River and Wetland Restoration in Greece: Lessons from Biodiversity Conservation Initiatives

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Abstract Rivers in Greece have seen extensive human-induced degradation, and there are increasing demands on the goods and services they provide along with increasing threats from future anthropogenic pressures. These multi-scale alterations to rivers and associated wetlands and riparian zones have severely impacted biodiversity. The Greek government has responded by creating various new protected areas and promoting interest in conservation, while attention to monitoring waters has increased with the implementation of the EU WFD. Unfortunately, bioassessment-based monitoring, long-term conservation programmes and restoration actions in rivers have lagged behind other EU countries. Here we outline the state of river and wetland restoration progress; we describe key restoration examples and discuss shortcomings, pitfalls and opportunities in various aspects of restoration.

Keywords Biodiversity conservation, Environmental history, Restoration, Rivers, Wetlands

Contents

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1 Introduction

Restoring rivers is somewhat like a complex medical therapy. Rivers are the "arteries and capillaries of the earth," providing pathways of water, sediments, nutrients and biota, and they are vital to human societies [1]. Rivers nourish and interact with wetlands and riparian zones creating living networks of corridors in the landscape [2]. The restoration of these ecosystems is not a straightforward undertaking; it requires the harmonised engagement of science, policy, local communities and management practices. Restoration does not solely mean returning ecosystems to a natural condition; rather it is an umbrella term to cover the full array of rehabilitation, mitigation, habitat enhancement, species transplants and other restorative measures meant to reduce the impact of human-induced degradation [3–5]. Ecological restoration in rivers should be understood as something concerning broader spaces than aquatic river channels; thus, an integrated river basin management approach should be pursued [6, 7]. A more science-based adaptive management framework takes careful planning and may have high costs. The challenge of scientifically guiding cost-effective restoration may help us to better understand the structure and functioning of complex river-wetland-riparian ecosystems and the management schemes required within specific sociocultural contexts [8].

In Greece, rivers and wetlands have been "managed" since prehistoric times [9, 10]. Some of the oldest reclamation projects, converting wetlands to agricultural land, were in karstic basins such as the lakes of Kopais (Boeotia) and Dystos (Euboea) [11]. Although extensive irrigation projects expanded in the 1950s, there is evidence that even in low-intensity traditional cultural landscapes, waters were often overexploited, long before the modern industrial era [12]. During the last five decades, water use for lowland agriculture has greatly increased, and large-scale water diversions and water storage structures have been created [13, 14]. Yet Greece remains a global hotspot for river and wetland conservation due to its rich aquatic biodiversity. The territory of Greece includes eight distinct freshwater ecoregions; it is a biological crossroad of unique international interest [15]. Remarkably, much of this diversity of river types and conditions is poorly documented, and there are no completed maps that accurately depict natural flow river regimes or a full wetland inventory for the entire country [16, 17]. In this context of data scarcity, long-term human-induced water stress, increasing anthropogenic pressures and threatened biodiversity, conservation and restoration actions may best be considered as a "crisis discipline" [18].

Various reasons have made restoration projects in Greek rivers and wetlands to lag behind in comparison to other EU Mediterranean countries. However, restoration is often mentioned as an important part of biodiversity conservation both in designated protected areas and in river water management units (i.e. the WFD 2000/60 water bodies); yet the restoration proposals are usually left "on paper." In this chapter, we provide a review based on accumulated experience of biodiversity restoration initiatives in rivers and associated wetlands in Greece. We also explore the shortcomings, pitfalls and opportunities in various aspects of restoration and propose some unmet needs and initiatives.

2 A History of River and Wetland Alteration in Greece

More than half of Greece's major river water bodies are now degraded by human-induced pressures [19, 20]. Furthermore, it is estimated that 68% of Greece's wetlands were completely drained or destroyed during the twentieth century [21, 22], while the larger ones endured important human pressures [14, 23]. Despite widespread impoverishment and loss, the concept of river and wetland restoration in Greece is something quite recent and poorly developed. In order to promote actions towards "therapy" for these degraded ecosystems, it is important to understand the historical context that has led to their current state.

There are historical and cultural reasons that explain a significant lag behind other European countries in the conservation and restoration of Greece's rivers and wetlands. Until 1974, malaria was endemic and widespread; Greece is said to have had the highest prevalence of malaria in Europe during the early twentieth century [24]. Wetlands and riparian zones of any kind, including lowland rivers and riparian floodplains, were considered "unhealthy" areas requiring drainage projects and mosquito poisoning campaigns [25, 26]. After WWII, hundreds of small wetlands and river floodplain ecosystems were destroyed or reclaimed to rid the country of these so-called unhealthy conditions. In the Greek islands, many wetlands were in-filled, drained or converted to industrial sites (e.g. many of the Greek island airports are on former wetland sites) [16].

Extensive efforts for agricultural development and land reclamation began in the 1920s and 1930s, in an effort to assist the resettlement of more than one million refugees who flooded in from Asia Minor after the 1919–1922 Greco-Turkish war. After the WWII occupation in the 1940s and the Greek civil war (1944–1949), an intensification of so-called agricultural reclamation and river engineering took place during the 1950s and 1960s [25]. The Greek Military Dictatorship (1967–1974) continued some unusual wetland drainage projects (e.g. the destruction of several wetlands on Euboea, Skopelos, etc.) [16]. Even as late as the early 1980s, wetland drainage and anachronistic river engineering and embankment-building anti-flooding works were ongoing due to efforts for regional economic development (e.g. the draining of Kandila Lake in the Peloponnese in 1981 and the raising of the Kerkini weir on the Strymon in the early 1980s). In one spectacular case, an entire deltaic lagoon was drained by local farmers in the Evros Delta, in 1987 [27]. In the name of supposed flood protection schemes, various river engineering projects, check dams and riparian modification works have been practised even in many upland areas [28] and especially in areas after wildfire damage.

