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

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28 **Abstract**

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

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

55

56 **1. Introduction**

57 Lotic freshwaters are either perennial or temporary (or non-perennial), according to
58 surface flow conditions. Perennial rivers and streams (herein PRS) flow throughout the year,
59 whereas temporary systems (herein non-perennial rivers and streams, NPRS) cease to flow
60 at the surface for some time of the year. Depending on the specific flow regime, NPRS can
61 be classified, according to the most common perceptions, as intermittent, ephemeral or
62 episodic. Intermittent rivers cease to flow seasonally or occasionally (usually for weeks to
63 months); Ephemeral streams flow only in response to precipitation or snowmelt events
64 (days to weeks); Episodic streams carry surface water only during very short periods (hours
65 to days), primarily after heavy rainfall events (McDonough et al., 2011; Arthington et al.,
66 2014).

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

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

85 Water use and management practices in the Mediterranean region are historically
86 adapted to natural water scarcity (Grantham et al., 2013). However, rising water demand for
87 agricultural, industrial, urban and touristic development have exerted widespread pressures

88 on water resources (Bradford, 2000), which fundamentally affect the natural flow regime
89 (Smith, 1997; UNEP/MAP, 2003; Ludwig et al., 2009; Skoulikidis, 2009). The natural seasonal
90 dryness regime is exacerbated by human activities, and natural PRS are converted into NPRS
91 (Datry et al., 2014a). These rivers and streams are considered "artificially dry" or "artificially
92 intermittent" (Benejam et al., 2010; Skoulikidis et al., 2011). On the other hand, natural
93 NPRS may be transformed into PRS after receiving effluents from WWTPs or urban and
94 industrial discharges (Hassan and Egozi, 2001). Artificial flow regime alterations enhance the
95 risk of unanticipated ecological changes (Poff and Zimmerman, 2010; Sabater and Tockner,
96 2010).

97 Historically, European Mediterranean (EU-Med) NPRS have been undervalued by
98 both water managers and ecologists (Larned et al., 2010; Nikolaidis et al., 2013), and they
99 remain among the least studied freshwater ecosystems worldwide (Uys and O’Keeffe, 1997;
100 Jacobson et al., 2004; Ryder and Boulton, 2005; TempQsim Consortium, 2006; Acuña et al.,
101 2014; Datry et al., 2014a). This corresponds to the widespread societal view that, according
102 to Sabater et al. (2009) "*People in arid and semi-arid regions have the least respect towards*
103 *rivers, since the rivers are often dry or have catastrophic floods, and are therefore viewed*
104 *more as a danger than as a natural resource to be preserved*". This is particularly evident in
105 urban areas, where they have been frequently covered by roads, with some NPRS being
106 today important avenues of EU-Med cities (e.g. the "Ramblas" in Barcelona, Spain, the Ilissos
107 and Iridanos streams in Athens, Greece, etc). In addition, NPRS in the EU-Med countries
108 have been used, and are still being used, as waste disposal sites, drains for sewage effluents,
109 roads, car parking areas and quarries for sand and gravel. Moreover, legal and illegal
110 constructions along NPRS courses, especially along episodic ones, are common. The
111 subsequent destructive consequences of these practices are perceived by the public only
112 after catastrophic floods.

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

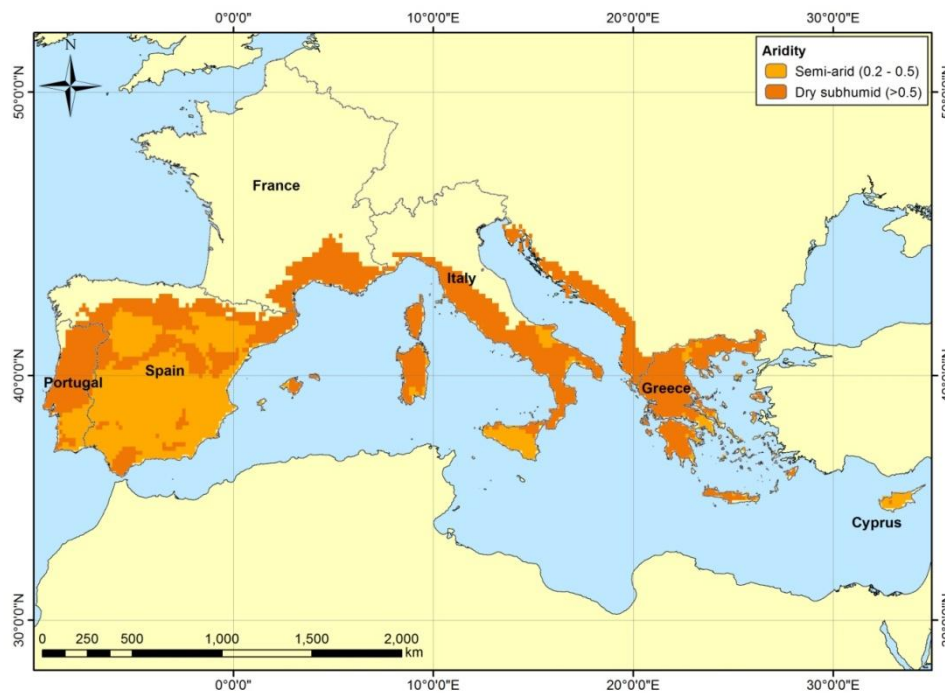
118 The present article focuses on the climatic and anthropogenic pressures affecting
119 NPRS in the EU-Med countries, reviews research achievements, identifies knowledge gaps

120 and research needs, explores the present state in terms of local knowledge and
121 management strategies, and proposes future avenues for research and management to
122 safeguard these pivotal albeit undervalued and threatened ecosystems.

