ARTICLE

The contrasting evolution of two volcanic lakes lying in the same caldera (Monticchio, Mt. Vulture, Italy) inferred from literature records

Renato Spicciarelli,[1*] Aldo Marchetto[2]

[1]School of Agricultural, Forest, Food and Environmental Sciences (SAFE), University of Basilicata, Viale dell'Ateneo Lucano 10, 85100 Potenza; [2]CNR Water Research Institute, Corso Tonolli 50, 28922 Verbania-Pallanza, Italy

ABSTRACT

Lago Piccolo and Lago Grande di Monticchio lie in the collapsed caldera of the volcanic structure of Mt. Vulture (Basilicata, Italy). In over two centuries, a number of studies on their water and on their submerged and riparian vegetation, were carried out, demonstrating an interesting biodiversity. The entire lake area, which is impacted by strong tourist pressure, is part of the "Monte Vulture" Special Area of Conservation (SAC IT9210210). The aim of this paper is to review the literature studies on these lakes, in order to identify the more suitable limnological parameters to infer the history of the trophic status of the two lakes. For this reason, we assess the current ecological status of the two lakes on the basis of physical, chemical and biological analyses deriving from two recent surveys carried out in 2005-2007 and in 2015, and compare these data with sparse, but relevant, historical records, in order to assess how human impacts affected both these lakes and to understand the differences in their present trophic status. Because of its peculiar water chemistry, Lago Piccolo is resulted in good and stable ecological conditions. On the contrary, water transparency of Lago Grande came out very low in summer, while total phosphorus and nitrogen concentration are proved high, leading to the persistence of critical environmental conditions in this lake, with high algal biomass and durable algal blooms in late summer, dominated by cyanobacteria. Finally, in absence of standard protocols and seasonal samplings, the macrophyte maximum growing depth should be considered the more reliable indicator of trophic status among those available for these specific lakes, being relatively independent from sampling methods and seasonal pattern.

INTRODUCTION

Many European lakes have been affected by a number of anthropogenic pressures, such as eutrophication, water level changes, toxic pollution and introduction of alien species. Mountain lakes, relatively far from heavy populated areas, receive contaminants by long-range transport of air pollutants (Rogora *et al.*, 2008; Poma *et al.*, 2017). In the case of the Monticchio lakes, even if they are relatively far from human activities, and enclosed in Mt. Vulture caldera, strong human impact was due to the touristic development in the 1960s, when houses, restaurants and a cableway were built, at present in large part abandoned.

In order to follow the temporal trend in the ecological quality of ecosystems, long-term monitoring using well defined protocols can be used, providing deep insight in the changes in ecosystem structure and function (Morabito *et al.*, 2018). However, apart some rare exception (Minder 1938) systematic monitoring programmes are often started after ecosystem alteration was evident (Vollenweider *et al.*, 1974; Keating and Dodd, 1975).

Scattered morphological, physical and biological observations are available for a number of lakes since the 1870s, concerning in particular the large lakes around the Alps (Marchetto, 1998), and the large volcanic lakes in Central Italy (Margaritora, 1992). Since the 1880s, a number of studies also deals with the Monticchio lakes, and in this paper we evaluate the possibility to use them to infer the ecological history of these lakes during the periods when they were affected by climate changes, by change of nutrient levels in water, mainly related to the tourist pressure.

A list of the studies used for this historical reconstruction is presented in the supplementary materials (Tab. S1). The older papers (Tata, 1778; Palmieri and Scacchi, 1852; De Giorgi, 1879; Cavanna, 1882; Marinelli, 1895; Vinciguerra, 1895; De Lorenzo, 1900; Casoria, 1901) only reported episodic information, frequently taken with rudimentary instruments. Later on, a number of studies are related to one or few specific aspects of the lake water or biota, such as water chemistry (Cannicci, 1952; Squicciarini, 1974; Mongelli *et al.*, 1975), phytoplankton (Cannicci, 1952; Musacchio, 1981-1982), zooplankton (Ruffo and Stoch, 2005; Alfonso, 2008), or macrophytes (Venanzoni *et al.*, 2003; Azzella *et al.*, 2010).

However, four detailed limnological studies, covering most biological communities, were carried out. The first, on July 6th-8th, 1905, concerned lake morphometry, water chemistry, phytoplankton, zooplankton, macrophytes and phytobenthos and was reported by Forti and Trotter (1908) and Stegagno (1908). In 1991, a second study concerned lake morphometry, water chemistry, phytoplankton, zooplankton (Marano and D'Aprile, 1991). After these two short campaigns, a two year study was carried out in 2005-2007 by the Institute of Ecosystem Studies of the National Research Council (CNR-ISE) (Ceccanti *et al.*, 2007), together with the Milano-Bicocca University, aiming to test the possibility to use the macrophytes to improve Lago Grande water quality and go into detail concerning water physical and chemical properties and phytoplankton and zooplankton communities. A last limnological campaign was carried out by the Basilicata University (Spicciarelli and Mirauda, 2015), together with the Umbria and Marche Experimental Zooprophylactic Institute and Umbria Regional Agency for Environmental Protection.

