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Non-perennial Mediterranean rivers in Europe: Status, pressures, and challenges for research and management

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Abstract

Non-perennial rivers and streams (NPRS) cover more than 50% of the global river network. They are particularly predominant in Mediterranean Europe as a result of dry climate conditions, further amplified by climate change and land use development. Historically, both scientists and policy makers underestimated the importance of NRPS for nature and humans alike, mainly because they have been considered as systems of low ecological and economic value. During the past decades, diminishing water resources have increased the spatial and temporal extent of artificial NPRS as well as their exposure to multiple stressors, which threaten their ecological integrity, biodiversity and related ecosystem services. In this paper, we provide a comprehensive overview about the structural and functional characteristics of NPRS in the European Mediterranean, and we discuss emerging tools for management. Because NPRS comprise highly unstable ecosystems, with strong and often unpredictable temporal and spatial variability – at least as far as we are able to estimate – we outline the future research needs required to better understand, manage and conserve them as highly valuable and sensitive systems. Efficient collaborative activities among multidisciplinary research groups aiming to create innovative knowledge are urgently needed in order to establish an appropriate methodological and legislative background. Close cooperation among scientists, EU and national policy makers and water management authorities are required in order to formulate the urgently needed economic alternatives to existing irrigated farming practices at the EU-Med scale, to reduce overall water consumption, in combination with more effective land use policies, and the linking of the current Common Agricultural Policy to the Horizon 2020 strategy. The incorporation of NPRS in forthcoming EU-Med River Basin Management Plans is a first step towards enhancing NPRS research and management efforts in order to effectively safeguard these highly valuable albeit threatened ecosystems.

Key words: non-perennial (temporary, intermittent, ephemeral) rivers and streams, climate, pressures, hydrology, hydrobiology, biogeochemistry, management, WFD.

1. Introduction

Lotic freshwaters are either perennial or temporary (or non-perennial), according to surface flow conditions. Perennial rivers and streams (herein PRS) flow throughout the year, whereas temporary systems (herein non-perennial rivers and streams, NPRS) cease to flow at the surface for some time of the year. Depending on the specific flow regime, NPRS can be classified, according to the most common perceptions, as intermittent, ephemeral or episodic. Intermittent rivers cease to flow seasonally or occasionally (usually for weeks to months); Ephemeral streams flow only in response to precipitation or snowmelt events (days to weeks); Episodic streams carry surface water only during very short periods (hours to days), primarily after heavy rainfall events (McDonough et al., 2011; Arthington et al., 2014).

NPRS are amongst the most dynamic, complex and diverse freshwater systems. They are located in all regions worldwide, and they are by far the most dominant river type in arid and semi-arid areas (Larned et al., 2010; McDonough et al., 2011; Acuña et al., 2014; Datry et al., 2014a). NPRS account for up to 40% of medium-sized and large rivers and up to 69% of low-order streams below 60° latitude (Datry et al., 2014a). In Mediterranean regions, NPRS are the dominant freshwater type (Tockner et al., 2009; Bonada and Resh, 2013). They encompass remarkable hydrogeomorphological diversity, including spring-fed karstic rivers and streams, braided channel networks, single-thread upland streams and lowland rivers, as well as snow-melt and rain-fed headwater streams.

NPRS provide habitat for a diverse and unique flora and fauna (Meyer et al., 2007; Larned et al., 2010; Bonada and Resh, 2013; Acuña et al., 2014). They function as biogeochemical hotspots that retain, transform, and transfer carbon, nutrients and particulate matter (Larned et al., 2010; McDonough et al., 2011; Bernal et al., 2013; Datry et al., 2014a). In Mediterranean cultures, “dry rivers” are very well-known in society, reflected by various popular names: *ribeiras* in Portugal, *arroyos, cañadas* or *ramblas* in Spain, and *rambles, torrents, rieres and rierols* in the eastern part of the Iberian Peninsula and Balearic Islands (Vidal-Abarca, 1990), *cours d' eau intermittent* or *ravines* in France, *torrenti*, *rii* and *fiumare* in Italy, and *xiropotamos*, or *xeropotamos* or *xeros potamos* in Greece and Cyprus.

Water use and management practices in the Mediterranean region are historically adapted to natural water scarcity (Grantham et al., 2013). However, rising water demand for agricultural, industrial, urban and touristic development have exerted widespread pressures on water resources (Bradford, 2000), which fundamentally affect the natural flow regime (Smith, 1997; UNEP/MAP, 2003; Ludwig et al., 2009; Skoulikidis, 2009). The natural seasonal dryness regime is exacerbated by human activities, and natural PRS are converted into NPRS (Datry et al., 2014a). These rivers and streams are considered "artificially dry" or "artificially intermittent" (Benejam et al., 2010; Skoulikidis et al., 2011). On the other hand, natural NPRS may be transformed into PRS after receiving effluents from WWTPs or urban and industrial discharges (Hassan and Egozi, 2001). Artificial flow regime alterations enhance the risk of unanticipated ecological changes (Poff and Zimmerman, 2010; Sabater and Tockner, 2010).

Historically, European Mediterranean (EU-Med) NPRS have been undervalued by both water managers and ecologists (Larned et al., 2010; Nikolaidis et al., 2013), and they remain among the least studied freshwater ecosystems worldwide (Uys and O'Keeffe, 1997; Jacobson et al., 2004; Ryder and Boulton, 2005; TempQsim Consortium, 2006; Acuña et al., 2014; Datry et al., 2014a). This corresponds to the widespread societal view that, according to Sabater et al. (2009) "*People in arid and semi-arid regions have the least respect towards rivers, since the rivers are often dry or have catastrophic floods, and are therefore viewed more as a danger than as a natural resource to be preserved*". This is particularly evident in urban areas, where they have been frequently covered by roads, with some NPRS being today important avenues of EU-Med cities (e.g. the "Ramblas" in Barcelona, Spain, the Ilissos and Iridanos streams in Athens, Greece, etc). In addition, NPRS in the EU-Med countries have been used, and are still being used, as waste disposal sites, drains for sewage effluents, roads, car parking areas and quarries for sand and gravel. Moreover, legal and illegal constructions along NPRS courses, especially along episodic ones, are common. The subsequent destructive consequences of these practices are perceived by the public only after catastrophic floods.

Recently, however, NPRS research has emerged as a multidisciplinary domain that integrates biology, ecology, biogeochemistry, hydrology, geomorphology, and river management (Larned et al., 2010; Leigh et al., 2015a). Several special issues have been published on this topic in scientific journals (e.g. Nadeau and Rains, 2007; Datry et al., 2011; Bonada and Resh, 2013), thereby advancing the perception and understanding of NPRS.

The present article focuses on the climatic and anthropogenic pressures affecting NPRS in the EU-Med countries, reviews research achievements, identifies knowledge gaps and research needs, explores the present state in terms of local knowledge and management strategies, and proposes future avenues for research and management to safeguard these pivotal albeit undervalued and threatened ecosystems.

2. Pressures and impacts in non-perennial EU-Med streams

2.1. Climatic pressures

The Mediterranean area is characterized by high temporal climate variation, with low precipitation during summer. When applying the "Mediterranean climate" classification scheme, according to the global climate assessment approach developed by Köppen (1936), the EU-Med area fits into the dry sub-humid (0.50 < P/PET < 0.65) and semi-arid (0.20 < P/PET < 0.50) climate zones (UNEP, 1992; Fig. 1).

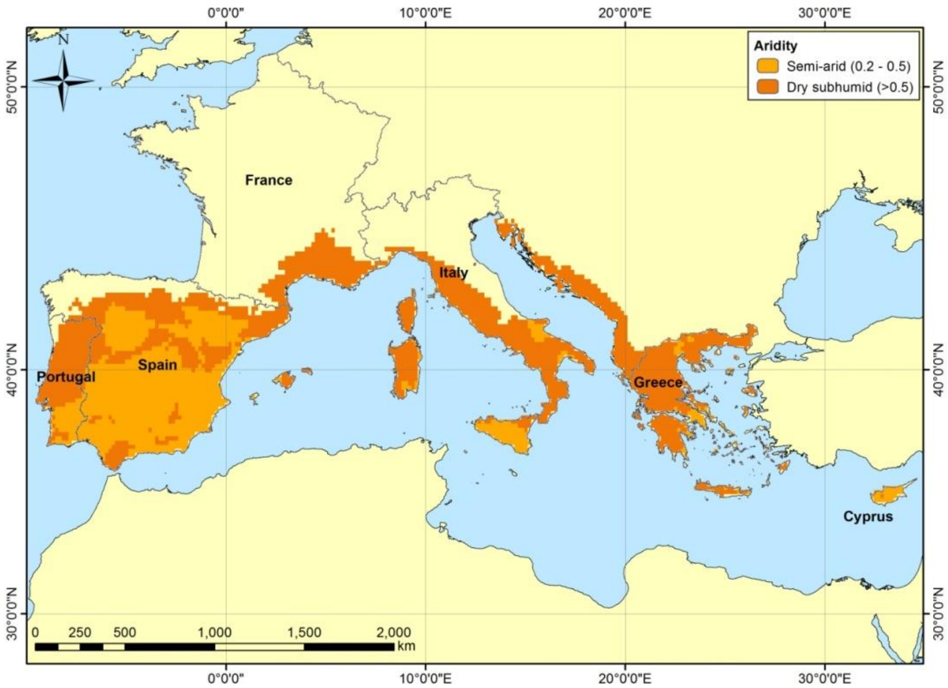

Figure 1. Map of Europe, delineating the Mediterranean Bio-geographical Region (EEA, 2016), including the distribution of aridity zones according to UNEP (1992).