By the late 1990s, many of the larger major wetland and lake areas were officially designated protected areas (i.e. including ten Ramsar sites, many sites in EU Natura 2000 network). As a result, many smaller, isolated wetland sites and small stream environments have been degraded to a greater extent than larger wetlands during the last 25 years [16]. In the rivers, although the rate of large dam building declined, many smaller dams and hydroelectric plants have been developed and are being planned on many small tributaries. The tapping of springs, over-abstraction and water transfer works continue to silently destroy aquatic life in small rivers and streams. Usually the small stretches of perennial waters that existed downstream of springs are given little consideration and are lost after a single water abstraction project. Despite attempts to protect the waters "on paper," as promoted by the EU Nature Directives, the war on "natural waters" has continued into the twenty-first century. Many incremental changes continue to degrade the state of rivers, small wetlands and riparian areas. In this century, some projects, which were supposedly acting as irrigation developments, have also masked actual drainage schemes, even in protected areas; one such case is the Acheron Delta drainage project, where a tunnel was dug through a hill to drain a wetland for agricultural and touristic development in the 2010s [29]. The artificial desiccation during the long summer period and total control of floodwaters aids the agricultural expansion of water-hungry crops in the smaller river deltas such as the Evrotas Delta [30]. These examples reinforce the fact that many smaller sites of lotic and wetland habitat are continually being degraded and much of the loss is poorly documented.

Although irrigation is responsible for approximately 85% of water consumption, adequate restrictions in this sector have not yet been developed and the domestic and industrial sectors are not water efficient [5, 31, 32]. In Mediterranean-type rivers, seasonal pollution is closely related to summer-autumn drought and associated declines in flows and water levels. Nitrogen fertilisers, nitrates, pesticides, phosphorous and organic discharges from urban and agricultural wastewater are the main pollutants of rivers in Greece [33] and these pressures intensify during drought periods. Moreover, mismanagement of irrigation schemes may lead to excessive irrigation water returning to rivers and wetlands which results in an increase of nutrient, sediment and pollution inputs into these systems [34]. Pollution crimes, such as illegal dumping of untreated sewage and industrial wastes directly into rivers and wetlands, are often documented, but polluters are rarely apprehended. The local pollution of groundwater is also a serious problem (e.g. Asopos river). Although the chemical quality of surface waters is generally satisfactory in the uplands, many lowland rivers, even small streams and wetlands, show the effects of seasonal pollution, while their impacts have been poorly monitored up until recently [35]. Implementation of EU legislation and structural funds in the last 25 years have been decisive in developing municipal waste water treatment infrastructure in all major cities, towns and industrial areas [36]. Some sewage treatment plants may periodically malfunction or are poorly planned and/or maintained, but overall, the large number of sewage treatment facilities has helped to ameliorate conditions in some river stretches, especially near certain cities [33].

The effects of drought and other meteorological extreme events, perhaps related to human-induced climate change, have caused significant damage to river and wetland biodiversity. The intensity of near-total desiccation during unusually prolonged summer droughts increases, since during these events, over-abstraction by humans also peaks. During prolonged drought, pollution or salinisation may often intensify [5, 37] and is usually signalled by mass fish deaths (e.g. [38, 39]; and references herein). In many cases, a lot of aquatic species eventually recolonise after the drought [40], but in some cases, certain invertebrates such as freshwater mussels and other molluscs and fish species will not be able to recolonise due to anthropogenic barriers to dispersal (such as dams and weirs). As a result, extirpation of many species, both locally threatened populations and widespread species, is commonplace, although inadequately documented in the literature [41]. One of the most dramatic periods of widespread desiccation took place between 1987 and 1992 in southern Greece [13, 42]. Although organised biological monitoring did not exist during this period, some species of fishes have been lost from certain river basins during this period [42, 43]. The effects of climate change and prolonged drought and ecosystem degradation due to ensuing climate variability and other associated effects on waters are predicted to have severe effects on biodiversity, such as cold-water fish species, in the near future [44].

Apart from the rivers and wetlands, riparian zones have also suffered, but these have been poorly inventoried or delineated in Greece [45]. The effects of riparian degradation are also seen in upland rivers [28] away from the lowland areas where agricultural intensification often erases any trace of riparian vegetation. Much of the damage in riparian areas and riverbank conditions is difficult to document and very widespread [46]. An increase in the roads next to streams and rivers, even within protected areas, has created remarkable damage particularly after the mid-1980s. The degradation of riparian zones in Mediterranean rivers often has powerful and unexpected effects on aquatic ecosystems (water temperature changes, increased siltation, erosion, instream habitat alteration, etc.).

Finally, a kind of "biological pollution" in the form of invasive animal and plant species is also a serious stress and mounting threat for Greece's river basins. Often influenced by changing hydrological conditions, water transfer projects, increased eutrophication and increased artificial storage of waters in reservoirs, many alien species in inland waters are on the rise [47]. Until the early 1990s, Greece had a relatively low incidence of alien fish species, but this number has increased especially in lakes and reservoirs and the lowland areas of the larger river basins [43]. Over 30 alien fish species are now present, some of which are the most invasive and harmful species in Europe, including eastern mosquitofish (*Gambusia holbrooki*), pumpkinseed (*Lepomis gibbosus*), Prussian carp (*Carassius gibelio*) and topmouth gudgeon (*Pseudorasbora parva*). Some species are spread by anglers, in order to increase recreation values; this includes species native to the country but artificially introduced outside the boundaries of their natural distribution. Trout and other native species, which are translocated from one river basin across ecoregional boundaries to other river basins, are a serious form of biological pollution. Although similar looking to the host basin species, these translocated alien fishes may result in hybridisation and genetic introgression (or effects such as outbreeding depression), which could affect reproductive success and cripple local native populations [48]. Furthermore, fish also transport fish diseases and alien invertebrates that can also infect areas where they did not formally exist. These anthropogenic changes could severely alter and/or homogenise previously endemic-rich ecosystems.

3 Conservation Policy and Cultural Context

Between the early 1990s and up until the first decade of this century, Greece increased its designated protected area cover from less than 3% to roughly 27% of the land territory [23, 49]. This was primarily a result of the EU Birds and Habitats Directives, which promoted the Natura 2000 network of protected areas and was supported by many NGOs and members of the scientific community [49]. Along with the WFD, which gives special reference to protected areas, grounds for management and restoration have ameliorated. Since the late 1990s, Greece has witnessed some positive institutional changes that assisted conservation management [50]. However, as is the case in other parts of southern Europe, Greece has struggled with severe implementation problems in its protected area network [51] and management plans [49, 52], and this has stalled progress in effective management, conservation measures and restoration, especially after the Athens 2004 Olympics.

