


Comparative Assessment of Environmental Flow Estimation Methods in a Mediterranean Mountain River

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Abstract The ecological integrity of rivers ultimately depends on flow regime. Flow degradation is especially prominent in Mediterranean systems and assessing environmental flows in modified rivers is difficult, especially in environments with poor hydrologic monitoring and data availability. In many Mediterranean countries, which are characterized by pronounced natural variability and low summer flows, water management actions usually focus on prescribing minimum acceptable flows estimated by hydrologic methods. In this study, a comparative assessment of environmental flow estimation methods is developed in a river with poorly monitored flows and limited understanding of past reference conditions. This assessment incorporates both a hydrologic and a fish habitat simulation effort that takes into consideration hydrologic seasonality in

a Greek mountainous river. The results of this study indicate that especially in data scarce regions the utilization of biotic indicators through habitat models, may provide valuable information, beyond that achievable with hydrologic methods, for developing regional environmental flow criteria. Despite the widespread use of the method, challenges in transferability of fish habitat simulation provide undefined levels of uncertainty and may require the concurrent use of different assessment tools and site-specific study.

Keywords Environmental flows · River hydrology · Ecohydrology · Habitat simulation method · Hydrologic model

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Introduction

Environmental flows are increasingly being adopted globally to address ecological damage caused by human-induced changes in flow regimes (LeQuesne et al. 2010). However, millions of kilometers of rivers remain unprotected from human-induced hydromorphological degradation (Poff et al. 2010). Growing demands for irrigation, hydropower, industry, and domestic uses may result in the over-allocation of water to consumptive uses, causing serious alterations to the natural flow regime of rivers (Skoulikidis et al. 2009).

There is a remarkable breadth of methods for environmental flow assessment (EFA); more than 207 individual methodologies are followed in over 40 different countries (Acreman and Dunbar 2004; Conallin et al. 2010; Tharme 2003). In the case of Mediterranean-type rivers EFA is particularly difficult due to their flow seasonality,

interannual variability, and data scarcity with respect to long-term monitoring of both abiotic and biotic variables. Furthermore, an important problem is that available discharge data are often insufficient to determine the water flow regime characteristics; thus, new approaches may be required to monitor surface water variables (Bhamjee et al. 2016).

When it comes to rivers in Greece, limited work has been carried out regarding the development of adequate EFAs considering local ecological conditions (Muñoz-Mas et al. 2016; Papadaki et al. 2016). Flow regime is often severely impacted by over-abstraction for agriculture and other uses, and some formerly perennial rivers now flow as artificially intermittent courses, with parts of the river stretch being totally desiccated during the summer period (Benejam et al. 2010; Skoulikidis et al. 2011). Since large parts of the country have a limestone geology and seasonally semi-arid climatic patterns, assessing natural reference conditions is especially difficult (Skoulikidis et al. 2009). Moreover, in Greece, there is a remarkable scarcity of historical flow data, as is the case for several other Mediterranean countries as well (Alvarez-Cobelas et al. 2005).

To overcome data scarcity limitations, river flow time series can be produced with hydrologic models based on available broad-scale environmental and atmospheric datasets. However, even this information is in most cases rather limited both in terms of spatial and temporal scales, thus introducing several uncertainties in the modeling process. For this reason, hydrologic methods which rely solely on the statistical analysis of hydrologic data (e.g. Mathews and Richter 2007) are only suitable for a first screening level analysis in these heterogeneous and data scarce environments.

A possible way to significantly reduce these uncertainties is the implementation of habitat simulation methods (e.g. Bovee 1998), in which relationships that link flow alteration to habitat response are developed through the utilization of biotic indicators (Poff et al. 2010). Furthermore, the use of biotic indicators is also required for assessing ecological quality through the EU Water Framework Directive 2000/60/EC (WFD) and fishes are one of the four prescribed biological quality elements (Acreman and Ferguson 2010; European Commission 2015). Moreover, the WFD requires the estimation of ecological flows, especially in water bodies stressed by hydrologic pressures for which relevant measures should be designed to minimize degradation impacts.

In this study, a comparative analysis for the implementation of environmental flows incorporating a hydrologic and a fish habitat simulation method was carried out. Due to the scarcity of historical flow data, a hydrologic model was used to generate the required historical flow time

