ARTICLE IN PRESS
STOTEN-21375; No of Pages 10

Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Depth-related response of macroinvertebrates to the reversal of eutrophication in a Mediterranean lake: Implications for ecological assessment

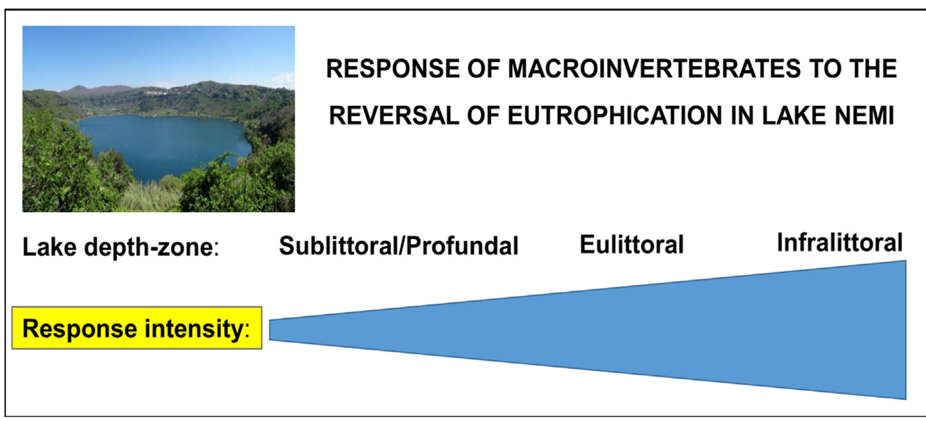
Marcello Bazzanti [a,*], Luciana Mastrantuono [a], Francesca Pilotto [b]

[a] Dept. of Environmental Biology "Sapienza", University of Rome, Viale dell'Università 32, 00185 Rome, Italy
[b] Landscape Ecology Group, Dept. of Ecology and Environmental Science, Umeå University, Tvistevägen 48, SE-901 87 Umeå, Sweden

HIGHLIGHTS

- We studied macroinvertebrates of Lake Nemi during its recovery from eutrophication.
- Communities inhabiting the different depth-zones responded differently.
- Infralittoral community showed the largest taxonomic and functional responses.
- The ecological status was correctly assessed by communities belonging to each zone.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 July 2016
Received in revised form 17 October 2016
Accepted 11 November 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Eutrophication reversal
Eulittoral sand
Infralittoral vegetation
Sublittoral/profundal zone
Benthic invertebrates
Lake Nemi

ABSTRACT

A better management of nutrient inflows into lakes has led to an improvement in their conditions (i.e. reversal of eutrophication) and the effects of this on macroinvertebrate communities that inhabit different lake-depth zones is largely unknown. This paper reports a comparison of macroinvertebrate communities living in the eulittoral, infralittoral and sublittoral/profundal zones of Lake Nemi (Central Italy) before and after its natural recovery from eutrophication following the deviation of domestic wastewater. The infralittoral zone responded more rapidly than the other two depth-zones to the improved ecological conditions, as shown by larger differences in community composition between the two periods. In the eulittoral sand, the combined effects of hydromorphological pressures and reversal of eutrophication hindered the biotic response. In the eulittoral and infralittoral zones, typical taxa of mesotrophic waters appeared or increased their abundances after the eutrophication reversal. Benthic invertebrate response was slower in the sublittoral/profundal zone due to deoxygenation that continued to prevail in the deepest area of the lake during summer. However, both tolerant and more sensitive taxa were collected there for the first time. After the reversal of eutrophication, the percentage of molluscan + large crustaceans increased in the infralittoral zone, whereas the oligochaete/chironomid ratio decreased in both sublittoral/profundal and infralittoral zones. Functional feeding metrics (percentages of

* Corresponding author.
E-mail address: marcello.bazzanti@uniroma1.it (M. Bazzanti).

http://dx.doi.org/10.1016/j.scitotenv.2016.11.073

filter-feeders, collector-gatherers, miners and scrapers/grazers) differently tracked the reversal of eutrophication in the three depth-zones probably according to the effects of the reduction of nutrients on food-web structure influencing macroinvertebrates. Biological Monitoring Working Party (BMWP) and the Average Score Per Taxon (ASPT) seemed to respond to eutrophication reversal only in the sublittoral/profundal zone, where deoxygenation plays a major role as a structuring agent of the community. Our results suggest that the effects of reversal of eutrophication can be better assessed by examining the response of the communities belonging to each zone individually.

1. Introduction

Human-induced lake eutrophication is a global problem which provokes significant environmental and societal damage (e.g. Hutchinson, 1967; Harper, 1992; O'Sullivan and Reynolds, 2004b). It is primarily caused by the increased input of nutrients into lakes deriving from human settlements and activities within its catchment. This results in heavily altered ecosystem structure, functions and services. Since the 1980s, thanks to a decrease in the use of phosphorus, the nutrient loading of many European lakes has declined (Sas, 1989; Harper, 1992). However, this has frequently failed to produce an improvement in the ecological state of the ecosystems, as recovery may be delayed or prevented by high internal phosphorus loading, unchanged external nitrogen loading, climate warming or irreversible changes in the biotic structure such as a macrophyte/phytoplankton regime shift or altered fish communities (Sas, 1989; Scheffer, 1998; Jeppesen et al., 2005).