Under these climatic conditions, many Mediterranean rivers naturally exhibit a non-perennial flow regime, with a distinct seasonal, inter-annual and spatial heterogeneity (Bonada and Resh, 2013). At the same time, the Mediterranean river basins are turning drier (annual precipitation decreased up to 20% during the 20th century), with more extreme events than a century ago (EC-JRC, 2005; EEA, 2008; García-Ruiz et al., 2011).

In Southern Portugal, river basins exhibit an average annual rainfall of less than 700 mm. Due to the lack of major aquifers, the average summer runoff is less than 10% of the average annual runoff (Afonso, 2007). There, NPRS are by far the most dominant watercourse type, with up to four dry months per year (INAG, 2001). Only large rivers, such as Guadiana, Sado and Mira, are perennial. The increasing frequency and intensity of droughts during the past 70 years has amplified the extent of artificial NPRS in the region (Afonso, 2007; Costa and Soares, 2009).

The south-eastern part of Spain belongs to the driest regions in Europe, with a mean precipitation of 120 mm/year, and summer temperatures reaching up to 47^{o}C (Estrela and Vargas, 2012). As a result, approximately 98% of the mapped water courses in the province of Murcia, which covers the driest part of the Iberian Peninsula, are NPRS (Gómez et al., 2005). Flow intermittency is further triggered by extended periods of low rainfall (Esteban-Parra et al., 1998) and high air temperature (De Castro et al., 2005).

In France, NPRS represent 20% to 39% of the river network. NPRS are common in regions with low annual rainfall, high air temperature and steep, small and elongated catchments, which are not restricted to the dry Mediterranean region (Snelder et al., 2013). In some areas a strong decrease of the groundwater table has caused surface drying of entire river sections (EEA, 2009).

In Italy, the mean annual precipitation drops to below 500 mm/year in areas such as Puglia, Sicily, and Sardinia (Gumiero et al., 2009). In Sardinia and Sicily, up to 90% of all rivers are NPRS (Mulas et al., 2009; Regione Siciliana, 2010; Fig. 2).

Greece exhibits a strong N–S gradient, with increasing temperature and evapotranspiration and decreasing precipitation towards the W-E and S–SE (Dalezios et al., 2002). There, the mean annual precipitation drops to 400 mm. Thus, in large parts of southern (Attika, Eastern Peloponnese and Crete) and eastern (Aegean Islands) Greece, semi-arid conditions prevail (Yassoglou et al., 1962). In total, only 45 out of the 765 Greek rivers and streams are permanently flowing (Ministry for Development, 2003), and NPRS catchments cover approximately 39% of the entire country (Fig. 2). This proportion may rise further because droughts are becoming longer and more intense (Livada and Assimakopoulos, 2005).

Cyprus is the most arid country in the European Union, with an average annual precipitation of 460 mm (Department of Meteorology of Cyprus, 2014). During the past century, average annual precipitation has decreased by 17%, and from 1976 to 2006, evapotranspiration has increased by 60-80 mm (Petrakis et al., 2012). Perennial river reaches in Cyprus are restricted to the upland areas of the central Troodos massif, while there is not a single river on the island with perennial flow along its entire course. Only 14% of the total river length is perennial. However, 48% of the total length exhibits an intermittent and 38% an ephemeral/episodic flow regime (ENVECO S.A. and I.A.CO Ltd, 2013).

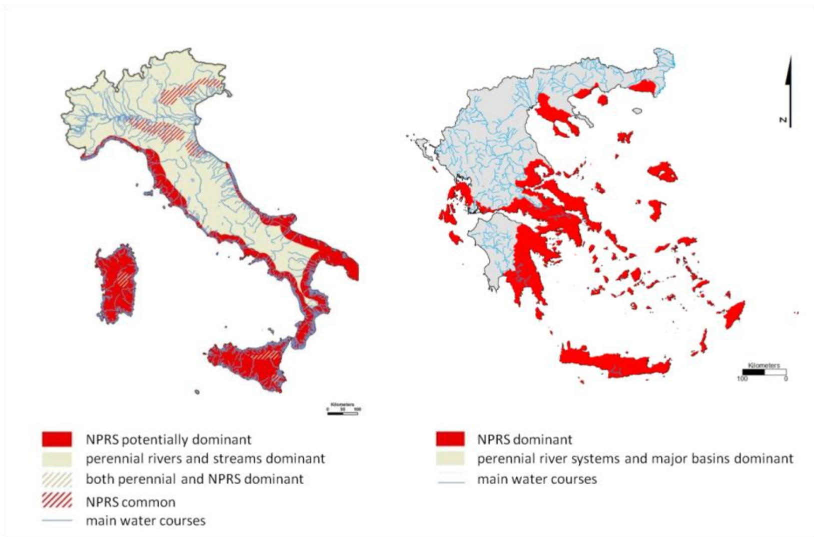

Figure 2. Maps of Italy (mainly based on Mulas et al., 2009; Regione Siciliana, 2010; Regione Autonoma Friuli Venezia Giulia, 2014; ARPA Emilia-Romagna, 2015) and Greece presenting the tentative distribution of NPRS basin areas.

2.2. Anthropogenic pressures

Long-lasting human activities and rapid urban and agricultural developments have led to a large-scale conversion of riparian areas into agricultural land, massive booms in reservoir and flood control constructions, and an extensive use of water for irrigation. Today, agricultural land covers vast areas of the EU-Med region, ranging from 30% in Greece to 48% in Italy, and most farmlands are now irrigated (Eurostat, 2000; 2003). Irrigated agriculture accounts for more than 60% of total water abstraction, with up to 89% in Greece (INAG, 2001). In most EU-Med countries, irrigation water is mainly obtained from rivers and streams, covering 64% (France) and 100% (Portugal) of the demand. In Cyprus, however, groundwater abstraction is the dominant water source for irrigation (81%; Zoumides et al., 2013). At the same time, coastal economic and touristic development contributes to an increasing water use, particularly in water scarce areas and during specific seasons.

To compensate for the decrease in water resources and to secure water supply during summer, numerous reservoirs have been constructed in the EU-Med during the past decades, favoured by the high topographic relief of the area (Conacher and Sala, 1998). However, this has led to the fragmentation of most rivers entering the Mediterranean Sea (Tockner et al., 2009). In Cyprus, for example, 67% of the overall mean annual surface runoff discharges into reservoirs (Rossel, 2002). Spain has the highest number of large dams of all EU-Med countries, Cyprus has the highest density (Table 1), whereas the highest dams are located in Italy and Greece. Some reservoirs that are currently at the planning stage are facing considerable resistance by the civil society. The Portuguese plan for hydropower development (PNBEPH) will entail the loss of several rivers in the northern part of the country. The Mesochora Dam, located in the Upper Acheloos River (Greece), comprises one of the largest and most controversial river diversion projects in the EU-Med. The Acheloos already contains six reservoirs, which cover a total surface area of up to 150 km^2. The total storage capacity is ~6.6 km^3, corresponding to ~1.5 times the total annual river discharge (Skoulikidis, 2009).

Table 1. Number and density of large dams in the EU-Med countries (source: International Commission on Large Dams, 2015).

Country	Number of large dams (>15m)	Number of dams/ 1000 km^{2}area	Number of dams/one million inhabitants
Portugal	217	2.35	20.4
Spain	1082	2.14	23.1
France	713	1.30	11.2
Italy	542	1.80	9.1
Greece	164	1.24	14.1
Cyprus	57	6.16	71.0
EU	7000	1.75	13.9

2.3. Climate and anthropogenic impacts

2.3.1. Hydrological impacts

A combination of extensive water abstraction, river fragmentation, and climate change has dramatically reduced river runoff in most EU-Med rivers during the past decades (UNEP/MAP, 2003). The majority of the rivers of the Balkan Peninsula, for example, experienced on average a 22% reduction in initial river discharge (data: Skoulikidis, 2009). At the same time, the long-term decrease of flow in NPRS is alarming (Fig. 3). This decrease favours the creation of disconnected pools and increases the number and extent of NPRS stretches (e.g. Benejam et al., 2010; Skoulikidis et al., 2011; Datry et al., 2014a).