Public awareness for water issues has risen in Greece. It is remarkable that a paradigm shift in many local communities' outlook on the values of river corridors and wetlands has taken place particularly since the early 1990s [5, 26, 53]. Wetlands and river valleys and deltas, once considered unhealthy wastelands, are being promoted for protection and "eco-development" [26, 54]. Although the value of Greece's river deltas and wetlands was originally promoted by visiting naturalists in the 1960s [55], the government commitment essentially began with the first delineation of large wetland areas in the 1980s enacted since Greece's ratification of the Ramsar Convention in 1975 and the Birds Directive's Special Protected Areas designations after 1980 [49]. Afterwards, many Greek NGOs and certain researchers and policymakers were effective in influencing society and state policy with effective protected area creation initiatives [54]. Especially the efforts of environmental NGOs are well known in the remarkable and rapid expansion of preliminary conservation areas or "paper parks" [56]. Much work by environmental NGOs promoted effective wetland protection and on-the-ground initiatives in particular. Few of these campaigns focused on restoration, and the focus was protection; for example, one of the longest and most bitter struggles concerned the Acheloos river transfer ([57] and references herein). Certain NGOs provided outstanding support for long-term conservation actions in certain showcase-protected areas such as Prespa, Zagori and Dadia, often touching on water-related conservation issues. Also, a small number of scientists in government institutions and academia effectively promoted a new interpretation of wetland values and the demand for protection of the larger wetlands and river delta areas [26, 58, 59]. Although problems did exist, conservation and restoration were often politically tied to efforts for EU-funded structural projects, tourism development and local identity promotion (see, e.g. [60–62]).

Efforts for protected area conservation, thus, gained an unprecedented rise in Greece especially after the early 1990s. By the early 2000s, a preliminary system of protected area management bodies was set up for 28 management bodies of the Natura 2000 network, many of them dominated by wetlands and lentic water bodies. Conservation and ecosystem restoration have become targets in the National Biodiversity Strategy [63]. Significant funding for biodiversity conservation developed after the Habitats Directive came into force in 1992. The EU financial instrument for the environment, the LIFE funding mechanism, achieved some important results, and it dominates Greece's aquatic-wetland-riparian restoration history.

4 Review of River and Wetland Restoration

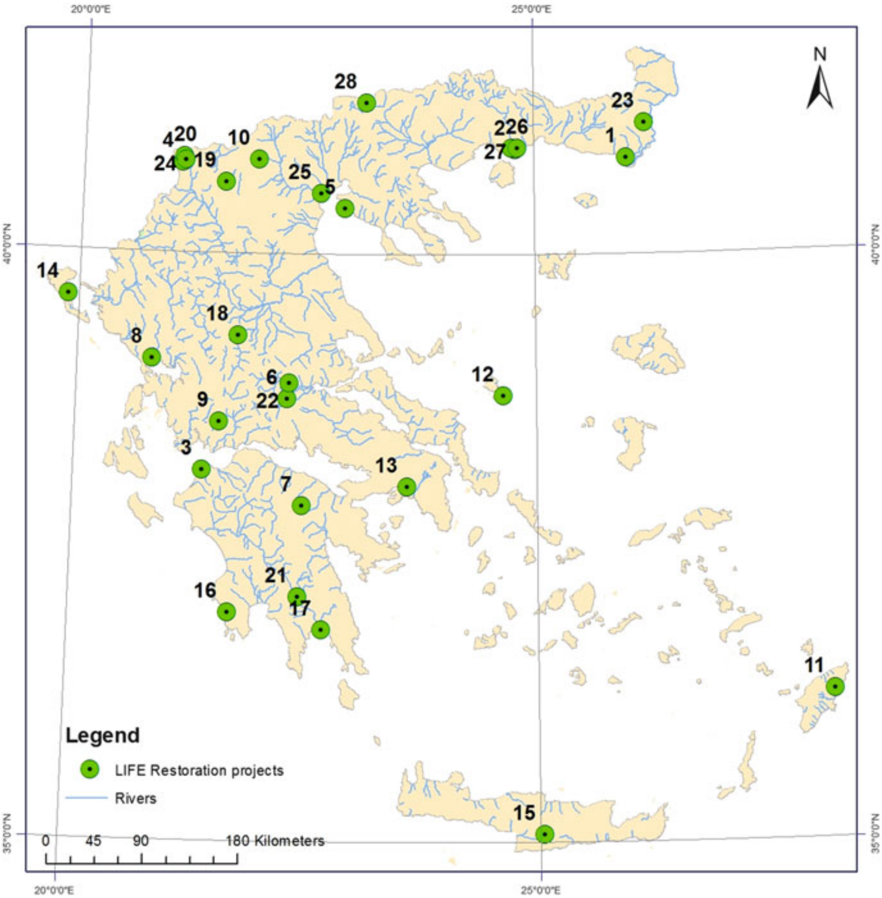
Restoration proposals, actions and monitoring are poorly reported in the scientific literature in Greece [5, 64]. During the 1970s and 1980s, there were no restoration actions aiming at conservation of the natural environment in rivers or wetlands in Greece. Very rarely were restoration works an advocacy issue in early conservation campaigns, which, until the early 1990s, concentrated on antipollution and preservation of natural areas or urban issues [49, 65]. Even urban park and stream engineering works are, by European standards, wholly anthropocentric, and there are few examples of creating or recreating new river habitat for river biodiversity, as was commonplace in many major cities in Europe and North America [66]. Restoration works are notably scarce in small rivers or intermittent and urban streams outside protected areas [45]. Until the mid-1990s, many studies and statements drafting interest for river restoration were made; however, nearly all of these ideas were left on paper.

