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Linking vegetation patterns, wetlands conservation, and ecosystem services provision: From publication to application

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Abstract

1. Natural wetlands emerge as the best sites to preserve the diversity of aquatic and riparian vegetation; however, especially in the lowlands, pristine wetlands and aquatic ecosystems have almost completely disappeared through land reclamation and agricultural development. Actions are needed, therefore, to maintain and recreate a wide network of wetlands able to preserve adequate levels of vegetation diversity.

2. Focusing on a complex wetland system located in an overexploited plain, the article entitled ‘The importance of being natural in a human-altered riverscape: Role of wetland type in supporting habitat heterogeneity and the functional diversity of vegetation’, published in 2016 in Aquatic Conservation: Marine and Freshwater Ecosystems (AQC) explored the role of wetland origin and hydrology as the main drivers of physical and vegetation functional diversity, following a hierarchical sampling approach.

3. The main results reinforced the key contribution of natural sites in maintaining vegetation diversity in heavily impaired riverine contexts, suggesting a direct effect of the interannual and seasonal dynamics of water-level variations in the observed vegetation patterns.

4. The article offered an important contribution to our knowledge of vegetation patterns in wetlands, partly attributed to the innovative functional, hierarchical approach applied which is able to guarantee reliable data on the distribution patterns of physical heterogeneity and wetland vegetation.

5. The findings of the article have been applied and adopted in a series of technical handbooks designed, inter alia, to support the monitoring programmes of habitats of community interest or vegetation of relevance for aquatic biodiversity conservation. In addition, this article has helped to raise awareness of the essential roles

played by wetlands in agricultural landscapes and has emphasized the need for a better synergy between the European Habitats Directive and the Water Framework Directive. Several ecological recovery projects have been funded in line with the results described in the AQC article.

Keywords: wetlands; floodplain; pond; biodiversity; conservation evaluation; ecosystem services; macrophytes; vegetation; pollution; nutrient enrichment.

Introduction to the paper "*The importance of being natural in a human altered riverscape*"

The preservation of aquatic plants is a key pillar in biodiversity conservation: inland aquatic ecosystems are among those most at risk on a global scale, and aquatic plants are one of the most threatened biological groups (Bolpagni, Laini, Stanzani, & Chiarucci, 2018; Dudgeon et al., 2006). Moreover, aquatic plants play crucial roles in colonized environments by actively regulating carbon and nutrient cycles, providing niches and food resources for heterotrophic metabolism, and by the physical and chemical stabilization of the water bodies colonized (O'Hare et al., 2018). Hence, aquatic plants are acknowledged to be 'engineer species' (Bolpagni, Laini, Soana, Tomaselli, & Nascimbene, 2015; Bouma, De Vries, & Herman, 2010; Marzocchi, Benelli, Larsen, Bartoli, & Glud, 2019; Ribaudo et al., 2018), the progressive disappearance of which results in drastic consequences for the metabolic and functional status of aquatic habitats (Hilt, Brothers, Jeppesen, Veraart, & Kosten, 2017; Scheffer, Hosper, Meijer, Moss, & Jeppesen, 1993). To counteract the continuing loss of aquatic plants and associated services and functions it is necessary to set effective global conservation strategies. This can take advantage of the increasing knowledge of aquatic plant spatial patterns (Murphy et al., 2019), and of the adaptive responses of aquatic plants to environmental drivers and perturbations (Alahuhta et al., 2017; Calero, Morellato, & Rodrigo, 2018; Stefanidis, Sarika, & Papastegiadou, 2019).

In this context, the article by Bolpagni and Piotti (2016), published in Aquatic Conservation: Marine and Freshwater Ecosystems (AQC), offers an important contribution to the understanding of the role of wetland origin (i.e. natural or artificial) and hydrology (i.e. lentic or lotic) in driving the physical heterogeneity and the functional diversity of the vegetation hosted by wetlands. This paper investigated a series of riverine wetlands (60 sites) across a riverscape (the Oglio River, in northern Italy) that is subject to severe impacts. It followed a hierarchical approach in order to allocate the sampling effort equally, at the scale of the site, based on the seasonal evolution of patterns in waterlevel variation (Bolpagni, Bartoli, & Viaroli, 2013) (Figure 1). This allowed us to discriminate the presence or absence of four distinct functional zones (FZs): 'persistently aquatic', 'riparian', 'seasonally emergent', and 'lateral' zones. Each zone was then sampled to describe the perennial and annual plant communities hosted using five replicates – in the range of 4–16 m2 – per FZ.