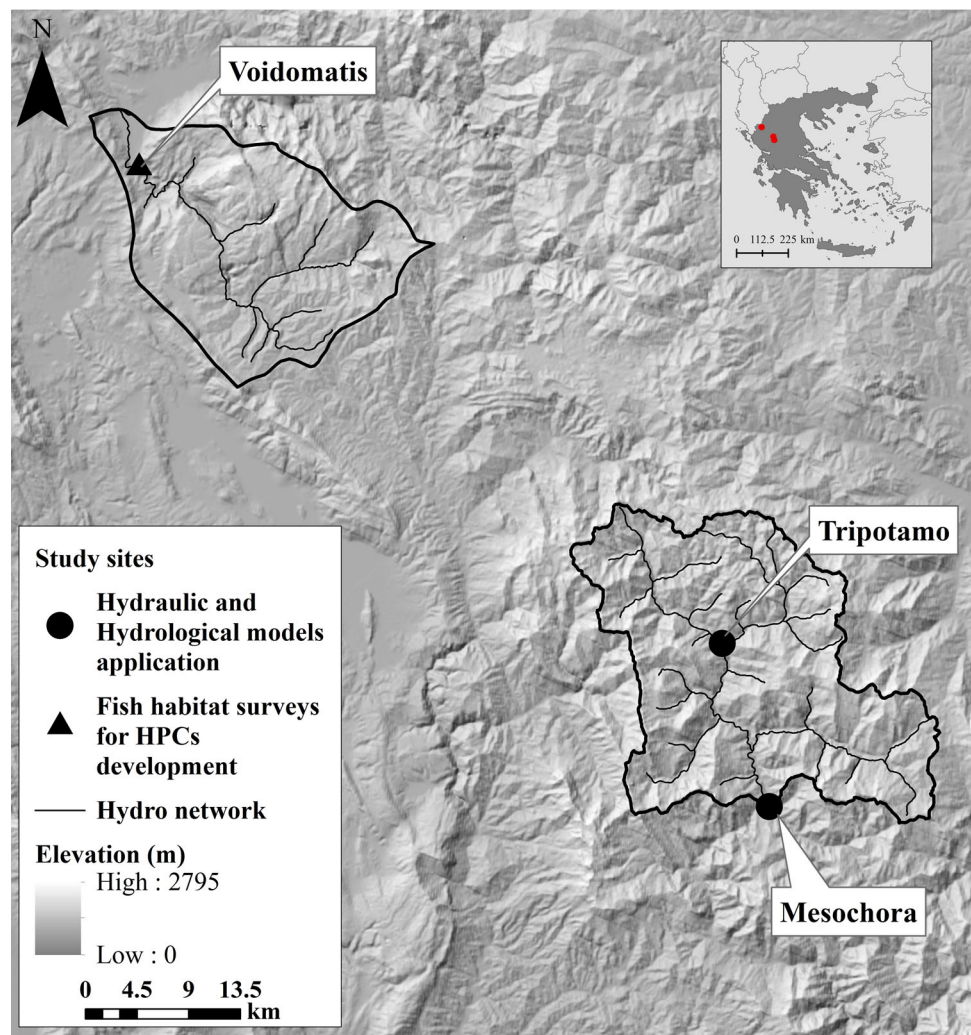
series for the hydrologic method, which was implemented by utilizing the global environmental flow calculator (GEFC 2016). The fish habitat simulation method with an adaptation of the optimization criterion, firstly introduced by Bovee (1982), was also applied. To identify the differences of the monthly minimum environmental flows proposed by the two approaches we compared their results among studied sites. The proposed approaches were both applied in two study sites of a Greek mountainous river (Acheloos River) which is characterized by pronounced natural variability and low summer flows as well as general data scarcity.

Materials and Methods

Study Area

Hydrologic and hydraulic data were collected in two study sites at the upper Acheloos River, (Fig. 1); Mesochora (390 m length) at 670 ma.s.l., (39.479443°N, 21.326510°E, WGS84) and Tripotamo (280 m length) at 870 ma.s.l., (39.609023°N, 21.277216°E, WGS84). These sites are likely to face hydrologic pressures in the near future due to the increased interest for hydropower development, which may limit the stream's ability to support natural aquatic biotic assemblages (Benejam et al. 2010). Both study sites have a mean annual discharge of approximately $23.5 \text{ m}^3 \text{ s}^{-1}$ (Panagoulia 1992). The river in this area is relatively pristine since no significant water abstraction schemes and/or pollution sources exist while riparian zones are also in near-natural conditions (Zogaris et al. 2009). This allowed us to study the impacts of hydrologic alteration on the natural habitats of the Western Balkan trout (*Salmo farioides*, Karaman 1938). One of the most characteristic fish species in the cold-water stretches of the mountainous part of the Acheloos River, *S. farioides*, is restricted to upland streams between Montenegro and western Greece (Kottelat and Freyhof 2007) and is assessed as vulnerable in a state-wide, "Red List" conservation status evaluation (Zogaris and Economou 2009). Furthermore, in the Acheloos River this species' populations have been affected by overfishing. Since local populations are artificially depressed, fish habitat surveys for the development of habitat preference curves (HPCs) were conducted in a nearby catchment (Voidomatis River, Fig. 1) within a strictly protected national park where *S. farioides* populations are in near-natural abundances. Typical mountain river habitat types in the study sites are mainly mid-gradient runs and pools (7–12 m wetted river width in summer), while substrate types are dominated by boulders and cobbles with sparse gravel areas.

Fig. 1 The Voidomatis (*left*) and the Mesochora (*right*) catchments in northwestern Greece. Hydrologic and hydraulic models were applied in the upstream part of Acheloos River, (the Mesochora and the Tripotamo sites). Fish data collections for HPCs development were undertaken in the nearby Voidomatis catchment



Hydrologic Analysis

Hydrological model

Due to the limited availability of the historical hydrologic data (only 2 years discharge data available in the study area) the soil and water assessment tool (SWAT, Arnold et al. 1998) was used to simulate daily hydrologic time series for the period from 1983 to 2004 for the two study sites (Mesochora and Tripotamo, Fig. 1). The particular model was selected because it is a robust, well-established model and has been successfully applied widely, under similar conditions (Papadaki et al. 2016; Rahman et al. 2013; Wang and Kalin 2011; Zion et al. 2011). SWAT is a process-based semi-distributed continuous hydrologic model incorporating various methods to simulate streamflow, snowmelt, and evapotranspiration (a detailed description is provided by Neitsch et al. (2005)). In this effort, the USDA soil conservation service curve number method (SCS-CN, Soulis et al. 2009; Soulis and Valiantzas 2012; Soulis and

Valiantzas 2013), was used for surface runoff volume estimation while evapotranspiration was estimated using the Hargreaves method (Hargreaves and Samani 1985).

Model setup

The model setup was based on the results of a recent study in the area (Papadaki et al. 2016). The spatial data used in this application for SWAT model parameterization included a 25×25 m digital elevation model (DEM), CORINE Land Cover for the years 1990 (EEA 2012) and 2000 (EEA 2014), soil data coming from the European Soil Database (Panagos et al. 2012) and geological maps of the National Institution of Geology and Mineral Exploration. The results of previous applications of SWAT in a nearby catchment (Panagopoulos et al. 2011), were also utilized to assist model parameterization due to the data availability limitations.

