Study of the zooplankton community (Branchiopoda and Copepoda) in the Alto Guadalquivir wetlands: diversity, distribution patterns and relationship with the trophic state

Juan Diego Gilbert Rus

December 2020

UNIVERSIDAD DE JAÉN

Departamento de Biología Animal, Biología Vegetal y Ecología
Área de Ecología

Study of the zooplankton community (*Branchiopoda* and *Copepoda*) in the Alto Guadalquivir wetlands: diversity, distribution patterns and relationship with the trophic state

Estudio de la comunidad zooplanctónica (*Branchiopoda* y *Copepoda*) en humedales del Alto Guadalquivir: diversidad, patrones de distribución y relaciones con el estado trófico

Tesis Doctoral

Juan Diego Gilbert Rus

Jaén, 2020

Study of the zooplankton community (*Branchiopoda* and *Copepoda*) in the Alto Guadalquivir wetlands: diversity, distribution patterns and relationship with the trophic state

Estudio de la comunidad zooplanctónica (*Branchiopoda* y *Copepoda*) en humedales del Alto Guadalquivir: diversidad, patrones de distribución y relaciones con el estado trófico

Memoria que para optar al Grado de Doctor por la Universidad de Jaén presenta

Juan Diego Gilbert Rus

Esta tesis doctoral ha sido realizada bajo la dirección de los doctores Francisco José Guerrero Ruiz e Inmaculada de Vicente Álvarez-Manzaneda

Los doctores Francisco José Guerrero Ruiz, catedrático de Ecología del Departamento de Biología Animal, Biología Vegetal y Ecología de la Universidad de Jaén e Inmaculada de Vicente Álvarez-Manzaneda, profesora Titular de Ecología del Departamento de Ecología de la Universidad de Granada,

INFORMAN

Que la presente memoria, titulada "Study of the zooplankton community (*Branchiopoda* and *Copepoda*) in the Alto Guadalquivir wetlands: diversity, distribution patterns and relationship with the trophic state" ha sido realizada bajo su dirección y autorizan su presentación y defensa para optar al Grado de Doctor internacional por la Universidad de Jaén.

Jaén, septiembre de 2020

Fdo: Dr. Francisco J. Guerrero   Inmaculada de Vicente

CONTENTS

Introducción
Hipótesis y objetivos
Resultados y discusión
Conclusiones

Introduction

A general overview about the relevance of Mediterranean wetlands

Wetlands are considered as one of the ecosystems with the highest environmental value, characterized by high production and habitat heterogeneity, which translates into great landscape and biological diversity (González-Bernáldez, 1989; Mitsch and Gosselink, 2000). Among wetlands, Mediterranean temporary ones represent unique repositories of biodiversity, which hold exclusive communities of aquatic organisms. Despite this importance, which at the political and social level has led to the existence of international conventions and programs for its protection and conservation (Ramsar Convention; World Program on Wetlands; IUCN Water Resources; Water Framework Directive) and, at the regional level, in the publication of the Andalusian Plan for Wetlands (VV.AA., 2004), its irreversible alteration and destruction has been a constant over time, and specially in recent decades (Casado and Montes, 1995; Guerrero *et al.*, 2006). Therefore, the scarcity of water resources that characterizes the south of the Iberian Peninsula makes that the conservation of humid areas, which diversify the landscape and contribute to the generation of microclimates in strong contrast to the surrounding aridity, constitutes a primary task in the management of the natural environment.

Traditionally, most attention has been focused on large temperate lakes, while Mediterranean wetlands have received much less consideration. Based on Cole et al. (2007) and Downing (2010), this is especially striking in view of: (i) recent inventories based on modern geographical and mathematical approaches have shown that small lakes and ponds dominate the areal extent of continental waters; (ii) several analyses have shown the disproportionately great intensity of many processes in small aquatic ecosystems, indicating that they play an unexpectedly major role in global cycles; (iii) in relation to carbon (C) cycle, it has been proved that inland waters and especially wetlands, are far from being neutral conduits of C from lands to the sea as they stored large amounts of C in their sediments and a major fraction of C is degassed to the atmosphere and (iv) small lakes and ponds are important to the maintenance of regional biodiversity and stability as they are characterized by greater species richness per unit than large lakes. Additionally, it is essential to consider that among all inland aquatic ecosystems, wetlands have unique characteristics (e.g. shallowness, high fluctuations in water level and anoxic sediment) that make them a "*hotspot*" for biogeochemical processes (e.g. Hernández and Mitsch, 2006; White and Reddy, 2009).

From ancient time, human society has realized that they depend on the natural world. However, the value of natural ecosystems has been ignored until their degradation has highlighted their importance (Daily, 1997). It is well known that natural ecosystems provide economical, ecological and social benefits essential for humans, the so called "ecosystem services" (Costanza *et al.*, 1997). Aquatic ecosystems in particular, play a vital role in human existence and specifically, wetlands which are important, among others, for flood control, groundwater replenishment, shoreline stabilization and storm protection, sediment and nutrient retention and export, reservoirs of biodiversity and climate change mitigation and adaptation. As Ramsar convention states, one problem has been the lack of hard economic data that prove the value of retaining intact ecosystems, but this is now changing. As an illustration, a recent study of the role of coastal wetlands in reducing the severity of impacts from hurricanes in the United States found that they provided storm protection services with an estimated value of US $23.2 billion per year. Accordingly, growing understanding of the economic benefits of wetlands is resulting in significant expenditure in some countries on wetland restoration and rehabilitation of lost or degraded hydrological and biological functions of wetlands.

Worldwide main wetlands perturbances: eutrophication

Among aquatic ecosystems, wetlands constitute highly dynamic and extremely fragile ecosystems, especially in the Mediterranean region. They are actually facing an increasing pressure derived from anthropogenic activities (agricultural, livestock, urban, industrial and tourist) that take place in the drainage basins of these ecosystems (Ortega *et al.*, 2006). Amongst these human disturbances, cultural eutrophication has been recognized worldwide as a serious environmental issue for more than half a century and remains a major water quality issue. Livestock and agricultural discharges, which provide fertilizers, organic wastes and other residues rich in phosphates and nitrates are, in most cases, the main causes of the increase in the trophic state of anthropogenic origin in Mediterranean wetlands (Guerrero *et al.*, 2005; 2006).

In the European Union, general concerns about water quality led to the Water Framework Directive (WFD). It provides a common framework to protect, manage and restore surface and groundwater in Europe, and it has prescribed as a legal requirement by 2027 that all water bodies must achieve "good status". Surface waters status is measured by both its ecological and chemical status assessed in the scale of "high", "good", "moderate", "poor" and "bad" based on the Ecological Quality Ratio, which is a ratio between the reference conditions and measured status of the biological quality conditions (Heiskanen, 2004; Willaarts *et al.*, 2014). In the last report of European Commission about the implementation of WFD in Spain it was stated that although 43% of surface water bodies present "high" or "good" ecological status, a very high proportion (39.2 %) were classified as "moderate" to "bad" status and a large number of surface water bodies are classified as “unknown" status representing 17 % of the total (EC, 2015).

For combating eutrophication of inland waters, in general, and of wetlands more specifically, the evaluation of the trophic state is a prerequisite and essential step (Schindler, 2006). In this context, the use of biotic indices to characterize the trophic status and ecological integrity of wetlands is receiving increasing attention from the scientific community, existing a wide array of biotic indices. Different taxonomic groups have been proposed to construct these indices, such as macrophytes (Cirujano *et al.*, 1992); birds (Furness and Greenwod, 1993); fish (Minns *et al.*, 1994); periphyton (McCormick and Stevenson, 1998); macroinvertebrates (Burton *et al.*, 1999); among others. Most of these indices have, however, been developed in wetlands of temperate regions, and there is less information for the case of Mediterranean wetlands (Fano *et al.*, 2003; Boix *et al.*, 2005).

Zooplankton: a key component of aquatic food webs

Zooplankton is one of the main components of the biological communities of aquatic systems acting as a link between phytoplankton and secondary consumers and actively participating in nutrients recycling. Despite of being a fundamental component, it has not been considered as a biological element for the classification of ecological status in the WFD, being excluded from the list in Annex V. This fact has been considered as an error by various authors (Moss *et al.*, 2003) since the viability of zooplankton as an indicator of water quality has been demonstrated in a large number and variety of aquatic ecosystems (Gulati, 1983; 1990; Pontin and Langley, 1993; Attayde and Bozelli, 1998; Duggan *et al.*, 2001).

In this context, several approaches have been carried out in recent years to assess the potential of using different zooplankton groups as indicators of ecological status, so that knowledge of the taxonomic composition of zooplankton and its relationship with variables of the trophic status of the system, allow its use as an indicator of its ecological status (Lougheed and Chow-Fraser, 2002; Bianchi *et al.*, 2003; Boix *et al.*, 2005; Badosa *et al.,* 2006; Boix *et al.*, 2007; Haberman *et al.*, 2007; Ejsmont-Karabin and Karabin, 2013; Haberman and Haldna, 2014). In fact, zooplankton presents a series of characteristics that make it an appropriate element for assessing water quality: (i) they are ubiquitous elements in lentic ecosystems (lakes, lagoons and wetlands), with an easy sampling (Boix *et al.*, 2005) and (ii) the set of zooplankton species varies with changes in the trophic state (Whitman et al., 2004) and in response to gradients of disturbance (Stemberger and Lazorchak, 1994; Stemberger *et al.*, 2001).