METHODS

Study area

Mount Vulture is a composite volcano located in the Basilicata region and formed by the superimposition of a number of volcanic edifices and affected by tectonic activity (La Volpe *et al.*, 1984). Its formation started 800-750 kyears ago (Principe, 2006). On the top of the mountain, at 650 m asl, a large caldera includes a tuff ring (Giannandrea *et al*., 2006) and two maars (Stoppa and Principe, 1997), hosting the two Monticchio lakes (Fig. 1), divided by a rock strip and connected by a narrow channel through which water flows from Lago Piccolo (LP) to Lago Grande (LG). LP is smaller (0.155 km^2) and deeper (44 m) than LG (0.41 km^2 and 40 m), but the shape of LP is closer to a cone, while LG presents a large shallow area, ca. 10 m deep (Fig. 2), so that the volume of LP (4.26 10^6 m^3) is larger than the volume of LG (3.40 10^6 m^3) (Spicciarelli and Mirauda, 2015).

For LG, morphometric data obtained in 2015 compare well with those collected by Stegagno (1908). LG sediment is mostly annually laminated and rich in tephras (Wulf *et al.*, 2004, 2008, 2012; Schettler and Alberic, 2008), and represents one of the best sedimentary records for paleoclimatic studies in the Central Mediterranean (Watts, 1985; Allen *et al*., 1999; Brauer *et al*., 2007).

The emerging watershed of the two Monticchio lakes comprises approximately the caldera, with a surface of ca. 4 km^2, mainly forested. Beside precipitation in the catchment, Monticchio lakes, and in particular LP, are also fed by a heterogenous volcanic aquifer, with alternatively high and low permeability structures and several underground water divides (Celico and Summa, 2004).

From the volcanic structure, carbon dioxide reaches the lakes, and the quantity of CO_2 released compares with the two largest volcanoes producing CO_2 (Gambardella,

Fig. 1. Winter image of Mt. Vulture caldera with the two Monticchio lakes, during Lago Piccolo (on the right) partial overturn.

2006), namely Mt. Etna (Sicily) and Popocatépetl (Mexico). For this reason, LP is considered at risk of limnic eruption (Chiodini *et al*., 1997, 2000; Cioni *et al*., 2006; Caracausi *et al*., 2009, 2013, 2015). In fact, a limnic eruption happened in 1810, and was described by Ferdinando Tortorella (1840) and quoted by another further visitor of Mt. Vulture (Gussone and Tenore, 1843; Malpica, 1847; Palmieri and Scacchi, 1852; Paci, 1853).

Human activity in Mt. Vulture caldera dates back to the 4th-3rd century BCE, but a permanent settlement started in the 9th century, with the foundation of a Basilian monastery. Later a powerful Benedictine abbey took over. Anthropogenic pressure strongly increased in the 19th century, when forest surface was reduced because of tree cutting for using wood for railroad construction, and agriculture development, using lake water for irrigation. Human pressure increased again in the 1950s when tourism activities developed, with a strong impact on the