The meteorological data used in this application were 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”) that were provided by the Public Power Company of Greece and the Hellenic National Meteorological Service, respectively. The “Theodoriana” and “Ioannina” stations cover the entire simulated period (1983–2004) and were used directly in the model, while the other two stations were used to estimate the precipitation and temperature lapse rates.

Calibration-validation

The available stream flow data were restricted to the “Mesochora” gauging station for a 2-year period (October 1986–September 1988). The 1st year was used for the calibration and the 2nd year for the validation of the model. Considering the scope of this study, model calibration focused on the low flows, which were examined at a daily time step. Nevertheless, the overall water balance and the seasonal variation, were examined at a monthly time step to get a better picture of the annual flow regime.

Model performance was evaluated statistically based on the typical Nash-Sutcliffe Efficiency (NSE) (Nash and Sutcliffe 1970), and the percent bias (PBIAS) statistical measures. The relative NSE (rNSE) and the NSE with logarithmic values (lnNSE), were used to reduce bias of the NSE in extreme values (Krause and Boyle 2005). NSE, rNSE, and lnNSE range between $-\infty$ and $+1$, and values close to $+1$ indicate optimal model performance. PBIAS, is an indicator of under-estimation or over-estimation, and values close to 0 indicate optimal model performance. The model performance is considered satisfactory if $NSE, rNSE, \text{ and } \lnNSE > 0.5$ and $PBIAS < \pm 25\%$ (Moriassi et al. 2007; Rahman et al. 2013).

The model calibration mainly focused on the low flows by adjusting the main base flow parameters: alpha factor (ALPHA BF = 0.35 days) and groundwater lag (GW DELAY = 31 days) as well as the SCS-CN parameter, which is the main parameter for surface runoff volume estimation. The calibration of these parameters was made on a trial and error basis, at a daily time step. Furthermore, the estimated temperature lapse rate (i.e., the rate at which atmospheric temperature decreases with increasing altitude) (TLAPS = 3.05 °C/km) was slightly modified to adjust the seasonal flow balances.

Global Environmental Flow Calculator (GEFC)

In this study, hydrologic simulated monthly flows from SWAT model, for the period 1983–2004 were introduced in the GEFC to estimate Environmental Management Classes. Each EMC is effectively an environmental flow scenario. The environmental flow (e-flow) estimation is based on a

monthly time series reflecting natural/unregulated flow conditions. Initially, the GEFC tool calculates the flow duration curves (FDC) in natural (reference) conditions. Secondly, the FDC in regulated (altered) conditions are calculated, and a set of hydrologic alteration indicators are determined by the lateral shift of the reference FDC towards the altered FDC along the probability axis. Thus, 17% points on the probability axis of the FDC are used as steps in this procedure: 0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9, and 99.99%. Details of the method are described in Smakhtin and Anputhas (2006).

Thus, in accordance with this approach, the e-flow aims at maintaining or upgrading the ecosystem to a prescribed or negotiated ecological status. Six EMC are used in the GEFC and six corresponding default levels of e-flows may be defined (DWAF 1997). The higher the EMC, the greater the allocation of water required for ecosystem conservation and the more natural flow variability needs to be preserved (Shaeri Karimi et al. 2012).

Physical Habitat Simulation Approach

Hydraulic modeling

Hydrologic Engineering Center (2010) model (HEC-RAS Version 4.1) was used to perform a pseudo-2D hydraulic simulation for several flows, focusing on low flow conditions (July to October) at the mountainous part of Acheloos River. The model solves the 1-D Saint-Venant equations, for steady state, gradually varied flow. To account for friction losses, Manning’s roughness coefficient (n) was applied to every cross-section and was horizontally varied for substrate variation, vegetation and cross section geometry. Roughness coefficient was set as a calibration parameter. Initial values of n , were assigned from the literature (Barnes 1967; Chow 1959; Cowan 1956).

A topographic survey was carried out with a geodesic GPS/GNSS Geomax - Zenith 20, encompassing the main channel and banks, using geodesic references (i.e., GGRS ‘87—Greek Geodetic Reference System) to generate DEMs as the basis for hydraulic simulation. Steady state simulations were performed at 27 cross-sections along the Mesochora site and at 22 cross-sections along the Tripotamo site. Cross-sections were located at points of hydro-morphological alteration, abrupt changes of riverbed slope and cross-section geometry, and at significant changes of riverbed material.

To account for the Pseudo-2D hydraulic simulation, every cross-section was subdivided in a number of cells both in the main channel and the overbank area. For the Mesochora site the number of cells were 12 and for the Tripotamo site 10. The number of cells was primarily a function of water velocity field measurements and substrate

variation along the cross-sections. The uniform depth was used as upstream and downstream boundary conditions in both sites.

For both sites field measurements of flow velocity and depth were conducted at specific cross-sections, using a propeller current meter and applying the standard procedure for calculating the river discharge (Turnipseed and Sauer 2010). Water surface elevation (WSE) for the surveyed cross-sections was calculated by adding the flow depth to the absolute riverbed elevation. Due to real flow conditions, the measured WSE for each cross-section was not horizontal, so an average WSE was calculated as a single value for every cross-section and this was used for the hydraulic model calibration.