Additionally, microcrustaceans such as Cladocera and Copepoda, displaying very different reproductive strategies, have been recently proposed as indicators of wetland hydroperiod (e.g. Serrano and Fahd, 2005; Sahuquillo and Miracle, 2013) and hence they can be used as a target group in monitoring the effects of land use and climate change (Seminara *et al.*, 2008; Céréghino *et al.*, 2014; Seminara *et al.*, 2016).

The sediment as an essential compartment of Mediterranean temporary wetlands

Apart from external nutrient inputs, internal sources such as sediment release notably affect the trophic state of aquatic ecosystems. This water-sediment coupling is further enhanced in the case of Mediterranean temporary wetlands, where extreme fluctuations in the water level cause a fraction of the sediment to be subject to more or less prolonged drying periods. This aspect will significantly affect sedimentary physico-chemical properties and, therefore, its ability to retain or release phosphorus (P) into the water column. There is currently a controversy about the last effect of desiccation and subsequent reflooding of the sediment on the adsorption and desorption P capacity. Some studies have shown that desiccation of the sediment leads to a substantial reduction in its affinity for phosphorus (Baldwin, 1996), although an inverse effect of desiccation on phosphorus adsorption properties has also been described (Barrow and Shaw, 1980; De Groot and Fabre, 1993). Undoubtedly, these contradictory results reflect the complexity of the biological, physical and chemical processes that occur during the drying of the sediment. Furthermore, the extension of the drying period and the initial composition of the sediment must play an essential role in the final result. Accordingly, it is essential to carry out *ad hoc* studies in the study sites for a better understanding of the final effect of recurrent dry and wet sedimentary conditions.

Even more, the shallowness characterizing temporary wetlands is responsible, on the one hand, for the fact that a large part of the organic matter synthesized in the water column itself reaches the superficial sediment without having been completely mineralized, so that benthic metabolic activity plays a fundamental role in global metabolism of this type of systems (Relexans, 1996; de Vicente *et al.*, 2010a). On the other hand, this shallow character (high surface/volume ratio) determines a close water-sediment interaction that largely affect the chemical composition of the overlying water column (e.g. Ryding, 1985; Boström *et al.*, 1988; de Vicente, 2004). So much so that a large part of the nutrients presents in the water column come from the sediment (internal load), evidencing that the restoration of eutrophic wetlands will require a drastic control of internal P load by adding chemical compounds that they adsorb P (e.g. Hupfer and Hilt, 2008).

An additional consideration is that, apart from the typical indices used for evaluating trophic state which are mainly based on water quality (see for example Carlson, 1977; Kratzer and Brezonik, 1981), in Mediterranean wetlands the use of the bioproduction number (BPN, Håkanson, 1984) may represent an appropriate indicator for wetlands, which are characterized by extremely large temporal variability (de Vicente *et al.*, 2010b). While the application of indices based on water column parameters usually requires repeated seasonal monitoring to obtain the annual mean values, the reproducibility of the BPN method shows constant BPN values every time. Hence, only one sampling including the spatial heterogeneity of the surface sediment can provide a reasonable composite measure of trophic condition in a wetland (de Vicente *et al.*, 2010b).

Study site: Alto Guadalquivir region

Andalusia is characterized by having a large number of wetlands, these representing in number 17% of Spanish water bodies and 56% in surface area (González-Capitel, 2003). The set of all of them is made up of a great variety of different ecological types, some of which stand out for being unique ecosystems within the context of the European Union (VV.AA., 2004). Most of them are endorheic countryside wetlands. This situation has led to a part of them having some type of protection (Natural Reserve, Natural Area, LIC, ZEPA, ZEC, Natural Parks and National Parks) both internationally, nationally and autonomically (Guerrero, 2009).

The Alto Guadalquivir region is located at the northeast of Andalusia (Spain), encompassing almost the entire province of Jaén and the easternmost part of the province of Córdoba. To date, a total of 90 wetlands have been inventoried in this region (Ortega *et al.*, 2003), the majority of these being seasonal wetlands, of varied size and geological origin. These wetlands, most of them lacking legal protection, show evident manifestations of the eutrophication process of their waters (Guerrero *et al.*, 2005; 2006; Ortega *et al.*, 2003; 2006).

The Alto Guadalquivir is conditioned by three large geological units: Sierra Morena, the Betic mountain ranges, and the Guadalquivir depression. Most of the Andalusian wetlands are located in the last ones, mainly in the Guadalquivir depression. This situation determines that its presence is fundamentally linked to depressions of karst origin on materials from the Guadalquivir olitostroma with predominance of clay-evaporitic sediments from Trias Keuper (Rodríguez-Rodríguez, 2007). Especially relevant is the effect of geology on the concentration and ionic composition of the water, being responsible for a wide range of wetlands from freshwater to hypersaline.

The orography of the region is responsible for most wetlands are located in areas of flat relief or in depressions in relation to the surrounding environment. According to the hydrology, it is possible to distinguish the next types: hypogenic or mixed hydrological regime, in which the contributions of water are produced by groundwater and surface runoff, having a permanent or semi-permanent character; and epigenics only with contributions of surface waters which lastly present the greatest seasonal and interannual variability. Additionally, the extreme temporal variability characterizing Mediterranean climate is responsible for drastic water level fluctuations on an annual and inter-annual basis. These fluctuations have a profound influence on the abiotic and biotic variables (Coops *et al.*, 2003).

Lastly, an important aspect that characterize the wetlands of the Andalusian community is the great influence of anthropogenic perturbances, mainly due to the agriculture causing both direct and indirect effect, through changes in their drainage basin (Guerrero, 2009). In general, four causes of wetlands degradation and/ or disappearance have been identified: changes in the buckets, changes in the hydrological and hydroperiod regime, changes in water quality and changes in the structure of the communities.

General and specific objectives

Wetlands of the Alto Guadalquivir region have been previously listed (Ortega et al., 2003) and inventoried (Guerrero *et al.*, 2006; Ortega *et al.*, 2001; 2003; 2004; 2007; Ortega and Guerrero, 2003; 2007). Therefore, the next step is their evaluation, a process that tries to identify the state of stress that these ecosystems are suffering and how the biotic communities cope with it. In this context, the assessment of the trophic state is a useful and necessary tool for the diagnosis of the situation as a previous step for the proposal of management programs. For this purpose, both extensive (36 wetlands) and intensive (7 wetlands) samplings have been carried out in a set of wetlands selected based on widely different limnological characteristics.

Specific objectives are as follows:

1. To develop monitoring methods to evaluate zooplankton diversity (using as target groups copepods and branchiopods) based on extensive samplings in order to build models for the entire Mediterranean region (*Chapter I*).
2. To identify priority areas for conservation using zooplankton assemblages and to measure the degree of nestedness to determine the best strategy for conservation of zooplankton diversity (*Chapter II*).
3. To compare the ability of taxon- and size-based analyses of the zooplankton community to predict the influence of environmental variables (*Chapter III*).
4. To test if zooplankton community is influenced by the seasonal environmental variability that characterize Mediterranean wetlands and if the community structure and composition reflect these environmental fluctuations (*Chapter IV*).
5. To test the hypothesis that zooplankton assemblages (branchiopods and copepods) are strongly affected by the catchment land uses in Mediterranean wetlands by assessing the relationship between wetland limnological characteristics and their different catchments land uses (*Chapter V*).
6. To estimate the trophic state by using a sediment-based index (bioproduction number, BPN) and to assess the effect of different land uses in the drainage basins of the Mediterranean wetlands on the BPN. Additionally, a comparison between BPN data and those obtained from the trophic state index (TSI) has been carried out (*Chapter VI*).

7. To determine the impact of sediment desiccation on nutrient dynamics in two selected Mediterranean wetlands. In particular, phosphate (PO_4^{3-}) adsorption and desorption properties were assessed by using laboratory experiments. Additionally, the main physicochemical drivers of PO_4^{3-} sorption were identified (*Chapter VII*).

Results and Discussion

Mediterranean region is considered as one of the most important biodiversity hotspots in the world (Myers *et al.*, 2000). In particular, the southern Iberian Peninsula is an area of special interest as it is located in one of the most arid zones of Europe and comprises a wide range of aquatic ecosystems, from freshwater to hypersaline ones (Sánchez-Fernández *et al.*, 2004), which represents an important component of the landscape. The importance of this region for the zooplankton diversity is confirmed by the results obtained in this PhD. A total of 60 species (branchiopods and copepods) were recorded in the Alto Guadalquivir region, belonging to seven orders (Gilbert *et al.*, 2015a; ***Chapter 1***). Twenty-two of the recorded species were copepods (7 Calanoida, 12 Cyclopoida and 3 Harpacticoida), and 38 were branchiopods (4 Anostraca, 1 Ctenopoda, 32 Anomopoda and 1 Notostraca). A large number (37%) of rare species (present in only one wetland) were found (15 branchiopods and 7 copepods) while only 11% of the total species (4 branchiopods and 3 copepods species) were common (i.e., present in more than 20% of wetlands). Species richness was related to wetland typology, with the largest number of species observed in temporary freshwaters-subsaline-hyposaline (TFSH = 51 species; 4±2 species per sample), followed by mesosaline-hypersaline (MH = 16 species; 3±1 species per sample) wetlands and by permanent freshwater-subsaline-hyposaline (PFSH = 12 species; 3±1 species per sample) wetlands. We have found that rare species are mainly present in temporary wetlands, the most vulnerable to hydrological changes. Hence, temporary wetlands represent unique sites deserving conservation and accordingly they must be considered for future conservative legislation.