The results confirmed the fundamental role played by natural sites in maintaining the diversity of aquatic and wetland vegetation in heavily impaired riverine contexts. Indeed, the artificial sites (ponds and ditches) showed reduced structural heterogeneity (i.e. a lower number of FZs) and vegetation functional diversity (i.e. a lower number of vegetation communities), compared with natural ponds and rivers. This outcome appears to be reliant on the inter-annual and seasonal patterns of water-level variations. The natural lotic sites (i.e. ponds) were characterized by marked semi-drying phases during summer, whereas the artificial lotic sites (i.e. ditches) were in use from May to late August for irrigation, and accordingly were constantly wet or inundated throughout the summer. Drying events, however, can also trigger negative successional dynamics, favouring the entry and establishment of terrestrial and ruderal plants into wetlands. At the same time, differentiated hydroperiods may expand the niches available for colonization by aquatic and wetland taxa (Brose, 2001; Toyama & Akasaka, 2017). These conflicting findings suggest the existence of complex, often hidden, interactions between physical and biotic factors in inland aquatic ecosystems, and call for further research attention.

Under high levels of human disturbance, typical of highly productive irrigated plains, the aforementioned evidence and reflections stress the need for active measures to support local aquatic biodiversity. This is especially true considering that almost all lowland natural aquatic environments have been reclaimed throughout the world (Junk et al., 2014), and that local aquatic biodiversity conservation strategies are often based on artificial wetlands (Guareschi, Laini, Viaroli, & Bolpagni, 2020). It follows that without action aimed at recreating a widespread network of wetlands it will not be possible to guarantee the survival of a consistent portion of wetland vegetation diversity. To achieve this global result, particular attention must be paid to the design phases of new wetlands in order to guarantee adequate levels of physical complexity.

2 | PRIMARY IMPACTS OF THE AQC PUBLICATION

2.1 | Analysis and management of habitats, vegetation, and species

The article by Bolpagni and Piotti (2016) has been part of a wider process of raising awareness of the pivotal contribution of small standing aquatic ecosystems (SWEs) and irrigation systems in supporting biodiversity (see Bolpagni et al., 2019, and references therein), especially in agricultural landscapes, as well as in urban environments (Oertli & Parris, 2019). Hence, when compared with larger lentic freshwater ecosystems the SWEs show lower area/perimeter ratios, emphasizing the role of ecotones in regulating local metabolism and functions (Schiemer, Zalewski, & Thorpe, 1995). These habitats are therefore characterized by high levels of productivity, which are often intimately associated with high levels of biodiversity (Oertli & Parris, 2019). In addition, SWEs are generally acknowledged as refuges, acting as stepping stones in landscapes of simplified structure known to be poor in natural and semi-natural habitats (Bolpagni et al., 2019).

In particular, the research discussed by Bolpagni and Piotti (2016) was supported by the Oglio Sud Regional Park (Lombardy Region, northern Italy), a regional institution that aims to improve local knowledge about these types of ecosystems within an agricultural matrix.

The results obtained stimulated the managers of the Natura 2000 network – an array of nature protection areas in the territory of the European Union specifically aimed at preserving nature and wildlife under the Habitats and Birds Directives (Council of the European Communities, 1992, 2009) – and other local stakeholders (municipalities, provinces, and regional and non-governmental organizations) to promote specific recovery programmes. These programmes were mainly aimed at: (i) guaranteeing the presence of water during the summer period, in order to prevent a complete drying out of wetlands; (ii) the creation of new aquatic environments (e.g. permanent or temporary pools and ponds); and (iii) increasing the connectivity between isolated environments. Focusing on the eastern sector of the Lombardy region, several active interventions for increasing aquatic biodiversity locally have been funded over the last 10 years. Among others, re-excavation works were carried out in a series of oxbow lakes of the Oglio River to rejuvenate filled water bodies (i.e. the oxbow lakes of Runate). Similar actions have been supported as part of the TESSERE project to enhance ecological connectivity across a complex series of marginal habitats in the Mincio and Oglio river basins (Figure 2). The project in the Mincio River basin ended in 2014, with a budget of €400,000; the project in the Oglio River basin finished in 2019, with a budget of approximately €1 million. A continuing project, ECOPAY CONNECT 2020 (also with a budget of approximately €1 million), which started in 2018, and aimed at spreading a new awareness of the importance of 'Payments for Ecosystem Services', will allow the revitalization of a large number of aquatic ecosystems (e.g. oxbow lakes, peatlands, ponds, and river banks) (Figure 3).

