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Zooplankton abundance: A neglected key element in the evaluation of reservoir water quality

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A B S T R A C T

Based on our results, we propose the use of zooplankton abundance (density or biomass) as an indicator to complement the information currently being used concerning the quality of water in reservoirs. Until now, the Water Framework Directive (EU) for lakes and reservoirs has not included zooplankton because the classification of the water trophic state is based on a bottom-up model: an increase in nutrients implies an increase in primary producers and, therefore, poorer water quality. The use of zooplankton has recently been claimed due to their sensitivity to environmental changes and their control over primary producers. From our work, carried out from 2006 to 2009 (summer and winter seasons) in 20 reservoirs found in various Mediterranean river basins, we prove the relationship of the abundance of zooplankton with the trophic state. Zooplankton abundance, with or without interaction with other agents, explained much of the distribution of total phosphorus in the reservoirs, thus relating the trophic status with the aquatic food chain. In addition, we have found, illustrated by the zooplankton: phytoplankton ratio, how the top-down control masked high production situations in the system. Zooplankton's ability to cover up these cases of poor water quality highlight that the indicators presently being used are frequently insufficient.

1. Introduction

Artificial dam reservoirs are aquatic systems with peculiar features in between lakes and rivers. They present limnetic characteristics near the dam, and more riparian ones near the river inflow, and their number has increased in many countries, particularly those with irregular rainy periods. In the Mediterranean region, where water can be scarce particularly in summer and is considered an endangered resource, reservoirs are much more abundant, larger and deeper than natural lakes (Garrido and Llamas, 2009). Their water quality is of great importance, since the majority of reservoirs store water for human consumption as well as for crop irrigation, a resource which at times may be scarce. Reservoirs mostly exhibit shorter residence time than natural lakes (Straškrabová et al., 2005) and Mediterranean reservoirs shows large water level fluctuations with high water requirements concentrated in summer (Naselli-Flores, 1999). High water renewal rates could be relevant for the structure of zooplankton communities (Obertegger et al., 2007), particularly at this season. The tendency towards eutrophication and the acute events of contamination (i.e. blooms of toxic cyanobacteria, harmful nitrate concentrations, etc.) are worrying phenomena affecting these sites (Moreno-Ostos et al., 2016). In order to control the quality of continental surface waters, in 2000 the European Union approved the Water Framework Directive (WFD, 2000/60/CE) with the aim of evaluating the ecological state of European surface waters. The ecological state is classified according to certain Biological Quality Indicators (which include phytoplankton, macrophytes and phytobenthic organisms, invertebrate benthic fauna and ichthyological fauna but surprisingly zooplankton is not included), supported by a series of hydromorphological and physical-chemical quality indicators (Annex V, 2000/60/EC). The degree of development of the standards for these indicators is not the same for different water bodies and between countries (i.e. Poikane et al., 2014).

Zooplankton community structure (species composition and abundances) has been used on numerous occasions to evaluate changes in the trophic state of reservoirs and lakes (for example: Duggan et al., 2002; Ejsmont-Karabin, 1995; Pinto-Coelho et al., 2005; Sprules, 1977), to assess pond restoration success (Antón-Pardo et al., 2013), recovery after acidification (Locke and Sprules, 1994) and other long-term changes as climatic ones (i.e. Brucet et al., 2010; Hooff and Peterson, 2006), moreover, the responses of zooplankton can be both to specific disturbances or to chronic changes (Attayde and Bozelli, 1998; Cairns et al., 1993). In addition, their species have very few limitations with regard to their geographical distribution (Carter et al., 1980; Shurin et al., 2000; Whitman et al., 2004) so the specific composition of an

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ecosystem is more likely to be due to local environmental conditions, and therefore it should be a good indicator of such conditions. Zooplankton (rotifers and microcrustaceans) includes organisms with short (few days) and medium (few weeks) life cycles (Lampert and Sommer, 1997); which can help to integrate the temporal variation of the system. Zooplankton taxonomy is not very complex, and the methods of sampling are easily compatible with general limnological methods, making the study of this group relatively cheap (Whitman et al., 2004). Thus, zooplankton seems to be an interesting group of organisms to consider for the environmental characterisation of aquatic systems. However, and surprisingly for most ecologists, zooplankton have not been included as a Biological Quality Indicator (BQI), which is an important omission and may undermine future studies on this group (Caroni and Irvine, 2010; Davidson et al., 2011; Ejsmont-Karabin, 2012; Jeppesen et al., 2011; Moss, 2007).

Furthermore, to evaluate the transfer of nutrients in aquatic food webs, knowledge of zooplankton is essential due to their pivotal position in pelagic food webs (Caroni and Irvine, 2010). Therefore, from an ecological point of view, zooplankton play an essential role within the trophic network of lakes and reservoirs, and they have a high indicator value that cannot be covered by the study of fish and phytoplankton (Jeppesen et al., 2011).