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

124 2.1. Climatic pressures

125 The Mediterranean area is characterized by high temporal climate variation, with
126 low precipitation during summer. When applying the “Mediterranean climate” classification
127 scheme, according to the global climate assessment approach developed by Köppen (1936),
128 the EU-Med area fits into the dry sub-humid ($0.50 < P/PET < 0.65$) and semi-arid ($0.20 <$
129 $P/PET < 0.50$) climate zones (UNEP, 1992; Fig. 1).



130
131 **Figure 1.** Map of Europe, delineating the Mediterranean Bio-geographical Region (EEA, 2016),
132 including the distribution of aridity zones according to UNEP (1992).

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

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

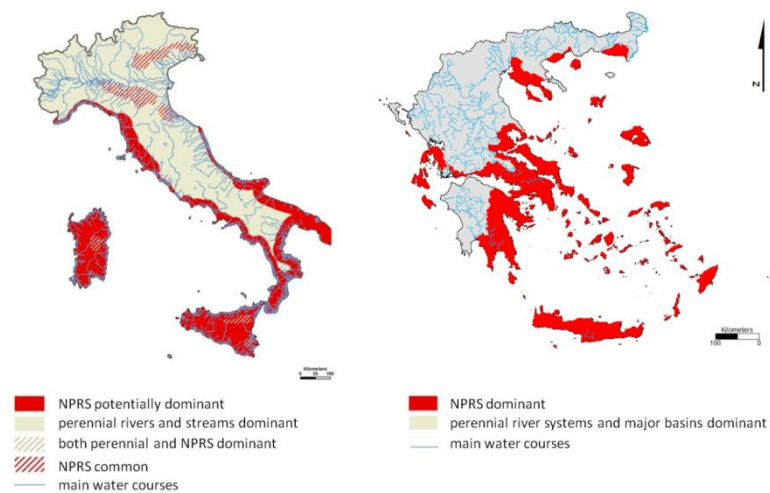
145 The south-eastern part of Spain belongs to the driest regions in Europe, with a mean
146 precipitation of 120 mm/year, and summer temperatures reaching up to 47°C (Estrela and
147 Vargas, 2012). As a result, approximately 98% of the mapped water courses in the province
148 of Murcia, which covers the driest part of the Iberian Peninsula, are NPRS (Gómez et al.,
149 2005). Flow intermittency is further triggered by extended periods of low rainfall (Esteban-
150 Parra et al., 1998) and high air temperature (De Castro et al., 2005).

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

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

159 Greece exhibits a strong N–S gradient, with increasing temperature and
160 evapotranspiration and decreasing precipitation towards the W-E and S–SE (Dalezios et al.,
161 2002). There, the mean annual precipitation drops to 400 mm. Thus, in large parts of
162 southern (Attika, Eastern Peloponnese and Crete) and eastern (Aegean Islands) Greece,
163 semi-arid conditions prevail (Yassoglou et al., 1962). In total, only 45 out of the 765 Greek
164 rivers and streams are permanently flowing (Ministry for Development, 2003), and NPRS
165 catchments cover approximately 39% of the entire country (Fig. 2). This proportion may rise
166 further because droughts are becoming longer and more intense (Livada and
167 Assimakopoulos, 2005).

168 Cyprus is the most arid country in the European Union, with an average annual
169 precipitation of 460 mm (Department of Meteorology of Cyprus, 2014). During the past
170 century, average annual precipitation has decreased by 17%, and from 1976 to 2006,
171 evapotranspiration has increased by 60-80 mm (Petrakis et al., 2012). Perennial river
172 reaches in Cyprus are restricted to the upland areas of the central Troodos massif, while
173 there is not a single river on the island with perennial flow along its entire course. Only 14%
174 of the total river length is perennial. However, 48% of the total length exhibits an
175 intermittent and 38% an ephemeral/episodic flow regime (ENVECO S.A. and I.A.CO Ltd,
176 2013).



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

181 2.2. Anthropogenic pressures

182 Long-lasting human activities and rapid urban and agricultural developments have
183 led to a large-scale conversion of riparian areas into agricultural land, massive booms in
184 reservoir and flood control constructions, and an extensive use of water for irrigation.
185 Today, agricultural land covers vast areas of the EU-Med region, ranging from 30% in Greece
186 to 48% in Italy, and most farmlands are now irrigated (Eurostat, 2000; 2003). Irrigated
187 agriculture accounts for more than 60% of total water abstraction, with up to 89% in Greece
188 (INAG, 2001). In most EU-Med countries, irrigation water is mainly obtained from rivers and
189 streams, covering 64% (France) and 100% (Portugal) of the demand. In Cyprus, however,
190 groundwater abstraction is the dominant water source for irrigation (81%; Zoumidis et al.,

191 2013). At the same time, coastal economic and touristic development contributes to an
 192 increasing water use, particularly in water scarce areas and during specific seasons.

193 To compensate for the decrease in water resources and to secure water supply
 194 during summer, numerous reservoirs have been constructed in the EU-Med during the past
 195 decades, favoured by the high topographic relief of the area (Conacher and Sala, 1998).
 196 However, this has led to the fragmentation of most rivers entering the Mediterranean Sea
 197 (Tockner et al., 2009). In Cyprus, for example, 67% of the overall mean annual surface runoff
 198 discharges into reservoirs (Rossel, 2002). Spain has the highest number of large dams of all
 199 EU-Med countries, Cyprus has the highest density (Table 1), whereas the highest dams are
 200 located in Italy and Greece. Some reservoirs that are currently at the planning stage are
 201 facing considerable resistance by the civil society. The Portuguese plan for hydropower
 202 development (PNBEPH) will entail the loss of several rivers in the northern part of the
 203 country. The Mesochora Dam, located in the Upper Acheloos River (Greece), comprises one
 204 of the largest and most controversial river diversion projects in the EU-Med. The Acheloos
 205 already contains six reservoirs, which cover a total surface area of up to 150 km². The total
 206 storage capacity is ~6.6 km³, corresponding to ~1.5 times the total annual river discharge
 207 (Skoulikidis, 2009).