Attending to the conservation criteria, a set of Mediterranean wetlands has been studied in order to identify priority areas for conservation by using zooplankton assemblages (Gilbert *et al.*, 2014a; ***Chapter 2***). In particular, the degree of nestedness was measured to identify the best strategy for conservation of zooplankton diversity. Two different but complementary approaches were used: cluster analysis and parsimony analysis of endemicity (PAE), with a presence–absence data matrix, in order to group wetlands as a function of zooplankton composition. To select conservation areas, four different criteria were used: (i) species richness; (ii) exclusive species occurrences; (iii) the number of wetlands in which species appeared and (iv) phylogenetic diversity. The results showed the existence of three different zones (subgroups of wetlands) that included 98% of the total species and 41% of the studied wetlands. These results confirm that zooplankton assemblages are essential for making wetland conservation decisions and for the identification of areas with connectivity (fluxes of species) in which efforts should be more intense to preserve their biodiversity.

Intrinsic ecological characteristics of Mediterranean wetlands make them excellent sites for studying biodiversity, specially for zooplankton diversity. We compared the ability of taxon- and size-based analyses of the zooplankton community to predict the influence of environmental variables (Gilbert *et al.*, 2017a; ***Chapter 3***). Our results comparing body size and taxonomic composition for rapid assessment of the influence of the environmental variables on zooplankton assemblages in temporary wetlands indicates that twelve species, eight were negatively and 4 were positively correlated with factors indicative of eutrophication. These results are consistent with the biology of these species described by Margalef (1953), Armengol (1978), and Alonso (1996) for the Iberian Peninsula. In the same way three coarse taxa, large cladocerans (LC), calanoida copepods (C) and cyclopoida copepods (CY) are affected by eutrophication. The positive relationship of LC and CY with factors related to eutrophication has been also previously reported in the literature. Last, three size classes are also affected by eutrophication. A shift in the body-size distribution toward smaller individuals as eutrophication progresses is in accordance with the general pattern of reduced size in stressed communities described by Kerr (1974).

Additionally, we could also state that zooplankton composition is also linked to the number of days of water inundation and turbidity, but also with other environmental variables (Gilbert *et al.*, submitted; ***Chapter 4***), that clearly affect to the appearance of different species in temporary wetlands during the hydroperiod, from the flooding to the desiccation period. In this sense, the initial stages after the flooding event are dominated by the copepods *Tropocyclops prasinus* and *Arctodiaptomus wierzejskii*. These species appear in sites with high values of turbidity and low percentages of macrophytes. On the other hand, the copepods *Diaptomus cyaneus*, *Macrocyclops albidus* and by the cladocerans *Chydorus sphaericus*, *Simocephalus vetulus* are typical from sites with an increase of the flood period, macrophytes coverage and reduction of turbidity. In the same way, the cladocerans *Daphnia magna*, *Ceriodaphnia dubia*, *Pleuroxus aduncus* and the copepod *Acanthocyclops venustus* are typical from wetlands with higher depths, while the anostraca *Chirocephalus diapahanus*, the cladocerans *Pleuroxus letourneuxi*, *Macrothrix hirsuticornis* and the copepod *Cyclops insignis* are characteristics from wetlands with high nutrient concentrations.

Furthermore, and to understand the role of human activities on the structure and functioning of the aquatic communities, specifically on the zooplankton community, we study the relationship between watershed land uses, wetland characteristics and zooplankton assemblages (branchiopods and copepods) in 24 Mediterranean wetlands of the southern Iberian Peninsula, which greatly differ in both wetland land uses (olive groves, pasture, scrublands, and forest) and in their morphometric and limnological features (Gilbert *et al.*, 2017b; ***Chapter 5***). Firstly, results from a Principal Component Analysis (PCA) allowed us to classify wetlands in two categories: impacted and non-impacted. Then, one-way analysis of variance (ANOVA) was performed to test differences in zooplankton species richness and a permutational analysis of variance (PERMANOVA) was performed to test differences in zooplankton assemblages between categories. Lastly, a non-metric multidimensional scaling analysis (NMDS) was chosen for the lake-by-species ordination. The results support the hypothesis that zooplankton richness and composition were negatively affected by watershed land uses, mainly agriculture practices. Moreover, species zooplankton assemblages were clearly linked to the two different wetlands categories. The present study puts forward the important role of zooplankton community for testing land use effects in Mediterranean wetlands. Consequently, the monitoring of zooplankton assemblages might be a very useful and less cost-effective management tool to improve our capacity for understanding the effects of watershed land uses on Mediterranean wetlands under future global change. We are agreeing with many authors who suggest that zooplankton could be considered as a biological quality element (BQE) in the European Water Framework Directive (WFD; 2000/60/EC) to determine the quality status of water bodies.

Next, and considering that one of the most direct effect of the increment of human activities on wetland watershed is the eutrophication of aquatic ecosystems, trophic state evaluation was carried out (Gilbert *et al.*, 2015b; ***Chapter 6***). At this point, it is worth to note that trophic state assessment is essential for the conservation, the management and the application of possible future restoration measures. To estimate the effect of different land use in the drainage basin of the Mediterranean wetlands, we use a sediment-base index such as the bioproduction number (BPN). For this, we selected seven wetlands with different areal extension of agricultural land in their catchment area. The data obtained from BPN were compared with those obtained from the trophic state index (TSI). The results showed that there is a discrepancy between TSI-TP, TSI-Chl*a* and BPN values in our wetlands, and that the application of the BPN for estimating trophic state in Mediterranean wetlands has clear limitations when the organic matter content in surface sediments is low. This occurs in wetlands with a great proportion of drainage area covered by intensive agricultural uses, which causes high soil losses by accelerated erosion. As a conclusion, not only high organic matter content, as it has been stated in previous literature, but also low organic matter content limits the validity of BPN.

Finally, and based on the drastic influence of eutrophication on zooplankton community, we evaluated the effect that climate change exerts on Mediterranean wetlands. In this sense, sediment desiccation is expected to drastically affect nutrient cycling in Mediterranean wetlands as global climate change models predict that many areas will become significantly drier than they currently are (Gilbert *et al.*, 2014b; ***Chapter 7***). In this study, we selected two Mediterranean wetlands that clearly differ in their water chemical composition (Honda and Hituelo wetlands) in order to determine the impact of sediment desiccation on phosphate (PO_4^{3-}) adsorption and desorption properties. A decrease in PO_4^{3-} sorption properties was observed in transects from the littoral zone to dry land in both lakes concomitantly with a reduction in organic matter content, revealing a critical role of organic matter for sequestering P in the lake sediment. Our experiments designed to determine if drying events would lead to an enhanced P release upon re-wetting have shown that, simulating natural conditions of re-flooding (that is without adding sodium azide), PO_4^{3-} concentrations were notably higher in the overlying water than those initially measured in the lake water. These results highlight the impact of drying sediment and the subsequent re-wetting on increasing P concentrations in lake water and accordingly, affecting to lake trophic state. Finally, we aimed on determining the overall effect of biotic versus abiotic activity on P release patterns observed upon re-wetting. Our results have evidenced that while in Honda, biotic processes upon re-wetting are crucial for increasing P retention in the sediment; P exchange across sediment and water upon dry sediment rewetting is basically mediated by abiotic processes in Hituelo.

Conclusions

(1) A total of 60 species (branchiopods and copepods) were recorded in the Alto Guadalquivir region, belonging to seven orders. Twenty-two of the recorded species were copepods (7 Calanoida, 12 Cyclopoida and 3 Harpacticoida), and 38 were branchiopods (4 Anostraca, 1 Ctenopoda, 32 Anomopoda and 1 Notostraca).

(2) A large number (37%) of rare species (present in only one wetland) were found (15 branchiopods and 7 copepods species), while only 11% of the total species number (4 branchiopods and 3 copepods species) were common (present in more than 20% of the wetlands).

(3) Species richness was related to wetland typology, with the largest number of species observed in temporary freshwater-subsaline-hyposaline wetlands, followed by mesosaline-hyposaline wetlands and by permanent freshwater-subsaline-hyposaline wetlands. We have found that rare species are mainly present in temporary wetlands, the most vulnerable to hydrological changes; hence, these types of wetlands represent unique sites deserving conservation.

(4) Zooplankton assemblages are essential for making wetland conservation decisions and for the identification of areas with connectivity (fluxes of species) in which efforts should be more intense to preserve their biodiversity. The conservation proposal made in our study area included 98% of the total species and 41.4% of the studied wetlands.

(5) Zooplankton assemblages differ in species composition, coarse-level-taxa, and body-size composition among wetlands, and thus, reflect the extreme variability among Mediterranean wetlands and their key role for the maintenance of regional biodiversity.

(6) Our results suggest that body size might be better than taxonomic composition for rapid assessment of the influence of the environmental variables on zooplankton assemblages in temporary wetlands. This is important due to species identification requires laborious analytical procedures and human and financial resources, whereas body-size approaches could be cost-effective tools for monitoring Mediterranean wetlands.

(7) Zooplankton composition is linked to environmental variables, that clearly affect to the appearance of different species in temporary wetlands along the hydroperiod, from the flooding to the desiccation period.