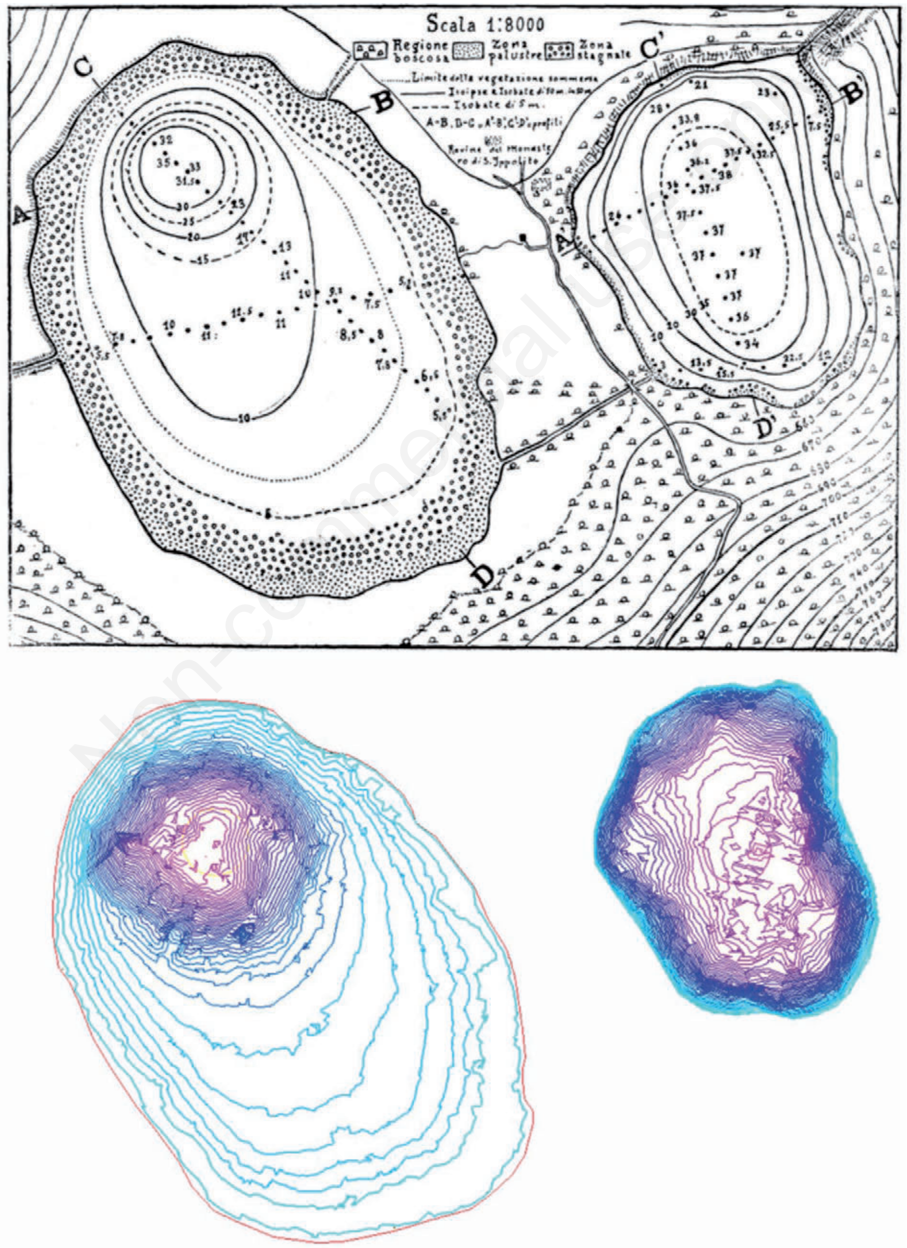

Fig. 2. Bathymetric maps of Lago Grande (left) and Lago Piccolo (right): top, in 1905 (Stegagno, 1908); bottom, in 2015. Reproduced from Spicciarelli and Mirauda, UE- P.O. FEP 2007-2013 Regione Basilicata, 2015, with permission.

ecosystems. In 1963, an endemic moth (*Brahmaea europaea* Hartig) living in the Vulture caldera and in the close Grotticelle wood was described, mainly feeding on narrow-leaved ash (*Fraxinus angustifolia* subsp. *oxycarpa* (Willd.)) (Spicciarelli, 2004, 2015, 2018a, 2018b). It is considered a Miocene relict by some authors. For this reason, the Nature Reserve of "Grotticelle" was set in 1971, today included in the Special Area of Conservation (SAC) "Grotticelle di Monticchio" (Spicciarelli, 2013).

At present, the intensity of the tourism activities is lower, and natural vegetation is recovering, but the filling of the LG outlet in 2011 caused the increase of lake level, damaging ash forest around the lake.

RESULTS

Temperature and transparency

Both lakes show a clear stratification in summer, with the thermocline located between 5 and 10 m, while the temperature is homogenous in winter (Fig. 3). However, in LP there is an increase in temperature (up to 2.5°C) below 20 m, due to the presence of underwater springs. In the western part of LG, during summer and autumn the temperature between 4 and 7 m is 8-12°C lower than in the rest of the lake (Spicciarelli and Mirauda, 2015), probably as an effect of underwater springs.