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

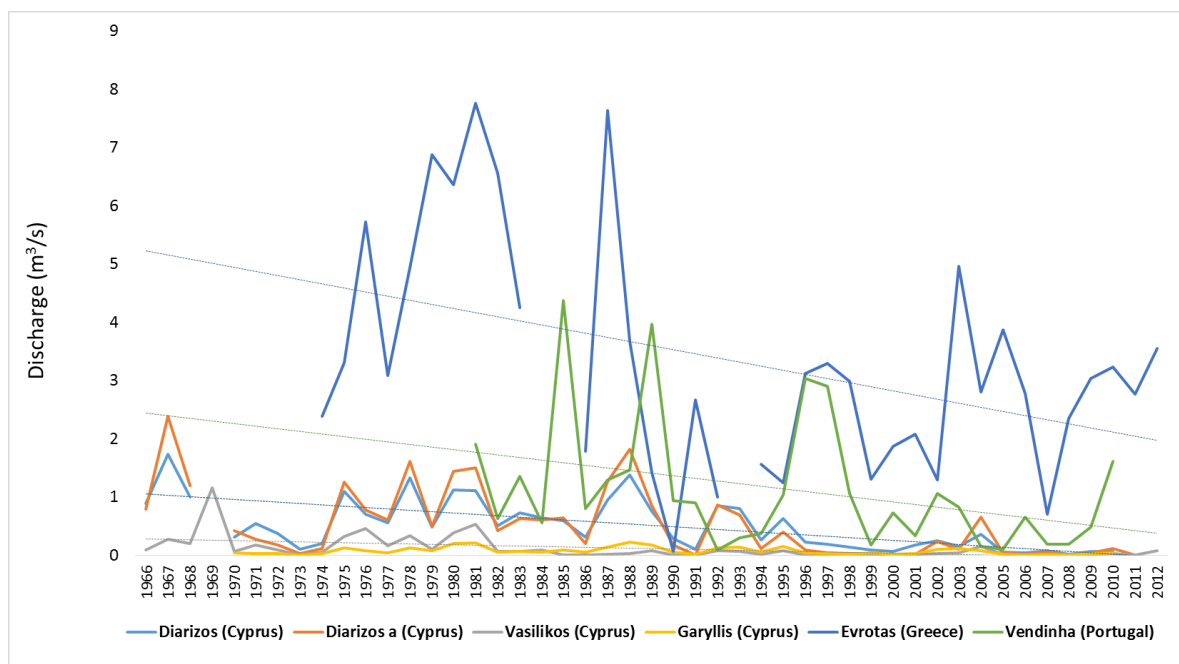
Country	Number of large dams (>15m)	Number of dams/1000 km ² area	Number of dams/one million inhabitants
Portugal	217	2.35	20.4
Spain	1082	2.14	23.1
France	713	1.30	11.2
Italy	542	1.80	9.1
Greece	164	1.24	14.1
Cyprus	57	6.16	71.0
EU	7000	1.75	13.9

210
 211

212 2.3. Climate and anthropogenic impacts

213 2.3.1. Hydrological impacts

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



221
222 **Figure 3.** Long-term flow diminishing in NPRS from Southern Portugal (Vendinha R.),
223 Southern Greece (Evrotas R.) and Cyprus (Diarizos R. and Vasilikos R.).

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

230 In Greece, unsustainable water resources management, together with a progressive
231 decline in precipitation, has altered the natural flow regime of most rivers (Skoulikidis,
232 2009). Many farmers face serious water shortage during very dry summers (Isendahl and
233 Schmidt, 2006). As a consequence, they construct provisional weirs along river courses for
234 water abstraction, which again favours further the artificial desiccation and the conversion

