

## REVIEW PAPER

# A review of the effects of pollution and water scarcity on the stream biota of an intermittent Mediterranean basin

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## Abstract

This review presents the main results of a 10-year research study conducted in a Mediterranean intermittent basin (Evrotas River). By assembling the main outcomes of past and ongoing research projects, this study provides an overview of multiple stressor effects, with emphasis on water scarcity, focusing on hydro-biogeochemical processes, as well as on spatial and temporal variations in benthic macroinvertebrates and fish fauna. The major impact in the basin has been the over-exploitation of surface and groundwater resources, which, in combination with droughts, has resulted in the recurrent artificial desiccation of large parts of the hydrological network. The response to intermittency of the macroinvertebrate fauna is characterized by high resilience through various drought-resistant evolutionary mechanisms, with assemblages recovering successfully after recurrent droughts. However, when pollution is evident in combination with drought, effects on benthic species richness, abundance, and assemblage structure can be severe. Similarly, pollution and water stress may result in massive fish mortalities due to hypoxic conditions, with fish populations requiring long periods to recover. However, the fish fauna appears to be relatively resilient to drought-driven reach-scale desiccation, and ultimately recovers, provided that aquatic refugia are available to supply colonists and that there are no physical barriers impeding recolonisation. Appropriate conservation measures are urgently required to address the effects of recurrent bouts of water stress, as well as of other stressors on the freshwater communities of the Evrotas River, both at the level of water management and of water policy and at the local and the national level.

## KEYWORDS

drought, fish, macroinvertebrates, temporary rivers, water stress

## 1 | INTRODUCTION

Intermittent (or temporary) rivers are among the most dynamic freshwater ecosystems (Arthington, Bernardo, & Ilhéu, 2014), but concurrently among the most vulnerable ones, because they are located in water scarce areas, where water resources are often over-exploited, accentuating natural interannual and intra-annual flow variability, (Sabater & Tockner, 2010; Skoulikidis et al., 2011; Skoulikidis, Vardakas, Amaxidis, & Michalopoulos, 2017b). Considering the Mediterranean region, natural and human-induced climate change, in combination with the over-exploitation of water resources, has resulted in a 20% decrease in river run-off within the past half century (Ludwig, Dumont, Meybeck, &

Heussner, 2009; Skoulikidis, 2016), simultaneously increasing the frequency, duration, and intensity of low flows (Demuth & Stahl, 2001; Skliris, Sofianos, & Lascaratos, 2007). Worldwide, several former perennial streams and rivers have become intermittent (Gleick, 2003), with similar reports for Greek watercourses (Skoulikidis, 2016).

It has long been acknowledged that such extreme climatic conditions of water scarcity and prolonged droughts influence both the physicochemical and the ecological status of water bodies (Barceló & Sabater, 2010). Extended low-flow periods result in increased water temperatures, which may rapidly equilibrate with the ambient terrestrial environment and cause modified evaporation patterns (Hamilton, Bunn, Thoms, & Marshall, 2005) and irregular pool-riffle succession.

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Algae growth also increases due to increased nutrient resuspension rates, resulting in decreased dissolved oxygen concentration (Petrovic et al., 2011) and eutrophication (Yang, Wu, Hao, & He, 2008). Pollutant concentrations in the water increase due to reduced dilution capacity (IPCC, 2014; Osorio et al., 2014); consequently, both the patterns and the magnitude of chemical exposure are highly affected by prolonged low-flow periods (Arénas-Sánchez et al., 2016).

These complex interactions between the hydrological and physico-chemical processes due to extended low flows influence the structural integrity of the aquatic communities (Skoulikidis et al., 2011; Theodoropoulos, Aspidris, & Iliopoulou-Georgudaki, 2015). The increased frequency and magnitude of ecosystem contraction and expansion dynamics (Doering, Uehlinger, Rotach, Schlaepfer, & Tockner, 2007) result in extended riparian and instream habitat loss during low-flow periods or droughts. Although biota in intermittent aquatic systems are adapted to often extremely variable hydrological conditions (Cid et al., 2017; Datry, Larned, & Tockner, 2014), it has been evidenced that the fish fauna of intermittent watercourses can only partially tolerate prolonged desiccation, with unsuccessful recovery after rewetting of the watercourse (Bêche, Connors, Resh, & Merenlender, 2009). Moreover, the importance of maintaining “refuge” pools to ensure proper recolonization has been often highlighted (Beesley & Price, 2010). Similarly, benthic-invertebrate communities are also influenced by extreme drying and rewetting patterns; statistically significant structural differences have been reported between the benthic communities of perennial and intermittent rivers (García-Roger et al., 2013; Leigh et al., 2016), in abundance; taxonomic richness; and the richness of Ephemeroptera, Plecoptera, and Trichoptera (EPT; Bonada, Rieradevall, & Prat, 2007; Boulton, Sheldon, Thoms, & Stanley, 2000; Theodoropoulos et al., 2015). Benthic-macroinvertebrate communities however show increased recovery rates after rewetting (Vorste, Corti, Sagouis, & Datry, 2016) in contrast to fish (Skoulikidis et al., 2011).