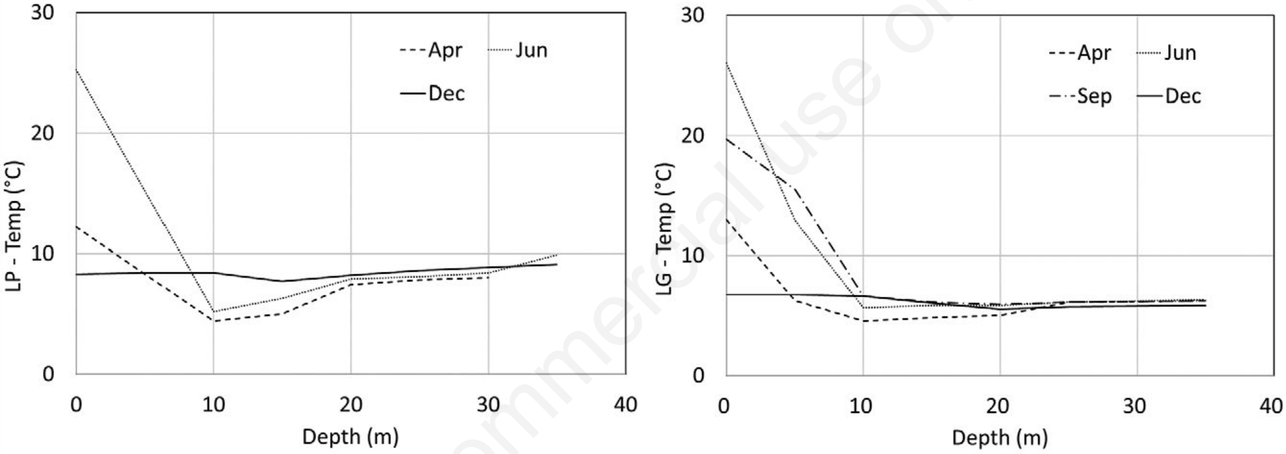

Fig. 3. Profiles of water temperature in Lago Piccolo (left) and Lago Grande (right) in April, June, September, December 2005 September data for LP were not available. Redrawn from Ceccanti *et al.*, CNR-ISE 2007, with permission.

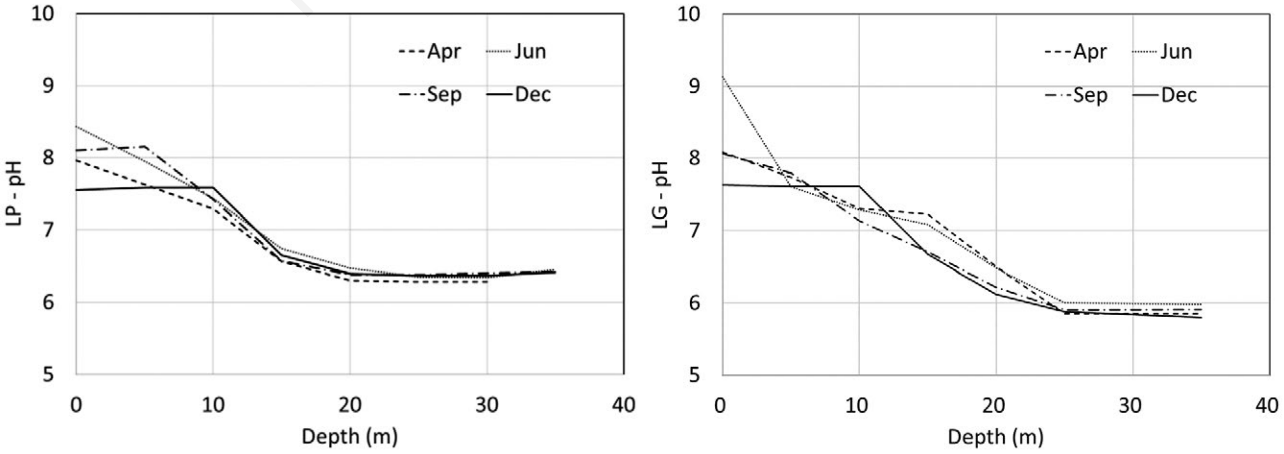

Fig. 4. Profiles of water pH in Lago Piccolo (left) and Lago Grande (right) in April, June, September, December 2005. Redrawn from Ceccanti *et al.*, CNR-ISE 2007, with permission.

During the recent studies, LG appeared warm monomictic, with full overturn in winter, as the volcanic lakes in central Italy (Margaritora, 1992). The same thermic regime was found by Mongelli (1964, 1975), Squicciarini (1974), and Nicolosi *et al.* (2010). However, LG may freeze in winter, behaving as a dimictic lake (Schettler and Albéric, 2008). On the contrary, in spite of the homoeothermic conditions reached in winter, LP is meromictic (see below).

Several authors reported Secchi disk depth measured in the Monticchio lakes (Tab. 1). Comparing data from the end of the 19th century and the last decades, water transparency decreased in LG and increased in LP.

Dissolved gases and water pH

Underwater sources feed both Monticchio lakes in carbon dioxide. In particular, in LP CO_2 concentration as high as 23 to 41 mmol L^{-1} were measured below the 20 m depth. In LG, values of 17-21 mmol L^{-1} were measured below the 20 m depth, with a maximum of 31 mmol L^{-1} close to the lake bottom in September and October 2008 (Caracausi *et al.*, 2013).