Major ecological and restoration targeting biodiversity in inland waters effectively began with EU policy-relevant actions under the LIFE initiative in the mid-1990s. Since the inception of the LIFE programme, 213 projects have been implemented in Greece (up until mid-2014), which involve environmental innovation, protection of nature or biodiversity as well as information and communication. These projects correspond to overall investments amounting to €280 million, of which the EE contributed €150 million [63]. A review of the LIFE-funded projects where funds were placed to actively restore or enhance attributes of the river, lake, riparian or wetland environment in Greece within the LIFE initiatives shows that very few projects affect river or lotic ecosystems in general. Twenty-four (24) LIFE project examples are shown in Fig. 1; all of these have some interaction with river sections and associated wetlands. These projects were often of fairly large scale, involving several separate conservation and restoration actions, most targeting species and habitat types that are of priority for conservation in the European Union. Focus on habitat enhancement work for particular bird species dominates the actions. In fact, by 2005 more than 1/3 of all funds given for LIFE-Nature projects in Greece targeted just four high-profile vertebrate species, namely, Mediterranean monk seal, loggerhead turtle, brown bear and bearded vulture [67].

The most effective restoration actions for inland water biodiversity conservation are associated with long-term investments (i.e. 3-year projects or more) in the larger protected areas, such as Prespa, Amvrakikos, Koronia-Volvi, Strofylia-Kotychi, Axios, Nestos Delta and Evros Delta [62, 64]. One such project in the Amvrakikos (1999–2003) created a sluice-controlled break in the artificial embankment of the Louros river to re-wet the former river delta swamp of Rodia [68, 69]. The work was associated with the reintroduction of water buffalo for reed control [70]. The Amvrakikos LIFE project (and an INTERREG project immediately after this) also promoted a restoration of riparian woods along the Louros [71] (Fig. 2). Similar works on various wetland types have taken place in the Evros and Nestos Deltas [64]. The largest riparian forest restoration work in Greece has taken place at the Nestos Delta, where about 80,000 trees have been planted in an area of 280 ha [72, 73]; this initiative is also one of the few well-monitored restoration efforts in the country [74, 75]. Many LIFE projects also promoted lesser actions that affected wetland habitats such as pond building, riparian tree planting and water control structures for management.

Other than the LIFE mechanism, other projects also promoted biodiversity restoration, but these were often of small spatial and temporal scale and are very poorly documented. The EU INTERREG programme and the EU Structural Funds have also assisted restoration efforts particularly in the late 1990s and early 2000s. NGOs, government research institutes and university departments have been active too, often in cooperation with the local and federal government [76]. Some of these small projects were promoted by NGOs and local government, most of them in the 1990s and 2000s. Examples include restoration works such as removing in-filled debris (garbage and construction site infill) from coastal wetlands in Attika [77, 78] and a remarkable project to remove in-filled debris at the Moronis river and river mouth wetland, Souda, Crete [79]. Mitigation measures that promote wetland biodiversity restoration have rarely been practised, apart for the exceptional example in Schinias Marathon National Park in Attika after the Olympic Games [80].

Although conditions were more mature after the year 2000, it is remarkable that few ecological restoration projects were initiated in this century. The 2004 Olympic



No	TITLE	REFERENCE
1	Restoration and conservation management of Drana lagoon in Evros Delta	LIFE00 NAT/GR/007198
2	Habitat Management and Raptor Conservation in Nestos Delta and Gorge	LIFE02 NAT/GR/008489
3	Conservation management in Strofylia-Kotychi	LIFE02 NAT/GR/008491
4	Conservation of priority bird species in Lake Mikri Prespa, Greece	LIFE02 NAT/GR/008494
5	Actions for the conservation of coastal habitats and significant avifauna species in NATURA 2000 network sites of Epanomi	LIFE09 NAT/GR/000343
6	Conservation of priority forests and forest openings in "Ethnikos Drymos Oitis" and "Oros Kallidromo" of Sterea Ellada	LIFE11 NAT/GR/001014
7	Sustainable management and financing of wetland biodiversity – The case of Lake Stymfalia	LIFE12 NAT/GR/000275
8	Conservation management of Amvrakikos wetlands	LIFE99 NAT/GR/006475
9	Actions for the protection of the calcareous fens	LIFE99 NAT/GR/006499
10	Implementation of management measures at the Agras wetland	LIFE03 NAT/GR/000092
11	Conservation measures for the endangered fish Ladigesocypris ghigii	LIFE98 NAT/GR/005279
12	Demonstration of the Biodiversity Action Planning approach, to benefit local biodiversity on an Aegean island, Skyros	LIFE09 NAT_GR_000323
13	Integrated approach for solving the problem of liquid hydrocarbons present in the Hellenic Aspropyrgos refinery (HAR)	LIFE96ENV/GR/000535
14	A Resource Exchange Programme For River Potamos	LIFE98 ENV/GR/000234
15	Mediterranean reservoirs and wetlands. A demonstration of multiple - objective management in the island of Crete	LIFE00 ENV/GR/000685
16,17	Implementation of management plan for Pylos Lagoon and Evrotas Delta	LIFE97 NAT/GR/004247
18	Implementation of management actions for Tavropos Lake area in Greece	LIFE99 NAT/GR/006480
19	Conservation management of Cheimaditida-Zazari wetlands	LIFE00 NAT/GR/007242
20	Bird conservation in Lesser Prespa Lake: benefiting local communities and building a climate change resilient ecosystem	LIFE15 NAT/GR/000936
21	Development of Ecotourism in the Riparian Ecosystem of Evrotas near Sparta	LIFE94 ENV/GR/001263
22	Integrated management of Sperchios River ecosystem	LIFE92 ENV/GR/000054
23	Conservation of birds of prey in the Dadia Forest Reserve, Greece	LIFE02 NAT/GR/008497
24,25,26	Conservation of Phalacrocorax pygmaeus and Anser erythropus in Greece	LIFE96 NAT/GR/003217
27,28	Living Lakes: Sustainable Management of wetlands and shallow lakes	LIFE00 ENV/D/000351

Fig. 1 Examples of conservation-oriented EU LIFE-funded projects that involved restoration practices in Greece's rivers and associated wetlands in the last 20 years

Fig. 2 Restoration works at Amvrakikos wetlands (clockwise from *top left*): the river Louros floodplain at Petra (riparian forest restoration actions); canal and sluice construction in the Louros floodplain (2001); reintroduced water buffalo to enhance reed-bed diversity; canal reconnecting to wetlands and buffalo fencing (Photos: S. Zogaris)

Games was an important catalyst for various mega-construction projects in Athens, and some ideas and mature proposals that were meant for conservation were actually displaced by pressing Olympic Games infrastructure timelines after late 1997, the year that the Games were awarded to Athens. After 2008, work on restoration also subsided due to Greece's economic recession. The economic crisis years helped shift the attention away from nature conservation and restoration aims which had been proposed since the 1990s [50]. A prime example of this is the notable delay in the application of the programme of measures in designated river water bodies for the implementation of the EU Water Framework Directive 2000/60/EC in Greece.