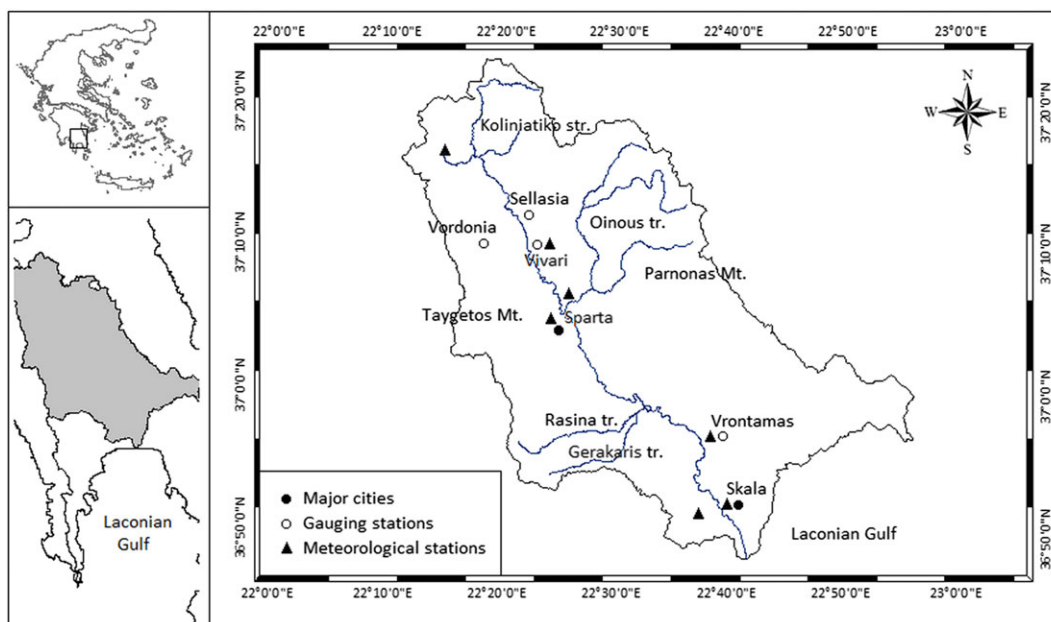
In an era of changing climate, relevant predictive scenarios suggest that the arid and semiarid regions of the planet, including the

Mediterranean, will be highly exposed to the impacts of climate change (IPCC, 2012; IPCC, 2014), namely, increasing terrestrial and water temperatures and decreasing annual precipitation rates, thus extending drought periods. These pressures, in combination with the constantly increasing anthropogenic water demand and the reduced availability of water resources, are expected to have irreversible impacts on the aquatic communities (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012), possibly stretching their resilience beyond levels of tolerance.

In this article, we review the long-term hydrological alteration in the Evrotas River Basin due to the increasing anthropogenic water demand and the effects of natural and artificial flow variability and organic pollution on the structural properties of the in-stream biotic communities. We also attempt to derive trends and relationships between the abiotic factors and the biotic elements of the Evrotas River ecosystem.

## 2 | THE EVROTAS RIVER BASIN

The Evrotas is a mid-altitude Mediterranean basin located in the south-eastern Peloponnese (Greece), covering an area of 2,418 km<sup>2</sup> (Figure 1). It is one of the last remaining free-flowing rivers in Greece, as there are no dams, neither along its main course nor at its tributaries. The basin is characterized as semiarid due to the low ratio (0.46; 1998–2000) of mean annual precipitation to potential evapotranspiration (for semiarid zones:  $0.20 \leq P/PET < 0.5$ ). According to historical information, the Evrotas was once permanently flowing throughout the year, but nowadays, it presents temporary flow characteristics (Skoulikidis et al., 2011; Skoulikidis et al., 2017a). Overall, the Evrotas River is a complex hydrological system consisting of perennial, intermittent, ephemeral, and episodic tributaries. Specific reaches of its main stem dry out every summer as a result of both downwelling



**FIGURE 1** The Evrotas River Basin. Black dots represent major towns in the basin. Blank dots represent villages and their relevant gauging stations. Major tributaries and streams are also depicted [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

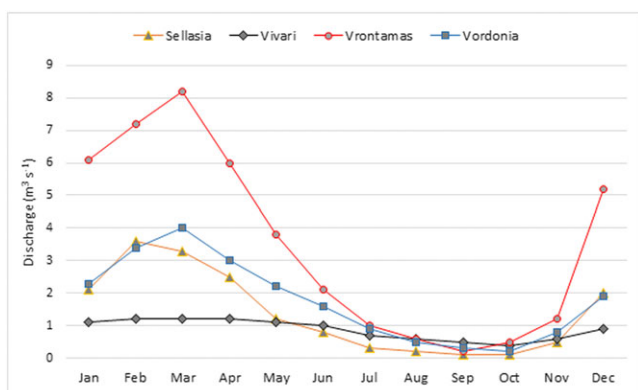
processes in the alluvial aquifers and water abstraction for irrigation, whereas others desiccate during prolonged droughts.