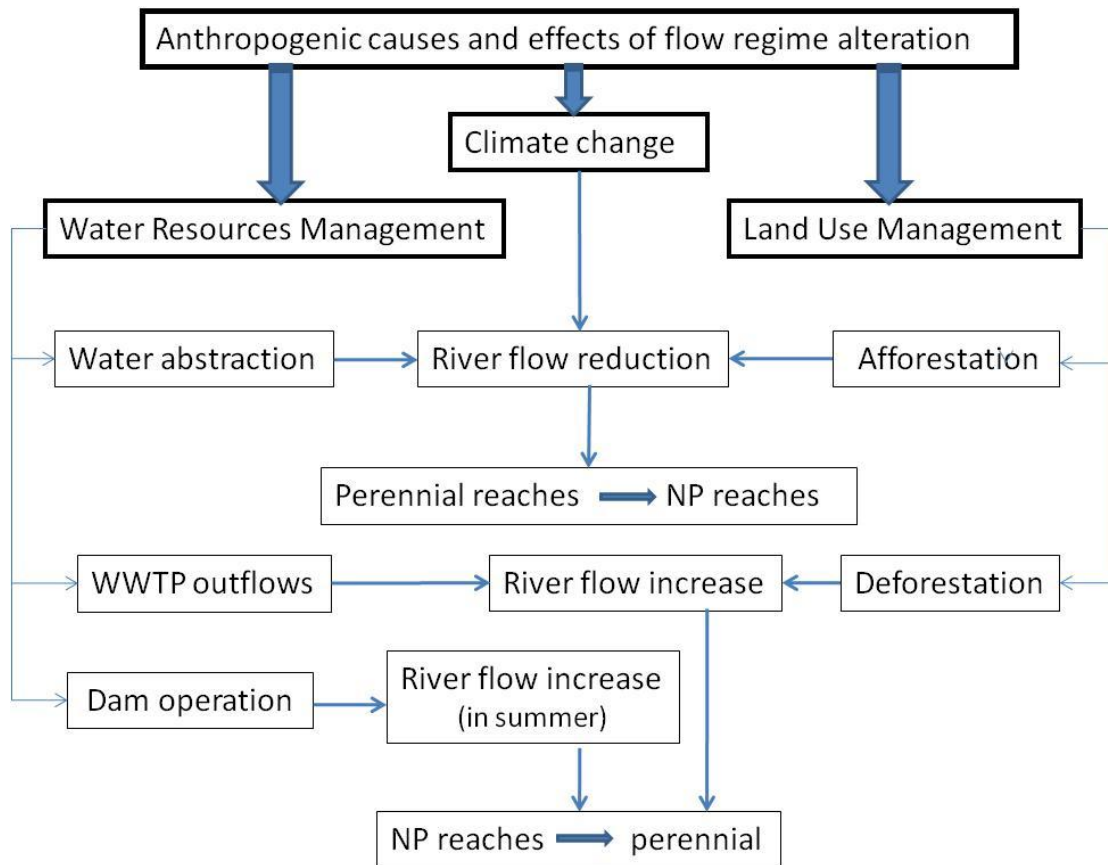
235 of PRS into NPRS (e.g. Chadzichristidi et al., 1991; Economou et al., 1999; Bobori and
236 Economidis, 2006). In the Pinios River basin (Central Greece), intensive agriculture has
237 caused the lowering of the groundwater tables by tens of meters (Loukas et al., 2007),
238 facilitating the widespread desiccation of entire river sections (Stefanidis et al., 2016). In the
239 Evrotas basin (Southern Greece), discharge has declined by 84% during the past three
240 decades, mainly due to water overexploitation for irrigation. During very dry years, such as
241 2007, up to 80% of the river network dries up completely, limiting available water for
242 irrigation and threatening the endemic freshwater fish fauna (Skoulikidis et al., 2011).

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

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

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

265



266
267

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

275 *2.3.2. Ecological impacts*

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

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

294 Water management infrastructures and practices alter key hydrological processes
295 that maintain riverine habitat diversity, longitudinal, lateral and vertical connectivity
296 gradients, and good water quality conditions (Prat and Ward, 1994; Bunn and Arthington,
297 2002; Pringle, 2003). The vast seasonal decline of river flow in NPRS makes them particularly
298 sensitive to anthropogenic pressures, especially regarding water quality (Morais et al., 2009;
299 Rosado and Morais, 2010; Rosado et al., 2012; Lopez-Doval et al., 2013). As a result, many
300 NPRS suffer from eutrophication, hypoxia and high concentrations of industrial and
301 agricultural contaminants (Cooper et al., 2013; Lopez-Doval et al., 2013).

302 Water stress and pollution may have cumulative impacts on aquatic biotic
303 assemblages, because habitats shrink, water quality deteriorates, and predation and
304 competition increase, as space and basic resources become even more limited (Magoulick
305 and Kobza, 2003; Magalhães et al., 2002; Robson et al., 2011). Hence, species with low
306 tolerance to multiple stressors are eliminated from artificial NPRS, and habitat
307 fragmentation constrains recolonization pathways (Phillipsen and Lytle, 2013; Datry et al.,
308 2016c). Chemical pollution derived from agricultural activity may have caused the observed
309 decline of amphibian populations in NPRS (e.g. Sparling et al., 2001). At the same time,
310 several aquatic and semi-aquatic birds are also affected by water pollution, primarily due to
311 declining abundances of pollution-intolerant macroinvertebrate prey (Feck and Hall, 2004).
312 Apart from pollution, NPRS are also subject to salinization. Increased salt concentrations,
313 caused by reduced runoff and irrigation water evaporation (Cañedo-Argüelles et al., 2012;

314 2016), affect invertebrates, diatoms and fungal biomass as well as key ecosystem processes
315 (Cañedo-Argüelles et al., 2014).

316 At the same time, knowledge about the ecological consequences of artificial
317 perennialization remains very poor (Datry et al., 2014a). While habitat availability for lotic
318 and lentic species increases with perennialization, habitat availability for terrestrial and
319 semi-aquatic species declines. Although perennial flow may be sustained by effluent
320 discharge, pollution can be detrimental for aquatic assemblages, as BOD₅, dissolved oxygen,
321 and nutrient concentrations frequently exceed the threshold of “good” water quality due to
322 limited dilution (De Girolamo et al., 2015a).

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



325

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



332

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

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

339 *3.1. History of research efforts in EU-Med NPRS*

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

350 At a European scale, research and management of NPRS are lagging behind,
351 compared to other freshwater ecosystems. Even the EU’s Water Framework Directive
352 2000/60/EC (WFD) does not specifically address NPRS (Nikolaidis et al., 2013), mainly as a

353 result of the inadequate involvement of EU-Med countries in the development of the WFD,
354 coupled with a general undervaluation of NPRS systems. Reasons include the low economic
355 value attributed to NPRS, the complexity of the Mediterranean biogeography coupled with
356 political and societal issues, the poor planning of effective environmental policies, the
357 inadequacy of legislation and its ineffective enforcement, the lack of political commitment,
358 and the inadequate knowledge of NPRS' hydrology, ecology and biogeochemistry
359 (Vogiatzakis et al., 2006; Acuña et al. 2014).