5 Achievements

5.1 Inventory and Classification Baselines

In-depth wetland and water body inventories were first introduced in the early 1990s [81], and they continue with policy-relevant applications. Baseline wetland site inventory work was done by the Greek Biotope-Wetland Centre (EKBY) [82] and by WWF Greece [16]. River, lake and riparian zone monitoring was promoted by HCMR and EKBY [17, 20]. Typologies for artificial water bodies and their values to biodiversity were also recently attempted [83]. These baselines are of outstanding value for conservation planning and are all fairly recent developments that require refining and completion [17]. These efforts were also important in providing the first surveys of Greece's richness in terms of all inland water ecosystems. They also assisted in promoting policy stakeholder and public sensitisation.

5.2 Local Studies and Restoration Planning

Due to EU policy directives and land use planning needs, many biodiversity conservation studies were commissioned particularly between the early 1990s and the first decade of the 2000s. Restoration was often mentioned and designs were set [84]. Some challenging issues such as artificial water bodies have also recently been investigated (e.g. reservoirs on Crete, see [85]). Proposed management plans within the policy-relevant special environmental studies for delineating and applying measures for protected areas provide many practical experiences [64]. In many cases, large-scale studies focused primarily on severe degradation problems in lakes and coastal lagoons (e.g. Lakes Pamvotis, Kastoria, Koumoundourou, Karla, Koronia) [86–88]. River basin management in an integrated form is being developed, and science-based management is being promoted in recent years, often incorporating needs for restoration (e.g. [84, 89]). Many of the studies have become interdisciplinary in recent years, but research and proposals continue to focus on lentic rather than lotic water bodies (e.g. [90]).

5.3 Learning by Practice

Biodiversity conservation-oriented restoration actions, particularly through the EU LIFE projects, focused on threatened species and, in particular, the so-called priority species and habitat types, as demanded by relevant EU directives. These included emblematic ecosystems such as lakes, coastal lagoons, riparian woods and various river delta habitats and wetlands. Efforts targeting habitats in places such as the Nestos Delta, Evros Delta, Amvrakikos Gulf wetlands, Gialova-Pylos, Strofylia-Kotychi wetlands and Prespa are in tune with local conservation awareness and should be regarded as important "initiating acts" for restoration [64, 91]. Much of this often complicated, restoration-conservation work had never before been attempted in Greece, so it is an important "practice" for future work. In fact, it has been said that without the LIFE-funding mechanism, modern biodiversity conservation practice, as we know it, would be "non-existent" in Greece! [92].

However, there are many biodiversity elements that have still received very little attention. Fish are rarely targeted by conservation-restoration projects, and there is very little experience in restoring the ichthyofauna in Greece. In the Spercheios river basin, one small government-funded conservation project successfully executed the first species transfer (assisted migration) of the endemic Greek stickleback *Pungitius hellenicus* to an adjacent spring-fed pool that harboured no fish in 1997 [93]. The small population of translocated fish survives to this day. Efforts for translocation of similarly range-restricted species have also recently begun in other parts of Greece (Kalogianni, E. pers. com). Another important fish-based project, this time a LIFE-Nature project, targeted the endemic Gizani of Rhodes, *Ladigesocypris ghighii*, and was also important as an initiation into river restoration actions for a threatened freshwater fish in Greece [94]. During the project's survey work, the threatened species was also discovered in new areas on the island [95]. Remarkably, no other LIFE project has applied integrated, scientifically led, restoration targeting endangered freshwater fish species in Greece [96].

Since Mediterranean riverine landscapes and riparian zones have seen a decrease in ungulate grazing regimes, the reintroduction of grazing by large herbivores is important. This kind of work was initiated in wetlands in the late 1990s. In Greece, reintroduction of water buffalo has seen success [97, 98]. Good evidence-based restoration results were produced during a LIFE project also in reed-bed management from the Amvrakikos wetlands (e.g. [99, 100]), and now water buffalo populations have increased and spread to other wetlands (e.g. Spercheios).

It should be noted that even small-scale restoration works, unrelated to large, long-term projects, seem to be important for conservation education and awareness at the local level; this has been well demonstrated by the WWF Greece campaign for small wetlands on Crete and other islands [79]. Work on urban rivers is important as an "initiating enterprise" for restoration [101–104]. Interest in this aspect through the concept of green infrastructure in cities has recently been given increased attention [66, 105], but on-the-ground applications are scarce. Focus on riparian corridors in cities in Greece is a very new subject that should see important developments in the coming years [104].

New technologies for restoration in polluted waters, such as sewage treatment and water purification, are also on the rise [36], and some are of immediate interest for restoration of rivers and associated wetlands [106–108]. A major problem in Greece is olive oil mill treatment waste that is usually dumped directly into small rivers and streams; some pilot-scale work on this issue has begun [109].

