggest the major impact of the A2 scenario in river flows (Van Vliet et al., 2013). Moreover, in a similar study in Spain, Salmoral et al. (2014) concluded that increasing mean temperature is the main factor supporting increasing evapotranspiration and thus driving streamflow reduction. Studies in Mediterranean-climate streams observed a lack of resilience and negative impacts to biodiversity due to prolonged droughts related with long-term habitat changes induced by the increment in frequency and magnitude of the low flow events (Bêche et al., 2009). Moreover innovative approaches, such as microsatellite DNA analyses, revealed that the effects of drought may be profound and long-lasting, resulting in population bottlenecks and altering the course of the evolution of species (Humphries and Baldwin, 2003).

Mountain streams in Mediterranean regions have highly variable seasonal discharge patterns, with torrential flood pulses and seasonal drought periods, being usually much less flashy and more variable than temperate stream systems (Bonada et al., 2007). The areas chosen for this study represent some of the most natural mountain river corridors as has been shown both by instream studies (Chatzinikolaou et al., 2006; Economou et al., 2007) and riparian corridor assessments (Zogaris et al., 2008); the study areas therefore provide excellent baselines to study biotic–abiotic interactions in near natural states before potential climate-driven changes take place. The south-western Balkan region, encompassing the Adriatic and Ionian basins, has a humid Mediterranean climate and receives a much higher precipitation compared to the eastern Balkans; it has distinctive aquatic biocommunities with a very high proportion of endemic species, being a biogeographically isolated region and a refugium area during the Pleistocene glaciations (Zogaris et al., 2008; Skoulikidis et al., 2009).

The study focused in the W. B. trout although the whole ecosystem is likely to be affected (Bêche et al., 2009; Humphries and Baldwin, 2003; Mantua et al., 2010; Wenger et al., 2011). The habitat alterations predicted in this study have been known to cause geomorphic simplification, floodplain disconnection and disruption of lateral and longitudinal connectivity, thereby affecting habitat dynamics and making it difficult for native biota to adapt (Poff et al., 2007). The prescribed scenario changes will not only affect instream biota but most probably the area's riparian vegetation, which currently supports species-rich near-natural floral assemblages (Zogaris et al., 2008). However, in many cases of mountain rivers there is a significant scarcity of historical flow data and very limited information about the flow requirements of the river's biota. Furthermore, the overfishing that is taking place especially in the recent years may influence predictions, specifically in the larger size class trout. Consequently, climate change together with inadequate water management along with the insufficient water conservation policy are now interpreted as major threats for mountain streams, leading to alterations which may rapidly degrade ecosystem structure and ecological processes and the services they provide (Postel and Richter, 2003). Moreover, the negative impacts of climate change are projected to be most pronounced particularly in relatively pristine, high-elevation and headwater streams where restoration measures are usually not possible (Battin et al., 2007). This situation is especially sensitive in the mountain rivers of the south-western Balkans were there are severe problems with changes in land-use and poor management of water resources, dam developments, pollution control