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

368 In the EU-Med countries, national institutions have mainly focused on monitoring
369 PRS, thus approaches, methods and data to quantify, locate and classify NPRS are often
370 missing. In France, for example, NPRS have been classified as “atypical” in the environmental
371 flow legislation (Decret, 2007); thus, no minimum flow management plans are required for
372 these systems. In Italy, the WFD has primarily been implemented for catchments larger than
373 10 km² (MATTM, 2008), thus ignoring a large number of NPRS. In Greece too, the 1st River
374 Basin Management Plans (RBMPs) refer to rivers and streams with a Strahler stream order
375 higher than 4 (EC, 2015), thus ignoring a vast number of headwater NPRS. Even in Spain,
376 with a much longer tradition in studying NPRS than in other EU-Med countries, a national
377 hydrological classification is still missing (Belmar et al., 2011). According to the Spanish
378 water legislation (“Instrucción de Planificación Hidrológica”, ORDEN ARM/2656/2008), 12
379 out of 32 WFD-ecotypes are termed as Mediterranean ecotypes. However, there is not a
380 particular ecotype that specifically addresses NPRS. In Cyprus, with few PRS, NPRS stream
381 flow data covering the whole gradient from perennial to episodic rivers does exist. However,
382 the spatial distribution of the different flow regime types has been quantified only very
383 recently (ENVECO S.A. and I.A.CO Ltd, 2013).

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

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

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

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

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

446 In Italy too, NPRS have been the focus of a number of national research projects,
447 funded by the Italian Ministry of Research and the EU, such as MICARI, INHABIT and
448 AQUASTRESS (FP6 IP 511231-2, 2004-2008 - <http://www.aquastress.net/>) (e.g. Amalfitano et
449 al., 2008; De Girolamo et al., 2012; Giordano et al., 2013). Within the MICARI project (MIUR,

450 D.M. 408 Ric. 20.03.2002 – Settore “RISORSE IDRICHE”, 2003-2005), the concept of lentic-
 451 lotic character of rivers was developed (Buffagni et al., 2009; 2010). Later on, the INHABIT
 452 project (LIFE08 ENV/IT/000413, 2010-2014 - www.life-inhabit.it) dealt explicitly with NPRS of
 453 Sardinia, focusing on lentic-lotic riverine habitat components, so that they can be effectively
 454 considered when classifying rivers, as well as planning and checking the effect of RBMP
 455 Program of Measures (PoMs).

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

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

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

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

Term	WEB OF SCIENCE		PROQUEST	
	# 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

474

475 Publications on Mediterranean temporary or intermittent rivers and streams
 476 comprise about 10% of the total number of related papers worldwide (Table 2). For
 477 ephemeral rivers and streams, the relative proportion is lower (6%). These numbers are
 478 deemed high, considering the surface area and the population of the EU-Med region (i.e.
 479 1.56% and 2.97% of the total human population and area, respectively; data: World Bank,
 480 2015), but also considering the low research expenditure of EU-Med countries compared to
 481 the world average. The majority of publications (37%) refer to macroinvertebrates, followed
 482 by biogeochemistry (14%), pollution (9%) and diatoms (5%). Domains such as hydrology,
 483 ecology, fish, biology-other, microbiology and management are less represented (1.6-3.7%
 484 each).

485 3.2. Specific research achievements in EU-Med NPRS

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

491 3.2.1. Geographical distribution of NPRS

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

495

496 3.2.2 Pressures and impacts

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

501 Sánchez-Montoya et al., 2009). In Spain, for example, the response of various
502 macroinvertebrate metrics to multiple stressor gradients typical for EU-Med streams,
503 including NRPS ones, has been studied (Munné and Prat, 2009; Sánchez-Montoya et al.,
504 2010). Cañedo et al. (2012, 2016) investigated the impacts of secondary salinization, which
505 reduces aquatic biodiversity and compromises the goods and services that rivers and
506 streams provide. Recently, Suárez et al. (2016) studied the functional responses of aquatic
507 invertebrate assemblages along two natural stress gradients, water salinity and flow
508 intermittency, in Mediterranean streams. They showed that functional richness and
509 redundancy decreased with increasing salinity and flow intermittency, with salinity being the
510 stronger environmental stressor. Wildfires, which frequently occur during periods of
511 extended drought, pose another major risk for NPRS. Initial floods following wildfires
512 enhance runoff and erosion rates in burned terrains, causing elevated sediment and
513 phosphorus concentrations in receiving downstream water bodies (Blake et al., 2010).
514 Finally, studies that focused on the relative vulnerability of PRS and NPRS to anthropogenic
515 stress have shown that habitat changes (García-Roger et al., 2011) and agro-industrial
516 pressures (Karaouzas et al., 2011; Karaouzas and Skoulikidis, 2011) exert severe effects on
517 aquatic macroinvertebrates in NPRS, more severe than in comparable PRS.

518 3.2.3 Hydrological processes

519
520 Gallart et al. (2008) investigated the hydrological regimes in a set of EU-Med NPRS
521 basins and showed that these were depended on karstic groundwater, human disturbance
522 and winter temperatures. Recently, a European stream classification method, based on flow
523 regime, has been proposed by Bussettini et al. (2015), whereas Oueslati et al. (2015)
524 classified hydrological regime types using stream flow data from EU-NPRS. At a local scale
525 (e.g., Pardiela River basin, Portugal), the duration of drought during a hydrological year has
526 been quantified (Rosado et al., 2012). Also, a hydrological classification of natural flow
527 regimes in the Segura River basin showed that NPRS are mainly restricted to the southern,
528 lowland basin (Belmar et al., 2011). Hydrological modeling has been applied to estimate the
529 temporal extent of desiccation. For example, Kirkby et al. (2011) addressed the relative
530 frequency of ecologically critical low flow stages in semi-arid rivers across Europe. Moreover,
531 using modeling approaches, it has been shown that entire river reaches may dry out as a
532 result of water abstraction for agriculture (Skoulikidis et al., 2011; De Girolamo et al.,
533 2015a). Thus, De Girolamo et al. (2015b) developed a new approach for evaluating the
534 hydrological status of NPRS, in which the divergence between the current (impacted) and

535 the natural flow conditions are assessed by using two hydrological indicators; the long-term
536 annual mean number of months with flow (MF) (Arscott et al., 2010), and the six-month
537 seasonal predictability of dry periods (SD6) (Gallart et al., 2012). A method suitable to
538 quantify hydrological alterations in the absence of stream flow data has also been tested (De
539 Girolamo et al., 2015b). Similarly, in order to estimate the flow regime of NPRS in the
540 absence of flow data, Gallart et al. (2016) have proposed alternative approaches based on
541 historical aerial photographs and on interviews.