Some evidence of notable conservation successes shows that strategic conservation actions can reduce the rate of species and population declines. The positive achievements of some of these species-centred conservation projects in Greece are seen primarily in effects on bird populations at specific sites. There is evidence that several species of birds requiring wetland and river delta habitats have increased during the last three decades [110]. In wetlands such as the Prespa, Kerkini, Karla, Evros, Amvrakikos and other sites, this is directly the result of targeted conservation and restoration efforts [111]. Since birds are not persecuted by humans as they were in the recent past, some populations have rebounded, such as pelican, cormorant and heron species [112]. Birds are good indicators of management of wetlands and other inland water bodies at the landscape scale [113, 114], and they have seriously promoted conservation designation and management [115] as well as restoration proposals in Greece (e.g. [116, 117]). Unfortunately, there are very few cases where there has been mention of benefits to other animals, such as fishes, from restoration projects in Greece (an exception is outlined in [118]). Despite the species-specific success stories, many species remain conservation dependent, requiring sustained, long-term investment that may require future restoration actions.

6 Failures, Shortcomings and Challenges

6.1 Problems with Past Restoration Projects

The largest restoration works that influence running water environments and their surroundings have very few follow-up actions, serious monitoring or adaptive management frameworks (e.g. Evrotas, Amvrakikos, Evros). In nearly all cases, the effectiveness and cost-effectiveness of these actions have been poorly assessed or monitored and disseminated in published works. One exception is the exemplary case of riparian woodland restoration in the Nestos river delta, which did provide a post-restoration monitoring plan [73], and in this case there is close cooperation with local Hellenic Forest Service workers and other stakeholders to monitor results at this important site.

It is rather unusual that most restoration efforts rest on large and often expensive engineering or forestry initiatives in high-profile degraded lentic or wetland habitats; there are very few efforts in the lotic environments and surprisingly few in small running waters and urban running water settings [45]. The lack of research, monitoring and understanding of river ecosystems functions, such as self-purification attributes of rivers, may also create complexities in applying ecological restoration [119]. Even some typical mitigation structures such as “fish ladders” in small hydroelectric works have no documented assessment of effectiveness in Greece.

Defining goals for the re-establishment of degraded river basin ecosystems such as drained foodplains and lakes has also created some examples of “failures.” Of course, assessing the success of a project should always consider local sociocultural and political circumstances, yet guidelines for assessing the success of ecological restoration works are fairly simple (see [7]). Although not related to a lotic environment but a unique semi-isolated sub-basin of the Pinios river, the Lake Karla area was the most expensive restoration project in Greece [120] and was originally designed primarily as an ecological restoration action [88]. Instead of working to restore a natural lake-floodplain system, Lake Karla was created as a multifunctional and ambitious reservoir system with huge embankments and artificial water pumping works that would also supply future water for irrigation. This situation created some serious problems, including harmful algal blooms [120, 121]. Other problems where EU funds have been spent on reservoir or irrigation development instead of real ecological restoration actions have also been documented; two examples are the Atzan wetlands [122] and Lake Taka [123].

6.2 EU WFD Challenges

River restoration is a critical part of the EU WFD (Water Framework Directive 2000/60/EC), which is guided by river basin management plans (RBMPs) that should implement a programme of measures (PoMs) for degraded river water bodies. There has been considerable delay in the implementation of the Water Framework Directive actions in Greece, and this has already led the European Court of Justice to rule against Greece for not having completed the RBMPs on time [124]. The roots for the majority of the implementation problems are in governance and its changing architecture in Greece (see [125]). Also, since there is a poor history of limnological and ecosystem research in rivers, there is a poorly defined understanding of real restoration needs. Monitoring of conditions, especially the biota, began very recently at a nationwide scale [126]. However, despite these serious shortcomings, the framework for monitoring, planning and river basin management that the WFD has brought to Greece has seriously changed and challenged river management issues [127].

6.3 Current Management Difficulties

In many cases, restoring rivers and wetlands may be impossible, even if economic constraints could be surpassed (i.e. in urban and agricultural landscapes). Local socio-economics and politics influence the work's effectiveness by challenging the administration, planning and management related to these restoration projects; such coordination difficulties have been observed in many large-scale EU-funded projects in Greece [23]. In some cases, poor decision-making at the central and regional levels can lead to bad practices that resonate with negative aspects, e.g. the case of Lake Karla [120, 128] and difficulties with river conservation management at the Spercheios River [129]. In other cases, governmental control and development, even when guided by strict policy demands, may falter or fall behind, as is the case with Greece's river basin management plans [125, 126]. The economics and socio-economics of restoration planning are very important: perhaps in some cases it may be more effective to simply protect what you have than to focus on expensive narrow-scale restoration efforts. Such management difficulties become more complicated in times of economic and political instability. For 8 consecutive years, Greece has been greatly affected by the most severe economic crisis since WWII: a deep economic recession, sharp reductions in government spending and constant increase in unemployment rates. With this in mind, and despite the demands of EU and national policies, conservation and restoration actions may continue to fall further behind.

6.4 The Research-Policy Disconnect

EU Directives guide management objectives; however, optimal river basin management is hindered by a disconnect between policy-relevant research and action on the ground. Although the WFD is a stringent bureaucratic process, many aspects of its implementation in Greece seem to have somewhat progressed but with many difficulties. Some of the problems are grounded in ecosystem management concepts and applications [126]. One of the most important aspects is the importance of understanding aquatic ecosystem ecological integrity and designing restoration actions through the development of river-type-specific baselines and water body-specific targets. The WFD demands the use of type-specific reference conditions for assessment and as measures for restoration. This is correct in an ecological restoration framework, since the design of an ecological river restoration project should be based on a specified guiding image of a healthier river that could exist at the site [7]. However, the concept of "reference" is still debated within the scientific community and among management and conservation practitioners [6, 130]. Reference conditions can be historically based, geographically based or process based, and absolute or relative, depending on context and the specific spatio-temporal and ecosystemic thresholds. Understanding the natural history of varied river types is very important to restoration planning [131], and this is vital in any kind of ecosystem-based river management. There is increasing emphasis in Europe on river restoration driven by demands of the WFD; however, Greece has yet to promote restorative measures in its river water bodies [125]. Moreover, the current focus on instream aquatic conditions and aquatic biota that is routinely monitored ignores that many of the pronounced effects of degraded hydromorphology relate to the headwater intermittent streams, riparian zones, related wetlands and their wider floodplains. This problem is pronounced in the Mediterranean countries as a whole but is accentuated in data-scarce and poorly monitored situations such as the case of Greece [126].