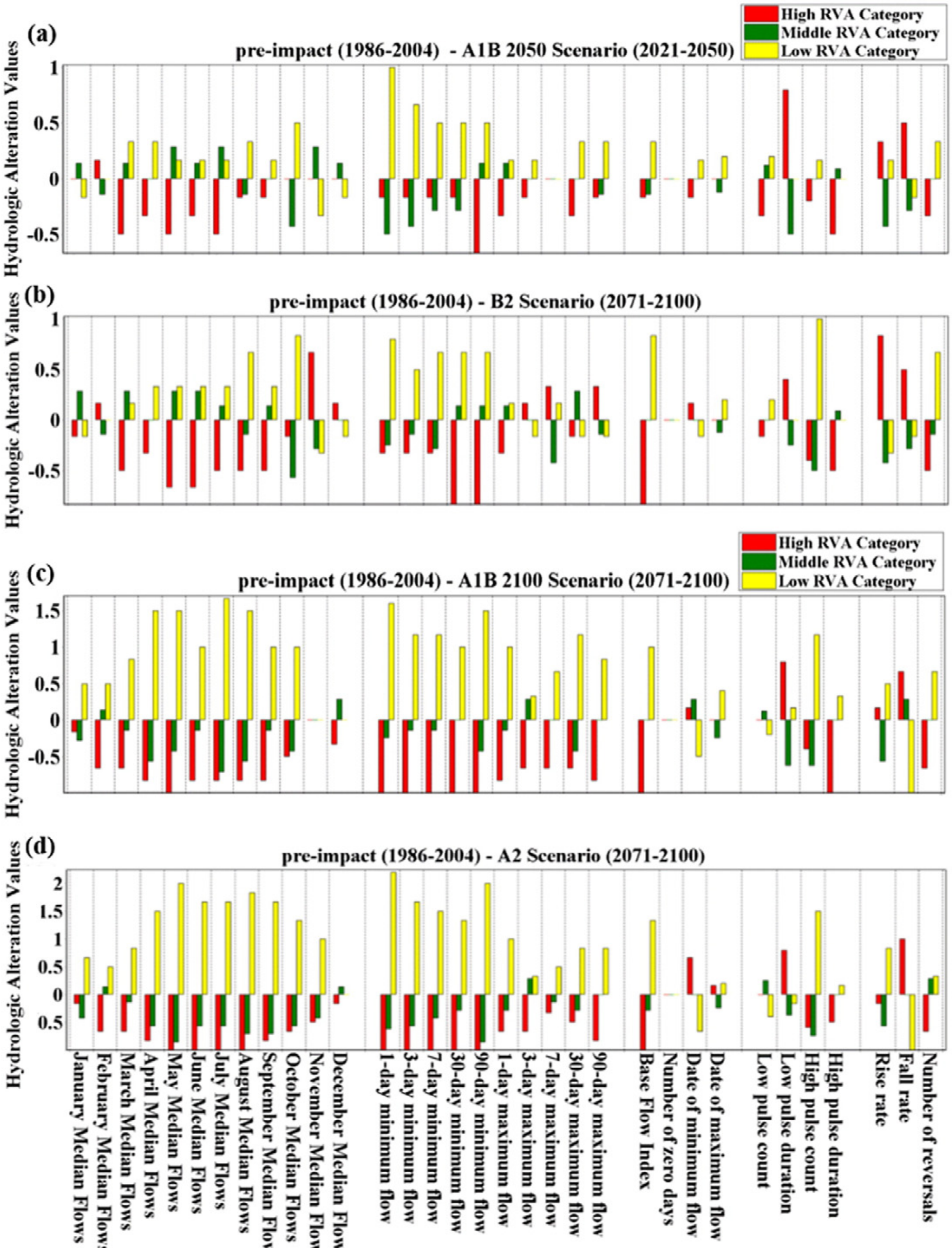

Fig. 4. Values of the Hydrologic Alteration Factors (HAF) comparing the pre-impact time period (1986–2004) and future climate change periods (a) A1B (2021–2050), (b) B2 (2071–2100), (c) A1B (2071–2100), (d) A2 (2071–2100).

and protected area development (Chatzinikolaou et al., 2006; ENVSEC, 2012).

4.3. Relationships of climate-impacted flow regimes and fish habitat

Using the native trout species as a habitat-specialized indicator is a practicable application because this species is phylogenetically related to the well-studied cold-water specialist, the European brown trout (*Salmo trutta* L.) often dominating mountain stream waters (Economou et al., 2007; Kottelat and Freyhof, 2007). Broad-scale studies of climate change effects on freshwater species have traditionally focused mainly on temperature, underrating critical drivers such as flow regime and biotic interactions (Wenger et al., 2011).