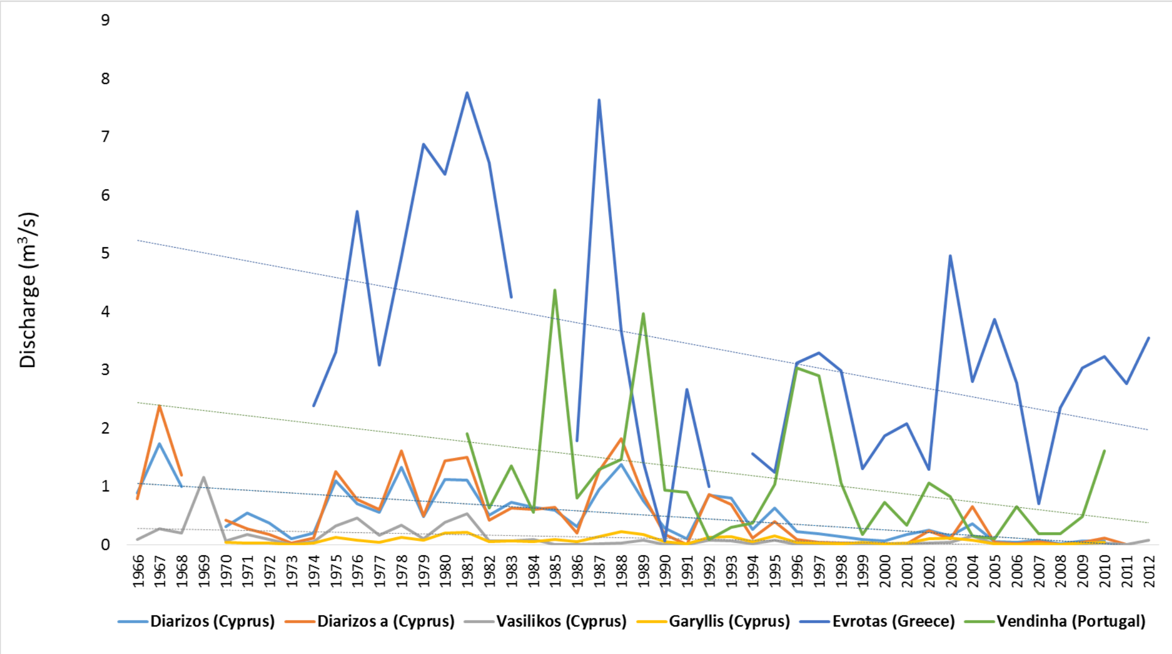

Figure 3. Long-term flow diminishing in NPRS from Southern Portugal (Vendihna R.), Southern Greece (Evrotas R.) and Cyprus (Diarizos R. and Vasilikos R.).

In Spain, the mean annual flow of the Ebro River has decreased by 40% during the past 50 years, mainly as a result of climate and land use changes, as well as of increased water abstraction, in particular for irrigation (Gallart et al., 2004). Similarly, surface flow of the Guadiana River has sharply decreased during the past 30 years, causing the drying of headwater sections. In some areas, the groundwater table has dropped by 30–40 m (Sabater et al., 2009).

In Greece, unsustainable water resources management, together with a progressive decline in precipitation, has altered the natural flow regime of most rivers (Skoulikidis, 2009). Many farmers face serious water shortage during very dry summers (Isendahl and Schmidt, 2006). As a consequence, they construct provisional weirs along river courses for water abstraction, which again favours further the artificial desiccation and the conversion of PRS into NPRS (e.g. Chadzichristidi et al., 1991; Economou et al., 1999; Bobori and Economidis, 2006). In the Pinios River basin (Central Greece), intensive agriculture has caused the lowering of the groundwater tables by tens of meters (Loukas et al., 2007), facilitating the widespread desiccation of entire river sections (Stefanidis et al., 2016). In the Evrotas basin (Southern Greece), discharge has declined by 84% during the past three decades, mainly due to water overexploitation for irrigation. During very dry years, such as 2007, up to 80% of the river network dries up completely, limiting available water for irrigation and threatening the endemic freshwater fish fauna (Skoulikidis et al., 2011).

Cyprus exhibits clear evidence of climate change, which in combination with unsustainable water management practices, has resulted in the recent transformation of PRS into NPRS. In addition, the slogan "Not a drop of water to the sea" has determined Cyprus water policy since the 1960s (Water Development Department, 2014). It impacted the flow regime of river sections downstream of dams and shifted them from intermittent to ephemeral and from ephemeral to episodic states. The impact of dams, the overexploitation of aquifers, the decrease in rainfall observed after 1970 and the reforestation of several mountainous areas have resulted in a 20-60% decrease in surface flow (Rossel, 2002). The flow of the Kouris river downstream of Kouris Dam, for example, decreased by 90% during the post-dam period, causing a deterioration of the delta as well as an erosion of the ecosystem services provided by the aquifer (Tzoraki et al., 2014).

On the other hand, reservoir operation for hydropower production, which is particularly required in the summer for cooling purposes, can reverse the seasonal flow regime of impounded and fragmented rivers. Today, large dammed rivers in Greece, such as the Acheloos, Nestos and Aliakmon Rivers, exhibit high to maximum discharge in summer (Skoulikidis, 2009). In the Acheloos River, for example, 30% of the annual runoff occurs during the summer months, compared to 11% prior to dam construction (Skoulikidis, 2002). Furthermore, WWTPs' effluents and releases from agricultural, industrial and mining operations, as well as inter-basin transfers lead to an increase in summer flow, transforming NPRS into perennial watercourses (Hassan and Egozi, 2001).

Figure 4 presents the most common anthropogenic causes of flow regime alteration in the EU-Med region.

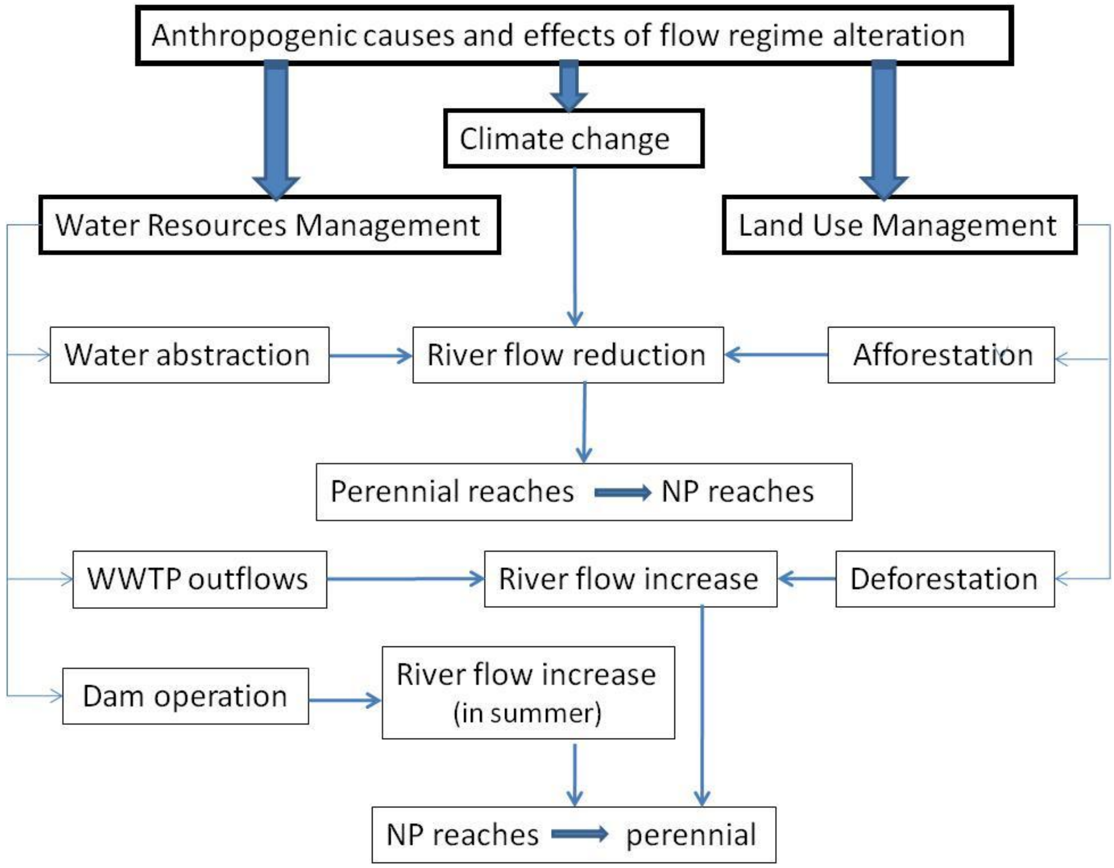

Figure 4. Schematic presentation of the causes of flow regime alterations in the EU-Med region. Anthropogenic causes include water and land use management. Climate change is considered separately. Dam operation for hydropower production is more intense during summer than during winter due to cooling purposes, leading to an increase of summer runoff. Afforestation, contrary to deforestation, causes a decrease of surface runoff (e.g. Buendia et al., 2015) as a result of higher evapotranspiration and infiltration rates. NP: non-perennial; WWTP: Waste Water Treatment Plant.

2.3.2. Ecological impacts

The Mediterranean region harbors a disproportionately high diversity of animals and plants. It is considered a global hotspot of biodiversity, endemism, and related ecosystem services (Cowling et al., 1996; Myers et al., 2000; Bonada et al., 2007a; Cuttelod et al., 2008; Tierno de Figueroa et al., 2013). At the same time, it contains the highest proportion of threatened freshwater species in Europe (Tockner et al., 2009) which are among the most endangered species worldwide (Myers et al., 2000; Cooper et al., 2013).

Artificial alterations of the hydrological regime affect the health, sustainability and biodiversity of fluvial ecosystems. While native species exhibit physiological, behavioral and life-history adaptations to natural drought events (Williams, 1996; Poff et al., 1997; Gasith and Resh, 1999; Magoulick and Kobza, 2003; Matthews and Matthews, 2003; Magalhães et al., 2007), the artificial increase in the frequency and severity of water stress may be considered a disturbance to which species are evolutionarily not adapted (Bunn and Arthington, 2002; Stanley et al., 2004; Magalhães et al., 2007; Datry et al., 2014b). Artificial intermittence may lead to a decline of freshwater species richness and abundances and to a loss of migratory pathways for many fish species (Larned et al., 2010). A major decline in native fish diversity has been already reported for rivers in the Iberian Peninsula, closely linked to unsustainable water management (Aparicio et al., 2000; Benejam et al., 2010; Clavero et al., 2010).