A further direct repercussion of the new awareness concerning the ecological roles of marginal wetlands is the financing of specific support measures within the Rural Development Programme. In the Emilia-Romagna and Lombardy regions, specific indemnities are funded to compensate for the additional costs or loss of earnings by farmers for maintaining and improving biodiversity in agricultural landscapes, such as by creating ponds and SWEs. To do this, a total of €95.5 million was allocated for the period 2014–2020 by the Emilia-Romagna region alone.

2.2 | New methods for biodiversity monitoring

The knowledge gained from the AQC article was used actively to develop the provisions in force in Italy for monitoring aquatic habitats of community interest, in alignment with the EU Habitats Directive (Council of the European Communities, 1992) (see Angelini et al., 2016; in Italian, http://www.isprambiente.gov.it/public_files/direttiva-habitat/Manuale-142-2016.pdf). In addition, the results described in the article were also taken into account by the regions of Lombardy and Emilia-Romagna in adopting consistent approaches for monitoring sites in the local Natura 2000 network (in Italian, http://www.naturachevale.it/wp-content/uploads/2016/08/Programma-di-monitoraggio-scientifico-della-rete_%20vegetazione%20e%20habitat.pdf).

For example, for the aquatic habitat codes 3140 ('hard oligomesotrophic waters with benthic vegetation of Chara spp.') and 3150 ('natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation'), as described in Annex I of the Habitats Directive (Council of the European Communities, 1992), the Italian handbook prescribes the collection of data regarding the main physical and chemical features of colonized aquatic environments. Special emphasis is given to nutrients (N and P) and the quality of surficial sediments, whereas additional information can also be derived from the use of the standardized biological indices developed for the national implementation programmes of the EU Water Framework Directive (Council of the European Communities, 2000). For example, several indices were developed to infer changes in macrophyte communities (e.g. the Macrophytes Italian MultiMetrics Index, MacroIMMI; Oggioni, Buzzi, & Bolpagni, 2013) or fish communities (Lake Fish Index, LFI; Volta & Oggioni, 2010) in lakes. Indeed, the practical outputs of the article by Bolpagni and Piotti (2016) also represented one of the few attempts at creating a strong synergy between the Habitats Directive and the Water Framework Directive. This is not trivial considering that this topic has been explored very little until now, despite the strong potential links between these two directives (Bolpagni et al., 2017). For the first time in Italy, the aforementioned documents advise on the need for acquiring information on the hydromorphological features of the ecosystems colonized by habitats belonging to Annex I of the Habitats Directive, confirming the importance of the main results provided by Bolpagni and Piotti (2016). This new awareness suggests also evaluating the relative importance of the different life forms of macrophytes (including aquatic plants, helophytes, or amphibious taxa) to understand the dynamic processes within the vegetation communities under investigation. Bolpagni and Piotti (2016) found different responses of aquatic vegetation types to hydrology and to wetland origin (natural or artificial), suggesting the existence of specific spatio-temporal dynamics for each of the plant communities investigated. This reinforces the general picture of inter-annual variation in flood disturbance, surface area, and age as the major drivers of vegetation diversity in wetlands (Ishida, Yamazaki, Takanose, & Kamitani, 2010; Renöfält, Nilsson, & Jansonn, 2005), stressing the key contribution of extreme flood events in preserving a predominant portion of native wetland species (Stokes, Ward, & Colloff, 2010).

3 | SECONDARY IMPACTS

3.1 | Future development of new conservation policies or legislation

The article helped to reinforce the idea of the great relevance of human intervention to support wetland vegetation diversity. In riverscapes subject to human impact, active management is essential to maintain the structural heterogeneity of aquatic and wetland vegetation. This is not an insignificant task, considering the difficulty of intervening in hydrologically isolated environments, where the possibility to restore fully a natural dynamic flow regime, including the periodic flooding of riverine areas, is often impossible (Charlton, 2007). The need for human-mediated action in the recovery of wetlands contrasts partly with previous evidence that emphasized the uselessness of restoration programmes for aquatic sites isolated from river dynamics (Van Looy & Meire, 2009). In the vast majority of cases, however, it is not possible to imagine alternative approaches. Only active and repeated management practices seem to guarantee the minimum levels of physical complexity able to support aquatic plant diversity over time in environments isolated from the hydrological network. This is especially true considering climate prediction models, which indicate a strong alteration in precipitation regimes in the future: for example, with a 50% reduction in summer rainfall in the Po plain by 2050 (Coppola & Giorgi, 2010). Without active intervention a complete disappearance of all the marginal wetlands of the Po valley can be presumed, in light of the impracticability of pursuing more natural and variable river flow regimes.