In the Mediterranean context previous efforts to quantify the expected effects of climate change on cold water salmonids (European brown trout) stated temperature alteration as the main driver for the expected shrinkage of the trout distribution area (Almodóvar et al., 2012) whereas other studies, in colder climatic conditions, considered the flow as the keystone to assess the impact of climate change on the distribution area of salmonids (*Oncorhynchus* spp.) (Wenger et al., 2011). Our results were in line with the latter study, suggesting that the alteration of stream flows, especially by reducing them, will turn in a reduction in the suitable habitat available for the target species. Furthermore, as it has been

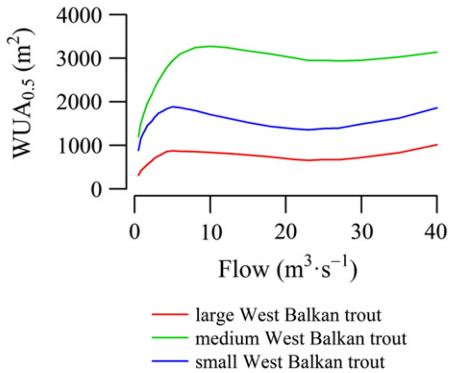

Fig. 5. Curves relating $WUA_{0.5}$ and stream flow within a range of summer flows which are possible to occur under all the examined scenarios for three size classes of W. B. trout.

pointed out in other studies (Mantua et al., 2010), it is very likely that more stable flow patterns and reduced flow predicted by our analysis may increase temperatures in our upland Mediterranean mountain streams, thus producing additive pressure against the survival of cold-water species such as the native salmonid. Regarding physico-chemical conditions of the aquatic habitat, it is also relevant to consider that a reduction of water quality, which would produce severe risks for the ecosystem integrity, is probable under future scenarios of water scarcity in Mediterranean rivers (Petrovic et al., 2011).

The specific results of the habitat analysis showed that the habitat suitability for W. B. trout will suffer the effects of hydrological changes with the A2 scenario corresponding to the worst situation for this keystone fish species. Furthermore, as it is also pointed out by Hauer et al. (2013) by analyzing the impact of altered stream flows in a smaller scale, the increased frequency of low flows, especially in the summer periods, will reduce habitat quality and quantity as a result of the changes in depths and velocities. The Mesochora reach resembles a relatively deep run with high velocities and medium depths; for this reason the potential impacts of climate change seem to induce relatively small changes on the quality of the habitats for small and large size trout, since the physical characteristics were out of their preference range (i.e. suboptimal habitat conditions for this species during summer flows). However, as well as the reduction of water resources at a monthly time scale, the reduction in the magnitude and frequency of high-flow events was consistent among scenarios, with severe potential impacts during the winter, when these events should prepare spawning habitats and provide with cues for the salmonid populations before the migration and spawning. Therefore, according with previous studies, we can hypothesize a very relevant impact of the smaller frequency of peak flows, producing a reduction in fish recruitment, turning into decreased abundance or extirpation of native fishes in the long term (Mathews and Richter, 2007; Poff and Zimmerman, 2010).

Thereby small trout selected relatively shallow and slow flow microhabitats, which were scarce in the study site, whereas large trout selected preferably deep and slow flow microhabitats (i.e. pools) which were, likewise, absent in the study site. As a consequence of the velocity-depth distribution the Mesochora study site became especially suited for medium size W. B. trout and then the forecasted reduction in the running flows will mostly affect this size class. Although in a different magnitude, the negative impact of the flow reduction affected all size classes. We have not predicted null $WUA_{0.5}$ for any considered scenario and class but the long term effect is likely to reduce the presence of the species