(8) Zooplankton richness and composition were negatively affected by watershed land uses, mainly agriculture practices. Consequently, the monitoring of zooplankton assemblages might be a very useful and less cost-effective management tool to improve our capacity for understanding the effects of watershed land uses on Mediterranean wetlands under future global change. We are agreeing with many authors who suggest that zooplankton could be considered as a biological quality element (BQE) in the European Water Framework Directive (WFD; 2000/60/EC) to determine the quality status of water bodies.

(9) Eutrophication is a key process in wetlands and determines zooplankton composition and community structure. Our results indicate that 12 species, 3 coarse taxa (large cladocerans, calanoida and cyclopoida), and 3 size classes (S1: <1 mm, S2: 1–2.5 mm, and S3: 2.5–10 mm) are affected by eutrophication. Eight of the 12 species were negatively and 4 were positively correlated with factors indicative of eutrophication.

(10) For estimating trophic state in Mediterranean wetlands, our results indicate that the application of the bioproduction number (BPN) has clear limitations when the organic matter content in surface sediments is low. It frequently occurs in wetlands with a great proportion of drainage area covered by intensive agricultural uses, causing high soil losses by accelerated erosion. As a conclusion, not only high organic matter content as it has been stated in previous literature, but also low organic matter content limit the validity of BPN.

(11) Considering the relevant role of sediment biogeochemistry in temporary Mediterranean wetlands, finally, the impact of sediment desiccation on phosphorus (P) cycle was achieved. Our results highlight the impact of drying sediment and the subsequent re-wetting on increasing P concentrations in lake water and accordingly, affecting to lake trophic state.

References

Alonso, M. (1996). *Crustacea, Branchiopoda*. Fauna Ibérica, 7. Ramos, M.A. (ed.). Museo Nacional de Ciencias Naturales, CSIC, Madrid.

Armengol, J. (1978). Los crustáceos del plancton de los embalses españoles. *Oecologia Aquatica*, 3: 3-96.

Attayde, J.L., R.L. Bozelli (1998). Assessing the indicator properties of zooplankton assemblages to disturbance gradients by canonical correspondence analysis. *Canadian Journal of Fisheries and Aquatic Sciences*, 55: 1789-1797.

Badosa, A., D. Boix, S. Brucet, R. López-Flores, X. Quintana (2006). Nutrients and zooplankton composition and dynamics in relation to the hydrological pattern in a confined Mediterranean salt marsh (NE Iberian Peninsula). *Estuarine, Coastal and Shelf Science*, 66: 513-522.

Baldwin, D.S. (1996). Effects of exposure to air and subsequent drying on the phosphate sorption characteristics of sediments from a eutrophic reservoir. *Limnology and Oceanography*, 41: 1725–1732.

Barrow, N., T.C. Shaw (1980). Effect of drying soil on the measurement of phosphate adsorption. *Communications in Soil Science and Plant Analysis*, 11: 347–353.

Bianchi, F., F. Acri, F.B. Aubry, A. Berton, A. Boldrin, E. Camatti, D. Cassin, A. Comaschi (2003). Can plankton communities be considered as bioindicators of water quality in the lagoon of Venice? *Marine Pollution Bulletin*, 46: 964–971.

Boix, D., S. Gascón, J. Sala, M. Martinoy, J. Gifre, X. D. Quintana (2005). A new index of water quality assessment in Mediterranean wetlands based on crustacean and insect assemblages: the case of Catalunya (NE Iberian Peninsula). *Aquatic Conservation: Marine and Freshwater Ecosystems,* 15: 635-651.

Boix, D., J. Sala, S. Gascón, M. Martinoy, J. Gifre, S. Brucet, A. Badosa, R. López-Flores, X. Quintana (2007). Comparative diversity of crustaceans and aquatic insects from various water body types in coastal Mediterranean wetlands. *Hydrobiologia*, 584: 347-359

Boström, B., J.M. Andersen, S. Fleischer, M. Jansson (1988). Exchange of phosphorus across the sediment-water interface. *Hydrobiologia*, 170: 229-244.

Burton, T.M., D.G. Uzarski, J.P. Gathman, J.A. Genet, B.E. Keas, A. Stricker (1999). Development of a preliminary invertebrate index of biotic integrity for Lake Huron coastal wetlands. *Wetlands*, 19: 869-882.

Carlson, R.E. (1977). A Trophic State Index for Lakes. *Limnology and Oceanography*, 22: 361.

Casado, S., C. Montes (1995). *Guía de los lagos y humedales de España*. Editorial J. M. Reyero. Madrid.

Céréghino, R., D. Boix, H.-M. Cauchie, K. Martens, B. Oertli (2014). The ecological role of ponds in a changing world. *Hydrobiologia*, 723: 1–6.

Cirujano, S., M. Velayos, F. Castilla, M. Gil (1992). *Criterios botánicos para la valoración de las lagunas y humedales españoles (península Ibérica e islas Baleares)*. Colección Técnica. Ministerio de Agricultura, Pesca y Alimentación. ICONA-CSIC, Madrid.

Cole, J.J., Y.T. Prairie, N.F. Caraco, W.H. McDowell, L. J. Tranvik, R.G. Striegl, C.M. Duarte, P. Kortelainen, J.A. Downing, J.J. Middelburg, J. Melack (2007). Plumbing the global carbón cycle: integrating inland waters into the terrestrial carbon budget. *Ecosystems*, 10: 171-184.

Coops, H., M. Beklioglu, T.L. Crisman (2003). The role of water-level fluctuations in shallow lake ecosystems workshop conclusions. *Hydrobiologia*, 506 (1-3): 23-27.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruedo, R.G. Raskin, P. Sutton, M. van den Belt (1997). The value of the world's ecosystem services and natural capital. *Nature*, 15 (387): 253-260.

Daily, G.C. (1997). *Nature's services: societal dependence on natural ecosystems*. Island Press.

De Groot, K.J., A.C. Fabre (1993). The impact of desiccation of a freshwater marsh (Garcines Nord, Camargue, France) on the sediment-water-vegetation interactions. Part 3. The fractional composition and the phosphate adsorption characteristics of the sediment. *Hydrobiologia*, 252: 105-116.

de Vicente, I. (2004). *Intercambio de nutrientes en la interfase agua-sedimento de dos lagunas costeras de elevado nivel trófico: La Albufera de Adra (Almería)*. Tesis Doctoral. Universidad de Granada.

de Vicente, I., V. Amores, F. Guerrero, L. Cruz-Pizarro (2010a). Contrasting factors controlling microbial respiratory activity in the sediment of two adjacent Mediterranean wetlands. *Naturwissenschaften*, 97: 627-635.

de Vicente, I., F.Ø. Andersen, H.C.B. Hansen, L. Cruz-Pizarro, H.S. Jensen (2010b). Water level fluctuations may decrease phosphate adsorption capacity of the sediment in oligotrophic high mountain lakes. *Hydrobiologia*, 651: 253-264.

Downing, J.A. (2010). Emerging global role of small lakes and ponds: little things mean a lot. *Limnetica*, 29: 9-24.

Duggan IC, J.D. Green R.J. Shiel (2001). Distribution of rotifers in North Island, New Zealand, and their potential use as bioindicators of lake trophic state. *Hydrobiologia*, 446/447: 155-164.

Ejsmont-Karabin, J., A. Karabin (2013). The suitability of zooplankton as lake ecosystem indicators: crustacean trophic state index. *Polish Journal of Ecology*, 61, 561–573.

European Commission (2015) *Towards an EU Research and Innovation policy agenda for nature-based solutions & re-naturing cities*. Final Report of the Horizon2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities. Brussels: European Commission.

Fano, E.A., M. Mistri, R. Rossi (2003). The ecofunctional quality index (EQI): a new tool for assessing lagoonal ecosystem impairment. *Estuarine, Coastal and Shelf Science*, 56: 709-716

Furness, R.W., J.J.D. Greenwood (1993). *Birds as Monitors of Environmental Change*. Chapman & Hall, London.

Gilbert, J.D., I. de Vicente, R. Jiménez-Melero, G. Parra, F. Guerrero (2014a). Selecting priority conservation areas based on zooplankton diversity: the case of Mediterranean wetlands. *Marine and Freshwater Research*, 65: 857-871.

Gilbert, J.D., F. Guerrero, I. de Vicente (2014b). Sediment desiccation as a driver of phosphate availability in the water column of Mediterranean wetlands. *Science of the Total Environment*, 466-467: 965-975.

Gilbert, J.D., I. de Vicente, F. Ortega, R. Jiménez-Melero, G. Parra, F. Guerrero (2015a). A comprehensive evaluation of the crustacean assemblages in southern Iberian Mediterranean wetlands. *Journal of Limnology*, 74: 169-181.

Gilbert, J.D., F. Guerrero, R. Jiménez-Melero, I. de Vicente (2015b). Is the bioproduction number a good estimator of the trophic state in Mediterranean wetlands? Comments of some limitations. *Knowledge and Management of Aquatic Ecosystems*, 416, 05.

Gilbert, J.D., I. de Vicente, F. Ortega, E. García-Muñoz, R. Jiménez-Melero, G. Parra, F. Guerrero (2017a). Linking watershed land uses and crustacean assemblages in Mediterranean wetlands. *Hydrobiologia*, 799: 181-191.