Habitat simulation method

An adaptation of the physical habitat simulation system (Bovee et al. 1998) was undertaken for the assessment of flow requirements in terms of depth, velocity, substrate, and cover for three size classes of the *S. farioides*. According to common procedures (Heggenes et al. 1990; Martínez-Capel et al. 2009), the microhabitat study was conducted by underwater observation (snorkeling) in the Voidomatis River during daylight in July–September 2014, to collect data on microhabitat-use by *S. farioides*. Visual data were gathered for 103 large sized (more than 20 cm), 87 medium sized (10–20 cm) and 94 small sized (less than 10 cm), individuals of *S. farioides*. The various fish size classes were associated with the measured depth, velocity, substrate, and cover type variables at a microhabitat scale. The HPCs were then developed following Bovee (1986); these curves relate the hydraulic or habitat variables with a suitability index, ranging from 0 (unsuitable for the aquatic species) to 1 (excellent).

The habitat assessment consists of the estimation of habitat suitability in the entire river stretch, using the weighted usable area (WUA), an index commonly used as a general indicator of habitat quality and quantity for each simulated flow.

Initially, the corresponding suitability from the HPCs was interpolated for every cell of the hydraulic model. Then the associated suitability for depth, velocity, substrate and cover was aggregated by using the product method yielding the so-called habitat suitability index (HSI). The product method assumes that fish select each particular variable independently of the rest (depth, velocity, substrate and cover) and therefore to estimate the final HSI, a multiplication of the different variables' suitability indices is applied (Bovee 1986). The percentage of each substrate class was visually estimated around the sampling point. The substrate classification was simplified from the American Geophysical Union size scale, similarly to previous works

(Martínez-Capel et al. 2009). The amount of cover was scored as follows; easy observation of the fish from the shore (1), observation of the fish possible by underwater observation from distant locations (2) and underwater observation of fish only from close locations (3). Finally, the WUA was calculated by summing the HSI weighted by the cell area, across the entire site. The whole procedure was carried out in R software (R Core Team 2015).

Development of HPCs for *S. farioides*

Univariate HPCs, as part of the habitat simulation method, were defined for three size classes of *S. farioides* (based on Klossa-Kilia and Ondrias (1994) research on the species biology in the Acheloos River). These size classes are: large-sized (>20 cm TL, adult fish of reproductive age), medium-sized (10–20 cm TL, juvenile fishes) and small-sized (<10 cm TL, less than a year old).

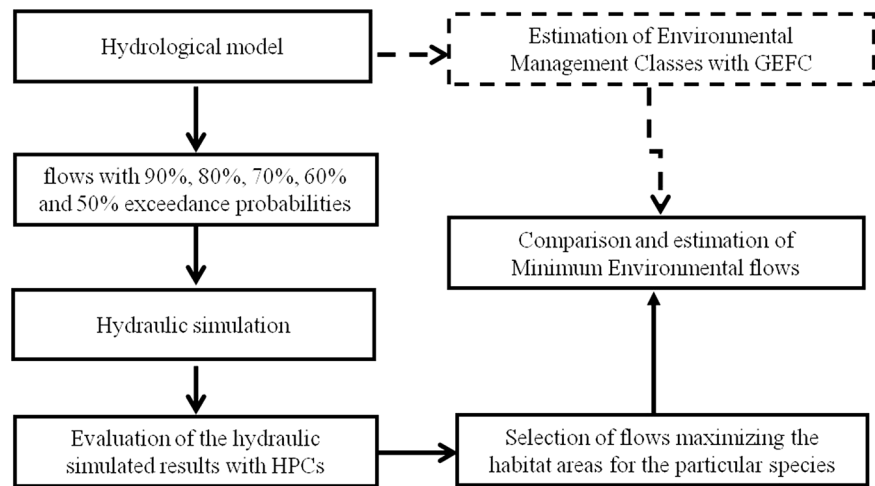
A modification of the equal effort approach (Bovee et al. 1998) was applied in the selection of the surveyed area. This approach reduces the bias derived of the unbalanced fast-waters and slow-waters sampling (Muñoz-Mas et al. 2016). Consequently, the study sites at the Voidomatis River (Fig. 1) were stratified in hydro-morphological units (hereafter, HMU) classified as pool, run, and riffle; then, the HMU were selected to balance the areas of slow (i.e., pool) and fast (i.e., run, riffle) (Table 1).

The habitat availability (i.e., unoccupied location) was sampled along each HMU in four cross-sections uniformly distributed with five pointy samplings each. Depth was measured with a wading rod to the nearest cm and the mean flow velocity of the water column was measured with a propeller current meter (OTT[®]). The dominant substratum was visually estimated around the sampling point or fish presence location. The substrate classification was the same specified above. Finally, the abundance of five different cover types was also recorded. Namely, vegetation, undercut banks, woody debris, shade, and boulders. These cover types are a simplification of those described in the literature (Heggenes et al. 1999; Strakosh et al. 2003; Zika and Peter 2002) and summarize the concept of structural cover (e.g., boulders, log jams), which provide either shelter from currents and thus become energetically profitable or visual isolation from competitors or predators (Bovee et al. 1998).

Table 1 General characteristics of voidomatis reach HMU

HMU	Mean depth (m)	Mean velocity (ms ⁻¹)	Dominant substrate
Pool	1.2	0.26	Gravel
Run	0.75	0.27	Boulder
Riffle	1.53	0.57	Boulder

Fig. 2 Framework for the estimation of minimum environmental flows, combining an adaptation of the physical habitat simulation (solid line) and a general hydrologic method operating at a monthly time scale (dashed line)



Besides the selected cover types encompassed the so-called escape cover, which usually corresponds to vegetation and undercut banks that allow specimens to take shelter (Raleigh et al. 1986).