The restoration of pristine sediment conditions is the landmark of a successful recovery of the whole lake from eutrophication, as lake sediments are located at the receiving end of all the processes going on within a lake (Levine and Schindler, 1989). Therefore, benthic macroinvertebrates, which are excellent bioindicators of trophic status (Saether, 1979; Wiederholm, 1980; Milbrink, 1983; Rosenberg and Resh, 1993), can be also suitable indicators of eutrophication reversal. Despite this, the studies that have attempted to assess lake recovery from eutrophication by means of biological tools have mainly focused on the responses of pelagic biota (i.e. phytoplankton, zooplankton and fish; Jeppesen et al., 2005; Köhler et al., 2005; Gerdeaux et al., 2006; Eigemann et al., 2016). The very few studies that have monitored macroinvertebrate communities have been mostly based on oligochaete and chironomid assemblages in the sublittoral/profundal zone of lakes (Lang and Reymond, 1992, 1993; Lang, 1997, 1998; Lang and Lods-Crozet, 1997; Nalepa et al., 2003), while there is an obvious research gap regarding the effects of eutrophication reversal on other benthic taxa and lake zones.

In lakes, macroinvertebrate studies traditionally focus on the different benthic zones separately, as they are considered as different subsystems. The rationale of this assumption relies on the fact that the structure of invertebrate assemblages in the eulittoral, infralittoral and sublittoral/profundal zones are driven by several different abiotic factors and can respond differently to natural and anthropogenic pressures. This can complicate the task of quantifying the relative sensitivity of macroinvertebrate communities to a certain pressure, and make it difficult to identify which taxon or metric is indicative of that pressure. In contrast, relatively few studies have directly compared the responses of macroinvertebrates to human pressures in different lake depth-zones (Bazzanti et al., 1994, 2012; Johnson, 1998; O'Toole et al., 2008; Donohue et al., 2009a; Pilotto et al., 2012; Pätzig et al., 2015).

Approximately ten years after the deviation of domestic wastewater, the trophic status of the volcanic Lake Nemi (Central Italy) has shifted from hypereutrophy to meso-eutrophy (according to OECD, 1982). This study compared benthic macroinvertebrates living in the eulittoral, infralittoral and sublittoral/profundal zones of this lake before and after its natural recovery from eutrophication. The aims of the research are:

- to quantify the effects of eutrophication reversal on macroinvertebrate communities living at the three lake depth-zones;
- to identify for each depth-zone a set of indicator species and metrics that can be used to track the recovery process of the lake.

2. Study area and methods

2.1. Study area and the environmental characteristics of Lake Nemi

Lake Nemi is a small volcanic lake in the Latium region of Italy located about 30 km from Rome (Fig. 1). It has a surface area of1.792 km^2 and a maximum depth of 31 m. Its water renewal time takes about 15 years. It is classified as a monomictic lake, which mixes from top to bottom normally during late winter/early spring.

The dataset refers to two different periods (1981–1982 and 2001–2002 for the eulittoral and infralittoral zones and 1982–1983 and 2001–2002 for the sublittoral/profundal zone), the information being collected to monitor its natural recovery after domestic discharge deviations which started in the early '90s. Its main physicochemical features are shown in Table 1. Following the OECD (1982) classification scheme based on total phosphorus and water transparency, Lake Nemi shifted from a hypereutrophic condition during 1982–1983 to a meso-eutrophic status in 2001–2002. From the '70s until the '80s, the lake was characterized by a total deoxygenation in all the hypolimnion (from 10 m to the maximum depth) during the summer-early autumn stratification, repeated fish kill (coregonids) and massive algal blooms (Cyanobacteria). A marked hypolimnetic deoxygenation (from 4.0 to 0.1 mg/L) persisted in summer-early autumn 2001–2002, whereas fish kill and algal blooms were not recorded. Apart from eutrophication, some hydrological changes have also affected Lake Nemi, whose water level lowered by about 1.5 m in the '90s. Following an increase in water transparency, in 2001, the littoral vegetation belt substantially improved its ecological characteristics (Mastrantuono and Sforza, 2008), with an increase in species richness and the size of the colonized area, and the appearance of Charales, which are typical of oligo-mesotrophic lakes (Blindow, 1992).

2.2. Macroinvertebrate sampling and dataset

In both study periods, samples were collected (Fig. 1) in the eulittoral, infralittoral and sublittoral/profundal zones (sensu Hutchinson, 1967; O'Sullivan and Reynolds, 2004a). Six sites (1–6) were sampled in the eulittoral zone (0.5 m depth; sand prevailing, silt and gravel) and infralittoral vegetation zones (depths: 1–4 m in 1981–1982, 1–4 m and 4–8 m in 2001–2002 when the vegetation belt extended to about 8 m depth). Seven sites (S10, G10, N10, G20, N20, G30, N30) were sampled in the sublittoral/profundal zone at different depths (indicated by the number after the letters; silt and clay prevailing and sand). Macroinvertebrates were collected (all specimens using a 0.280 mm mesh) by different methods which were suitable for sampling in the three lake zones: a hand grab and a hand net in the sandy eulittoral area, a sledge dredge in the vegetated infralittoral zone, and

Please cite this article as: Bazzanti, M., et al., Depth-related response of macroinvertebrates to the reversal of eutrophication in a Mediterranean lake: Implications for ecologica..., Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.11.073