The river is fed by numerous springs, which are the main contributors to its baseflow during summer, including several karstic springs at the upper and mid parts of the basin with significant inputs. Groundwater in the basin is concentrated in hydraulically communicating karstic and alluvial aquifers. The mean monthly discharge of the Evrotas main stem exhibits a gradual increase from summer towards early spring (March) reaching a minimum in October (Figure 2). Based on this variation, the river may be classified as a spring type (after the classification of Malikopoulos, in Therianos, 1974); autumn and winter rainfalls are initially held within the extensive karstic aquifers of the basin, which, after reaching their maximum capacity in March (when snow melts), they supply the river with maximum amounts of water. Minimum discharge is observed in October despite autumn rainfall occurring at that time, because karstic and alluvial aquifers need first to be filled up.

### 3 | EFFECTS OF DROUGHT ON THE EVROTAS AQUATIC ECOSYSTEM

#### 3.1 | Hydrological alteration

Up until the mid-20th century, the vast majority of the basin's agricultural land was not irrigated and the extraction of substantial surface and subsurface water resources was maintained at low levels (Wagstaff, 2002). In the last three decades, the basin has experienced rapid hydromorphological alterations as irrigated cultivations expanded towards natural and seminatural land including riparian areas, whereas natural riparian vegetation has been dramatically altered. In addition, more recently, the irrigation network expanded to olive groves, greatly enhancing water demand. Surface and groundwater overexploitation, especially during extremely dry periods (e.g., 1989–1993 and 2007–2008), affected the basin's hydrological regime and resulted in the lowering of groundwater tables (Gamvroudis, Nikolaidis, Tzoraki, Papadoulakis, & Karalemas, 2015; Nikolaidis, Skoulikidis, Kalogerakis, & Tsakiris, 2009; Skoulikidis et al., 2011; Tzoraki et al., 2011). This led to the artificial desiccation of extensive



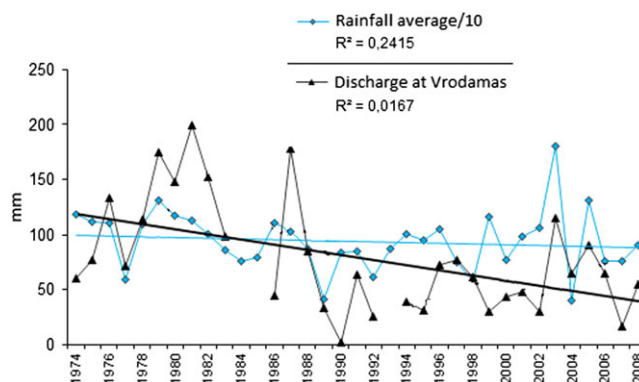
**FIGURE 2** Monthly variation of discharge at the upstream (Vivari), the mid (Vordonia), and downstream (Vrontamas) reaches of the Evrotas River (data: Prefecture of Laconia). See Figure 1 for the location of gauging stations [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

parts of the river network as well as to significant morphological degradation of the river system, thus limiting water and habitat availability and severely affecting aquatic and riparian biota (Nikolaidis et al., 2009; Skoulikidis et al., 2011). In Skoulikidis et al. (2011), the effects of agricultural water exploitation on the Evrotas' flow regime were quantified by estimating the water balance at the basin according to the current water uses, excluding irrigation of olive grove irrigation, as it has only recently been introduced into the basin. Considering that the total irrigation requirements prior to the irrigation of olive groves (77% of the ERB's agricultural land) were 30% of the current uses, the discharge at the river outflow during the dry period was estimated at 9.4 m<sup>3</sup>/s, which is over three times higher than the current one (2.9 m<sup>3</sup>/s).

Two studies (Skoulikidis, 2009; Skoulikidis et al., 2011) also indicate decreasing trends in rainfall and discharge within the last 35 years (Figure 3). However, a 10.5% decrease in rainfall for 1974–2008 was accompanied by a disproportionately higher reduction of discharge (51.2%), whereas the relevant estimated rainfall elasticity to stream flow was very low (0.54) compared to other catchments elsewhere in the world, indicating a very weak relationship between rainfall and discharge (Skoulikidis et al., 2011). Probably, factors other than long-term rainfall changes are mainly responsible for the identified decrease in the Evrotas' discharge, which is the highest among 15 major Balkan rivers (Skoulikidis, 2009).