Assessing the state of ecological integrity and measuring degradation are not easy or straightforward in Mediterranean river basins dominated by such long human history in complex cultural landscapes. The influence of humans on water resources is confounded by the region's inherent climate variability, since it drastically influences river flow regimes, river hydromorphology, biodiversity patterns and habitat structure. The degradation of the flow regime is the most widespread and often most destructive human-induced pressure in Mediterranean rivers; it is also difficult to accurately assess what is a natural or anthropogenic variation. Scientific reconstructions of the wider region's climate demonstrate a series of alternating periods with varying climatic characteristics with fluctuation lengths spanning from a few decades to many centuries [132]. In Crete, for example, during the little ice age (ca. 1,500–1,850 AD), it has been estimated that nearly two dozen perennial rivers run straight to the sea, whereas now less than five major streams do so during the summer months [12]. Part of this change is attributed to recent climate warming and part due to overexploitation for modern agriculture. Without in-depth study within each river basin, it is difficult to assess the degree that human-induced pressures have on recently altered waters [33, 40]. Building adequate and adaptive monitoring and multidisciplinary collaborative research at the regional and ecosystem scale is required for more effective and efficient restoration application in such complex conditions.

7 Unmet Needs and New Challenges

In the last few decades, three major types of restoration measures have been widely promoted in streams and rivers in Europe, America and Australia: riparian buffer and floodplain management, instream habitat enhancement and the removal of weirs and dams [131]. In Greece, even these basic actions have rarely been attempted in river environments, so there is much opportunity for this kind of policy-relevant restoration work in the future.

The following initiatives are deemed important in terms of ecological restoration, focusing particularly on river ecosystems and associated wetlands in Greece:

- Water pollution-related issues. Acute problems caused by poorly functioning sewerage treatment plants, small industry and poor controls on dumping still exist despite cleanup efforts.
- River floodplain restoration for flood control and flood protection. This synergy with restoration involves riverbed widening and embankment dismantling.
- Hydromorphological restoration in combination with habitat enhancement in protected areas. The channel, riparian zone, sediment and flow regimes may be restored in some cases through biodiversity conservation initiatives (e.g. in protected areas).
- Ecological flow issues below dams. This includes mitigation measures for fish migration (fish ladders).
- Water management issues in irrigation networks. Control and recharge, allowing more water to follow a natural flow regime in the extensive irrigated lowlands.
- Small urban stream restoration. Many cities could have greenways and rehabilitated stream reaches in an effort to expand constrained bed and riparian zones for green infrastructure and flood protection.
- Alien species management. Strategic management must be developed to clean problems associated with this form of "biological pollution."
- Monitoring and follow-up on restoration initiatives. These include works in the larger wetlands and river engineering areas; these can become "schooling" experiences for technique and educational development (Fig. 3).

Fig. 3 Challenges for restoration ecology in Greece (clockwise from *top left*): urban stream restoration, the flood-prone area of the Pikrodaphne stream in the Metropolitan Athens basin; road culvert creates artificial fish barrier in the Erymanthos river basin, Peloponnese; poorly designed urban spring-fed river park creation at the town of Skala, Peloponnese (Photos: S. Zogaris)

Some other outstanding and rather difficult issues that have intriguing idiosyncrasies and are important for biodiversity conservation in the future are outlined below:

7.1 Insect-Borne Diseases

After 2009 there is evidence that the malaria situation in Greece has been changing as locally acquired cases of *Plasmodium vivax* malaria have been repeatedly documented [133]. A reason for this spread is an influx of human immigrants from Asia and Africa and a change in the agricultural workforce that uses undocumented migrant workers, the majority of whom are from malaria-endemic tropical countries. As malaria cases and some other insect-borne diseases that are sometimes thought to be associated with "wetlands" increase, vector control will become important and may alter societal views of wetland and natural river habitats in the affected areas. The issue of malaria and other mosquito-borne diseases (such as West Nile virus) is serious for wetland and river conservation. Careful planning and multisectoral collaborations are needed both for human health protection and evidence-based treatment and for scientifically guided public awareness. Local communities and local government in Greece have recently wrongly targeted wetland drainage referring to mosquito control [29]. The issue of mosquito-borne disease and its relation to human migrants has recently been called a "public health tragedy" [134]. Great care is needed not to skew the public and policy approaches to wetland ecosystem conservation due this potentially serious health management issue.

7.2 Assisted Migration or Reintroduction of Fishes and Other Species Groups

Assisted migration refers to the human-aided translocation of select species or populations of plants and animals to suitable habitats outside their current ranges as well as to new sites within their current ranges. Although this issue is a source of debate among some conservationists [135], it is an imperative for saving rare species especially within conditions of extreme climate variability and change in situations of human-induced water stress and habitat and/or species population fragmentation [136, 137]. Already, some fish species have been extirpated and some are already extinct in the wild in Greece. This issue applies to fishes such as sturgeon, shad, salmonids, lampreys and local populations of several endemics in Greece. Many of these species are on the edge of extinction, and it seems that all sturgeon populations (four native species) have completely collapsed in Greece, in recent years [43]. Well-designed restocking programmes within a framework of fisheries management, protection measures and habitat rehabilitation may serve as valuable tools for reintroduction or enhancement of wild stocks. However, the risk of losing genetic variability, which happened after the massive restocking programmes abroad, should be thoroughly considered in advance. A strong level of scientifically led conservation genetics is required to do this kind of work (see [138]). Unfortunately, most previous efforts in Greece have had poor or no results (e.g. [139, 140]).