Gilbert, J.D., I. de Vicente, R. Jiménez-Melero, F. Guerrero (2017b). Zooplankton body size versus taxonomy in Mediterranean wetlands: implication for aquatic ecosystem evaluation. *Freshwater Science*, 36: 774-783.

González-Bernáldez, F. (1989). Ecosistemas áridos y endorreicos españoles. In: *Seminario sobre zonas áridas en España*. Real Academia de Ciencias Exactas, Físicas y Naturales, Madrid. pp: 223-238.

González-Capitel, E. (2003). Humedales: los primeros pasos de un plan. *Medioambiente*, 42: 22-24.

Guerrero, F. (2009). Humedales continentales andaluces. In: *Proyecto Andalucía Naturaleza*. *Ecología V*. F.X. Niell (coordinador de la serie). Ed. Publicaciones Comunitarias. Sevilla. pp: 357-400

Guerrero, F., G. Parra, F. Jiménez-Gómez, M.C. Castro, R. Jiménez-Melero, A. Galotti, F. Ortega (2005). Los ecosistemas acuáticos en el contexto de los agrosistemas: la comarca del Alto Guadalquivir. In: *La cultura del olivo: ecología, economía y sociedad.* Anta, J.L., J. Palacios, F. Guerrero (eds.). Universidad de Jaén. Jaén. pp: 377-398

Guerrero, F., G. Parra, F. Jiménez-Gómez, C. Salazar, R. Jiménez-Melero, A. Galotti, E. García-Muñoz, M.L. Lendínez, F. Ortega (2006). Ecological studies in Alto Guadalquivir wetlands: a first step towards the application of conservation plans. *Limnetica*, 25: 95-106

Gulati, R.D. (1983). Zooplankton and its grazing as indicators of trophic status in Dutch lakes. *Environmental Monitoring and Assessment*, 3: 343-353.

Gulati, R.D. (1990). Zooplankton structure in the Loosdrecht lakes in relation to trophic status and recent restoration measures. *Hydrobiologia*, 191: 173-188.

Haberman J., R. Laugaste, T. Nõges (2007). The role of cladocerans reflecting the trophic status of two large and shallow Estonian lakes. *Hydrobiologia*, 584: 157-166.

Haberman, J., M. Haldna (2014). Indices of zooplankton community as valuable tools in assessing the trophic state and water quality of eutrophic lakes: long term study of Lake Vortsjärv. *Journal of Limnology*, 73: 61-71.

Hakanson, L. (1984). On the relationship between lake trophic level and lake sediments. *Water Research*, 18: 303-314.

Heiskanen, A. S., W. van de Bund, A. C. Cardoso, P. Noges (2004). Towards good ecological status of surface waters in Europe - interpretation and harmonisation of the concept. *Water Science and Technology*, 49: 169-177.

Hernández M.E., W.J. Mitsch (2006). Influence of hydrologic pulses, flooding frequency and vegetation on nitrous oxide emissions from created riparian marshes. *Wetlands*, 26: 862-877.

Hupfer, M., S. Hilt (2008). Lake restoration. In: *Encyclopedia of Ecology*, Vol. 3, S.E. Jørgensen, B.D. Fath (eds.). Elsevier, Oxford. pp. 2080-2093.

Kerr, S.R. (1974). Theory of size distribution in ecological communities. *Journal of Fisheries Research Board of Canada*, 31: 1859-1862.

Kratzer C.R., P.L. Brezonik (1981). A Carlson-type trophic state index for nitrogen in Florida lakes. *Water Resources Bulletin*, 17: 713-715.

Lougheed, V.L., P. Chow-Fraser (2002). Development and use of a zooplankton index to monitor wetland quality in the Laurentian Great Lakes basin. *Ecological Applications*, 12: 474-486.

Margalef, R. (1953). *Crustáceos de las aguas continentales ibéricas*. Biología de las aguas continentales. Volumen X.

McCormick, P.V., R.J. Stevenson (1998). Periphyton as a tool for ecological assessment and management in the Florida Everglades. *Journal of Phycology*, 34: 726-733.

Minns, C.K., V.W. Cairns, W.G. Randall, I.E. Moore (1994). An Index of Biotic Integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' Areas of Concern. *Canadian Journal of Fisheries and Aquatic Sciences*, 51: 1804-1822.

Mitsch, C.F., J. Gosselink (2000). *Wetlands*. John Wiley & Sons. Nueva York.

Moss, B., D. Stephen, C. Álvarez, E. Becares, W. van de Bunt, S.E. Collings, E. van Donk, E. de Eyto, T. Feldmann, C. Fernández-Aláez, M. Fernández-Aláez, R.J.M. Franken, F. García-Criado, E.M. Gross, M. Gyllstrom, L. Hansson, K. Irvine, A. Jarvalt, J.P. Jenssen, E. Jeppesen, T. Kairesalo, R. Kornijow, T. Krause, H. Kunnap, A. Laas, E. Lill, B. Lorens, H. Luup, M. Miracle, P. Noges, T. Noges, M. Nykannen, I. Ott, W. Peczula, E.T.H.M. Peeters, G. Phillips, S. Romo, V. Russell, J. Salujoe, M. Scheffer, K. Siewertsen, H. Smal, C. Tesch, H. Timm, L. Tuvikene,

I. Tonno, T. Virro, E. Vicente, D. Wilson (2003). The determination of ecological quality in shallow lakes—a tested system (ECOFRAME) for implementation of the European Water Framework Directive. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 13: 507-549.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A. da Fonseca, J. Kent (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403: 853-858.

Ortega, F., M.C. Castro, G. Parra, M. Conradi, F. Guerrero (2001). Vegetación de las lagunas endorreicas del Alto Guadalquivir. El complejo lagunar de Martos. In: *Valoración y Gestión de Espacios Naturales*. Actas de las XVII Jornadas de Fitosociología. Universidad de Jaén. Jaén. pp: 229-240.

Ortega, F., F. Guerrero (2003). Vegetación de las lagunas y humedales del Alto Guadalquivir. El complejo lagunar de Alcaudete-Valenzuela. In: *In Memoriam al Prof. Dr. Isidoro Ruiz Martínez*. J.Mª. Pérez (ed.). Universidad de Jaén. Jaén. pp: 101-116.

Ortega, F., F. Guerrero (2007). Vegetación de los humedales del Alto Guadalquivir: lagunas asociadas materiales sedimentarios y olitostromas. *Acta Granatense*, 6: 15-29

Ortega, F., G. Parra, F. Guerrero (2003). Los humedales del Alto Guadalquivir: inventario, tipologías y estado de conservación. In: *Ecología, manejo y conservación de los humedales*. Actas de la XIII Aula de Ecología. M. Paracuellos (ed.). Instituto de Estudios Almerienses. Almería. pp: 113-123

Ortega, F., G. Parra, F. Guerrero (2004). Las lagunas del Alto Guadalquivir: propuestas para su protección y conservación. In: *Congreso de restauración de ríos y humedales*. J. Cachón (ed.). Ministerio de Fomento-Ministerio de medio Ambiente-CEDEX. Madrid. pp: 131-142.

Ortega, F., G. Parra, F. Guerrero (2006). Usos del suelo en las cuencas hidrográficas de los humedales del Alto Guadalquivir: importancia de una adecuada gestión. *Limnetica,* 25: 723-732.

Ortega, F., C. Salazar, F. Guerrero (2007). Vegetación de los humedales del Alto Guadalquivir: las lagunas de origen kárstico y lagunas sobre rañas del noreste de la provincia de Jaén. *Acta Granatense*, 6: 1-14.

Pontin, R.M., J.M. Langley (1993). The use of rotifer communities to provide a preliminary national classification of small water bodies in England. *Hydrobiologia*, 255/256: 411-419.

Relexans, J.C. (1996). Measurement of the respiratory electron system (ETS) activity in marine sediments: state of the art and interpretation. I. Methodology and review of literature data. *Marine Ecology Progress Series*, 136: 277-287.

Rodríguez-Rodríguez, M. (2007). Hydrogeology of ponds, pools, and playa-lakes of southern Spain. *Wetlands*, 27: 819-830.

Ryding, S.O. (1985). Chemical and microbiological processes as regulators of the exchange of substances between sediments and water in shallow eutrophic lakes. *Internationale Revue der Gesamten Hydrobiologie*, 70: 657-702.

Sahuquillo, M., M.R. Miracle (2013). The role of historic and climatic factors in the distribution of crustacean communities in Iberian Mediterranean ponds. *Freshwater Biology*, 58: 1251-1266.

Sánchez-Fernández, D., P. Abellán, J. Velasco, A. Millán. (2004). Selecting areas to protect the biodiversity of aquatic ecosystems in a semiarid Mediterranean region. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 14: 465-479.

Schindler, D.W. (2006). Recent advances in the understanding and management of eutrophication. *Limnology and Oceanography*, 51: 356-363.

Seminara M., D. Vagaggini, F.G. Margaritora (2008). Differential responses of zooplankton assemblages to environmental variation in temporary and permanent ponds. *Aquatic Ecology*, 42: 129-140.

Seminara, M., D. Vagaggini, F. Stoch (2016). A comparison of Cladocera and Copepoda as indicators of hydroperiod length in Mediterranean ponds. *Hydrobiologia*, 782: 71-80.

Serrano, L., K. Fahd (2005). Zooplankton communities across a hydroperiod gradient of temporary ponds in the Doñana National Park (SW Spain). *Wetlands*, 25: 101-111.