#### 3.2 | Effects of drought on the invertebrate fauna

Despite the natural and anthropogenically induced drought, the benthic fauna is well adapted to the intermittent character of the river, as it has been concluded from several studies (Kalogianni et al., 2017; Skoulikidis et al., 2011). Differences in species richness variation and macroinvertebrate assemblages between perennial and intermittent streams that are not affected by pollution are not significant (Skoulikidis et al., 2011). Furthermore, the macroinvertebrate fauna of the Evrotas shows high resilience to drought, as many species recover rapidly when flow is re-established; postdrought macroinvertebrate community can be relatively similar to the predrought one (approx. 70% similarity) with minimum differences in assemblages attributed to seasonality (Skoulikidis et al., 2011). Faunal assemblages of perennial streams did not show statistically significant differences between seasons and within sites, thus suggesting a stable and well-



**FIGURE 3** Long-term (1974–2008) variation of average rainfall and discharge at Vrontamas [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

established community (Skoulikidis et al., 2011). Although intermittency may decrease or even diminish certain species populations and size, summer drying does not seem to affect the recolonization potential of the Evrotas benthic fauna.

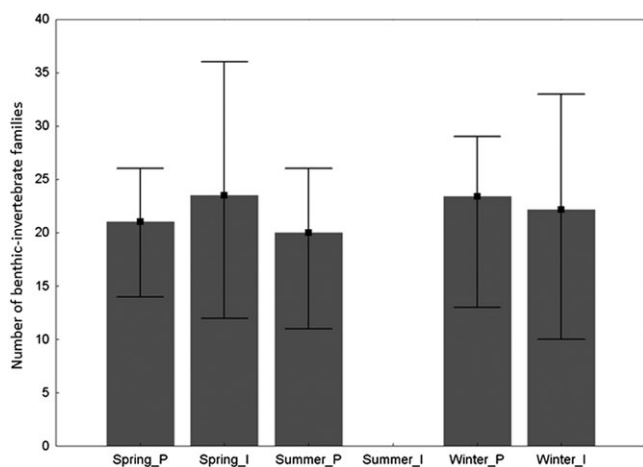
A study conducted by Muñoz (2003) in an intermittent and a permanent stream of NE Spain showed that fauna richness was lower in the intermittent stream than in the permanent stream (Muñoz, 2003), agreeing with Williams (1996) in which richness variation was observed between permanent and intermittent streams. A similar study carried out by Bonada et al. (2007) showed that annual and seasonal macroinvertebrate richness, EPT and COH (Coleoptera, Odonata, and Heteroptera) metrics did not differ between permanent and intermittent sites. Miller and Golladay (1996) observed similar number of taxa in both stream types, which is consistent with findings in the Evrotas basin (Figure 4). Miller and Golladay (1996) found, however, that the total abundances of macrozoobenthos were much higher in permanent than in intermittent streams. A recent study, conducted in two different hydrologic years, at higher (2015) and lower summer discharge (2016) at several longitudinal reaches of Evrotas, indicated high resilience to intermittency; however, variation in benthic community structure and composition did occur at acute water stress, due to microhabitat and water chemistry alteration (Kalogianni et al., 2017).

### 3.3 | Effects of drought on the Evrotas fish fauna

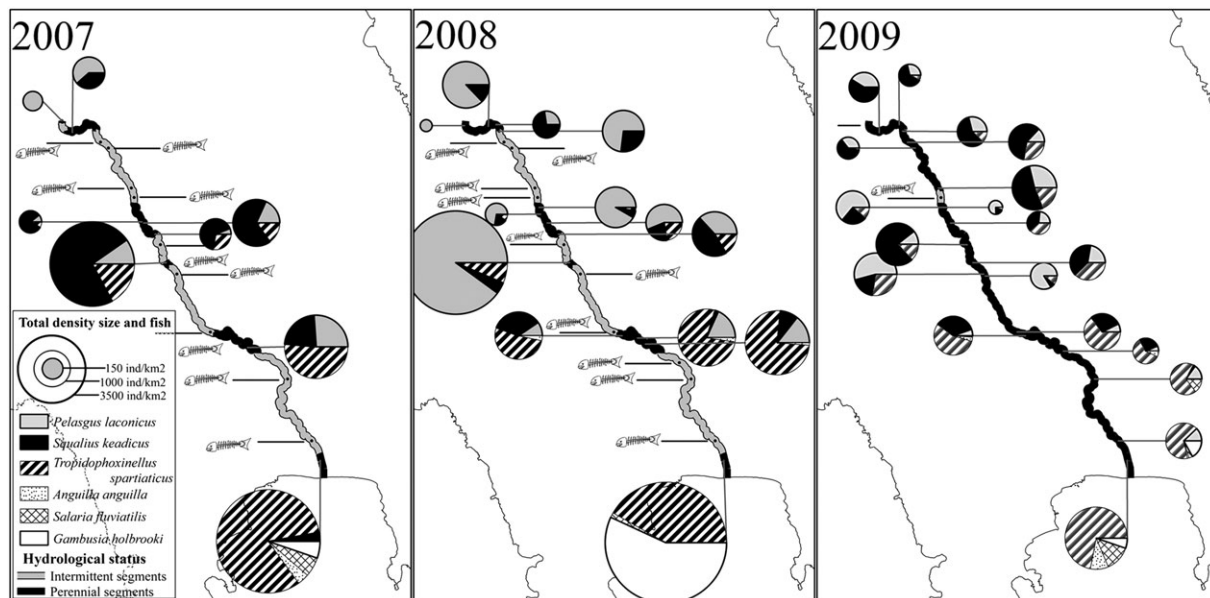
Ichthyological surveys conducted during the last decade (Kalogianni et al., 2017; Skoulikidis, 2009; Skoulikidis et al., 2011; Vardakas et al., 2015; Vardakas et al., 2017) have contributed to a better understanding of water scarcity effects on the spatial patterns and community attributes of the Evrotas freshwater fish fauna. The two extreme drought events that occurred during the summer periods of 2007 and 2008 offered the opportunity to study the effects of drought on fish populations, whereas in 2009, that was characterized as a wet year, the re-establishment rate and recolonization process was investigated (Skoulikidis et al., 2011). The most severe impact of the 2007 drought event was the local extinction of all species from the Evrotas