Water management infrastructures and practices alter key hydrological processes that maintain riverine habitat diversity, longitudinal, lateral and vertical connectivity gradients, and good water quality conditions (Prat and Ward, 1994; Bunn and Arthington, 2002; Pringle, 2003). The vast seasonal decline of river flow in NPRS makes them particularly sensitive to anthropogenic pressures, especially regarding water quality (Morais et al., 2009; Rosado and Morais, 2010; Rosado et al., 2012; Lopez-Doval et al., 2013). As a result, many NPRS suffer from eutrophication, hypoxia and high concentrations of industrial and agricultural contaminants (Cooper et al., 2013; Lopez-Doval et al., 2013).

Water stress and pollution may have cumulative impacts on aquatic biotic assemblages, because habitats shrink, water quality deteriorates, and predation and competition increase, as space and basic resources become even more limited (Magoulick and Kobza, 2003; Magalhães et al., 2002; Robson et al., 2011). Hence, species with low tolerance to multiple stressors are eliminated from artificial NPRS, and habitat fragmentation constrains recolonization pathways (Phillipsen and Lytle, 2013; Datry et al., 2016c). Chemical pollution derived from agricultural activity may have caused the observed decline of amphibian populations in NPRS (e.g. Sparling et al., 2001). At the same time, several aquatic and semi-aquatic birds are also affected by water pollution, primarily due to declining abundances of pollution-intolerant macroinvertebrate prey (Feck and Hall, 2004). Apart from pollution, NPRS are also subject to salinization. Increased salt concentrations, caused by reduced runoff and irrigation water evaporation (Cañedo-Argüelles et al., 2012;

2016), affect invertebrates, diatoms and fungal biomass as well as key ecosystem processes (Cañedo-Argüelles et al., 2014).

At the same time, knowledge about the ecological consequences of artificial perennialization remains very poor (Datry et al., 2014a). While habitat availability for lotic and lentic species increases with perennialization, habitat availability for terrestrial and semi-aquatic species declines. Although perennial flow may be sustained by effluent discharge, pollution can be detrimental for aquatic assemblages, as BOD_5, dissolved oxygen, and nutrient concentrations frequently exceed the threshold of “good” water quality due to limited dilution (De Girolamo et al., 2015a).

Figures 5 and 6 present indicative reference and hydro-morphologically impacted NPS throught the EU-Med countries.

Figure 5. Reference NPS presenting various hydrological conditions: wet and partly wet to disconnected pools and dry river bed; a) Xeros stream –Cyprus (Photo by Zogaris S.), b) Celone stream – Apulia Region, Southern Italy (Photo by De Girolamo), c) Kritharorema stream – Central Greece (Photo by Zogaris S.), d) Celone stream – Apulia Region, Southern Italy (Photo by De Girolamo A.M.) e) Malcamino stream- South-eastern Spain (Photo by Sánchez-Montoya M.M.).

Figure 6. Hydro-morphologically altered and pollution impacted NPRS .a) Vozvozis stream – North-eastern Greece (Photo by Gritzalis K.), b) Candelaro stream – Puglia, Italy, (Photo by Buffagni A.), c) Candelaro stream – Puglia, Italy, (Photo by Buffagni A.), d) Rio Foddeddu stream – Sardinia, Italy, (Photo by Buffagni A.), e) Pikrodafni stream – Athens, Greece (Photo by Mentzafou A.).

3. Research and Management - Historical review and state-of-the-art

3.1. History of research efforts in EU-Med NPRS

Until recently, NPRS have been considered as species-poor or even biologically-inactive ecosystems (e.g. Poff and Ward, 1989; Stanley et al., 1997; Larned et al., 2010). Therefore, we have scant information about their spatial extent (Meyer and Wallace, 2001; Benstead and Leigh, 2012; Datry et al., 2014a) and, as they have been excluded from bioassessment programs (e.g., Hall et al., 1998; Peck et al., 2006; Acuña et al., 2014), about their ecology (Williams, 2008; Larned et al., 2010; Datry et al., 2014a). Thus, as stated in Mazor et al. (2014), "*many surveys of ambient stream conditions are incomplete, biomonitoring programs do not provide comprehensive evaluations of stream health or complete assessments of watershed or regional conditions, and watershed-management and resource-protection programs based on these assessments might be compromised*".

At a European scale, research and management of NPRS are lagging behind, compared to other freshwater ecosystems. Even the EU's Water Framework Directive 2000/60/EC (WFD) does not specifically address NPRS (Nikolaidis et al., 2013), mainly as a result of the inadequate involvement of EU-Med countries in the development of the WFD, coupled with a general undervaluation of NPRS systems. Reasons include the low economic value attributed to NPRS, the complexity of the Mediterranean biogeography coupled with political and societal issues, the poor planning of effective environmental policies, the inadequacy of legislation and its ineffective enforcement, the lack of political commitment, and the inadequate knowledge of NPRS' hydrology, ecology and biogeochemistry (Vogiatzakis et al., 2006; Acuña et al. 2014).

Limited knowledge and ineffective conservation and management of NPRS in the EU-Med are also related to the limited availability of resources for research and development (R&D) in most EU-Med countries. The average R&D expenditure (as percentage of Gross Domestic Product, GDP) for EU-Med countries amounts to 1.05%, compared to an EU average value of 2.1% (World Bank data for 2012). This imbalance is even more pronounced if one considers the relatively low average GDP per capita for the EU-Med countries (20,130 US$) compared to the EU average (36,320 US$, World Bank data for 2014).

In the EU-Med countries, national institutions have mainly focused on monitoring PRS, thus approaches, methods and data to quantify, locate and classify NPRS are often missing. In France, for example, NPRS have been classified as "atypical" in the environmental flow legislation (Decret, 2007); thus, no minimum flow management plans are required for these systems. In Italy, the WFD has primarily been implemented for catchments larger than 10 km^2 (MATTM, 2008), thus ignoring a large number of NPRS. In Greece too, the 1st River Basin Management Plans (RBMPs) refer to rivers and streams with a Strahler stream order higher than 4 (EC, 2015), thus ignoring a vast number of headwater NPRS. Even in Spain, with a much longer tradition in studying NPRS than in other EU-Med countries, a national hydrological classification is still missing (Belmar et al., 2011). According to the Spanish water legislation ("Instrucción de Planificación Hidrológica", ORDEN ARM/2656/2008), 12 out of 32 WFD-ecotypes are termed as Mediterranean ecotypes. However, there is not a particular ecotype that specifically addresses NPRS. In Cyprus, with few PRS, NPRS stream flow data covering the whole gradient from perennial to episodic rivers does exist. However, the spatial distribution of the different flow regime types has been quantified only very recently (ENVECO S.A. and I.A.CO Ltd, 2013).

During the past 15 years several EU-Med research institutions have started to consider NPRS, stimulated by a number of European projects, supporting the implementation of the WFD. Projects included AQEM (http://www.aqem.de/), STREAMES (http://www.streames.org/), STAR (http://www.eu-star.at/), INHABIT (http://www.life-inhabit.it/), REFORM (http://www.reformrivers.eu/) and MARS (http://www.mars-project.eu/). Gradually, the EC funded a number of projects that focused exclusively on NPRS, such as tempQsim (http://www.tempqsim.net/), MIRAGE (http://www.mirage-project.eu/). and more recently GLOBAQUA (http://www.globaqua-project.eu/), LIFE+ TRivers (http://www.lifetrivers.eu/) and SMIRES (COST Action CA15113). The tempQsim project addressed the dynamics of NPRS and the integrated water management in semiarid Mediterranean river catchments. The MIRAGE project focused on the development of knowledge and tools required for a sound management of NPRS. Recently, the REFORM project addressed a number of important issues including hydromorphological aspects, directly or indirectly related to NPRS, in order to support adequate restoration and management activities. The current GLOBAQUA and MARS projects apply a multidisciplinary approach in order to study the interaction of multiple stressors, including water stress conditions. The specific aims are to better understand how current management practices and policies could be improved by identifying main drawbacks and developing alternative opportunities (Navarro-Ortega et al., 2014). The LIFE+ TRivers project aims to create new tools in order to improve the management of NPRS, according to the WFD. Finally, SMIRES, a consortium of natural, social and economic scientists, aims at compiling and synthesizing knowledge and management practices on NPRS across all biomes in Europe, in order to produce organised data bases on hydrology, biogeochemistry and biodiversity and to provide uniform and innovative management tools at the EU scale. To date 40 researchers and 25 managers from 23 European countries are participating in this program. Furthermore, an international team of ecologists is attempting to synthesise and analyse biodiversity patterns (including plants, fish, invertebrates) across NPRS in Europe and worldwide (IRBAS, http://www.irbas.fr/en; Datry et al., 2014a; Datry et al., 2015a,b; Leigh et al., 2015a,b). This research initiative aims to better understand and manage NPRS. Recently, another relevant international initiative, the 1000 NPRS project, started (http://1000_intermittent_rivers_project.irstea.fr/), involving more than 120 researchers from 32 countries (Datry et al., 2016d). The aim is to conduct synoptic sampling campaigns and experiments in hundreds of NPRS in all parts of the world, thereby advancing the understanding of fundamental biogeochemical and ecological processes in NPRS.

Simultaneous to the implementation of European research projects related to NPRS, and despite the slow progress in incorporating them into national legislation frameworks, regional and national research projects have started to better integrate NPRS into management practices and schemes; these projects are briefly presented below.

More specifically, in Portugal, the Foundation for Science and Technology (FCT) supported a number of projects on NPRS. The Portuguese Environmental Agency (APA) is implementing a Program of Surveillance and Warning of Droughts that closely follows the spatiotemporal variations in precipitation. In 2001, APA started implementing a national monitoring network that includes NPRS too (SNIRH, http://www.snirh.pt/).