Stemberger, R.S., J.M. Lazorchak (1994). Zooplankton assemblage responses to disturbance gradients. *Canadian Journal of Fisheries and Aquatic Sciences*, 51: 2435-2447.

Stemberger, R.S., D.P. Larsen, T.M. Kincaid (2001) Sensitivity of zooplankton for regional lake monitoring. *Canadian Journal of Fisheries and Aquatic Sciences*, 58: 2222-2232.

V.V.A.A. (2004). *Plan Andaluz de Humedales*. Junta de Andalucía. Sevilla

White, J.R., K.R. Reddy (2009). Biogeochemical dynamics I: Nitrogen cycling in wetlands. In: *The Wetlands Handbook*. Blackwell Publishing. Maltby, E., T. Barker (eds.). pp. 213-227.

Whitman, R.L., M.B. Nevers, M.L. Goodrich, P.C. Murphy, B.M. Davis, (2004). Characterization of Lake Michigan coastal lakes using zooplankton assemblages. *Ecological Indicators*, 4: 277-286.

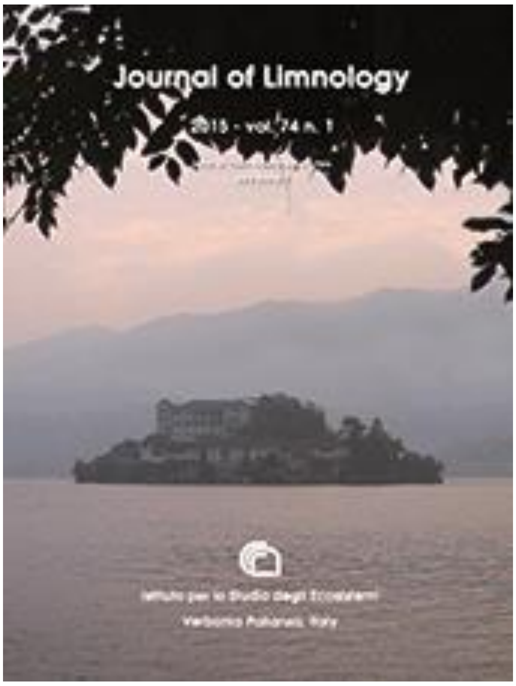
Willaarts, B.A., M. Ballesteros, N. Hernández-Mora (2014). Ten years of the water framework Directive in Spain: An overview of the ecological and chemical status of surface water bodies. In: *Integrated Water Resources Management in the XXIst Century*, VI Botín Foun- dation Water Workshop. P. Martínez Santos, M. Aldaya (eds.). Taylor & Francis Group.

Chapter 1: *A comprehensive evaluation of the crustacean assemblages in southern Iberian Mediterranean wetlands*

Gilbert, J.D.; I. de Vicente; F. Ortega; R. Jiménez-Melero; G. Parra; F. Guerrero (2015)

Journal of Limnology, 74: 169-181

DOI: https://doi.org/10.4081/jlimnol.2014.993



J. Limnol., 2015; 74(1): 169-181
DOI: 10.4081/jlimnol.2015.993

ORIGINAL ARTICLE

A comprehensive evaluation of the crustacean assemblages in southern Iberian Mediterranean wetlands

Juan Diego GILBERT,[1] Inmaculada DE VICENTE,[2] Fernando ORTEGA,[1] Raquel JIMÉNEZ-MELERO,[1,3] Gema PARRA,[1,3] Francisco GUERRERO[1,3*]

[1]Department of Animal Biology, Plant Biology and Ecology, University of Jaén, Campus de Las Lagunillas, s/n, 23071 Jaén, Spain; [2]Department of Ecology, University of Granada, Campus de Fuentenueva, s/n, 18071 Granada, Spain; [3]Center for Advanced Studies in Earth Sciences, University of Jaén, Campus de Las Lagunillas, s/n, 23071 Jaén, Spain
*Corresponding author: fguerre@ujaen.es

ABSTRACT

Although Mediterranean wetlands were recognized as biodiversity hotspots, most of them are nowadays threatened by human activities that have led to habitat loss and degradation. A total of 36 wetlands were monitored to assess species richness of branchiopods and copepods by using accumulation curves and non-parametric estimators. Three different types of wetlands were identified: i) temporary freshwaters-subsaline-hyposaline (TFSH); ii) permanent freshwaters-subsaline-hyposaline (PFSH); and iii) mesosaline-hypersaline (MH) wetlands (including temporary and permanent ones). A total of 60 species were recorded; they belong to seven different orders. A large number (37%) of rare species (present in only one wetland) were found while only 11% of the total species were common (i.e., present in more than 20% of wetlands). Species richness was related to wetland typology, with the largest number of species observed in TFSH, followed by MH and by PFSH wetlands. We have found that rare species are mainly present in temporary wetlands, the most vulnerable to hydrological changes; hence, these types of wetlands represent unique sites deserving conservation.

Key words: Biodiversity, conservation, Mediterranean wetlands, non-parametric estimators, zooplankton.

Received: April 2014. Accepted: August 2014.

INTRODUCTION

The Mediterranean region is considered as one of the most important biodiversity hotspots in the world (Myers *et al.*, 2000). In particular, the southern Iberian Peninsula is an area of special interest as it is located in one of the most arid zones of Europe and comprises a wide range of aquatic ecosystems, from freshwater to hypersaline ones (Sánchez-Fernández *et al.*, 2004), which represent an important component of the landscape.

Mediterranean wetlands are characterized by social, economic, cultural, scientific and environmental values (see Williams, 1999 among others). These ecosystems have been considered as unique because of their ecological characteristics, which frequently hold exclusive communities of aquatic organisms, and play an important role in the maintenance of regional biodiversity (Williams, 1999; De Meester *et al.*, 2005; Oertli *et al.*, 2005; Céréghino *et al.*, 2008). However, this value has been frequently overlooked, contributing to their neglect and inadequate management (Semlitsch and Bodie, 2005). In fact, nowadays, Mediterranean wetlands are highly endangered, suffering widespread degradation and loss due to increase of intensive cultivation, livestock, and urban uses (Beja and Alcazar, 2003; García-Muñoz *et al.*, 2010).

Zooplankton is one of the most important communities present in these wetlands. Zooplanktonic assemblages have previously been used for the ecological evaluation of wetlands (Gannon and Stemberger, 1978; Caramujo and Boavida, 2000; Bianchi *et al.*, 2003; Boix *et al.*, 2005; Parra *et al.*, 2009). However, recently the European Water Framework Directive (WFD) has excluded this community from the evaluation criteria in the protection of wetlands. Some authors have considered this exclusion as an error (Jeppesen *et al.*, 2011 and references therein), because the knowledge of zooplankton diversity is a necessary tool for the development of strategies for the management and protection of aquatic biodiversity at landscape level (Marrone *et al.*, 2006; De Bie *et al.*, 2008). Moreover, the lack of fish community in temporary wetlands, denote the importance to include zooplankton in the evaluation of ecological quality and conservation procedures in Mediterranean wetlands.

Previous studies focusing on zooplankton richness in the Mediterranean area are scarce in comparison to other climatic regions (Álvarez-Cobelas *et al.*, 2005). The aim of this study has been the development of monitoring methods to evaluate zooplankton biodiversity (using as target groups copepods and branchiopods) in a Mediterranean area in southern Spain in order to build models for the entire Mediterranean region.

OPEN ACCESS

press

MARINE & FRESHWATER RESEARCH

Chapter 2: *Selecting priority conservation areas based on zooplankton diversity: the case of Mediterranean wetlands*

Gilbert, J.D.; I. de Vicente; R. Jiménez-Melero; G. Parra; F. Guerrero (2014)

Marine and Freshwater Research, 65: 857-871

DOI: https://doi.org/10.1071/MF13143


CSIRO PUBLISHING

Selecting priority conservation areas based on zooplankton diversity: the case of Mediterranean wetlands

Juan Diego Gilbert[A], Inmaculada de Vicente[C], Raquel Jiménez-Melero[A,B], Gema Parra[A,B] and Francisco Guerrero[A,B,D]

Freshwater Science

Volume 36, Number 4 | December 2017

Chapter 3: *Zooplankton body size versus taxonomy in Mediterranean wetlands: implication for aquatic ecosystem evaluation*

Gilbert, J.D.; I. de Vicente; R. Jiménez-Melero; F. Guerrero (2017)

Freshwater Science, 36: 774-783

DOI: https://doi.org/10.1086/694321

Zooplankton body size versus taxonomy in Mediterranean wetlands: implications for aquatic ecosystem evaluation

Juan Diego Gilbert[1,2,4], Inmaculada de Vicente[3,5], Raquel Jiménez-Melero[1,2,6], and Francisco Guerrero[1,2,7]

[1]Departamento de Biología Animal, Biología Vegetal y Ecología, Universidad de Jaén, Campus de Las Lagunillas, s/n. E–23071, Jaén, Spain

[2]Centro de Estudios Avanzados en Ciencias de la Tierra CEACTierra, Universidad de Jaén, Campus de Las Lagunillas, s/n. E–23071, Jaén, Spain

[3]Departamento de Ecología, Universidad de Granada, Campus de Fuentenueva, s/n. E–18071, Granada, Spain

Abstract: Intrinsic ecological characteristics of Mediterranean wetlands make them excellent sites for studying biodiversity, but these wetlands have been studied much less frequently than temperate lakes. The invertebrates that inhabit them, and zooplankton specifically, play important roles in these wetlands. We compared the ability of taxon- and size-based analyses of the zooplankton community to predict the influence of environmental variables. We sampled environmental variables and zooplankton at 7 Mediterranean wetlands in the Iberian Peninsula (southern Spain) monthly along 1 hydroperiod cycle (2009–2010). We used 3 arrays for classifying the zooplankton community: 1) species occurring in >5% of the samples, 2) coarse-level taxa easily identified by a nonexpert (large branchiopods, small branchiopods, calanoid copepods, cyclopoid copepods, and harpacticoid copepods), and 3) 4 body-size classes (<1, 1–2.5, 2.5–10, and >10 mm in length). We used permutational analysis of variance (PERMANOVA) and canonical correspondence analysis (CCA) to test our hypotheses. Communities differed significantly among wetlands, and body size (55.8% of explained variance) was more useful than taxonomic composition (common taxa: 24.4%, coarse-level taxa: 26.5% of explained variance) for rapid assessment of the influence of the environmental variables on zooplankton community in temporary wetlands.