intermittent sections (Skoulikidis et al., 2011). Despite the reduction of the wetted surface during the drought years, the three Evrotas endemic fish species (the Evrotas chub *Squalius keadicus*, the Laconian minnow *Pelagius laconicus*, and the Spartian minnow roach *Tropidophoxinellus spartiaticus*) appeared regularly in the catches in the few perennial sections along the main stem between years, indicating that their spatial distribution and species richness were not affected by the drought events (Figure 5). However, the effects of hydrological disturbance on species density and percentage composition were more pronounced in the intermittent than in the perennial sites (Figure 5); a switch of species composition was observed after the drought of 2007, related to the contrasting habitat requirements of the Evrotas fish species, namely, between the larger bodied, rheophilic Evrotas chub and the two smaller bodied, limnophilic species, the Spartian minnow roach and the Evrotas minnow (Vardakas et al., 2017). Thus, whereas the stagnophilic, small-bodied and short-lived, r-strategist minnow benefited from the drought event as its average percentage in the intermittent sites increased during 2008, the rheophilic, larger-bodied and longer-living chub in contrast, was negatively affected as it gradually decreased (Figure 5). Additionally, perennial sites retained a natural age structure of the two larger bodied species in contrast to the intermittent sites, which presented a disturbed size structure (Figure 6), with large individuals missing and small fish and mostly YOY (young of the year) dominating the catch. Research conducted at the upper section of the river in the summer of 2015 and 2016 (Kalogianni et al., 2017), which were characterized by increasing water scarcity, showed an increase in fish abundance under acute water stress, coupled with a fish density increase, indicating crowding effects with progressive habitat shrinkage. Species presented contrasting responses, with the two small-sized, limnophilic species (the minnow roach and the minnow) increasing their abundances under acute water stress. This was coupled to their aggregation in the faster flowing riffle habitats (Kalogianni et al., 2017). In contrast, the large-bodied, rheophilic chub decreased in abundance in all habitats, with this decrease being significant for large individuals in riffles (Kalogianni et al., 2017).

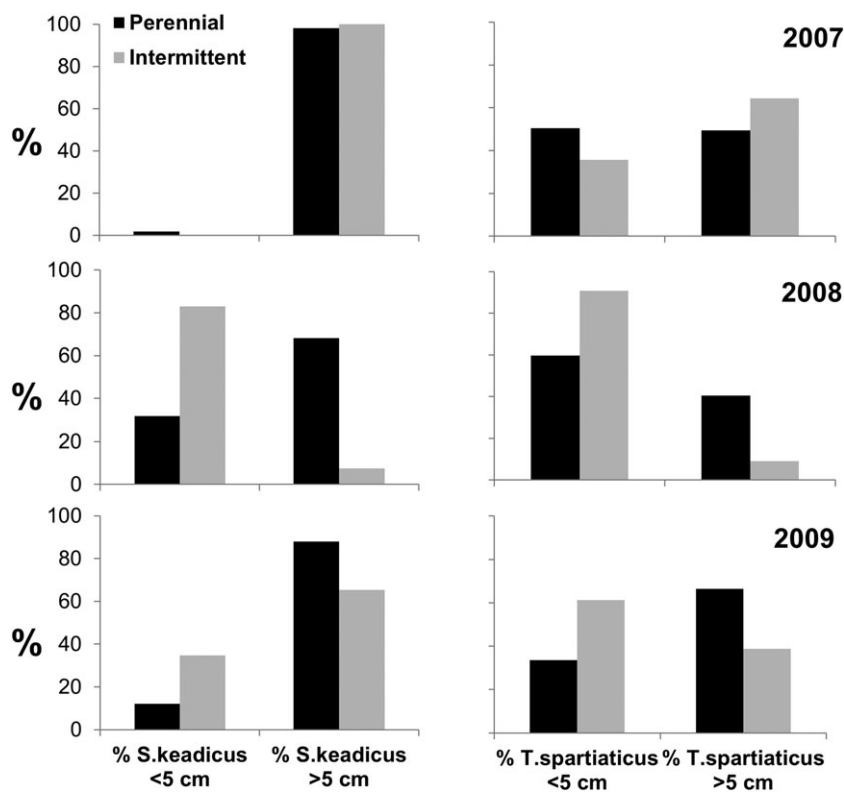
The recovery of the Evrotas fish after desiccation is a function mainly attributed on the longitudinal undisturbed connectivity between refugia and the drought-affected sections (Vardakas et al., 2015). The basic hypothesis is that, upon flow resumption, the recolonisation of the drought affected reaches takes place initially through passive drift from the perennial sections, thereby permitting a partial re-establishment of the depleted fish communities (Skoulikidis et al., 2011). Recovery in terms of density and richness is considered a relatively quick process; however, it takes about 1 year for richness and fish densities to reach values comparable to those in perennial segments of the river (Skoulikidis et al., 2011). Recovery in terms of community species composition is considered a relatively slower process, depending largely on habitat connectivity and on dispersal from nearby perennial sites rather than local environmental variables (Vardakas 2017), indicating that spatial dynamics predominantly shape fish metacommunity structure of Evrotas river. Similarly, population age structure may need 2–3 years to indicate signs of recovery. Evidently from the above, different community elements recover at different rates.