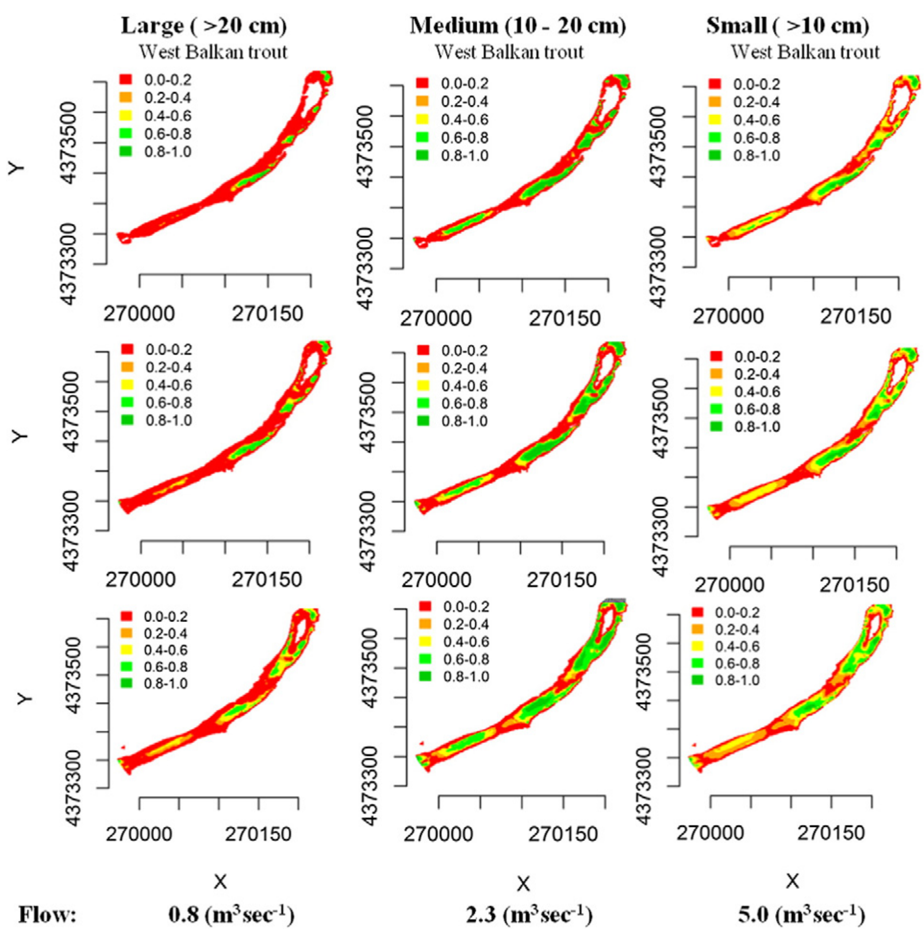

Fig. 6. Habitat suitability maps depicting the *combined* SI of the study area for three flows and the three size classes of the West Balkan trout.

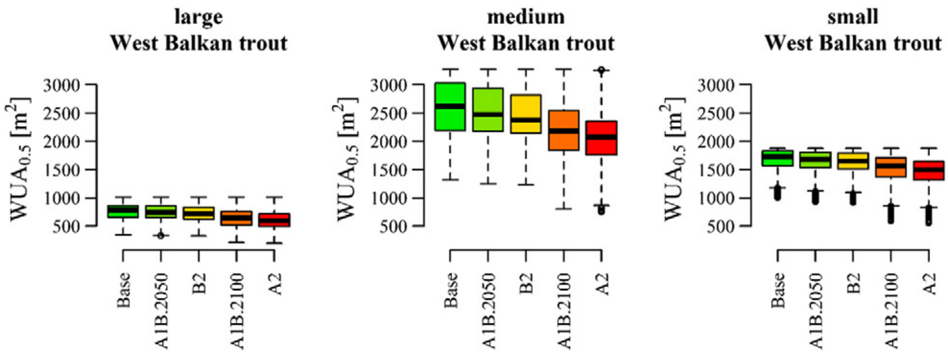

Fig. 7. Box-plots showing the projected changes in $WUA_{0.5}$ for three size classes of the West Balkan trout under summer conditions (July to August) for the pre-impact period and the examined climate changed scenarios.

in the study area which is already affected by the severe overfishing, even involving illegal spear fishing and electrofishing imperiling the W. B. trout populations. Furthermore we considered the W. B. trout the target species neglecting the effect on the rest of the ecosystem when it is well documented that flow regime and temperature but also biotic interactions can drive differential declines of trout species under climate change (Wenger et al., 2011) thus composing a synergic suite of factors that could lead to species extirpations (Brook et al., 2008).