When considering top-down effects, it should be noted that zooplankton can substantially modify the phytoplankton populations (Naselli-Flores and Rossetti, 2010), an important fact when carrying out a monitoring program. A low zooplankton density can imply oligotrophic aquatic conditions or scarcity of edible food (predator-prey mismatch), for instance when filamentous cyanophytes or colonial algae are dominant (Lampert and Sommer, 1997). However, a high consumer density is only possible in a eutrophic system where resources are abundant. Therefore, when primary production is the indicator (Carlson, 1977; OECD, 1982; Willén, 2000), which is usually the most common situation, we can find massive developments of zooplankton in aquatic systems classified as oligotrophic (clear water phases). This fact alerts us to the need to revise the current system of parameters and indicators used for water quality and eutrophication assessment in order to include zooplankton. Moreover, in order to introduce the cascade effect (Carpenter et al., 1985), or top-down control of zooplankton on phytoplankton, the biomass coefficient of zooplankton compared to phytoplankton (Z:P) has been used (Jeppesen et al., 2000). Predator-prey conversion efficiencies tend to diminish with eutrophication (Welch, 1992), therefore a negative relationship between the Z:P coefficient and the trophic state of the system is expected (Jeppesen et al., 2003). Finally, quantifying the total phosphorus variance, which could be explained by dissolved phosphorus, planktonic primary production and zooplankton abundance, will highlight the relevance of bottom-up and top-down mechanisms in the trophic state of the systems.

Within this context, our study aims to analyse the role of zooplankton (mainly its abundance) as an indicators of the water quality (particularly of trophic conditions) in Mediterranean reservoirs. We used data obtained over a four year period (in winter and summer) in 20 reservoirs situated in seven Mediterranean river basins in eastern Spain. Hence, we aim to understand how the top-down control of zooplankton over primary producers may affect the evaluation of water quality. We also aim to confirm that the parameters and indicators currently being used to evaluate water quality, according to the Framework Directive, are not always the most effective, and the use of zooplankton as an indicator would improve our ability to characterize the real trophic state.

2. Materials and methods

2.1. Study sites and field sampling procedures

The study comprises 20 reservoirs from several Mediterranean river basins; the Jucar river being the largest (498 Km with a basin of 21578 Km^2), but also including other rivers such as the Turia, Palancia and Mijares, as well as some smaller ones in the south (Fig. 1); all of them in the territory administrated by the Jucar Hydrographic Confederation (JHC). Despite the fact that the study of zooplankton is not necessary according to WFD legislation, the monitoring campaign to evaluate the reservoirs' water quality included two zooplankton samples (summer and winter) per year, starting in the summer of 2006 and ending in the summer of 2009. Standard procedures were followed for sampling and transport of nutrients (including total and dissolved phosphorous), Chlorophyll *a* and phytoplankton biomass (Munné et al., 2016). Samples were taken at the deepest part of the reservoir, hundreds of meters away of the dam, in a station (marked by a buoy), which was commonly used by the JHC for the reservoir monitoring. To obtain concentrations of Chlorophyll *a* and phytoplankton, an integrated sample of the photic zone (core sample) was used; water for nutrient analyses was taken at a 2 m depth approximately. For zooplankton, an integrated sample was obtained by pooling three samples taken with a 2-L Ruttner at three depths. When the water column was stratified, they corresponded to the centre of epilimnion, metalimnion and hypolimnion (always in the oxic zone); when the water column was mixed, the three samples were equidistant. The water was filtered through 45 μm nytal filters and fixed with 4% formaldehyde.

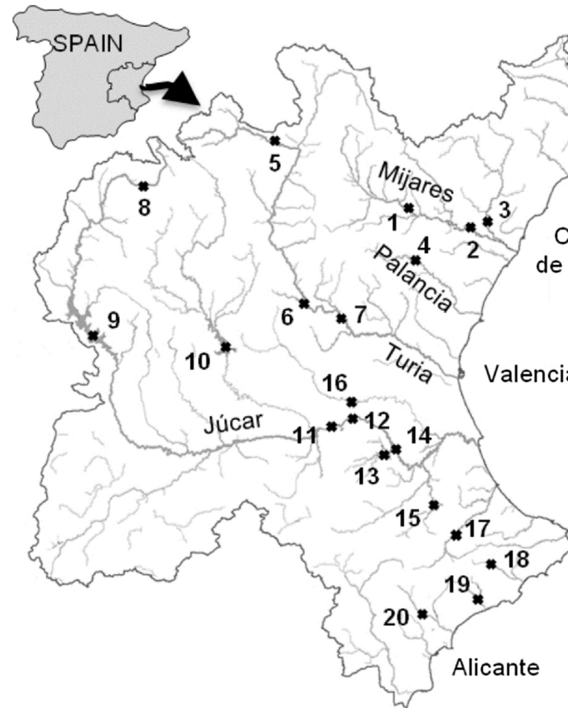

Fig. 1. Reservoirs belonging to this study. Their location on the east coast of Spain. 1-Arenós (ARE), 2-Sitjar (SIT), 3-Maria Cristina (MCR), 4-Regajo (REG), 5-Arquillo de San Blas (ARQ), 6-Benageber (BNG), 7-Loriguilla (LOR), 8-La Toba (TOB), 9-Alarcón (ALA), 10-Contreras (CON), 11-Cortes (COR), 12-Naranjero (NAR), 13-Escalona (ESC), 14-Tous (TOU), 15-Bellús (BEL), 16-Forata (FOR), 17-Beniarrés (BNR), 18-Guadalest (GUA), 19-Amadorio (AMA), 20-Tibi (TIB).

2.2. Laboratory analysis of phosphorus, chlorophyll a and micro-organisms

Total phosphorous concentration and orthophosphate were analysed by molecular absorption spectrometry using UV–vis spectroscopy (following ISO 17025, registry number 366/LE523). Chlorophyll *a* concentration was determined by spectrometry (following ISO 10260:1992; "Water quality. Measurement of biochemical parameters. Spectrometric determination of the Chlorophyll-a concentration"). Protocols were accredited by the National Accreditation Entity ENAC