Such high CO_2 concentration affects water pH, which drops below 6 in the deeper parts of both lakes (Nicolosi, 2010). At lake surface, water pH varies seasonally between 7 and 9 in both lakes (Fig. 4), depending on the intensity of algal photosynthesis (Dumontet *et al.*, 2003; Ceccanti *et al.*, 2007), which also affect oxygen content. In fact, during summer the high photosynthetic activity leads to O_2 oversaturation (Dumontet *et al.*, 2003). In LP, O_2 concentration increases in summer from 11-12 mg L^{-1} at the surface to 23-25 mg L^{-1} at 5 m depth, dropping to zero below 20 m (Ceccanti *et al.*, 2007; Spicciarelli and Miraudа, 2015). In LG, the seasonal pattern is similar, but the depth of water anoxia fluctuates between 5 m in summer and 20 m in winter (Fig. 5), when a large portion of lake bottom, lying at 12 m depth, is oxygenated. A seasonal pattern also affects methane concentration in LG, but not in LP: Nicolosi (2010) reports that in the LP, the lowest methane concentration was measured in shallow

Tab. 1. Reported Secchi disk depth (SD) and maximum macrophyte growing depth (MMGD) in Lago Grande and Lago Piccolo.

Date	Lago Grande		Lago Piccolo		Source
	SD (m)	MMGD (m)	SD (m)	MMGD (m)	
July 1905	3.3	7	4.3	4	Forti and Trotter, 1908; Stegagno, 1908
Jun-Sep 1991	1.0-1.5	-	3-5		Marano and D'Aprile, 1991
Summer 1994	0.3	-	"High"		Schettler and Alberic, 2008
May 2001	0.5-1.0	-	3-3.5		Dumontet *et al.*, 2003
February 2005	1.9	-	-		Ceccanti *et al.*, 2007
August 2010	1.4	3.3	6.2	6.2	Azzella *et al.*, 2010
September 2015	1.0-1.2	3.2-3.4	4.7-7	5-6	Spicciarelli and Miraudа, 2015

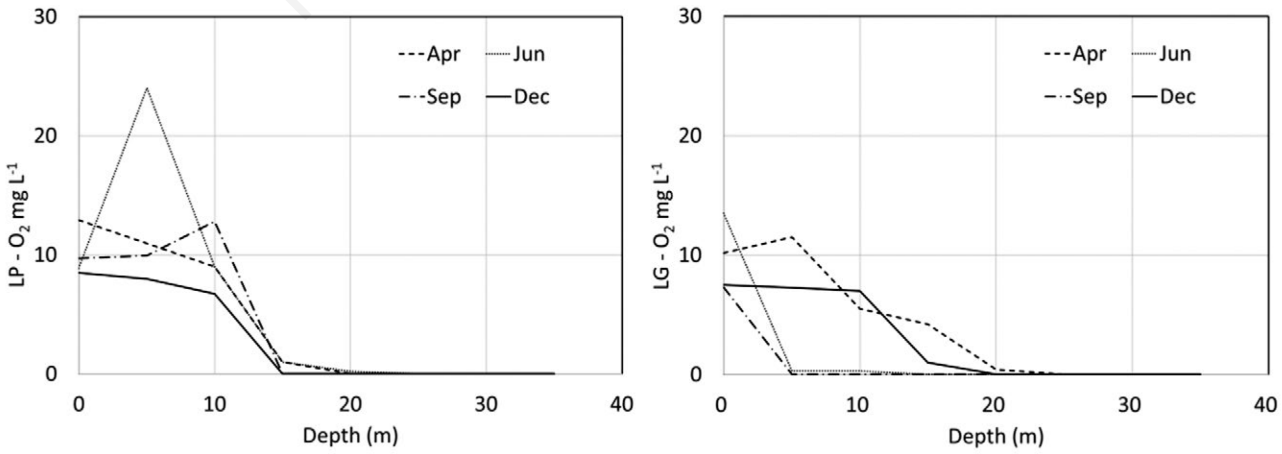

Fig. 5. Profiles of dissolved oxygen concentration in Lago Piccolo (left) and Lago Grande (right) in April, June, September, December 2005. Redrawn from Ceccanti *et al.*, CNR-ISE 2007, with permission.

waters, increasing towards the lake bottom in the monimolimnion, without a marked seasonal pattern. In LG, methane increases with depth and the highest concentrations in the entire hypolimnion have been measured during summer and autumn, while lower values were found in winter and spring.

Water chemistry

The most striking aspect of the ionic composition of LP water is the very high iron concentration (Fig. 6), reaching values higher than 100 mg L^{-1} in the anoxic deep water and causing lake meromixis (Ceccanti *et al.,* 2007; Spicciarelli and Mirauda, 2015). High values of Mn (up to 2 mg L^{-1} in LP), Ba and Sr were measured in anoxic water in both lakes (Tab. 2).