HPCs were developed to depict the habitat selection of the three size classes of the *S. farioides*. HPCs relate each hydraulic parameter to a habitat index which, in this case, scores the range of water velocities and depths from 0 (unsuitable) to 1 (excellent). Firstly, histograms for the continuous variables were developed (i.e., depth and mean flow velocity) and a smooth curve was adjusted to encompass them with the smooth.spline function of the R statistical software (R Core Team 2015) where a smoothing function was applied to the input data with 3rd order polynomials. As a consequence, in order to be coherent with the ecological gradient theory (Austin 2007), which stated that the effects of the environmental variable must be unimodal or straight (monotonic), the number of splines was properly adjusted for every developed curve. For non-continuous variables the histograms obtained from habitat use were applied. Secondly, smoothed habitat use curves were divided by smoothed curves of availability (by intervals) to obtain the forage ratio (Voos 1981); therefore, the resulting curves are preference curves (category III, Bovee 1986).

Minimum EFA Based on the Physical Habitat Simulation

Based on the hydrologic simulated series, we calculated the mean monthly flows for the months July–October (representing dry period conditions) with 90, 80, 70, 60, and 50% exceedance probabilities, in each of the study sites, which is the typical range of exceedance probabilities for instream flow studies (Bovee 1982). Then, these flow values were introduced in the habitat simulation method to estimate the WUA for each of the three size classes. Optimization

matrices were developed depicting the aforementioned flows for the three classes of the *S. farioides*, according to the optimization criterion of Bovee (1982). These flows were arrayed across the top of the matrix and the WUA value for all size classes of *S. farioides* was recorded accordingly. Then the minimum WUA value among the three size classes was identified for each flow. Finally, minimum environmental flows were estimated based on the flow with the highest WUA value among all size classes (Bovee et al. 1998). This value corresponds to the flow that maximizes the habitat area for the particular fish species for each of the study sites. The indicated flow values from the optimization matrices were those proposed for monthly minimum environmental flows for the dry period conditions. Fig. 2 shows the steps performed in this approach.

Results

Hydrologic Modeling

The model performance results for the water balance and the seasonal variation (monthly time step), were: NSE = 0.69 and PBIAS = 5.6% in the calibration stage and, NSE = 0.51 and PBIAS = 22.2%, in the validation stage. Regarding the estimation of low flows (daily time step) the performance indicators were: rNSE = 0.89 and lnNSE = 0.85 for the calibration stage and rNSE = 0.59 and lnNSE = 0.96 for the validation stage.

The estimated average daily flow for the period 1986–2004 (Fig. 3), in the Mesochora site was $25.26 \text{ m}^3 \text{ s}^{-1}$ while the minimum and the maximum daily values fluctuate from 0.5 to $845 \text{ m}^3 \text{ s}^{-1}$ (Table 2). The median flow value in the Mesochora site for the aforementioned period was $12 \text{ m}^3 \text{ s}^{-1}$ while the 10th and 90th percentiles were 2.4 and $49 \text{ m}^3 \text{ s}^{-1}$, respectively. There were significant fluctuations at an interannual level, with years of relatively low average

Fig. 3 The estimated mean and the minimum annual discharges for the period 1986–2004, at the sites of Mesochora and Tripotamo

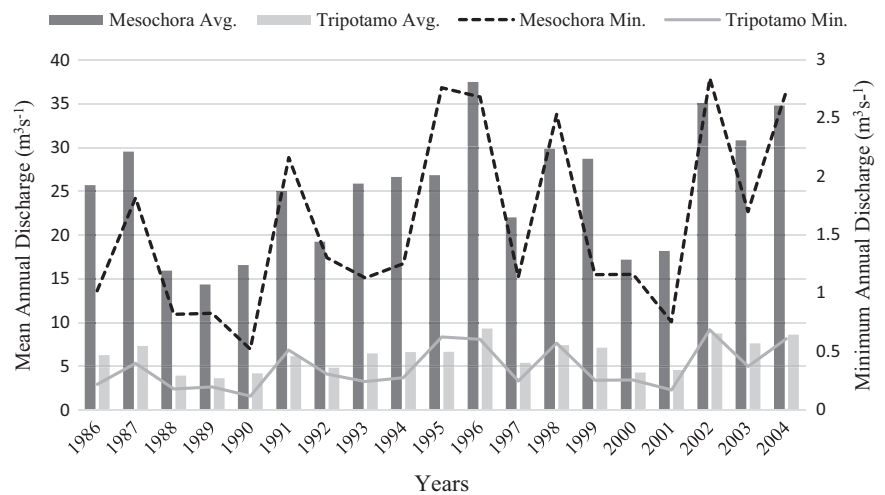


Table 2 Descriptive statistics for the time series of stream flow, which were simulated at the the Mesochora and the Tripotamo sites

Statistic/Site	Mesochora $\text{m}^3 \text{s}^{-1}$	Tripotamo $\text{m}^3 \text{s}^{-1}$
Mean	25.26	6.29
Minimum	0.52	0.12
Maximum	844.7	217.0
Median	11.84	2.72
10th Percentile	2.35	0.54
90th Percentile	49.23	12.25
SD	52.57	13.92

flow values (e.g., 1992, lower than $20 \text{ m}^3 \text{ s}^{-1}$) but with extremely high maximum values (above $800 \text{ m}^3 \text{ s}^{-1}$). On the contrary, there were years with annual average results above the average but relatively smooth intra-annual variations (e.g., 1987 and 1997). The Tripotamo site has significantly lower flow values (Fig. 3) since it is located upstream of the Mesochora site, with an annual average flow of $6.3 \text{ m}^3 \text{ s}^{-1}$ and minimum and maximum daily flow values of 0.12 and $217 \text{ m}^3 \text{ s}^{-1}$, respectively (Table 2). The median daily flow value was $2.7 \text{ m}^3 \text{ s}^{-1}$ while the 10th and 90th percentiles were 0.54 and $12.25 \text{ m}^3 \text{ s}^{-1}$, respectively, which means that during the dry period (i.e., September) the flow levels fluctuated between 0.12 and $0.5 \text{ m}^3 \text{ s}^{-1}$. The inter-annual variations in the flow values were also relatively lower in the Tripotamo site than in the Mesochora site.