In Spain, several NPRS research projects were initiated in the last 15 years, such as the GUADALMED project (1998-2005) that aimed to assess the ecological status assessment of Mediterranean rivers and streams in accordance with the WFD (Prat, 2002). More recently, the Consolider-Ingenio SCARCE project “Assessing and predicting effects on water quantity and quality in Iberian rivers caused by global change (2009-2014)” specifically addressed the relevance of water scarcity for water quality, water availability, the ecological status and the related services of NPRS (Navarro-Ortega et al., 2012).

In France, during the last 10 years five regional and national research programs have been conducted on NPRS. One project specifically addressed biological assemblages and physico-chemical conditions in the Rhône-Alpes Region (Datry et al. 2014b). A second project attempted to model the distribution of NPRS reaches across the national hydrological network (Datry et al., 2012; Snelder et al. 2013). Another program predicted the effects of climate change on flow intermittency and biodiversity in two rivers located in the Mediterranean region of France (https://r2d2-2050.cemagref.fr/). An on-going project examines the resilience of river assemblages to drying in relation to the spatial distribution of drying events across river networks (Vander Vorste et al., 2015a,b). Finally, a project that is now at its initial stage (2015-2019) explores how fragmentation by drying in headwaters alters beta diversity patterns and metacommunity dynamics of fish and invertebrates, using morphological and molecular approaches.

In Italy too, NPRS have been the focus of a number of national research projects, funded by the Italian Ministry of Research and the EU, such as MICARI, INHABIT and AQUASTRESS (FP6 IP 511231-2, 2004-2008 - http://www.aquastress.net/) (e.g. Amalfitano et al., 2008; De Girolamo et al., 2012; Giordano et al., 2013). Within the MICARI project (MIUR, D.M. 408 Ric. 20.03.2002 – Settore "RISORSE IDRICHE", 2003-2005), the concept of lentic-lotic character of rivers was developed (Buffagni et al., 2009; 2010). Later on, the INHABIT project (LIFE08 ENV/IT/000413, 2010-2014 - www.life-inhabit.it) dealt explicitly with NPRS of Sardinia, focusing on lentic-lotic riverine habitat components, so that they can be effectively considered when classifying rivers, as well as planning and checking the effect of RBMP Program of Measures (PoMs).

In Greece, the rapid implementation of the WFD, which has lagged behind in the past, has not yet allowed state authorities to particularly focus on NPRS research and management. However, the WFD national monitoring network already includes a number of NPRS.

In Cyprus finally, NPRS research has also lagged behind due to a lack of competent research institutions. Nonetheless, due to obligations stemming from the WFD, Cyprus has progressively introduced a water status assessment based on biological quality elements such as benthic invertebrates, benthic diatoms and aquatic macrophytes (e.g., Karavokyris et al., 2011). The outcome of these assessments, coupled with a re-examination of hydrological data and classification, may advance the development of adequate management strategies.

Globally, the number of scientific publications focusing on NPRS has increased exponentially in the past 20 years; with an average of 20-25 papers published annually in the last years, half of them in the fields of biology and ecology (Datry et al., 2011; Table 2). To estimate the recent research activities on EU-Med NPRS, a query was performed to compare scientific publications worldwide and at the Mediterranean basin level (Table 2).

Table 2. Scientific publications on NPRS globally, and the relative proportion of publications on Mediterranean NPRS (sources: Web of Science and ProQuest, period: 1900-2015, accessed: October 2015)

	WEB OF SCIENCE		**PROQUEST**	
Term	**# of publications worldwide**	**% publications Med**	**# of publications worldwide**	**% publications Med**
"temporary river*"	1319		1564	
"temporary stream*"	1128		834	
"Mediterranean temporary river*"	126	9.6	102	6.5
"Mediterranean temporary stream*"	125	11.1	88	10.6
"intermittent river*"	1114		1336	

"intermittent stream*"	1653		1206	
"Mediterranean intermittent river*"	129	11.6	115	8.6
"Mediterranean intermittent stream*"	149	9.0	121	10.0
"ephemeral river*"	1017		1082	
"ephemeral stream*"	1095		873	
"Mediterranean ephemeral river*"	66	6.5	67	6.2
"Mediterranean ephemeral stream*"	62	5.7	52	6.0

Publications on Mediterranean temporary or intermittent rivers and streams comprise about 10% of the total number of related papers worldwide (Table 2). For ephemeral rivers and streams, the relative proportion is lower (6%). These numbers are deemed high, considering the surface area and the population of the EU-Med region (i.e. 1.56% and 2.97% of the total human population and area, respectively; data: World Bank, 2015), but also considering the low research expenditure of EU-Med countries compared to the world average. The majority of publications (37%) refer to macroinvertebrates, followed by biogeochemistry (14%), pollution (9%) and diatoms (5%). Domains such as hydrology, ecology, fish, biology-other, microbiology and management are less represented (1.6-3.7% each).

3.2. Specific research achievements in EU-Med NPRS

Many European and national projects advanced our knowledge about EU-Med NPRS regarding their geographical extent, pressures and impacts, hydrological character and the relationship with biotic assemblages as well as with biogeochemical and ecological processes. This increasing knowledge is facilitating the development of adequate management strategies for NPRS.

3.2.1. Geographical distribution of NPRS

Efforts have been made to estimate the spatial distribution and extent of NPRS at the country (Snelder et al., 2013; Mulas et al., 2009; Regione Siciliana, 2010; Fig. 2), regional (Gómez et al., 2005) and river basin scales (Skoulikidis et al., 2011; Rosado et al., 2012).

3.2.2 Pressures and impacts

A fundamental research topic has been the assessment of the impacts of anthropogenic pressures on EU-Med NPRS. Pressures include agricultural land use, exotic species, grazing, rubbish disposal, release of effluents, and habitat destruction such as through the use of NPRS as roads (Gómez et al., 2005; Suárez and Vidal-Abarca, 2008;

Sánchez-Montoya et al., 2009). In Spain, for example, the response of various macroinvertebrate metrics to multiple stressor gradients typical for EU-Med streams, including NRPS ones, has been studied (Munné and Prat, 2009; Sánchez-Montoya et al., 2010). Cañedo et al. (2012, 2016) investigated the impacts of secondary salinization, which reduces aquatic biodiversity and compromises the goods and services that rivers and streams provide. Recently, Suárez et al. (2016) studied the functional responses of aquatic invertebrate assemblages along two natural stress gradients, water salinity and flow intermittency, in Mediterranean streams. They showed that functional richness and redundancy decreased with increasing salinity and flow intermittency, with salinity being the stronger environmental stressor. Wildfires, which frequently occur during periods of extended drought, pose another major risk for NPRS. Initial floods following wildfires enhance runoff and erosion rates in burned terrains, causing elevated sediment and phosphorus concentrations in receiving downstream water bodies (Blake et al., 2010). Finally, studies that focused on the relative vulnerability of PRS and NPRS to anthropogenic stress have shown that habitat changes (García-Roger et al., 2011) and agro-industrial pressures (Karaouzas et al., 2011; Karaouzas and Skoulikidis, 2011) exert severe effects on aquatic macroinvertebrates in NPRS, more severe than in comparable PRS.

3.2.3 Hydrological processes

Gallart et al. (2008) investigated the hydrological regimes in a set of EU-Med NPRS basins and showed that these were depended on karstic groundwater, human disturbance and winter temperatures. Recently, a European stream classification method, based on flow regime, has been proposed by Bussettini et al. (2015), whereas Oueslati et al. (2015) classified hydrological regime types using stream flow data from EU-NPRS. At a local scale (e.g., Pardiela River basin, Portugal), the duration of drought during a hydrological year has been quantified (Rosado et al., 2012). Also, a hydrological classification of natural flow regimes in the Segura River basin showed that NPRS are mainly restricted to the southern, lowland basin (Belmar et al., 2011). Hydrological modeling has been applied to estimate the temporal extent of desiccation. For example, Kirkby et al. (2011) addressed the relative frequency of ecologically critical low flow stages in semi-arid rivers across Europe. Moreover, using modeling approaches, it has been shown that entire river reaches may dry out as a result of water abstraction for agriculture (Skoulikidis et al., 2011; De Girolamo et al., 2015a). Thus, De Girolamo et al. (2015b) developed a new approach for evaluating the hydrological status of NPRS, in which the divergence between the current (impacted) and the natural flow conditions are assessed by using two hydrological indicators; the long-term annual mean number of months with flow (MF) (Arscott et al., 2010), and the six-month seasonal predictability of dry periods (SD6) (Gallart et al., 2012). A method suitable to quantify hydrological alterations in the absence of stream flow data has also been tested (De Girolamo et al., 2015b). Similarly, in order to estimate the flow regime of NPRS in the absence of flow data, Gallart et al. (2016) have proposed alternative approaches based on historical aerial photographs and on interviews.

