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Original Research Article

Consequences of eutrophication in the management of water resources in Mediterranean reservoirs: A case study of Lake Cedrino (Sardinia, Italy)

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ABSTRACT

One of the primary detrimental effects of eutrophication is the tendency of nuisance cyanobacterial species to increase in number and biomass in freshwater ecosystems. The aim of this study was to investigate possible management actions to control eutrophication and assure water use of a eutrophic deep Mediterranean climate reservoir, dominated by cyanobacteria. With this goal, we defined the trophic state of Lake Cedrino (Sardinia, Italy) and studied its phytoplankton, paying particular attention to cyanobacteria, and to seasonal variation of phytoplankton in relation to seasonal variation of environmental variables. The water samples were collected monthly from September 2010 to August 2011 at differing depths from the surface of the water to the bottom at a station located in the deeper portion of the reservoir. Physical, chemical, nutrient, qualitative and quantitative analyses of phytoplankton were performed, and the trophic state was evaluated based on the Trophic State Index and the OECD model. Abundance of nutrients and phytoplankton (cell density, biomass and chlorophyll *a*) indicated a eutrophic condition of the reservoir. In summer, phytoplankton species composition was dominated by nuisance cyanobacteria, particularly *Aphanizomenon flosaquae*, thereby requiring management plans for harmful blooms. On the base of lake features, we propose management actions at different scales and levels to resolve eutrophication and to allow water use: from nutrient load reduction in the watershed (primarily from point-sources) to deep water aeration, to immediately face an attenuation of eutrophic effects. This study is the first explorative step in planning restoration of Lake Cedrino.

1. Introduction

Water reservoirs are man-made ecosystems of particular scientific interest, being the combination of natural phenomena and human manipulation. These ecosystems exist because of their uses and the relative goods and services that they assure to

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humans (e.g., they are sources for drinking and irrigation water, energy production, aquaculture exploitation, flood management, touristic and leisure activities). Reservoirs have rapidly increased in number and size in the last century, mainly in response to increased water demands for irrigation and energy (Jørgensen et al., 2005). Nowadays, there are more than 500,000 reservoirs in the word covering at least 0.1 km^2 with a highly heterogeneous geographical distribution, being more concentrated where lakes are scarce (Marcé and Armengol, 2010). In semi-arid areas, such as those of the Mediterranean climate, reservoirs represent the main source of water supply for human populations (Marcé and Armengol, 2010). In the Mediterranean climate, which dominates regions from 32° to 40° north and south of the Equator and is one of the five major climatic regions (Gulati et al., 2005), water is becoming the most limiting natural resource due to climate change. In particular, the Mediterranean basin is considered one of the most vulnerable area of the world for the impacts of warming and modification of precipitation regime (Erol and Randhir, 2012). Consequently, further water restriction is waited. While attempting to maximize economic profit from water resources exploitation, strong management conflicts are arising among the different stakeholders and institutions for management of reservoirs uses (Ribas, 2014).

Eutrophication is the most important worldwide environmental issue regarding reservoirs and many other types of aquatic ecosystems (Smith et al., 1999; Schindler, 2006), and is responsible for water quality degradation and severe restriction in water uses (Codd, 2000). In eutrophic conditions, hypolimnetic oxygen depletion can occur, due to the excessive amount of organic matter, produced by algal blooms, that cannot be completely degraded, increasing levels of toxic reduced substances, with development of bad odours and tastes (Jørgensen, 2001; von Sperling et al., 2008; Yu et al., 2016). Phytoplankton is the main primary producer in Mediterranean climate reservoirs, due to the high water level fluctuations that characterize these ecosystems (Naselli-Flores and Barone, 2005). In Mediterranean reservoirs, strong seasonal variations are found in phytoplankton growth and species composition, requiring adaptive management of water resources, especially in drinking treatment plants (Baker et al., 2006; Pahl-Wostl, 2006). Summer, in particular, is reported as the most favourable season for cyanobacteria dominance, even though their harmful blooms can also occur in autumn and winter (Mariani et al., 2015a,b).

For drinking and irrigation purposes, one of the main detrimental effects of eutrophication is the increased occurrence of harmful algal blooms (HABs), especially of cyanobacteria (Cyano-Habs) (Codd, 2000). Cyanobacteria are the most competitive and pervasive organisms among phytoplankton (Paerl and Otten, 2013). In addition to nutrient availability, their establishment is also favoured by high temperatures, intense solar radiation, a stable water column (Paerl and Huisman, 2008; Salmaso et al., 2012) and high pH (Paerl and Otten, 2013). Additional advantages are the ability to regulate their position within the water column with gas vacuoles, to overcome adverse periods by forming dormant cells (*akinetes*), to directly fix gaseous nitrogen by means of specialized cells (*heterocysts*) (Komarek and Anagnostidis, 1999, 2005).

Among the varying issues linked to cyanobacteria, the most serious is the ability of roughly forty species within ten genera to produce a wide variety of toxic compounds which seriously affect water use as well as the environment and cause human health hazards and sanitation alarms (Burch, 2008). Therefore, knowledge of the ecology of cyanobacteria is an essential step towards proper management of water resources.

Defining the environmental characteristics of reservoirs, their seasonal variations and the factors that influence phytoplankton growth and cyanobacteria proliferation are indispensable steps for planning both water resource management and, if necessary, ecological quality improvement, in compliance with the Water Framework Directive's (European Union, 2000) requirement of reservoirs being in good condition by 2027 (Poikane et al., 2014). Moreover, climate change is expected to further increase eutrophication, Cyano-HABs and their impacts worldwide, including areas at different latitudes than the Mediterranean climate, raising new challenges for their mitigation and management (Sahoo and Schladow, 2008; Paerl and Huisman, 2008). However, with the current levels of knowledge, researchers cannot comprehensively evaluate the complex interactions between eutrophication, Cyano-HABs and climate change, and filling these knowledge gaps is, nowadays, of paramount importance (Mariani et al., 2015a,b).

In this paper, we present a study carried out on Lake Cedrino, a deep Mediterranean climate reservoir located in Sardinia (Italy), used for drinking water and irrigation supplies. Since its first years of water accumulation, Lake Cedrino has exhibited very poor water quality (Padedda and Sechi, 2008). In the present work, we investigated its recent trophic state and phytoplankton abundance and composition, paying particular attention to cyanobacteria. Our hypotheses were that i) due to Mediterranean climate condition, there would be a strong seasonality in the phytoplankton of Lake Cedrino and, ii) because of the eutrophic state of the lake, cyanobacteria would dominate, especially in summer. These aspects influence water uses and require an adaptive approach in water management, particularly in the case of drinking use (Pahl-Wostl, 2006), such as in the case considered. Specifically, the main objective was to study the seasonal variation of phytoplankton in relation to seasonal variation of environmental variables to assess which of the considered environmental drivers most greatly affected phytoplankton, particularly cyanobacteria. In this way, we have been able to propose right interventions required to improve the water quality of the lake, assuring a multiple use of the resource, e.g. for drinking and agriculture. Our study represents the first experimental explorative step in planning reservoir restoration to control eutrophication since, at the moment, no actions have been taken to reduce the eutrophic process or to tackle the problem of phytoplankton and cyanobacteria growth in Lake Cedrino.