Hydraulic Modeling

The calibration of the model was achieved by adjusting Manning's number (n) for two surveyed flows ($4, 8.8 \text{ m}^3 \text{ s}^{-1}$) at the Mesochora site and one ($0.26 \text{ m}^3 \text{ s}^{-1}$) at the Tripotamo site, by comparing the simulated water stage and the

flow velocities with the observed ones from field measurements. The calibrated values of the roughness coefficient (n) ranged from 0.033 to 0.052 for the main channel and from 0.06 to 0.08 for the overbank areas for the Mesochora site. Respectively, for the Tripotamo site n varied from 0.03 to 0.047 for the main channel and from 0.07 to 0.09 for the overbank areas. The root mean square error for the WSE was 0.029 m at the Mesochora site and 0.047 m at the Tripotamo site. The R^2 coefficient was 0.996 for the Mesochora site and 0.998 for the Tripotamo site.

Habitat Analysis

In the middle stretch of our reference river (Voidomatis), the preference curve for depth (Fig. 4a) for the small sized *S. farioides* indicates maximum suitability from 1.3 to 2 m depth. The curve tails off towards 2.75 m depth. For the medium-sized trout the maximum suitability was assigned to 1.8 m depth with a constant habitat suitability value of 0.5 at the tail of the curve. The large sized trout preferred greater depths in comparison with the smaller individuals (a maximum towards 2 m depth, while the tail of the curve was flat with a suitability of 0.6).

The mean flow velocity preference curve (Fig. 4b) for the small-sized trout indicated high suitability values for velocities between 0 and 0.65 ms^{-1} . For the medium-sized trout, maximum suitability was recorded at 0.65 ms^{-1} . Lower velocities were preferred by the large-sized trout with a slightly higher suitability at the tail of the curve than for the other two counterparts.

The maximum suitability for the dominant substrate (Fig. 4c) was assigned to gravel for both small and medium-sized trout, while for the large-sized trout the maximum suitability was assigned to sand. Regarding the cover (Fig. 4d), the maximum suitability for both small and medium-sized trout was assigned to woody debris while for

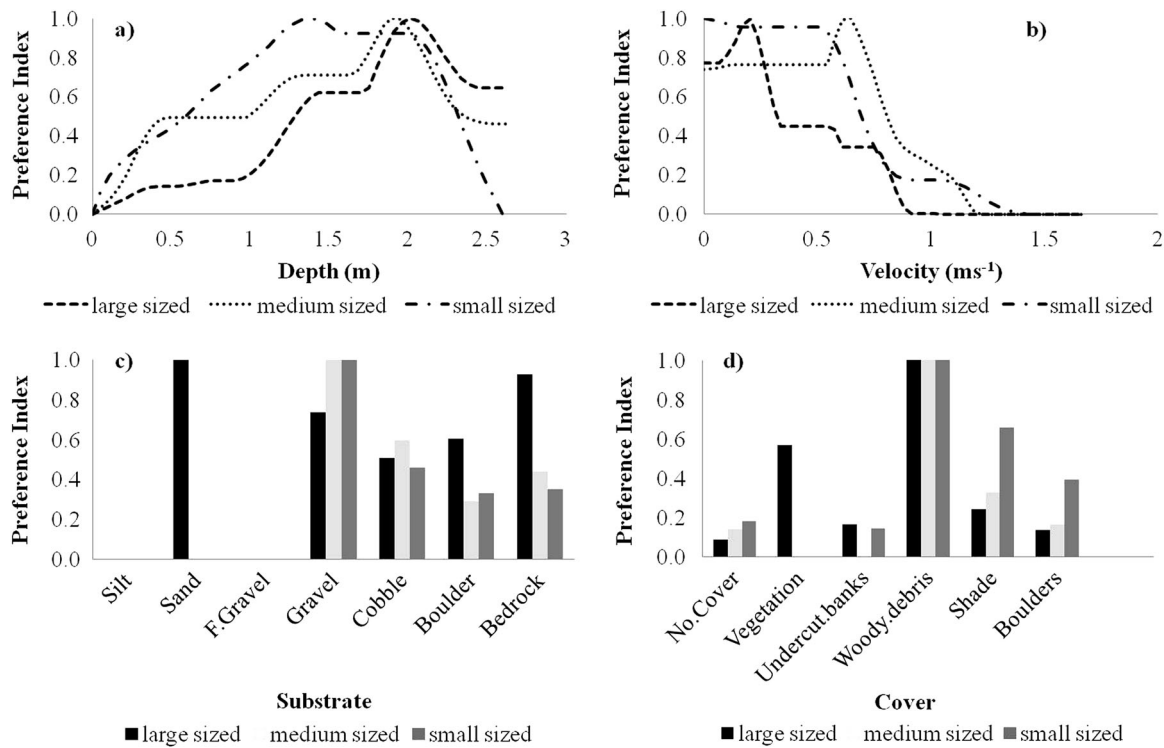


Fig. 4 Large, medium and small-sized *S. farioides* HPCs for depth (a), velocity (b), and preference histograms for non-continuous variables, substrate (c) and cover (d)

the large-sized the most appropriate cover was aquatic vegetation and woody debris.

Observations on the habitat assessment results of the medium-sized *S. farioides* indicate lower habitat suitability in comparison to the other two size classes. The same observation applies for almost every flow as shown in the optimization matrixes for both study sites (Table 3), where habitat assessment results are expressed as WUA values. Small-sized trout (<10 cm) are not present in September and October in the Mesochora site and from August to October in the Tripotamo site.