3.2.4 Biotic responses to flow intermittency

Recent research has led to a better inventory and understanding of biotic assemblages in NPRS, including aquatic (Graça et al., 2004; Datry, 2012; Bonada and Resh, 2013; García-Roger et al., 2013) and terrestrial invertebrates (Corti and Datry, 2012; 2015; Sánchez-Montoya et al., 2016), diatoms (Novais et al., 2014; Barthès et al., 2014), microbial and algal assemblages (Amalfitano et al., 2008; Romani et al., 2013) as well as vertebrate assemblages, such as fish (Pires et al., 1999; Zogaris et al., 2012; Vardakas et al., 2015) and semi-aquatic carnivores (Clavero et al., 2003; Ruiz-Olmo et al., 2002; 2007). Other recent studies focused on the mechanisms allowing species to cope with recurrent drying as well as to produce quantitative relationships between drying duration and frequency (Datry et al., 2014b). In most cases, taxa richness of aquatic macroinvertebrates is lower in NPRS than in PRS (Muñoz, 2003; Morais et al., 2004; Sánchez-Montoya et al., 2009; 2010; Belmar et al., 2012; Datry, 2012; Datry et al., 2014b), but see Bonada et al. (2007b; 2008) and Skoulikidis et al. (2011). The seasonal community composition differed between PRS and NPRS (Bonada et al., 2008). In NPRS, invertebrates exhibiting low dissolved oxygen requirements and pool-like strategies dominate during the contracting phase (Pires et al., 2000; Acuña et al., 2005; Bonada et al., 2007b; García-Roger et al., 2013), whereas resilient taxa and species with riffle-like strategies dominate during the expansion phase (Bonada et al., 2007b; Datry et al., 2014b). Overall, collectors are more abundant in NPRS than in PRS and, in particular for NPRS, the number of predators increases in remaining pools during the contracting phase (Sabater et al., 2006; Bonada et al., 2007b).

Flow intermittency not only affects aquatic invertebrate assemblages but may also control terrestrial invertebrate assemblages in the channel and in adjacent terrestrial habitats of NRPS. Recently, Sánchez-Montoya et al. (2016), who studied two Mediterranean NRPS streams, reported that not only river drying, but also the length of the dry period, changes the composition of terrestrial arthropod assemblages, although taxonomic richness and total abundance were similar between perennial and intermittent reaches.

In respect to the biological assessment of NPRS, specific macroinvertebrate indices, such as the Iberian Mediterranean Multimetric Index (Sánchez-Montoya et al., 2010) and the multimetric IM9 for Portuguese rivers (Pinto et al., 2004), have been developed to support the implementation of the WFD. Furthermore, methodologies to guide managers on the timing of macroinvertebrate sampling for the purpose of assessing the ecological status have been also developed (Prat et al., 2014); also the applicability of various methods during the different hydrological phases of NPRS has been assessed (Cid et al., 2016). In this sense, the LIFE+ TRivers project could provide very useful information for managing NPRS in EU-Med countries.

The hydrological disturbance of NPRS affects species richness, density, biomass, composition, and size (age) structure of fish assemblages (Benejam et al., 2010; Skoulikidis et al., 2011). Several studies have indicated significantly lower fish densities in NPRS (Mas-Martí et al., 2010), while others reported higher densities due to crowding effects (Pires et al., 1999; Skoulikidis et al., 2011). Species composition and size structure shifts are also evident in many NPRS (Mas-Martí et al., 2010; Skoulikidis et al., 2011), where the species remaining in non-perennial sites are usually small-sized tolerant species. However, harsh conditions imposed by the dry period favour many exotic species, due to their preference for limnophilic conditions (Vila-Gispert et al., 2002). Species such as mosquitofish, pumpkinseed sunfish and common carp are well-known examples of exotic species common in many EU-Med countries, mainly as a consequence of the large number of EU-Med reservoirs.

Regarding benthic diatom assemblages, Tornés and Ruhí (2013) found that species in NPRS were less nested and more generalist than those in PRS. Barthès et al. (2014) observed a significant and long-lasting impact of even short-term drought events on diatom assemblage structure. On the contrary, Novais et al. (2014) revealed differences in diatom assemblages between PRS and NPRS; and richness increased with flow intermittency.

There are only a few studies on vertebrates in EU-Med NPRS. These have shown that desiccation influences the availability of prey such as fish, which again may strongly affect the European otter (*Lutra lutra*) (Clavero et al., 2003; Ruiz-Olmo and Jimenez, 2009). Consequently, the mortality rate of otters increases, their abundance diminishes, and breeding success declines (e.g., Ruiz-Olmo et al., 2001). Furthermore, due to summer droughts, the breeding time of otters occurs earlier in Mediterranean than in temperate streams (Ruiz-Olmo et al., 2002).

The species composition of the riparian vegetation is also determined by flow intermittency. Bruno et al. (2014), for example, detected that drought duration is one of the most important environmental determinants of the composition and variation of the herbaceous and woody riparian vegetation in the Segura river basin (Southeastern Spain). Drought duration leads to a reduction in functional redundancy and thereby decreases ecosystem resistance and resilience to future disturbances (Bruno et al., 2016).

3.2.5 Hydromorphology vs ecological quality

The relationship between hydrology and ecological quality in NPRS has been frequently explored in various studies that showed that the ecological status depends on the alteration of flow-related natural components (e.g. Coimbra et al. 1996, Buffagni et al., 2009, 2010). Water abstraction, for example, favours lentic habitat conditions, thereby affecting the structure and traits of aquatic assemblages (Buffagni et al., 2010, García-Roger et al., 2013). Gallart et al. (2012) defined six aquatic states for NPRS and developed a new approach to analyse the regime types of NPRS in relation to their controls on the composition and structure of aquatic biota. Prat et al. (2014) developed an integrated assessment strategy for NPRS (i.e. the MIRAGE tool-box). Based on the aforementioned aquatic states, the MIRAGE tool-box entails a series of methodologies for determining and analysing NPRS' aquatic regimes, and for relating the ecological and chemical status to their specific hydrological status. Similarly, Cid et al. (2016) developed a biological tool (BioASTool) to assess flow connectivity in NPRS reference systems based on benthic invertebrates. This tool can also be applied when hydrological data are missing, using the taxonomic and biological trait composition of the macroinvertebrate community as predictors. Likewise, Buffagni et al. (2010) stressed that the lentic-lotic character of rivers (e.g. quantified by proxies such as the Lentic-lotic River Descriptor (LRD) score system, see Buffagni et al., 2009) has to be taken into account when assessing their ecological status. Furthermore, the potential adverse effects of water management, or of climatic variation, have to be considered in the formulation of sound PoMs too. In NPRS of Sardinia, it has been demonstrated that the impact of the morphological alteration of river channels and banks is well detected by the benthic metrics (Buffagni et al., 2016) that are commonly used for monitoring PRS and NPRS. In the absence of water pollution and/or water abstraction, the large majority of stream reaches that showed evident morphological alteration were correctly classified as medium to low ecological status (Buffagni et al., 2016). Therefore, even if the influence of the highly variable hydrological regime of NPRS on benthic assemblages is undeniable, effects subtler than those of pollution, such as of morphological modification, can be detected and quantified.

3.2.6 Biogeochemical processes

NPRS are recognised as biogeochemical reactors (Larned et al., 2010), and alternating wetting and drying cycles create biogeochemical hot spots and hot moments (McClain et al., 2003). Mineralisation, demineralisation, nitrification, denitrification, and nitrate reduction are among the processes that prevail during desiccation and rewetting (Peterjohn and Schlessinger, 1991, Mummey et al., 1994, McDonough et al., 2011).

Dry watercourses may cause substantial CO_2 emissions, higher than running or stagnant waters, which demonstrates the importance of NPRS for the global carbon cycle (Von Schiller et al., 2014; Gómez-Gener et al., 2016). In NPRS, coarse particulate organic matter (CPOM) accumulates in standing pools and at the surface of dry habitats, and as the river dries, the primary agents of CPOM decomposition shift from leaching and processing by aquatic micro-organisms and invertebrates to photo-degradation by UV and processing by terrestrial micro-organisms and invertebrates (Corti et al., 2011, Dieter et al., 2011). The decomposition rate decreases according to drying duration and the progressive disappearance and inactivity of aquatic fungi and shredders (e.g. Corti et al., 2011, Datry et al., 2011, Foulquier et al., 2015). In dry habitats, the decomposition rate is reduced to almost zero due to the low abundance of terrestrial shredders, low microbial activity and absence of mechanical breakdown (Corti et al. 2011). Experimental desiccation in microcosms with sediments from different EU-Med NPRS revealed a prompt decline of the initial bacterial carbon production during desiccation, while complete desiccation led to a delay in mineralization processes and synthesis of new biomass (Amalfitano et al. 2008). These studies led to a better understanding of how the tempos, rates and timing of organic matter processing differ between PRS and NPRS (Datry et al. 2014a). Other studies focused on stream metabolism by continuous oxygen measurements (Acuña et al., 2004, Izagirre et al., 2008). Regarding the nutrient processes, Von Schiller et al. (2011) stressed that hypoxic conditions in disconnected pools can cause rapid ammonium and phosphate release from sediments. Microcosm experiments showed that drying increased the sediment nitrate content (Arce et al. 2014) and that in the initial stages of desiccation, N-mineralization and nitrification were stimulated (Tzoraki et al. 2007, Gómez et al. 2012).

The decomposition of organic matter (Corti and Datry 2012, Rosado et al. 2014) and its effects on nutrient variability during rewetting have been also researched. Skoulikidis and Amaxidis (2009) and Ramos et al. (2015) showed that annual nutrient concentrations and cycles, as well as sediment transport during initial autumn floods were very dynamic and extremely variable in space and time. This indicates the importance of initial floods on water quality issues, particularly for nutrients. Upon rewetting, rapid mineralization of organic matter and subsequent nitrification controlled N species in river water (Skoulikidis and Amaxidis 2009). Arce et al. (2015) conducted microcosm experiments which provided evidence that during rewetting of dry sediments, nitrate, favoured by anoxic conditions, can be rapidly denitrified, suggesting an improvement of water quality in polluted streams. To simulate the time response of NPR reaches on geochemical and hydrologic mass balances, Tzoraki and Nikolaidis (2007) developed a biogeochemical model. Finally, the crucial role of biofilm in recovering ecosystem functions upon flow resumption has been also revealed (Timoner, 2014, Timoner et al., 2014a,b,c).