Such high iron concentration, coupled with the different thermal regime of the two lakes, dramatically affects the seasonal pattern of phosphorus concentration (Fig. 7). In LP, iron concentration in oxygenated water causes the formation of insoluble Fe^{3+} salts, which settle towards the deepest part of the lake, so that total P concentration in the upper 20 m of the lake never reaches 0.02 mg L^{-1}. In LP anoxic bottom water, Fe^{3+} is reduced to Fe^{2+}, and P is released, reaching a concentration of 0.9 mg L^{-1} in June 2005 (Ceccanti *et al.*, 2007).

In LG iron concentration is lower, and epilimnetic

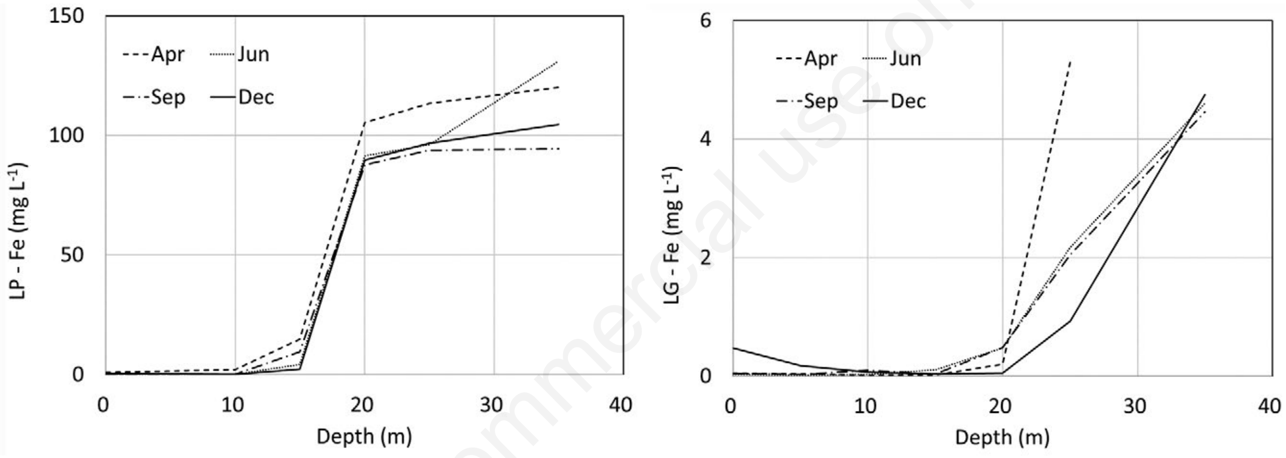

Fig. 6. Profiles of iron concentration in Lago Piccolo (left) and Lago Grande (right) in April, June, September, December 2005. Note the different scale. Redrawn from Ceccanti *et al.*, CNR-ISE 2007, with permission.

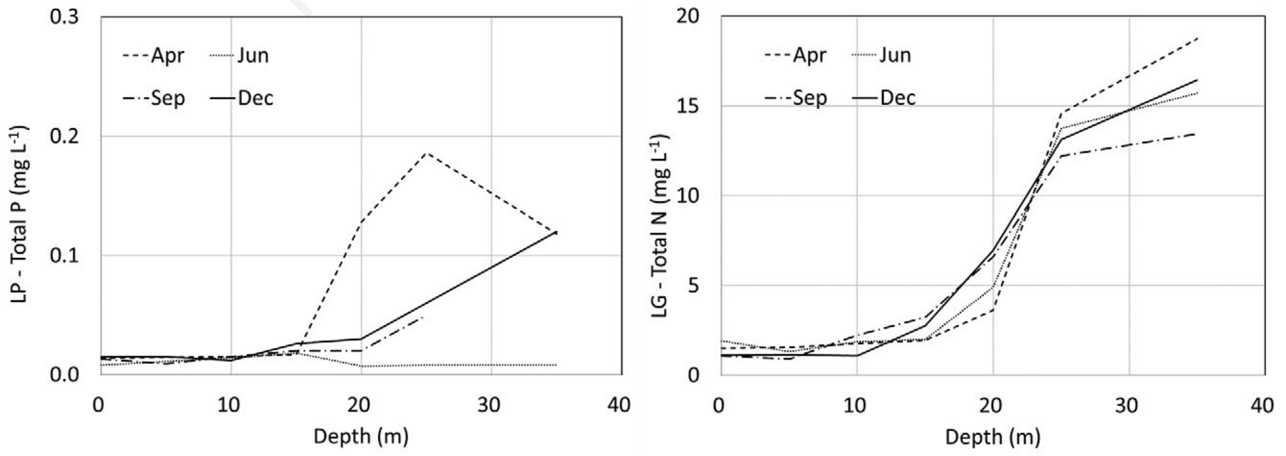

Fig. 7. Profiles of total P concentration in Lago Piccolo (left) and Lago Grande (right) in April, June, September, December 2005.Note the different scale. Redrawn from Ceccanti *et al.*, CNR-ISE 2007, with permission.

total P concertation reaches 0.06 mg L^{-1}. During summer, in the anoxic hypolimnion total P concentration increases to values over 2 mg L^{-1} (Ceccanti *et al.,* 2007; Spicciarelli and Mirauda, 2015). Winter overturn causes on one hand a small increase in bottom O$_2$ concentration, causing a drop in total P concentration. On the other hand, water mixing leads to a P flux from deep water to surface water. During summer, total P concentration increases, suggesting the presence of local sources, such as the touristic activities on the lake shore.