**FIGURE 4** Mean, minimum, and maximum number of benthic-invertebrate families for permanent (P) and intermittent (I) streams during spring, summer, and winter of 2006 and 2007



**FIGURE 5** Maps of the study area presenting the hydrological status of the main stem of Evrotas River, the distribution, composition, and relative areal density of the fish species during three successive summer surveys.



**FIGURE 6** Size comparisons of the Evrotas chub and the Spartan minnow roach between perennial and intermittent sites during the drought years (2007–2008) and the wet year (2009)

## 4 | COMBINED EFFECTS OF DROUGHT AND POLLUTION ON THE EVROTAS AQUATIC ECOSYSTEM

### 4.1 | Aquatic chemistry and biogeochemical processes

The vast majority of the Evrotas river network belongs to the most representative hydrochemical river type found in Greece (Ca > Mg > Na > K – HCO<sub>3</sub> > SO<sub>4</sub> > Cl; Skoulikidis, Amaxidis, Bertahas,

Laschou, & Gritzalis, 2006), mainly resulting from the dissolution of carbonate rocks. Due to its southern geographical location, and hence, the influence of dry climatic conditions on river hydrochemistry, the Evrotas River is characterized as very hard (median total hardness 307 mg/L CaCO<sub>3</sub>) and highly mineralized (median total dissolved ion concentration 491 mg/L). As expected, maximum solute concentration occurs during the dry period as a result of (a) low dilution capacity of the river water due to the lack of rainfalls, (b) increased evapotranspiration, and (c) contribution of alluvial aquifers, with higher solute concentrations than the river. Due to the substantial karstic spring inputs,

higher hydrogen carbonate concentrations along the Evrotas main stem were found upstream, at the midway, and near the estuary. Sodium and chloride, in contrast, together with electrical conductivity, revealed a downstream increase as a result of (a) soil salinization processes (due to irrigation of agricultural land and associated evapotranspiration), (b) impacts of olive mill wastewater (OMW) discharge that are rich in salts (Karaouzas, Skoulikidis, Giannakou, & Albanis, 2011a) and, regarding the river outflow, (c) salinization of coastal aquifers, and (d) transport of sea salt aerosol.

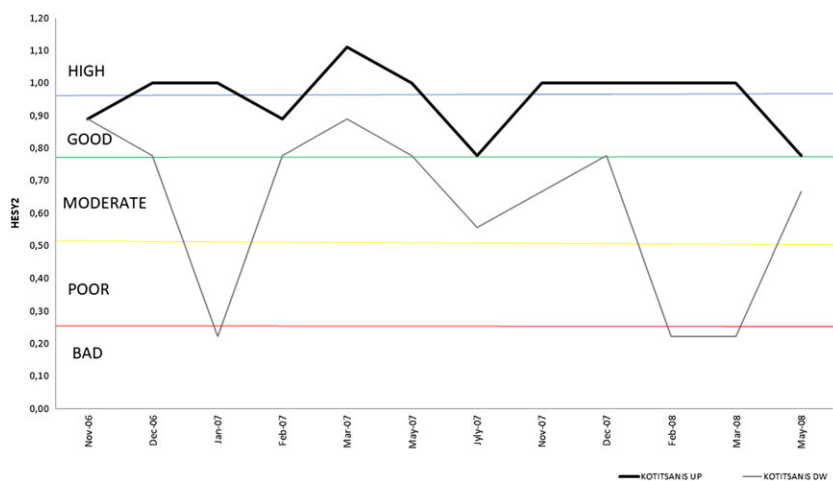
Although the Evrotas River has satisfactory oxygenation conditions (dissolved oxygen [DO] concentration 5–8 mg/L), the uncontrolled discharge of domestic and agro-industrial wastewaters may cause anoxic conditions (DO < 1 mg/L). In fact, automatic monitoring revealed recurrent zero drops of dissolved oxygen lasting for several consecutive days during the summer months of 2009 downstream of the WWTP (Waste Water Treatment Plant; Lampou, Skoulikidis, Papadoulakis, & Vardakas, 2015) when water discharge and flow were low. Anoxic conditions were accompanied by low pH levels suggesting increased respiration of organic matter.