7.3 Managing "Novel Aquatic Ecosystems"

Heavily modified and artificial water systems may drastically change ecological integrity of wider river basins. Artificial water bodies, such as ditches and artificial channels, trans-basin transfer canals and instream reservoirs have been constructed in many river basins in Greece, and these are rarely managed for their biodiversity or ecological potential [83, 141]. Recently, these human-modified systems are

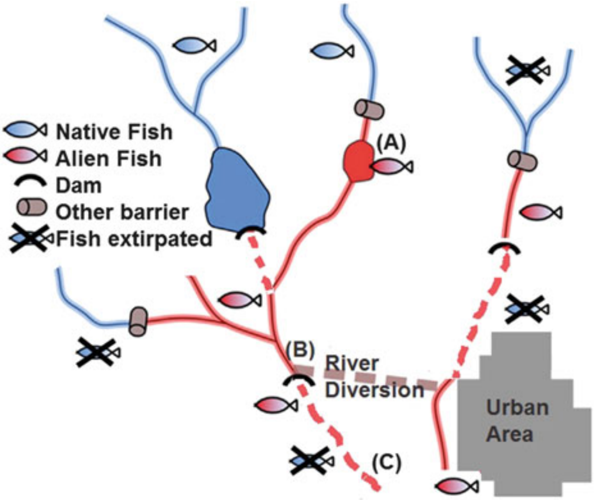


Fig. 4 Schematic representation of the interactive effects of artificial changes in aquatic connectivity and intermittency producing significant biotic changes and novel freshwater ecosystems. (**a**) Alien fish stocking in a lake spreads invasive fish species (*red* stretches), and (**b**) inter-basin diversion of stream flow to a city in a neighbouring basin (indicated by broken *red/grey line*) further assists invasive spread. Native fish species populations become fragmented into a series of isolated populations in headwaters (*blue-shaded* streams) above artificial barriers. (**c**) Artificial barriers and dams have produced stretches where fish are extirpated, and some of these are artificially intermittent (shown by *dotted line* for the river stretch) Adapted from [144]

being called novel aquatic systems, and their management is being treated as being important for biodiversity [142, 143]. The interaction of these systems with natural stream conditions and the spread of alien species is a growing conservation concern [144], and often several basins may be degraded when human-induced connectivity, artificial flow and alien species interact (Fig. 4). The degraded novel systems may function as reservoirs for the spread of alien invasive species further degrading ecological integrity. A scientifically led precautionary approach is needed to assess both the negative impacts and conservation opportunities provided by novel aquatic ecosystems.

7.4 Adaptations to Climate Change

A key characteristic in Mediterranean climate conditions is the remarkable climatic variability observed during the last few centuries [132]. The southern Balkans are among the regions which are predicted to become drier under IPCC climate scenarios, and the hydrological effects have concerned several researchers [145]. In recent years, there has been evidence of increased climatic dryness in parts of Greece, and an alarming indicator is the decline of spring-fed water systems [146]. Hydromorphological and flow regime change evidence is also being compiled (e.g. [147]). Ecohydrological modelling has shown that predicted scenarios will alter ecosystems, for example, cold-water biota such as trout streams [148]. For the conservation of biodiversity, it is important to focus on four initiatives for adaptation to climate change: (a) land and water protection and management, (b) direct species management, (c) monitoring and planning, and (d) law and policy (see [149]). Gaining experience in restoration and in assessing and understanding scientific ecosystem change and evolution is critical for effective adaptation to this broad-scale and largely poorly predictable environmental change. The need to promote adaptive management frameworks in aspects of conservation and monitoring is also an imperative within the climate change context.

8 Conclusions

Until recently a wholly anthropocentric development worldview has exploited rivers and wetlands solely as commodities and for human health risks (as related to insect-borne disease and flooding). This paradigm has changed in Greece as many rivers and wetlands have been designated as protected areas primarily for their biodiversity. Still, progress in integrated conservation and restoration has been very slow [51]. There are many opportunities to develop restoration in rivers in Greece; some important approaches include the following:

- The WFD's programmes of measures (PoMs) for water bodies represent the most important opportunity for widespread policy-relevant restoration in river corridors.
- Ecological flow measures are an important unmet challenge, and beneath many hydroelectric dams, there are significant degradations due to flow regime alteration (e.g. hydropeaking). Holistic approaches should be developed that are both policy relevant and satisfy site-based optimal mitigation measures.
- Reintroduction or assisted migration schemes for fishes and other species could assist both biodiversity conservation and community restoration; fish pass construction is also important and poorly implemented in Greece.
- Biodiversity restoration applications should work synergistically with WFD demands in protected areas (e.g. aimed specifically at habitats and species assemblages that have been degraded by hydrological and hydromorphological changes).
- Antipollution initiatives and strictly enforced regulations can make a very big difference especially targeting point-source pollution problems (light industry, agriculture, sewage treatment plant outfalls).
- Taking advantage of land abandonment, which facilitates renaturing and rewilding in river riparian zones, could promote the conservation/restoration of floodplain buffers.

– Riparian and river restoration in urban and peri-urban areas in combination with flood protection schemes should enhance best practice, green infrastructure and public awareness.
– Involving the public in volunteer and citizen sciences, that is, promoting restoration actions also for education, recreation and ecotourism. This is again important especially in urban, peri-urban and touristic protected areas.

Significant positive synergies may be created especially with respect to flood control and river engineering requirements in agricultural areas and WFD measures within protected areas. An example of this is "river widening" engineering practices, since this can become an important tool to link ecological objectives with flood protection and habitat enhancement, recreating multichannel networks in previously artificially constrained channelised systems. Although this is now widely practised in Western Europe, efforts in Greece are usually only at the proposal stage (e.g. [101]).

Ecological restoration is not an easy and straightforward undertaking [8], especially in Mediterranean rivers [150]. In Greece, a problem is the disconnect among scientists, society and conservation/water management practitioners. Since the 2008 economic crisis, it is inevitable that many members of the public may see restoration actions as a luxury. This negative perspective must change for serious broad-scale restoration work to move forward. It has been shown that volunteer involvement is extremely important and valuable for guiding conservation planning and promoting positive stakeholder involvement and science-guided public awareness. Citizen science may also provide screening-level information for river and wetland conditions; data from participatory monitoring networks are not less informative and may sometimes be more informative, than those collected in professional schemes [151]. The Natura 2000 protected sites and their management agencies could play a leading role in providing best practice applications that involve citizen scientists [64]. Scientific monitoring of rivers is now a policy-relevant imperative, and this should develop into an adaptive monitoring approach that can guide, prioritise and better inform conservation and restoration needs.

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