Key words: zooplankton, Mediterranean wetlands, body size, eutrophication, wetland evaluation

Wetlands are accepted globally as singular ecosystems (Mitsch and Gosselink 2000 and references therein). Nevertheless, small lentic ecosystems, and more specifically Mediterranean wetlands, have received much less attention than other aquatic ecosystems, such as large temperate lakes (Álvarez-Cobelas et al. 2005, Downing 2010). Mediterranean wetlands are unique because of their ecological characteristics. Most of them are very small with catchment area much larger than wetland surface area, and they experience a long vegetation period and strong seasonality in water supply (Álvarez-Cobelas et al. 2005). They are excellent repositories of biodiversity, frequently hold exclusive communities of aquatic organisms, and play an important role in the maintenance of regional biodiversity (Williams 1999, De Meester et al. 2005, Céréghino et al. 2008, Kagalou et al. 2010, Gilbert et al. 2014a, 2015a). They are recognized as essential hot spots of aquatic biodiversity, but the scarcity of research done in these ecosystems has made possible strongly detrimental human disturbance leading to the disappearance of many of them (Brinson and Malvárez 2002).

A great fraction of Mediterranean wetlands are temporary and fishless (Conlon 2002). Thus, knowledge of the invertebrate communities that inhabit them is essential for modeling their trophic web structure (Wellborn et al. 1996, Quintana et al. 2006). Among invertebrates, the zooplankton assemblage is a good indicator for wetland assessment because zooplankton are easy to identify, play a key role in food webs, respond to environmental gradients (Jeppesen et al. 2000), and, in some cases, act as keystone species (Badosa et al. 2007).

E-mail addresses: [4]dgilbert@ujaen.es; [5]ivicente@ugr.es; [6]rmelero@ujaen.es; [7]To whom correspondence should be addressed, fguerre@ujaen.es

DOI: 10.1086/694321| Received 26 April 2017; Accepted 23 June 2017; Published online 22 August 2017.
Freshwater Science. 2017. 36(4):774–783. © 2017 by The Society for Freshwater Science.

Chapter 4: Zooplankton community dynamics in temporary Mediterranean wetlands: what´s drivers regulates tha annual species replacement?

Gilbert, J.D.; I. de Vicente; F. Ortega; F. Guerrero (2021)

Water, 13: 1447 **DOI:** https://doi.org/10.3390/w13111447

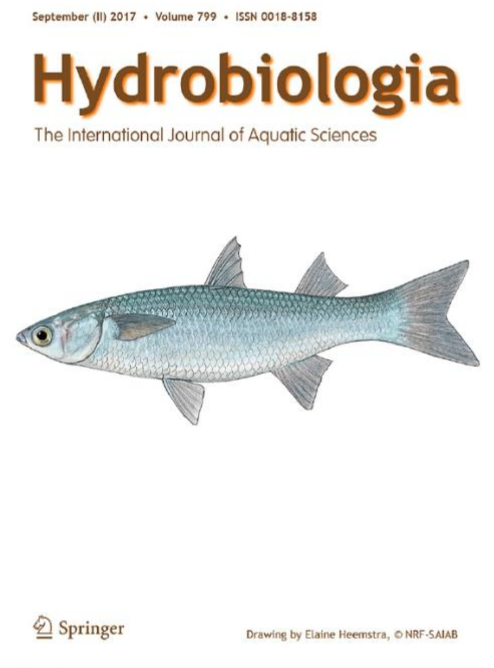
Hydrobiologia
Springer

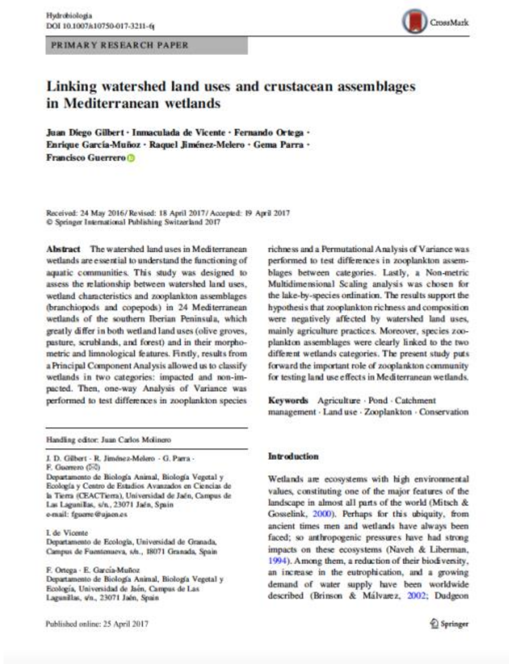
Chapter 5: *Linking watershed land uses and crustacean assemblages in Mediterranean wetlands*

Gilbert, J.D.; I. de Vicente; F. Ortega; E. García-Muñoz; R. Jiménez-Melero; G. Parra; F. Guerrero (2017)

Hydrobiologia, 799: 181-191

DOI: https://doi.org/10.1007/s10750-017-3211-6





Hydrobiologia
DOI 10.1007/s10750-017-3211-6

PRIMARY RESEARCH PAPER

Linking watershed land uses and crustacean assemblages in Mediterranean wetlands

Juan Diego Gilbert · Inmaculada de Vicente · Fernando Ortega · Enrique García-Muñoz · Raquel Jiménez-Melero · Gema Parra · Francisco Guerrero

Received: 24 May 2016 / Revised: 18 April 2017 / Accepted: 19 April 2017

Abstract The watershed land uses in Mediterranean wetlands are essential to understand the functioning of aquatic communities. This study was designed to assess the relationship between watershed land uses, wetland characteristics and zooplankton assemblages (branchiopods and copepods) in 24 Mediterranean wetlands of the southern Iberian Peninsula, which greatly differ in both wetland land uses (olive groves, pasture, scrublands, and forest) and in their morphometric and limnological features. Firstly, results from a Principal Component Analysis allowed us to classify wetlands in two categories: impacted and non-impacted. Then, one-way Analysis of Variance was performed to test differences in zooplankton species richness and a Permutational Analysis of Variance was performed to test differences in zooplankton assemblages between categories. Lastly, a Non-metric Multidimensional Scaling analysis was chosen for the lake-by-species ordination. The results support the hypothesis that zooplankton richness and composition were negatively affected by watershed land uses, mainly agriculture practices. Moreover, species zooplankton assemblages were clearly linked to the two different wetlands categories. The present study puts forward the important role of zooplankton community for testing land use effects in Mediterranean wetlands.

Keywords Agriculture · Pond · Catchment management · Land use · Zooplankton · Conservation

Handling editor: Juan Carlos Molinero

J. D. Gilbert · R. Jiménez-Melero · G. Parra · F. Guerrero (✉)
Departamento de Biología Animal, Biología Vegetal y Ecología y Centro de Estudios Avanzados en Ciencias de la Tierra (CEACTierra), Universidad de Jaén, Campus de Las Lagunillas, s/n., 23071 Jaén, Spain
e-mail: fguerre@ujaen.es

I. de Vicente
Departamento de Ecología, Universidad de Granada, Campus de Fuentenueva, s/n., 18071 Granada, Spain

F. Ortega · E. García-Muñoz
Departamento de Biología Animal, Biología Vegetal y Ecología, Universidad de Jaén, Campus de Las Lagunillas, s/n., 23071 Jaén, Spain

Introduction

Wetlands are ecosystems with high environmental values, constituting one of the major features of the landscape in almost all parts of the world (Mitsch & Gosselink, 2000). Perhaps for this ubiquity, from ancient times men and wetlands have always been faced; so anthropogenic pressures have had strong impacts on these ecosystems (Naveh & Liberman, 1994). Among them, a reduction of their biodiversity, an increase in the eutrophication, and a growing demand of water supply have been worldwide described (Brinson & Málvarez, 2002; Dudgeon

Published online: 25 April 2017

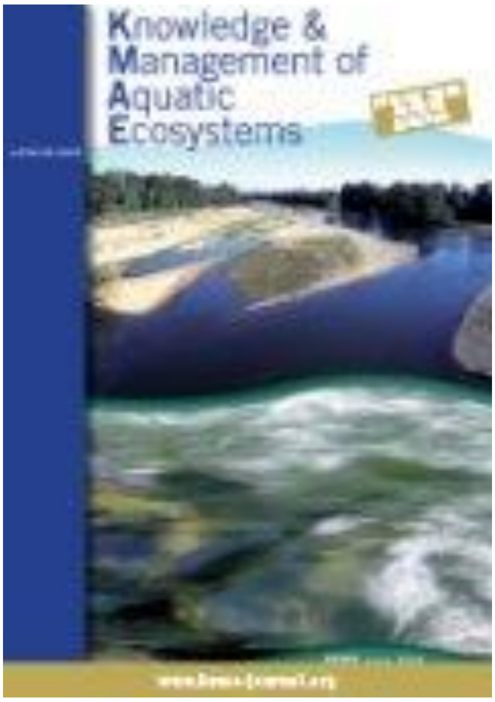
Springer

Chapter 6: *Is the bioproduction number a good estimator of the trophic state in Mediterranean wetlands? Comments of some limitations*

Gilbert, J.D.; F. Guerrero; R. Jiménez-Melero; I. de Vicente; (2015)

Knowledge and Management of Aquatic Ecosystems, 416, 05

DOI: https://doi.org/10.1051/kmae/2015002



Knowledge and Management of Aquatic Ecosystems (2015) 416, 05 http://www.kmae-journal.org
© ONEMA, 2015
DOI: 10.1051/kmae/2015001

Is the bioproduction number a good index of the trophic state in Mediterranean wetlands?