3.2 | Raising awareness of biodiversity loss and associated ecosystem services

The global crisis for biodiversity is particularly severe for fresh waters, especially for marginal and small ecosystems (World Wide Fund for Nature (WWF), 2016). The article by Bolpagni and Piotti (2016) complements the strategic plans needed to counteract the loss of aquatic biodiversity by discussing the opportunity to include artificial systems, as well as active management practices. In this context, some of the sites studied by Bolpagni and Piotti (2016) have been investigated further to obtain field evidence on their metabolism, including their selfpurifying capacity (e.g. Racchetti et al., 2011, and references therein).

Stressing the potential services that they provide to humans (such as denitrification, for example) represents a great opportunity to increase interest in these ecosystems, which are often neglected by most local administrators and stakeholders.

Racchetti et al. (2011) verified higher rates of nitrogen removal via denitrification for riverine wetlands temporarily connected to the surficial hydrological network, emphasizing the necessity of restoring or improving hydraulic connectivity to enhance the important biogeochemical functions of wetlands. Similarly, recent estimations of the contribution in N metabolism mediated by rooted vegetation in artificial canals of the Po plain highlighted new opportunities for eutrophication control (Soana, Bartoli, Milardi, Fano, & Castaldelli, 2019). Here, the maintenance of dense fringes of Glyceria maxima, Phragmites australis, and Typha latifolia can increase the mitigation of excess N from agriculture by up to 50%. This opens new perspectives on the 'non-material services' offered by the stewardship of habitats and aquatic environments (Small, Munday, & Durance, 2017). It also confirms the pressing need to link more and more conservation issues with those of the services provided by aquatic ecosystems. We strongly believe that this might represent a turning point for the effective conservation of wetlands, especially in nutrient-enriched croplands.

4 | CONCLUSIONS

The most relevant aspects of the AQC article by Bolpagni and Piotti (2016) are related both to the methodological approach and to the specific context of application: a riverscape subject to severe human impacts (the Oglio River in northern Italy). In this context, the paper represents one of the first attempts to investigate systematically the complexity of wetland vegetation (perceived as a mosaic of aquatic and amphibious plant communities) in relation to the pre-eminent ecosystem determinants (i.e. direct human influence and water-level variations). A functional, hierarchical approach was used to determine the sampling effort needed to test the results and to find the causes of the observed distribution patterns of physical heterogeneity and wetland vegetation. The article has also underpinned the necessity of human-mediated actions to reinforce vegetation diversity in over-exploited lowlands. In addition, the pivotal role of water-level fluctuations in promoting the diversity and distribution of aquatic and wetland vegetation clearly emerged as a predominant driver. All of these aspects need to be taken into account to ensure the success of ecosystem recovery programmes. This must necessarily imply a clear understanding of the continuing context of climate change, as well as of the local and global implications of economic strategies.

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Figure legends

355
356 Figure 1. Graphical abstract of the paper by Bolpagni & Piotti (2016): aquatic, amphibian and
357 riparian plant communities were characterized via a hierarchical approach to evaluate the role of
358 origin and hydrology in driving vegetation patterns and to suggest the most effective conservation
359 strategies.
360
361 Figure 2. Photographs of some of the areas of the Mantua province included in the TESSERE
362 project funded on the base of the awareness on the local key ecosystem roles played by lowland
363 wetlands as stressed by Bolpagni & Piotti (2016). “a and b” belong to the “Zona di Valle” area (the
364 pale blue area delimits a newly-formed pond); “c” belongs to the “Monzambano” area (the white
365 line delimits a newly-formed pond).
366
367 Figure 3. Photographs of the excavation intervention of the “Lanca delle Bine” area (Cremona
368 province), included in the ECOPAY CONNECTION 2020 project funded on the base of the
369 awareness on the local key ecosy stem roles played by lowland wetlands as stressed by Bolpagni
370 & Piotti (2016). “a” pre-intervention conditions; “b1 and b2” excavation activities; “c” post371
intervention conditions.