3.3. Management in EU-Med NPRS

In the framework of the implementation of the WFD and through the application of the intercalibration exercise (Commission Decision, 2013), the EC recognized the need to include NPRS (RM-5 type) in the common Mediterranean intercalibration types. However, according to the WFD, a NPRS may not be considered a water body, and therefore may not be protected, depending on the typology applied and the water body classification method adopted in a particular region (Munné and Prat, 2004). The different criteria used in each river basin have fostered a patchy implementation of the WFD, which has resulted in the recognition of NP waterways in only a few river basin districts in the EU (Acuña et al., 2014).

Nevertheless, the EU-Med countries, acknowledging the adverse effects of inadequate water management on lotic ecosystems, started incorporating ecological flow requirements into their national legislation. In Portugal, the Ordinance 1450/2007 made mandatory a study defining an ecological flow regime downstream of dams, and Law Nº 7/2008, although not yet implemented, states that the owner must sustain a flow regime adapted to fish life cycles, with the aim of maintaining ecosystem integrity (EU, 2015). In addition, the management and conservation of a NPR basin (Pardiela) has been addressed

(Rosado et al., 2012). The Spanish Water Law (RDL 1/2001, L11/2005) imposes environmental flows, as well as the laws for the conservation of fish assemblages and riparian vegetation. Ecological flow requirements were defined for over 400 water bodies, based on hydrological and hydrobiological methods for target species (EEA, 2012). In France, regulation of water abstraction is implemented in the RBMs in basins with quantitative water deficits, to ensure the good functioning of aquatic ecosystems (EU, 2015). Environmental flows are prescribed in the Italian national legislation too. As a general rule, at least 10% of the natural flow (yearly average with possible adjustments for specific months and conditions) should be assured, but often this can be reduced to 5%, or in justified cases to complete surface desiccation. It is the responsibility of the individual River Basin Authority to set up specific rules for rivers under their jurisdiction, and in some cases this leads to more protective flow rates. Similarly, in Greece, a provisional law (Greek Official Gazette 2464/03.12.2008) defines minimum ecological flow requirements based on hydrological criteria and a preliminary RBMP has been developed (Evrotas River basin, Greece; see Nikolaidis et al. 2009, Vardakas et al. 2009, Demetropoulou et al. 2010). In Cyprus, the Integrated Water Management Law (N.79(I)/2010) provides guidelines to impose ecological flows. The Cyprus River Basin Management Plan (RBMP) includes minimum flow thresholds for all major dams (Karavokyris et al., 2011).

In the course of the WFD implementation, technical reports (ETC/ICM Technical Report 2/2012, EEA 2012) indicated that habitat and hydromorphological alterations are affecting almost 40% of river water bodies in Europe, preventing them from reaching good ecological status. In an effort to balance water allocation between human water needs and aquatic ecosystems, the European Commission provided an ecological flows (e-flows) CIS Guidance (EU, 2015) to facilitate the achievement of the WFD environmental objectives, ecosystem functionality and a sustainable use of the European water resources. In this document, e-flows are considered within the context of the WFD as “a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)”. Thus, in cases where hydrological alterations are likely to prevent the achievement of the WFD environmental objectives, an assessment of the gap between the current flow regime and the e-flows should be conducted. This is particularly important for artificial NP water bodies where, if good status is not achieved, the restoration of an appropriate, near-natural flow regime should be ensured by the PoMs within the RBMPs. It is thus expected that national legislations on ecological-flows will be modified accordingly.

In addition, in a recent decision of the European Court of Justice (ECJ) (01.07.2015) it is stated that Member States (MS), should take into consideration the environmental objectives of the WFD. This decision may protect more efficiently NPRS, especially regarding the maintenance of near natural flow regimes. In this sense, the LIFE+ TRivers Project (2014-2018) focuses on the hydrology and ecology of Spanish NPRS, aiming at creating new tools to improve their management, according to the objectives of the WFD.

4. Future perspectives

4.1 Basic research priorities

4.1.1 Hydrological research needs (Estimation and restoration of natural flow regimes)

The general lack of long-term hydrological data impedes reconstructing the "natural" flow regime of NPRS, as well as defining environmental flow regime requirements (e.g. e-flow CIS Guidance 2015), and developing adequate flow restoration measures to maintain/restore a good ecological status. Hydrological models have limitations due to the highly unpredictable flow regime and the karstic character of many NPRS in the EU-Med, the complex interactions with and among anthropogenic pressures, and the lack of information on the physiographic and environmental conditions of many catchments (Singh and Woolhiser 2002, De Girolamo et al., 2015b). Indeed, a common methodology to define the "natural" flow regime, in the absence of historical hydrological data, is still missing. This is further complicated by major knowledge and information gaps, notably on water abstraction for agriculture (WWF 2003, Wriedt et al., 2009). In countries such as Greece and Spain, the reported data on water abstraction most probably underestimate the water uses for agriculture, mainly due to a high percentage of illegal and unrecorded abstractions. In Spain, for example, it is estimated that agriculture abstracts about 45% more water than officially reported (Wriedt et al., 2009), whereas in Greece, the scale of Illegal water abstraction is believed to be enormous and impossible to estimate under the current organisational status. Therefore, the EU-Med state authorities must put much more effort into monitoring flow conditions and groundwater levels, and into calculating the relative proportion of water resources that are abstracted for irrigation and other uses. In the case of NPRS, modelling approaches cannot substitute for real data gathering.

4.1.2 Biological research challenges

- *Diversity, metapopulation and metacommunity dynamics*

Up to now, most NPRS research has focused on the differences in taxonomic and functional diversity between PRS and NPRS in the EU-Med countries. Less information is, however, available on the genetic diversity and structure of populations and assemblages in NPRS (but see Múrria, et al. 2010). Moreover, most population and community-ecology studies in NPRS have focused on lotic habitats. Understanding the underlying mechanisms of drying effects on metapopulation and metacommunity dynamics remains also a major challenge (see Múrria, et al., 2010, Datry et al., 2016a), though it is critical for conservation and restoration planning. Furthermore, thorough analyses of the ecological consequences of artificial river drying on biodiversity require a distinct aquatic–terrestrial perspective, both in space and time (Datry et al., 2014a). Moreover, it remains unclear if assemblages from natural and artificial NPRs are similar during flowing and non-flowing phases. Finally, we know very little about the importance of the dry phase for terrestrial organisms, despite commendable ongoing research efforts.

- *Seasonal dynamics of biotic assemblages*

Limited information exists on the seasonal dynamics (including flood events) of invertebrate and fish assemblages in Mediterranean NPRS (Hershkovitz and Gasith, 2013), due to the lack of adequate data. Hence, research on the natural variation of these assemblages during the different water phases of the NPRS, as well as on habitat availability at various time scales, is urgently needed (Robson et al., 2005). This will allow re-defining representative reference conditions and metrics for the ecological classification of NPRS.

- *Environmental requirements of biota*

Natural drying and rewetting cycles may enhance the resilience and adaptation of populations to future environmental changes (Datry et al., 2014a). However, a further increase in artificial desiccation, in combination with a deterioration in water quality and habitat conditions, makes imperative the research on species-specific environmental linkages, feedbacks and thresholds, such as flow requirements, temperature and salinity preferences, as well as on dispersal limitations of aquatic and terrestrial biota (Hershkovitz and Gasith 2013, Datry et al. 2014b).

- *Dry phase (dry river beds) and bioassessments*

Despite recent progress in understanding the role of dry channels as important habitats for terrestrial arthropods (e.g. Wishart, 2000, Larned et al., 2007, Steward et al., 2011, Steward et al., 2012, Corti and Datry 2015, Corti et al. 2013, 2014), the terrestrial phase is not yet integrated into bioassessment strategies. In addition, the role of a dry river bed as a movement and dispersal corridor for terrestrial vertebrates has only recently been explored (Sánchez-Montoya et al., 2015). At the same time, the role of microbial assemblages during the dry phase has been studied more recently (Timoner, 2014, Timoner et al. 2014 a,b,c), and has shown their relevant resistance to drying and resilience to flow return of these assemblages. A major environmental tipping point is when PRS turn into NPRS; therefore, we need to identify the areas that are most sensitive to shifting from one environmental state to an alternate state (i.e. early warning assessment). We also need to consider the entire hydrological cycle in order to allow a more comprehensive assessment of the ecological status of Mediterranean NPRS (Prat et al., 2014).

4.1.3 Biogeochemical research needs

Understanding the role of intermittent rivers in catchment-, regional-, and global-scale biogeochemical cycles requires identifying the singularities of biogeochemical processes in NPRS. Organic matter and nutrient storage and transfer rates may be higher in NPRS compared to PRS due to their pulsed nature (Datry et al., 2014a), while *in situ* transformation rates may be more important in PRS. Therefore, we need to consider the spatial and temporal linkages of perennial and temporary sections and periods within whole river networks. Even small changes in the hydrological regime may turn a system from a source to a sink, and vice versa, for nutrients and organic carbon. However, relevant empirical evidence is still lacking.