A recent study conducted at an intermittent reach of the Evrotas (Skoulikidis, Sabater, et al., 2017a) indicated that as water level and flow diminished, an intensification of photosynthesis was apparent. This resulted in nitrate and silicate assimilation and carbonate precipitation as changes in aquatic chemistry and surface precipitates on riverbed pebbles and cobbles indicated. With increasing lenticification, respiration processes become more dominant and a decrease of nitrate accompanied with a rise in ammonium may be attributed to nitrate reduction (Baldwin & Mitchell, 2000). In isolated pools, a reduction of total nitrogen (TN) may result from denitrification and/or ANAMMOX (anaerobic ammonium oxidation; Hu, Shen, Xu, & Zheng, 2011) processes associated with benthic sediments colonized by microalgae (Nimick, Gammons, & Parker, 2011). However, the expression of opposing processes in the same water body as a result of differing microhabitat characteristics is not to be excluded (Skoulikidis, Sabater, et al., 2017a). During complete drying, processes slow down due to low microbial activity (Amalfitano et al., 2008; Corti, Datry, Drummond, & Larned, 2011; Foulquier, Artigas, Pesce, & Datry, 2015). Initial floods caused a rise in nitrate, nitrite, ammonium, TN, and silicate, compared to their annual averages (Skoulikidis, Sabater, et al., 2017a). The increase of nitrate and nitrite, during the flood events, resulted in a

decrease of nutrient quality (from moderate to poor for nitrate and from high to moderate for ammonium) and is attributed to the release of nutrients due to rewetting as a result of osmolysis of soil microbial biomass (McDonough, Hosen, & Palmer, 2011) and, shortly after, to mineralization and subsequent nitrification of labile organic matter accumulated during the dry season in riparian soils and river bed sediments (Mummey, Smith, & Bolton, 1994; Peterjohn & Schlessinger, 1991). Initial floods also caused substantial sediment mobilization and flushing of epsomite-type salts (Skoulikidis, Sabater, et al., 2017a).

#### 4.2 | Effects on stream macroinvertebrates and fish

Drought and pollution have significant impacts on water quality and consequently on macroinvertebrates (Arenas-Sánchez et al., 2016; Bonada et al., 2007; Sánchez-Montoya, Vidal-Abarca, & Suárez, 2010; Sabater et al., 2016). A study assessing the effects of OMWs on perennial and intermittent streams of the Evrotas basin (Karaouzas et al., 2011b; Karaouzas, Skoulikidis, et al., 2011a) revealed significant impacts on the aquatic fauna and the ecological status of the sites receiving wastewater discharges. The vast majority of macroinvertebrate taxa were eliminated, and only a few tolerant Diptera species (i.e., Chironomidae, Simuliidae, and Syrphidae) survived at very low abundances. Macroinvertebrate assemblages downstream the OMW outlets were dominated by Diptera species, whereas the pollution intolerant EPT were almost depleted during and after the OMW discharge period. The intermittent tributaries of the Evrotas receiving OMW did not recover successfully, as perennial ones did, after polluting episodes as their self-purification capacity had been significantly reduced (Karaouzas, Cotou, et al., 2011b; Karaouzas, Skoulikidis, et al., 2011a). Duration and volume of wastewater discharge, as well as, water flow duration and microhabitat composition were crucial determinants of intermittent benthic communities (Karaouzas, Skoulikidis, et al., 2011a). The ecological status of mountainous sites upstream of olive mills varied from good to high during all sampling months, whereas minimal variations among and within sites were mainly attributed to seasonality (Karaouzas, Skoulikidis, et al., 2011a). In contrast, sites downstream of olive mills varied between good and high, before the wastewater discharge period, to moderate and bad during the discharge period (Figure 7). Sites with relatively high slope, altitude, and oxygen presented moderate ecological status



**FIGURE 7** Variation of biological quality in the olive mill wastewaters receiving tributary (Kotitsanis stream) upstream and downstream of the olive mill outlet during 2 years of monitoring. The biological quality of the sites was estimated with the HESY2 Index (Lazaridou, Ntislidou, Karaouzas, & Skoulikidis, 2018) [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

due to their high self-purification capacity, whereas sites located in lowlands were classified from moderate to bad (Karaouzas, Skoulikidis, et al., 2011a). The ecological status of intermittent sites affected by pollution was more degraded than permanent ones (Figure 8).