542

543 3.2.4 Biotic responses to flow intermittency

544 Recent research has led to a better inventory and understanding of biotic
545 assemblages in NPRS, including aquatic (Graça et al., 2004; Datry, 2012; Bonada and Resh,
546 2013; García-Roger et al., 2013) and terrestrial invertebrates (Corti and Datry, 2012; 2015;
547 Sánchez-Montoya et al., 2016), diatoms (Novais et al., 2014; Barthès et al., 2014), microbial
548 and algal assemblages (Amalfitano et al., 2008; Romani et al., 2013) as well as vertebrate
549 assemblages, such as fish (Pires et al., 1999; Zogaris et al., 2012; Vardakas et al., 2015) and
550 semi-aquatic carnivores (Clavero et al., 2003; Ruiz-Olmo et al., 2002; 2007). Other recent
551 studies focused on the mechanisms allowing species to cope with recurrent drying as well as
552 to produce quantitative relationships between drying duration and frequency (Datry et al.,
553 2014b). In most cases, taxa richness of aquatic macroinvertebrates is lower in NPRS than in
554 PRS (Muñoz, 2003; Morais et al., 2004; Sánchez-Montoya et al., 2009; 2010; Belmar et al.,
555 2012; Datry, 2012; Datry et al., 2014b), but see Bonada et al. (2007b; 2008) and Skoulikidis
556 et al. (2011). The seasonal community composition differed between PRS and NPRS (Bonada
557 et al., 2008). In NPRS, invertebrates exhibiting low dissolved oxygen requirements and pool-
558 like strategies dominate during the contracting phase (Pires et al., 2000; Acuña et al., 2005;
559 Bonada et al., 2007b; García-Roger et al., 2013), whereas resilient taxa and species with
560 riffle-like strategies dominate during the expansion phase (Bonada et al., 2007b; Datry et al.,
561 2014b). Overall, collectors are more abundant in NPRS than in PRS and, in particular for
562 NPRS, the number of predators increases in remaining pools during the contracting phase
563 (Sabater et al., 2006; Bonada et al., 2007b).

564 Flow intermittency not only affects aquatic invertebrate assemblages but may also
565 control terrestrial invertebrate assemblages in the channel and in adjacent terrestrial
566 habitats of NRPS. Recently, Sánchez-Montoya et al. (2016), who studied two Mediterranean
567 NRPS streams, reported that not only river drying, but also the length of the dry period,

568 changes the composition of terrestrial arthropod assemblages, although taxonomic richness
569 and total abundance were similar between perennial and intermittent reaches.

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

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

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

595 There are only a few studies on vertebrates in EU-Med NPRS. These have shown that
596 desiccation influences the availability of prey such as fish, which again may strongly affect
597 the European otter (*Lutra lutra*) (Clavero et al., 2003; Ruiz-Olmo and Jimenez, 2009).
598 Consequently, the mortality rate of otters increases, their abundance diminishes, and

599 breeding success declines (e.g., Ruiz-Olmo et al., 2001). Furthermore, due to summer
600 droughts, the breeding time of otters occurs earlier in Mediterranean than in temperate
601 streams (Ruiz-Olmo et al., 2002).

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

608 3.2.5 Hydromorphology vs ecological quality

609 The relationship between hydrology and ecological quality in NPRS has been
610 frequently explored in various studies that showed that the ecological status depends on the
611 alteration of flow-related natural components (e.g. Coimbra et al. 1996, Buffagni et al., 2009,
612 2010). Water abstraction, for example, favours lentic habitat conditions, thereby affecting
613 the structure and traits of aquatic assemblages (Buffagni et al., 2010, García-Roger et al.,
614 2013). Gallart et al. (2012) defined six aquatic states for NPRS and developed a new
615 approach to analyse the regime types of NPRS in relation to their controls on the
616 composition and structure of aquatic biota. Prat et al. (2014) developed an integrated
617 assessment strategy for NPRS (i.e. the MIRAGE tool-box). Based on the aforementioned
618 aquatic states, the MIRAGE tool-box entails a series of methodologies for determining and
619 analysing NPRS' aquatic regimes, and for relating the ecological and chemical status to their
620 specific hydrological status. Similarly, Cid et al. (2016) developed a biological tool
621 (BioASTool) to assess flow connectivity in NPRS reference systems based on benthic
622 invertebrates. This tool can also be applied when hydrological data are missing, using the
623 taxonomic and biological trait composition of the macroinvertebrate community as
624 predictors. Likewise, Buffagni et al. (2010) stressed that the lentic-lotic character of rivers
625 (e.g. quantified by proxies such as the Lentic-lotic River Descriptor (LRD) score system, see
626 Buffagni et al., 2009) has to be taken into account when assessing their ecological status.
627 Furthermore, the potential adverse effects of water management, or of climatic variation,
628 have to be considered in the formulation of sound PoMs too. In NPRS of Sardinia, it has been
629 demonstrated that the impact of the morphological alteration of river channels and banks is
630 well detected by the benthic metrics (Buffagni et al., 2016) that are commonly used for
631 monitoring PRS and NPRS. In the absence of water pollution and/or water abstraction, the

632 large majority of stream reaches that showed evident morphological alteration were
633 correctly classified as medium to low ecological status (Buffagni et al., 2016). Therefore,
634 even if the influence of the highly variable hydrological regime of NPRS on benthic
635 assemblages is undeniable, effects subtler than those of pollution, such as of morphological
636 modification, can be detected and quantified.