The drought-induced hydrological disconnection in NPRS entails a distinct spatiotemporal heterogeneity along watercourses, which translates into very different sources of dissolved organic matter, potentially to be respired by the biota (Casas-Ruiz et al. 2016). Microbes in dry stream beds exhibit a higher respiration capacity than those in flowing channels, and reach similar microbial activity rates than in upland soils (Gómez-Gener et al. 2016). The biogeochemical understanding of dry channels is still at its infancy, and much more effort is needed to quantify their relevance at the catchment and network scale. Furthermore, the ecological and societal consequences of major organic and nutrient pulses from NPRS during first flood events remain mostly unexplored (Bernal et al., 2013). Also the impact of first pulses on the transport and retention of priority substances and specific pollutants remains unknown (Dahm et al. 2016).

Future research should take advantage of the achievements in hydrology, aquatic biogeochemistry and advanced sensor and information technologies, to focus on in-situ monitoring and on targeted field and mesocosm experiments. This should include surface/ groundwater interactions, as well as C, N and P metabolism and interactions at the water/sediment interface. Moreover, the cause/effect relationships between pressures and biogeochemical processes on the one hand, and biotic impacts on the other, are still unexplored. Thus, targeted experiments are required that can contribute to unravel short-term variability and "tipping points" of biogeochemical and ecological processes during the desiccation phase and during flush flood events, as well as to explore their effects on water quality and biota. Understanding these processes may help quantifying particular pressures causing ecosystem degradation, and thus contributing to the application of appropriate measures to maintain/restore the remaining near-natural NPRS.

4.2. Applied research priorities

- *Monitoring*

Pronounced hydrological variations of NPRS cause pulsed biogeochemical and ecological processes that translate into short-term alterations in ecosystem structures and functions. Thus, hydrological and ecological monitoring schemes must consider and adapt to this variation, in order to capture short-term changes in hydromorphological, ecological and biogeochemical processes, and to understand water quality and biotic response variations.

- *Definition and mapping*

We do not know yet the detailed numbers, location, areal extent and length of NPRS in the EU-Med area. “Dotted lines” on topographic maps are spatially inaccurate, and therefore unreliable in efforts to locate and estimate numbers of NPRS. Moreover, EU-Med Member States still have different perceptions on how to define NPRS; EU-Med countries use different topographic mapping resolutions, which lead to very different estimations of the total number and length of streams (McDonough et al., 2011). Hence, many NPRS are excluded from assessments. It is obvious that a Europe-wide definition of NPRS is urgently required, as well as a common registration and mapping strategy for the EU-Med basins, taking into consideration local variations. Since NRPS are often considered as possessing no economic value, it is unlikely that managers are going to install flow gauging stations in these catchments; thus, mapping of NPRS could be, alternatively, achieved through citizen-science projects. In some regions of France, for example, fisher associations are mapping flow states across more than 3500 km of river networks, by means of visual observation (Datry et al. 2016b). Such efforts could be applied at the European scale, currently one of the goals of the Cost Action SMIRES.

- *Typological classification*

The typological approach of Mediterranean rivers, especially of NPRS, is inadequate, and improperly incorporated into the RBMPs. Since, flow-gauging monitoring programs have generally ignored NPRS, hydrological information is generally missing (Acuña et al., 2014, Datry et al., 2014a). We thus lack the data required for assessing hydrological regimes and quantifying zero-flow days, in order to define the hydrological type of a given NPRS. A more dynamic typology, compared to the existing ones, coupled with advanced hydrological monitoring techniques, should be developed, considering hydromorphological changes along the river continuum, seasonal and inter-annual variability, as well as biological responses. When a river typology has to be compatible with biology, e.g. for WFD monitoring and classification, habitat variability and expected biological conditions should be defined after identifying the actual habitat conditions experienced by biota (e.g. Buffagni et al., 2009).

- *Development of appropriate metrics for ecological status assessment*

High biological variability due to high hydrological instability of NPRS, in particular under climate change conditions (e.g. Bonada and Resh, 2013), pose a challenge in devising suitable approaches to assess ecological status. The cumulative effects of hydrologic variability, antecedent hydrologic conditions and drought events on biological assessment systems currently used, are largely unknown. Setting reference conditions, that may vary seasonally, can be problematic (Feio et al., 2014, Cid et al., 2016), while classifying ecological status in periods close to the dry season is also an issue, as biological assemblages can show quite different attributes compared to those during other flow periods (García-Roger et al., 2013). In this latter circumstance, an increase in lentic conditions is often associated with a decrease in the value of the metrics normally applied, possibly causing a serious underestimation of the ecological status. In altered water bodies, these hydrology-related factors often mask pollution, water abstraction and morphological alteration, and make it arduous to disentangle the effects of different pressures on benthic assemblages.

A first step towards a successful and cost-effective ecological status appraisal in NPRS would be to test the performance of existing classification systems and, if necessary, refine them. Furthermore, in order to better understand the differences in biotic assemblages between PRS and NPRS and to develop appropriate metrics for NPRS, future research should consider rivers and streams with similar typological and habitat characteristics. Moreover, special focus has to be placed on detecting effects other than those of pollution only, identifying the contribution of specific causes and pressures in shaping NPRS assemblages (e.g. Buffagni et al., 2016). Also, the ranking of the potential influence of different pressures and the definition of the breadth of biological response gradients are major issues of recent research activities (Gallart et al., 2012, Prat et al., 2014). New approaches and metrics, or alternatively dedicated refinements of existing classification systems, are required for NPRS, while reviews of specific methodological aspects would be also highly valuable. In fact, though there were some recent initiatives to improve the effectiveness of ecological status assessment in NPRS (e.g. Prat et al., 2014, Cid et al., 2016), more efforts are required in order to allow application in ephemeral/episodic streams too (Argyroudi et al., 2009, Nikolaidis et al., 2013). Finally, data use on physico-chemical elements and related classification systems for NPRS has to be revised, since biogeochemical cycles may differ between NPRS and PRS, and organic matter dynamics may vary more distinctly in NPRS than in PRS (Datry et al., 2014a).

4.3. Conclusions

The current paper reviews the state-of-the-art of research efforts, achievements and management aspects regarding EU-Med NPRS, and proposes future research and management priorities. Major research activities during the last 15 years have considerably improved our understanding of the various structural and functional aspects of NPRS. However, NPRS still remain one of the least known aquatic ecosystems globally. The Greek philosopher Heraclitus (c. 535 - c. 475 BCE) stated "Everything flows and nothing abides” and "Ever-newer waters flow on those who step into the same rivers" emphasizing the perpetual flux of all things. These famous aphorisms apply perfectly to NPRS and particularly to EU-Med NPRS, which are characterized by complex and highly unstable functions, driven by dynamic and often unpredictable hydro-meteorological and habitat processes, further augmented by human pressures and climate change.

In order to better understand and efficiently manage NPRS, targeted interdisciplinary research is required. Therefore, a close cooperation among research groups actively involved in various disciplines related to the study of NPRS, such as hydro(geo)logy, hydrobiology, biogeochemistry and advanced monitoring technologies, is urgently needed. The incorporation of social scientists and economists will be also very fruitful in order to highlight the value of NPRS to society from an ecosystem service point-of-view. Recent initiatives, such as the SMIRES COST Action, may contribute to setting and implementing such research and management priorities.

NPRS are particularly vulnerable, because they lack adequate legislative and policy protection, as well as appropriate management practices. In the EU-Med, the legal framework and therefore an appropriate protection status of NPRS is still missing. Moreover, minimum flow requirements and hydropeaking issues have been only partly incorporated in previous RBMPs by the Member States (Sans and Schmidt, 2012). It is thus vital to improve and implement effective measures concerning efficient monitoring, sustainable management, as well as conservation and protection of EU-Med NPRS. As our scientific understanding of NPRS is increasing, the importance of including them in policy and management decisions of the EU-Med states will be highly recognised. In fact, the translation of scientific work to legislation is a critical stage in management and protection. Within this frame, the MIRAGE project recommended specific additions to WFD (Articles 2, 4, 5 and 11), by addressing the particular characteristics of NPRS, ultimately aiming to their efficient management and protection (Nikolaidis et al., 2013). At the regional scale, the ‘‘Instrucción de Planificación Hidrológica’’ (2008), in Spain, includes guidelines for water management, following the WFD and the indices proposed to evaluate the ecological status of Spanish rivers, mostly based on the work produced within the GUADALMED project. In order to integrate NPRS in forthcoming RBMPs as specific river types, a close cooperation between scientists, EU and national policy makers, as well as local management authorities is urgently required.

The incorporation of the e-flows CIS Guidance (EU, 2015) in forthcoming RBMPs, as well as the deterioration principle of the ECJ, may further promote efforts for NPRS protection by securing the restoration of flow regimes. At the local scale, there is a need to protect off-site refuges that are essential for maintaining the ecological integrity of NPRS (e.g. see Pires et al., 1999), while measures, such as riparian reforestation to reduce pollutant loadings during flood events (Tzoraki et al., 2014), and to increase quality and quantity of tree-related habitats (Buffagni et al., 2016) should be also considered. The application of floating islands may be a technical and economical efficient measure to combat pollution, particularly during low flow periods (Pavlineri et al., 2016). Concurrently to the implementation of specific conservation measures, there is an urgent need to define economic alternatives to existing practices in irrigated farming at an EU-Med scale, in order to reduce overall water consumption, in particular during the ecologically most sensitive periods. This must coincide with the development of modern planning instruments, more effective land use policies and the linking of the current Common Agricultural Policy to the Horizon 2020 strategy (Nikolaidis et al., 2013).

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