Similar results were observed with orange juice processing wastewaters; ecological quality monitoring and assessment carried out in orange juice processing wastewater-receiving waterways with intermittent character revealed significant loss of the benthic fauna all year round (Karaouzas, 2011). Due to the sites' intermittent character, benthic fauna could not recover even when wastewater discharge ceased. Site rewetting coincided with the beginning of wastewater discharge; thus, only species very tolerant to anoxic conditions were found at all months.

As widely recognized, during low flows, water velocity declines due to water abstractions and thus, the dilution potential of pollutants, such as municipal wastewaters, is highly reduced (Gasith & Resh, 1999). Despite the fact that WWTPs are highly increasing in numbers and efficiency in the Mediterranean region (Kellis, Kalavrouziotis, & Gikas, 2013), many streams and rivers still receive nontreated or insufficiently treated sewage effluents (Figuerola, Maceda-Veiga, & de Sostoa, 2012; Hermoso & Clavero, 2011), due to malfunction of WWTPs as in the case of Evrotas River during the summer of 2015 (Skoulikidis et al., 2011). A recent study conducted in the summer of 2014 aimed to compare early summer microhabitat use by the three endemic Evrotas fish species in a reference and a pollution-impacted river reach, receiving the effluents of the Sparta WWTP (Vardakas et al., 2015). The results indicated shifts in habitat use in the impacted reach, where the rheophilic species, Evrotas chub, showed a tendency to abandon lentic habitats (pools and glides), concentrating mostly in runs and riffles. It was postulated that this shift may have been related to the limited food availability of slow-flowing habitats due to siltation and/or to high algae. As stated elsewhere, the complexity of inputs into municipal effluents, the diversity of treatment processes, and the receiving environments make generalizations about their potential effects difficult (Brown et al., 2011). Hence, the tentatively suggested shifts in habitat use by the Evrotas cyprinids require further

investigation. Research conducted in the summer of 2015 and 2016 (Kalogianni et al., 2017), which were characterized by different levels of water stress, at the lower section of the Evrotas river affected by higher pollution loads, provided some first insight on the combined effects of water stress and pollution; at high water stress, abundances of all three species decreased dramatically at the pollution impacted reach, possibly due to anoxic conditions, as a result of eutrophication. These effects were more acute on the smaller bodied limnophilic species, possibly due to movement limitations (Kalogianni et al., 2017).

## 5 | CONCLUSIONS

Despite the lack of water management actions in the basin, the aquatic communities of the Evrotas River have shown high resilience to human-induced pressures combined with climatic variations until today. During drought, reduced habitat availability and deterioration of water quality lead to an overall reduction of ecological integrity. However, the few river segments that retain flow during drought are critical for the survival of the Evrotas aquatic biota, providing colonists upon flow resumption. The lack of barriers disrupting the longitudinal connectivity of the Evrotas River is the vital factor for rapid population recovery of aquatic communities. The above scheme falls into the metacommunity dynamic theory, where future research studies on Evrotas basin should focus.

Successful conservation actions in Evrotas basin should incorporate long-term ecological studies regarding the ecological and chemical status of the river. Biodiversity protection should be of high priority within a sustainable agricultural approach without affecting agricultural production. Significant reductions in water abstractions can be achieved by alternative irrigation systems and minimization and control of agrochemical pollution must be implemented. In addition, protection and restoration of the riparian zone is essential for preventing bank erosion and floods and for filtering pollutants entering the water course. Finally, public authorities, with the appropriate scientific assistance, should define and provide ecological flows to ensure water flowing in the river throughout the year, as was the situation few decades ago.

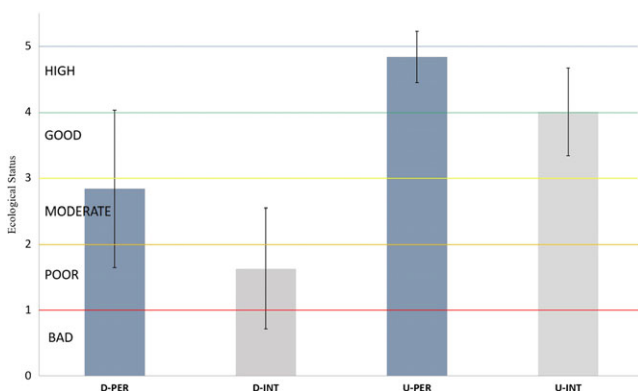
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**FIGURE 8** Mean ( $\pm$ SD) ecological status for permanent (PER) and intermittent (INT) streams upstream (U) and downstream (D) the olive mill discharge point for the 2-year sampling period. (Ecological status classification was estimated based on physicochemical and biological quality indices) [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

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