4.4. Conclusions

This study suggests that a changing climate may affect instream flow conditions in mountain rivers which will probably impact ecological integrity. In the Upper Acheloos river, as in many other mountain rivers in the southwest Balkans, there are many influences affecting the flow regime as well as other essential habitat characteristics (Mathews and Richter, 2007; Skoulikidis et al., 2009). Effective conservation of biodiversity in mountain river systems requires accurate downscaling of climatic trends to local habitat conditions. Nevertheless, downscaling is difficult in complex and diverse terrains, as those of the mountains, with varied microclimates and special local characteristics (Isaak et al., 2010). Our study is one of the few attempts to use a prominent indicator fish species to explore specific habitat changes based on its studied requirements within reference mountain river stretches.

The IHA analysis of the Upper Acheloos River indicates that the flood regime under all the examined scenarios, including both small and large floods, will be altered. The physical habitat simulation method suggested severe changes on the habitat quality and quantity since impacted flow regimes showed a lack of flood-pulse peaking and reduced water quantity. This important element may lead to warmer more stable conditions and some microhabitats required by rheophilic cold-water fauna may show marked decline. According to our results from the current case-study, the most affected trout size class will be the middle sized, then the small and finally the large. However apart from the empirical evidence, it is probable that the large-sized trout in the Acheloos have suffered severe declines from overfishing, and in this case there is still uncertainty for this size-class category. Flow-ecology relationships need further investigation by identifying specific hydrologic alterations that may impact particular species, biocommunities and ecological processes.

To refine predictions based on climate change instream alterations, further research should be conducted to understand the mechanisms associated with the biological responses to the climate effects. Possible interactions between climate change, water quality, and food availability due to ecosystem changes; fragmentation of species populations due to thermal constraints; increases in predation; and changes in species interactions and competition within aquatic ecosystems should be analyzed towards a holistic approach. Finally, future changes in other anthropogenic stresses on fish habitat, such as increasing water withdrawals, dams or changing land use must also be quantified and analyzed. Thereafter, more research is needed to investigate the effects of flow reduction and flow regime change on the instream environments of mountain rivers (Dewson, 2007). This is especially important in sensitive areas with high-endemicity aquatic ecosystem within restricted freshwater ecoregions such as in the southernwestern Balkans.

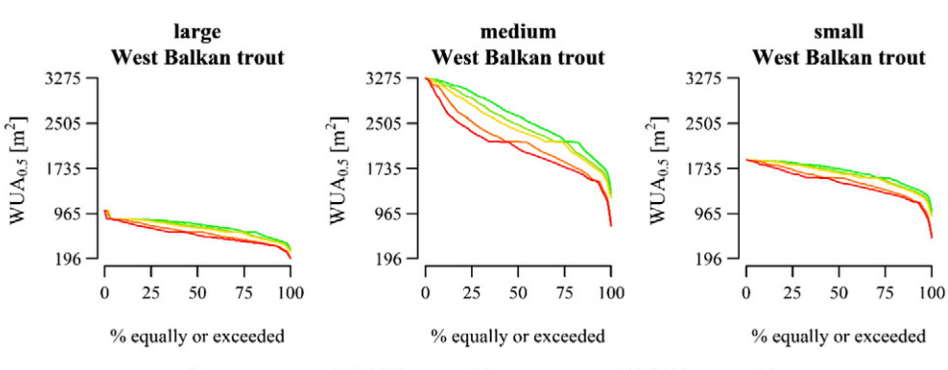

Fig. 8. Habitat duration curves (HDC) for the comparison between the pre-impact conditions (baseline) and the expected ones under the four examined scenarios in terms of probability of exceedance.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.scitotenv.2015.06.134. These data include Google map of the most important areas described in this article.

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