Using this information, the minimum environmental flows that minimize habitat losses for dry period conditions, were estimated for both study sites (Table 4)

Comparison of Approaches

In Fig. 5 the comparison between unmodified (reference) conditions, monthly minimum environmental flows (Bovee’s criterion) and five environmental flows scenarios according to the GEFC are presented.

The monthly minimum environmental flows (Table 4) illustrate significantly different values in comparison to the scenarios estimated by the GEFC. The fish habitat simulation method recommended higher flow requirements than the hydrologic method for the Mesochora site (Fig. 5a),

while the opposite occurs for the months August–October for Tripotamo site (Fig. 5b). Hydrologic method’s environmental flow scenarios decrease progressively with decreasing water discharge levels according to the desired state of modification.

Discussion

Complementary approaches applied concurrently such as in this study allow us to compare among different tools and detect any shortcomings. Combining assessment approaches that utilize both abiotic and abiotic relevant ecohydrologic methods may aid progress towards a more holistic approach, while still maintaining a rapid assessment screening level study. The results of this study indicate that especially in data scarce regions the utilization of biotic indicators through habitat models, may provide valuable information, beyond that achievable with hydrologic methods, in developing regional environmental flow criteria, since those methods can set operational benchmarks for flow and water level conditions during the most stressful seasonal period in Mediterranean mountain rivers. The fish habitat simulation approach recommended higher flows than the hydrologic method for summertime in the downstream site (Mesochora), while the opposite was suggested

Table 3 WUA values for both study sites and three life stages of the *S. farioides* over a range of monthly flows with exceedance probabilities 90, 80, 70, 60, and 50%

% Exceedance	July					August					September					October				
	90	80	70	60	50	90	80	70	60	50	90	80	70	60	50	90	80	70	60	50
Mesochora																				
Discharge (m ³ s ⁻¹)	2.6	3.1	3.6	4.1	4.7	1.9	2.1	2.5	2.9	3.2	1.5	1.5	1.7	2.1	2.7	1.5	1.6	2.4	3.3	4.8
WUA large	227	218	215	214	220	301	274	227	212	212	318	318	291	274	227	317.9	311.2	230.7	212.4	220.6
WUA medium	127	135	142	147	153	120	123	127	132	138	106	106	110	123	129	106.2	108.5	123.4	138.0	153.4
WUA small	168	173	178	182	166.7	169.5	165.5	1717.4	175.3	-	-	-	-	-	-	-	-	-	-	-
Tripotamo																				
% Exceedance	90	80	70	60	50	90	80	70	60	50	90	80	70	60	50	90	80	70	60	50
Discharge (m ³ s ⁻¹)	0.6	0.7	0.8	0.9	1	0.4	0.5	0.6	0.7	0.7	0.3	0.3	0.4	0.5	0.6	0.3	0.4	0.6	0.8	1.2
WUA large	907.3	917.7	920.6	935.6	929.6	882.5	900.8	907.3	917.7	917.7	891.2	891.2	882.5	900.8	907.3	891.2	882.5	907.3	917.7	908.2
WUA medium	28.0	29.1	30.2	31.2	32.3	25.5	27.2	28.0	29.1	29.1	23.7	23.7	25.5	27.2	28.0	23.7	25.5	28.0	29.1	33.3
WUA small	66.0	66.7	68.0	68.3	68.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4 Minimum environmental flows for dry periods

Minimum environmental flows (m ³ s ⁻¹)	July	Aug	Sept	Oct
Mesochora	4.7	3.2	2.7	4.8
Tripotamo	1.0	0.7	0.6	1.2

for the upstream site (Tripotamo). According to Freeman et al. (1997), habitat criteria developed in streams supporting dense fish populations (as in the case of Voidomatis River), can better describe a species' habitat requirements than criteria developed on-site, but only if those criteria accurately reflect habitat quality independently of site-specific habitat features. This assumption could be useful where it is not logistically or economically feasible to develop habitat criteria for all environmental conditions that may influence fish habitats (Mäki-Petäys et al. 2002; Millidine et al. 2016). Nevertheless, if there is a poor knowledge of the fish species needs in terms of habitat characteristics, this may result in erroneous estimates of habitat suitability (Freeman et al. 1997; Thomas and Bovee 1993).

Voidomatis HMUs are dominated by deep long pools, which are roughly similar to the HMUs of Mesochora, although they differ from the shallower riffle dominated site of Tripotamo. This high spatiotemporal variability between Tripotamo and Voidomatis, especially in key hydrologic variables (depth, velocity), implies limited transferability of fish habitat models among sites. We therefore detected a risk that the transferability problem would produce unreliable environmental flow estimations especially for the Tripotamo site. Millidine et al. (2016) and Choi et al. (2015) also provided evidence that transferring models among locations with different geomorphologic and environmental characteristics should be avoided especially without model validation. Additionally, more variables such as water temperature should be incorporated for the quantification of the vulnerability of *S. farioides* to water withdrawal (Zorn et al. 2012).