637 3.2.6 Biogeochemical processes

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

643 Dry watercourses may cause substantial CO₂ emissions, higher than running or
644 stagnant waters, which demonstrates the importance of NPRS for the global carbon cycle
645 (Von Schiller et al., 2014; Gómez-Gener et al., 2016). In NPRS, coarse particulate organic
646 matter (CPOM) accumulates in standing pools and at the surface of dry habitats, and as the
647 river dries, the primary agents of CPOM decomposition shift from leaching and processing by
648 aquatic micro-organisms and invertebrates to photo-degradation by UV and processing by
649 terrestrial micro-organisms and invertebrates (Corti et al., 2011, Dieter et al., 2011). The
650 decomposition rate decreases according to drying duration and the progressive
651 disappearance and inactivity of aquatic fungi and shredders (e.g. Corti et al., 2011, Datry et
652 al., 2011, Foulquier et al., 2015). In dry habitats, the decomposition rate is reduced to almost
653 zero due to the low abundance of terrestrial shredders, low microbial activity and absence of
654 mechanical breakdown (Corti et al. 2011). Experimental desiccation in microcosms with
655 sediments from different EU-Med NPRS revealed a prompt decline of the initial bacterial
656 carbon production during desiccation, while complete desiccation led to a delay in
657 mineralization processes and synthesis of new biomass (Amalfitano et al. 2008). These
658 studies led to a better understanding of how the tempos, rates and timing of organic matter
659 processing differ between PRS and NPRS (Datry et al. 2014a). Other studies focused on
660 stream metabolism by continuous oxygen measurements (Acuña et al., 2004, Izagirre et al.,
661 2008). Regarding the nutrient processes, Von Schiller et al. (2011) stressed that hypoxic
662 conditions in disconnected pools can cause rapid ammonium and phosphate release from
663 sediments. Microcosm experiments showed that drying increased the sediment nitrate

664 content (Arce et al. 2014) and that in the initial stages of desiccation, N-mineralization and
665 nitrification were stimulated (Tzoraki et al. 2007, Gómez et al. 2012).

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

680 *3.3. Management in EU-Med NPRS*

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

689 Nevertheless, the EU-Med countries, acknowledging the adverse effects of
690 inadequate water management on lotic ecosystems, started incorporating ecological flow
691 requirements into their national legislation. In Portugal, the Ordinance 1450/2007 made
692 mandatory a study defining an ecological flow regime downstream of dams, and Law N^o
693 7/2008, although not yet implemented, states that the owner must sustain a flow regime
694 adapted to fish life cycles, with the aim of maintaining ecosystem integrity (EU, 2015). In
695 addition, the management and conservation of a NPR basin (Pardiela) has been addressed

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

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

728 ensured by the PoMs within the RBMPs. It is thus expected that national legislations on
729 ecological-flows will be modified accordingly.

730 In addition, in a recent decision of the European Court of Justice (ECJ) (01.07.2015) it
731 is stated that Member States (MS), should take into consideration the environmental
732 objectives of the WFD. This decision may protect more efficiently NPRS, especially regarding
733 the maintenance of near natural flow regimes. In this sense, the LIFE+ TRivers Project (2014-
734 2018) focuses on the hydrology and ecology of Spanish NPRS, aiming at creating new tools
735 to improve their management, according to the objectives of the WFD.

736 **4. Future perspectives**

737 *4.1 Basic research priorities*

738 *4.1.1 Hydrological research needs (Estimation and restoration of natural flow regimes)*

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

759 *4.1.2 Biological research challenges*

760 • *Diversity, metapopulation and metacommunity dynamics*

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

774 • *Seasonal dynamics of biotic assemblages*

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

781 • *Environmental requirements of biota*

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

789 • *Dry phase (dry river beds) and bioassessments*

790 Despite recent progress in understanding the role of dry channels as important
791 habitats for terrestrial arthropods (e.g. Wishart, 2000, Larned et al., 2007, Steward et al.,

792 2011, Steward et al., 2012, Corti and Datry 2015, Corti et al. 2013, 2014), the terrestrial
793 phase is not yet integrated into bioassessment strategies. In addition, the role of a dry river
794 bed as a movement and dispersal corridor for terrestrial vertebrates has only recently been
795 explored (Sánchez-Montoya et al., 2015). At the same time, the role of microbial
796 assemblages during the dry phase has been studied more recently (Timoner, 2014, Timoner
797 et al. 2014 a,b,c), and has shown their relevant resistance to drying and resilience to flow
798 return of these assemblages. A major environmental tipping point is when PRS turn into
799 NPRS; therefore, we need to identify the areas that are most sensitive to shifting from one
800 environmental state to an alternate state (i.e. early warning assessment). We also need to
801 consider the entire hydrological cycle in order to allow a more comprehensive assessment of
802 the ecological status of Mediterranean NPRS (Prat et al., 2014).

803 4.1.3 Biogeochemical research needs

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

813 The drought-induced hydrological disconnection in NPRS entails a distinct
814 spatiotemporal heterogeneity along watercourses, which translates into very different
815 sources of dissolved organic matter, potentially to be respired by the biota (Casas-Ruiz et al.
816 2016). Microbes in dry stream beds exhibit a higher respiration capacity than those in
817 flowing channels, and reach similar microbial activity rates than in upland soils (Gómez-
818 Gener et al. 2016). The biogeochemical understanding of dry channels is still at its infancy,
819 and much more effort is needed to quantify their relevance at the catchment and network
820 scale. Furthermore, the ecological and societal consequences of major organic and nutrient
821 pulses from NPRS during first flood events remain mostly unexplored (Bernal et al., 2013).
822 Also the impact of first pulses on the transport and retention of priority substances and
823 specific pollutants remains unknown (Dahm et al. 2016).