Total nitrogen profiles (Fig. 8) compare with the total phosphorus ones. Most inorganic N is in the form of nitrate in oxygenated water and of ammonium in anoxic water. Epilimnetic total N concentrations (0.5 to 3 mg L^{-1}) are high enough to assure that N is not a limiting factor for algal growth (Teubner & Dokulil, 2002).

Tab. 2. Range of metal concentration in Lago Grande and Lago Piccolo in 2005.

Metal (µg/L)	Lago Piccolo		Lago Grande	
	Min	Max	Min	Max
Al	5.25	55.9	7.8	182
As	<DL	6	<DL	6.8
B	42.7	483.3	24.7	74.2
Ba	58.4	424.85	69	289
Cd	<DL	11.7	<DL	1
Co	0.1	434	<DL	20
Cr	<DL	0.9	<DL	0.9
Cu	<DL	2.45	<DL	3.75
Fe	20.55	131055	14.25	5900
Li	4.5	7.3	1.4	3.6
Mn	1.35	2031.5	72.9	3688.5
Ni	<DL	4.5	<DL	2.75
Pb	<DL	20.2	<DL	2.5
Pt	<DL	82.7	<DL	11.5
Se	<DL	3.2	<DL	8.7
Sr	256.65	605.15	363.9	630
Tl	<DL	8.7	<DL	9.3
V	14.8	46	21.2	38.7
Zn	0.25	15.2	<DL	17.7

<DL, lower than detection limit.

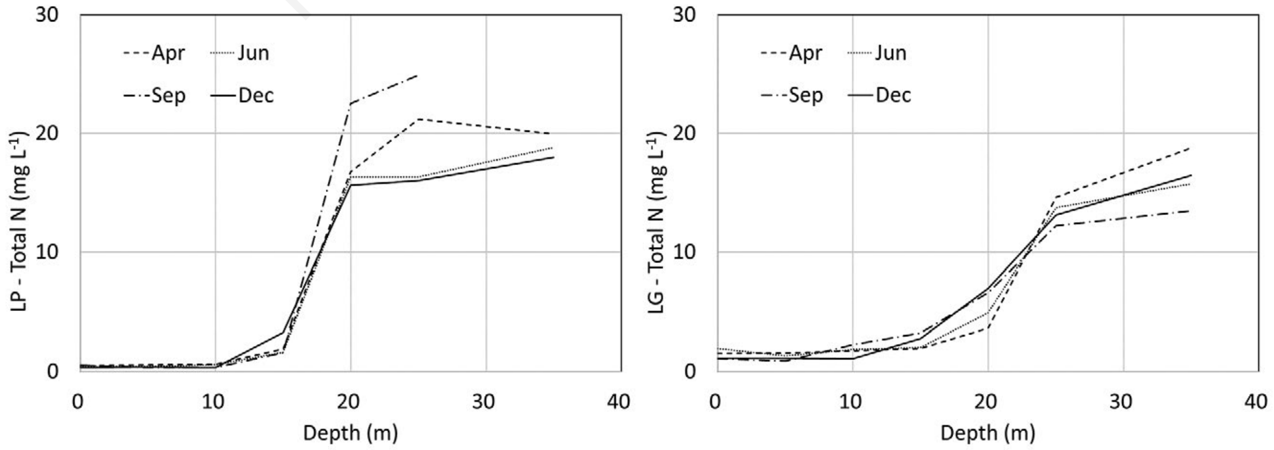

Fig. 8. Profiles of total N concentration in Lago Piccolo (left) and Lago Grande (right) in April, June, September, December 2005. Redrawn from Ceccanti *et al.*, CNR-ISE 2007, with permission.

Macrophytes

An increase in the maximum macrophyte growing depth (MMGD) reached by submerged vegetation in LP, paralleled by a decrease in MMGD in LG, were recorded, in good agreement with changes in water transparency discussed above.