J.D. Gilbert[(1),(2)], F. Guerrero[(1),(2)], R. Jiménez-Melero[(1),(2)], I. de Vicente[(3),*]

Received October 27, 2014
Revised December 30, 2014
Accepted January 5, 2015

ABSTRACT

Key-words: *sediment, trophic state, wetlands, bioproduction number*

Eutrophication is one of the major problems affecting water quality of inland waters. Therefore trophic state evaluation is essential for the conservation, the management and the application of possible future restoration measures. The main aim of this work was to assess the effect of different land uses in the drainage basins of the Mediterranean wetlands on the bioproduction number (BPN), an indicator of the wetland trophic state. For this, we selected seven wetlands with different areal extension of agricultural land in their catchment area. The data obtained from BPN were compared with those obtained from the trophic state index (TSI). The results showed that there is a discrepancy between TSI_{TP}, $TSI_{Chl\ a}$ and BPN values in our wetlands, and that the application of the BPN for estimating trophic state in Mediterranean wetlands has clear limitations when the organic matter content in surface sediments is low. This occurs in wetlands with a great proportion of drainage area covered by intensive agricultural uses, which causes high soil losses by accelerated erosion. As a conclusion, not only high organic matter contents, as it has been stated in previous literature, but also low organic matter contents limit the validity of BPN.

RÉSUMÉ

L'indice de bioproduction est-il un bon indice de l'état trophique des zones humides méditerranéennes ?

Mots-clés : *sédiments, état trophique, zones humides, indice de bioproduction*

L'eutrophisation est l'un des principaux problèmes affectant la qualité des eaux intérieures. Par conséquent l'évaluation de l'état trophique est indispensable pour la conservation, la gestion et l'application de futures mesures possibles de restauration. L'objectif principal de ce travail était d'évaluer l'effet de différentes utilisations des terres dans les bassins de drainage des zones humides méditerranéennes sur l'indice de bioproduction (BPN), un indicateur de l'état trophique des zones humides. Pour cela, nous avons sélectionné sept zones humides avec des extensions surfaciques différentes des terres agricoles dans leur bassin versant. Les données obtenues à partir de BPN ont été comparées à celles obtenues à partir de l'indice de l'état trophique (TSI). Les résultats ont montré qu'il y a une divergence entre TSI_{TP}, $TSI_{Chl\ a}$ et les valeurs BPN dans nos zones humides, et que

(1) Departamento de Biología Animal, Biología Vegetal y Ecología, Campus de Las Lagunillas, s/n. 23071 Jaén, Spain
(2) Centro de Estudios Avanzados en Ciencias de la Tierra, Campus de las Lagunillas, s/n. 23071 Jaén, Spain
(3) Departamento de Ecología, Campus de Fuentenueva, s/n. 18071 Granada, Spain
* Corresponding author: ivicente@ugr.es

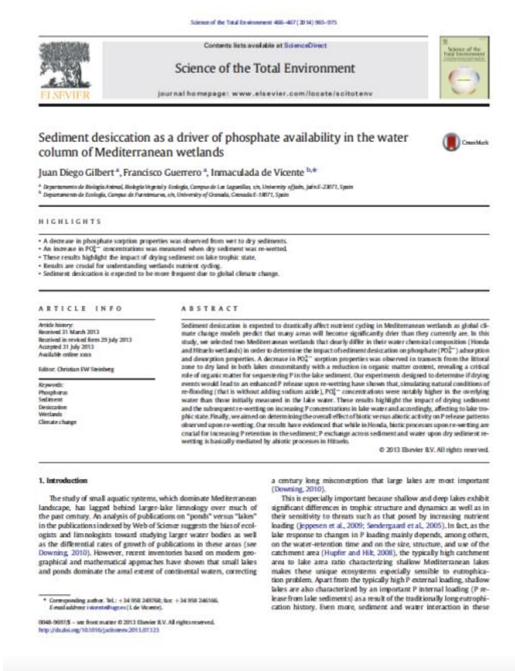
Article published by EDP Sciences

Chapter 7: *Sediment desiccation as a driver of phosphate availability in the water column of Mediterranean wetlands*

Gilbert, J.D.; F. Guerrero; I. de Vicente; (2014)

Science of the Total Environment, 466-467: 965-975

DOI: http://dx.doi.org/10.1016/j.scitotenv.2013.07.123



Science of the Total Environment 466–467 (2014) 965–975

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Sediment desiccation as a driver of phosphate availability in the water column of Mediterranean wetlands

Juan Diego Gilbert [a], Francisco Guerrero [a], Inmaculada de Vicente [b,*]

[a] Departamento de Biología Animal, Biología Vegetal y Ecología, Campus de Las Lagunillas, s/n, University of Jaén, Jaén E-23071, Spain

[b] Departamento de Ecología, Campus de Fuentenueva, s/n, University of Granada, Granada E-18071, Spain

HIGHLIGHTS

- A decrease in phosphate sorption properties was observed from wet to dry sediments.
- An increase in PO_4^{3-} concentrations was measured when dry sediment was re-wetted.
- These results highlight the impact of drying sediment on lake trophic state.
- Results are crucial for understanding wetlands nutrient cycling.
- Sediment desiccation is expected to be more frequent due to global climate change.

ARTICLE INFO

Article history:
Received 31 March 2013
Received in revised form 29 July 2013
Accepted 31 July 2013
Available online xxxx

Editor: Christian EW Steinberg

Keywords:
Phosphorus
Sediment
Desiccation
Wetlands
Climate change

ABSTRACT

Sediment desiccation is expected to drastically affect nutrient cycling in Mediterranean wetlands as global climate change models predict that many areas will become significantly drier than they currently are. In this study, we selected two Mediterranean wetlands that clearly differ in their water chemical composition (Honda and Hituelo wetlands) in order to determine the impact of sediment desiccation on phosphate (PO_4^{3-}) adsorption and desorption properties. A decrease in PO_4^{3-} sorption properties was observed in transects from the littoral zone to dry land in both lakes concomitantly with a reduction in organic matter content, revealing a critical role of organic matter for sequestering P in the lake sediment. Our experiments designed to determine if drying events would lead to an enhanced P release upon re-wetting have shown that, simulating natural conditions of re-flooding (that is without adding sodium azide), PO_4^{3-} concentrations were notably higher in the overlying water than those initially measured in the lake water. These results highlight the impact of drying sediment and the subsequent re-wetting on increasing P concentrations in lake water and accordingly, affecting to lake trophic state. Finally, we aimed on determining the overall effect of biotic versus abiotic activity on P release patterns observed upon re-wetting. Our results have evidenced that while in Honda, biotic processes upon re-wetting are crucial for increasing P retention in the sediment; P exchange across sediment and water upon dry sediment re-wetting is basically mediated by abiotic processes in Hituelo.

1. Introduction

The study of small aquatic systems, which dominate Mediterranean landscape, has lagged behind larger-lake limnology over much of the past century. An analysis of publications on "ponds" versus "lakes" in the publications indexed by Web of Science suggests the bias of ecologists and limnologists toward studying larger water bodies as well as the differential rates of growth of publications in these areas (see Downing, 2010). However, recent inventories based on modern geographical and mathematical approaches have shown that small lakes and ponds dominate the areal extent of continental waters, correcting a century long misconception that large lakes are most important (Downing, 2010).

This is especially important because shallow and deep lakes exhibit significant differences in trophic structure and dynamics as well as in their sensitivity to threats such as that posed by increasing nutrient loading (Jeppesen et al., 2009; Søndergaard et al., 2005). In fact, as the lake response to changes in P loading mainly depends, among others, on the water-retention time and on the size, structure, and use of the catchment area (Hupfer and Hilt, 2008), the typically high catchment area to lake area ratio characterizing shallow Mediterranean lakes makes these unique ecosystems especially sensible to eutrophication problem. Apart from the typically high P external loading, shallow lakes are also characterized by an important P internal loading (P release from lake sediments) as a result of the traditionally long eutrophication history. Even more, sediment and water interaction in these

* Corresponding author. Tel.: +34 958 240768; fax: +34 958 246166.
E-mail address: ivicente@ugr.es (I. de Vicente).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.07.123