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

836 4.2. Applied research priorities

837 • *Monitoring*

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

843 • *Definition and mapping*

844 We do not know yet the detailed numbers, location, areal extent and length of NPRS
845 in the EU-Med area. "Dotted lines" on topographic maps are spatially inaccurate, and
846 therefore unreliable in efforts to locate and estimate numbers of NPRS. Moreover, EU-Med
847 Member States still have different perceptions on how to define NPRS; EU-Med countries
848 use different topographic mapping resolutions, which lead to very different estimations of
849 the total number and length of streams (McDonough et al., 2011). Hence, many NPRS are
850 excluded from assessments. It is obvious that a Europe-wide definition of NPRS is urgently
851 required, as well as a common registration and mapping strategy for the EU-Med basins,
852 taking into consideration local variations. Since NRPS are often considered as possessing no
853 economic value, it is unlikely that managers are going to install flow gauging stations in
854 these catchments; thus, mapping of NPRS could be, alternatively, achieved through citizen-
855 science projects. In some regions of France, for example, fisher associations are mapping

856 flow states across more than 3500 km of river networks, by means of visual observation
857 (Datry et al. 2016b). Such efforts could be applied at the European scale, currently one of the
858 goals of the Cost Action SMIRES.

859 • *Typological classification*

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

872 • *Development of appropriate metrics for ecological status assessment*

873 High biological variability due to high hydrological instability of NPRS, in particular
874 under climate change conditions (e.g. Bonada and Resh, 2013), pose a challenge in devising
875 suitable approaches to assess ecological status. The cumulative effects of hydrologic
876 variability, antecedent hydrologic conditions and drought events on biological assessment
877 systems currently used, are largely unknown. Setting reference conditions, that may vary
878 seasonally, can be problematic (Feio et al., 2014, Cid et al., 2016), while classifying ecological
879 status in periods close to the dry season is also an issue, as biological assemblages can show
880 quite different attributes compared to those during other flow periods (García-Roger et al.,
881 2013). In this latter circumstance, an increase in lentic conditions is often associated with a
882 decrease in the value of the metrics normally applied, possibly causing a serious
883 underestimation of the ecological status. In altered water bodies, these hydrology-related
884 factors often mask pollution, water abstraction and morphological alteration, and make it
885 arduous to disentangle the effects of different pressures on benthic assemblages.

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

905 *4.3. Conclusions*

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

917 In order to better understand and efficiently manage NPRS, targeted
918 interdisciplinary research is required. Therefore, a close cooperation among research groups

919 actively involved in various disciplines related to the study of NPRS, such as hydro(geo)logy,
920 hydrobiology, biogeochemistry and advanced monitoring technologies, is urgently needed.
921 The incorporation of social scientists and economists will be also very fruitful in order to
922 highlight the value of NPRS to society from an ecosystem service point-of-view. Recent
923 initiatives, such as the SMIRES COST Action, may contribute to setting and implementing
924 such research and management priorities.

925 NPRS are particularly vulnerable, because they lack adequate legislative and policy
926 protection, as well as appropriate management practices. In the EU-Med, the legal
927 framework and therefore an appropriate protection status of NPRS is still missing.
928 Moreover, minimum flow requirements and hydropeaking issues have been only partly
929 incorporated in previous RBMPs by the Member States (Sans and Schmidt, 2012). It is thus
930 vital to improve and implement effective measures concerning efficient monitoring,
931 sustainable management, as well as conservation and protection of EU-Med NPRS. As our
932 scientific understanding of NPRS is increasing, the importance of including them in policy
933 and management decisions of the EU-Med states will be highly recognised. In fact, the
934 translation of scientific work to legislation is a critical stage in management and protection.
935 Within this frame, the MIRAGE project recommended specific additions to WFD (Articles 2,
936 4, 5 and 11), by addressing the particular characteristics of NPRS, ultimately aiming to their
937 efficient management and protection (Nikolaidis et al., 2013). At the regional scale, the
938 “Instrucción de Planificación Hidrológica” (2008), in Spain, includes guidelines for water
939 management, following the WFD and the indices proposed to evaluate the ecological status
940 of Spanish rivers, mostly based on the work produced within the GUADALMED project. In
941 order to integrate NPRS in forthcoming RBMPs as specific river types, a close cooperation
942 between scientists, EU and national policy makers, as well as local management authorities
943 is urgently required.

944 The incorporation of the e-flows CIS Guidance (EU, 2015) in forthcoming RBMPs, as
945 well as the deterioration principle of the ECJ, may further promote efforts for NPRS
946 protection by securing the restoration of flow regimes. At the local scale, there is a need to
947 protect off-site refuges that are essential for maintaining the ecological integrity of NPRS
948 (e.g. see Pires et al., 1999), while measures, such as riparian reforestation to reduce
949 pollutant loadings during flood events (Tzoraki et al., 2014), and to increase quality and
950 quantity of tree-related habitats (Buffagni et al., 2016) should be also considered. The
951 application of floating islands may be a technical and economical efficient measure to

952 combat pollution, particularly during low flow periods (Pavlineri et al., 2016). Concurrently
953 to the implementation of specific conservation measures, there is an urgent need to define
954 economic alternatives to existing practices in irrigated farming at an EU-Med scale, in order
955 to reduce overall water consumption, in particular during the ecologically most sensitive
956 periods. This must coincide with the development of modern planning instruments, more
957 effective land use policies and the linking of the current Common Agricultural Policy to the
958 Horizon 2020 strategy (Nikolaidis et al., 2013).

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