In varied and dynamic Mediterranean mountain river conditions special care is needed for selection of the study scale (Fausch et al. 2002; Mäki-Petäys et al. 2002), for the building of the models and for evaluating flow scenarios. Habitat availability and fish population density are highlighted as rather important factors influencing study scale selection (Paton and Matthiopoulos 2016). Representative river reaches identifying habitat availability, may be defined by habitat mapping techniques using minimal time and effort to cover long stretches of river (Maddock 1999). Expert judgment approaches may provide help to consistently describe habitat units and select a potential study reach with a similar habitat composition in relation to the broader river segment conditions. In cases where the habitat

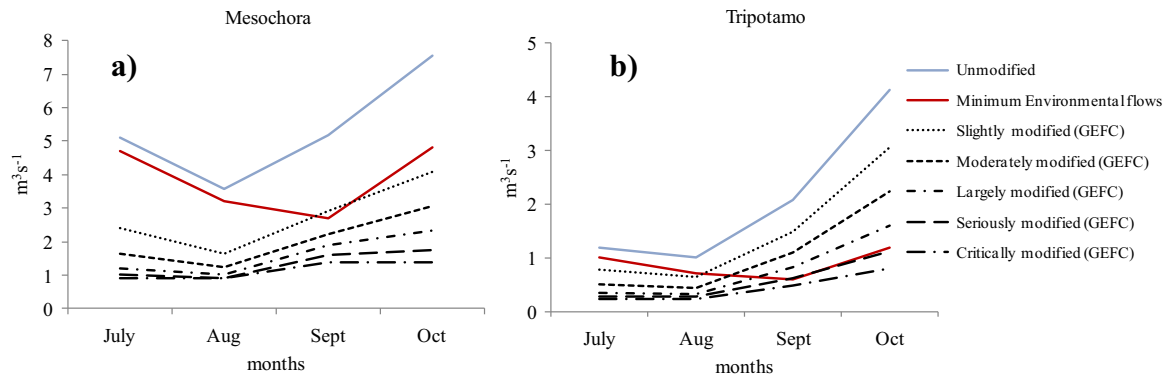


Fig. 5 Comparison between monthly unmodified conditions, minimum environmental flows and five environmental flow scenarios according to the GEFC for the Mesochora site (a) and the Tripotamo site (b)

composition is rather complex, and not appropriately represented in the selected study reach, significant habitat model errors may occur. Wider spatio-temporal conditions and resources should also be considered, highlighting the importance of exploring broader river networks before the study scale selection (Fausch et al. 2002). Nevertheless, fish habitat simulation methods may provide operational benchmarks for flow and water level conditions during the most stressful period in Mediterranean mountain rivers (July–October). Our results agree with Nikghalb et al. (2016) who used a similar approach in a river located in a Semi-Mediterranean Region. Highly specialized applications require tools that can increase accuracy and precision; still those tools are rarely applied because they require greater investments in time and resources (Dyson et al. 2003; Linnansaari et al. 2013). Simple, user-friendly tools are also needed to empower and support multi-stakeholder bodies that operate at basin and local levels (IUCN 2004). Moreover, the EU WFD's Eflows Guidance document (CIS no 31, European Commission 2015) suggests that hydrologic methods could be applied at a catchment scale while more detailed methodologies connecting the hydrologic regime with multiple biological quality elements should be developed and applied when decisions on water uses or restoration measures have to be made. In Mediterranean mountain river catchments, the ability of hydrologic models to efficiently simulate hydrologic response is hampered by the high spatial variability of hydromorphological (elevation differences, high relief valleys) and meteorological conditions (Rahman et al. 2013; Soulis and Dercas 2007). Especially in Mediterranean countries, the hydrologic model's efficiency is further constrained by meteorological and hydrologic data scarcity, and by meteorological stations being confined to lower altitudes or coastal locations (Skoulikidis et al. 2009; Soulis 2015). However, given these significant obstacles, the observed model performance is considered acceptable according to the criteria posed

(Moriassi et al. 2007; Rahman et al. 2013), even if the remaining uncertainty is an important constraint.

Fishes are good indicators of hydromorphological conditions, and in upland trout-dominated lotic systems their requirements assist in promoting the conservation of varied natural habitat conditions (Ayllón et al. 2014). Moreover, fishes are also important in promoting policy-relevant water management and this is an area of rising interest in Eastern Mediterranean EU countries, such as Greece (Economou et al. 2016). However the results of this work does detect some interesting transferability challenges and further validation is required. In the future, it is important to review biota requirements at more than one level of river biodiversity (several species, including keystone instream and riparian biota) in order to promote a more holistic interpretation.

Conclusions

Different EFA approaches can be used to recommend environmental flow requirements from different perspectives as required. Hydrologic methods applied in data scarce regions such as the current study area may provide a first screening level analysis. In this study, the reliability of the hydrologic method's results for low flows during a stressful period (July–October) was further examined with a fish habitat suitability method. The required data were collected from a near-pristine trout dominated river and applied to near-natural mountain river reaches in an adjacent basin. Comparison among the different assessment approaches to estimate minimum environmental flows, indicated significant discrepancies in this application.

Since the fish habitat suitability relationships were collected from a large spring-fed river (Voidomatis) which differed from the assessed sites it is possible that these results may be biased towards different river conditions.

Development of on-site criteria is not, however, always feasible, and criteria applicable across rivers are therefore needed (Nykanen and Huusko 2004). Fish habitat preferences vary locally depending on different environmental variables, therefore seemingly universal criteria may have poor applicability (Greenberg et al. 1996; Heggenes 1990; Moyle and Baltz 1985) especially if applied without transferability tests (Thomas and Bovee 1993).

The hydrologic regime of the particular perennial stream sites present high intra-annual and inter-annual flow fluctuations, partially due to the mountainous character of the area and the existing karstic springs in some catchments. Transferring fish habitat models among locations with even slight differences in geomorphologic and environmental characteristics can be challenging in Mediterranean Mountain Rivers. Therefore, estimating the environmental flow requirements in the particular sites is not a straightforward since these highly varying hydrologic conditions should be classified into type-specific river forms before making the flow assessment study.

Although fishes are important indicators of instream conditions, there may be some externalities and habitat relationships that are poorly understood which may confound the habitat suitability models. This may result in poor transferability, even among trout streams within close proximity. Finally, a river-type and site-specific assessment should involve steps towards a more holistic approach, which takes into account the natural history of local biotic elements. This preliminary application promotes the need for further science-based ecohydrologic approaches in order to respect both local biodiversity and current EU water management policies.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

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