In fact, in 1880 Biondi reported the presence of a number of macrophytes, such as *Ceratophyllum demersum* L., *Potamogeton natans* L., *P. pectinatum* L., *P. crispus* L., *Myriophyllum verticillatum* L., *Sparganium ramosum* Huds., *Conium maculatum* L. (Cavanna, 1882). In 1905, Trotter detailed the distribution of the vegetation, finding 3 vegetation belts in LG and two in LP (Forti and Trotter, 1908). However, in the recent studies performed by Venanzoni *et al.* (2003) and Azzella *et al.* (2010), macrophyte cover appeared simplified in both lakes, composed by wet meadows and reed beds of *Carex, Juncus* and *Phragmites*, because of the strong human impact on the shore habitat.

Detailed analysis of macrophyte cover using aerial photographs showed an increase in the presence of *Nymphaea alba* L. and a decrease in *Potamogeton lucens* L. and *Myriophyllum spicatum* L. Furthermore, *Taxodium distichum* (L.) Rich. is invading lake shores, causing a reduction in the presence of *Fraxinus angustifolia* subsp. *oxycarpa*, an important species forming the main food source for the endemic moth *Brahmaea europaea* (Spicciarelli and Mirauda, 2015; Spicciarelli *et al*., 2016).

Plankton

A number of field campaign on Lakes Monticchio were performed from 1905 to 2015 (see Tab. S1). However, results are not directly comparable, as Forti and Trotter (1908) and Cannicci (1952) collected phytoplankton samples using nets, while later studies used sampling bottles and the Utermöhl technique (1952). Concerning the more recent studies, Ceccanti *et al.* (2007) collected samples in LG monthly in 2005 and bi-monthly in 2006 and they were able to describe the seasonal pattern of phytoplankton assemblages. On the contrary, Musacchio (1981-1982) and Marano and D'Aprile (1991) collected samples in both lakes, only in one date (in June 1981 and in October 1991, respectively), while Spicciarelli and Mirauda (2015) in two dates (July and October). In LP Ceccanti *et al.* (2007) only collected one sample in March 2005.

In LP, all studies agree in describing a typical oligotrophic assemblage, dominated by diatoms and dinophytes or chlorophytes, with low algal abundance. On the contrary LG phytoplankton dominant species belonged to cyanobacteria, while the higher biomass was formed by chloropythes.

In 2005, cyanobacterial assemblages were dominated in spring by *Woronichinia naegeliana* (Unger) Elenkin and *Dolichospermum planctonicum* (Brunnthaler) Wacklin, L.Hoffmann & Komárek, and in summer and autumn by *Microcystis aeruginosa* (Kützing) Kützing and *Romeria leopoliensis* (Raciborski) Koczwara, while *Merismopedia trolleri* Bachmann was present in both periods (Ceccanti *et al.*, 2007). In 2006, a summer bloom of *Aphanocapsa delicatissima* West & G.S.West with the presence of *Snowella atomus* Komárek & Hindák and *Anagnostidinema amphibium* (C.Agardh ex Gomont) Strunecký, Bohunická, J.R.Johansen & J.Komárek (Ceccanti *et al.*, 2007).

In LG, the maximum abundance value was reached in August 2006 (*ca*. 430 10^6 cells L^{-1}), while in the other studies lower abundances values were detected, from 150 to 230 10^6 cells L^{-1}, but samples were not collected in August. The monthly distribution of the measured phytoplankton abundance is reported in Fig. 9, showing the importance of the choice of the sampling period for evaluating phytoplankton biomass. Results of Marano and D'Aprile (1991) apparently did not include small cyanobacteria, so that the total density resulted very low (20.5, 20.2 and 15.5 10^6 cells L^{-1} in spring, summer and autumn, respectively).

In the case of zooplankton, sampling and analysis were more consistent among the studies. At the beginning of the 20th century, Forti (1908) found both lakes dominated by rotifers. Unfortunately, Marano and D'Aprile (1991) did not considered rotifers, but Ceccanti *et al.* (2007) and Spicciarelli and Mirauda (2015) found again their numerical importance in the zooplankton assemblages, while biomass was dominated by Cladocera. Most zooplankton species were found in both lakes (Tab. S2), but assemblages were different in the two lakes: LP hosted a typical lacustrine community, while in LG species typical of pond habitats were found (Spicciarelli and Mirauda, 2015). Ceccanti *et al.* (2007) also found the zooplankton biomass increased in spring, falling down in July because of both cyanobacterial blooms and the predation by *Chaoborus flavicans* (Meigen) and *C. crystallinus* (de Geer) (Leoni and Garibaldi, 2009).

Fauna

After the collection and description of the endemic bleak *Alburnus albidus* O. G. Costa (Tenore, 1844), the first systematic description of Monticchio fauna was edited by Cavanna (1882), involving a number of specialists, and reporting lists of *Arachnidae*, *Myriopoda*, *Exapoda*, *Pisces*, *Amphibia*, *Reptilia*, *Aves*, *Mammalia*, mainly related to the aquatic environment.

On the riparian hygrophytes, they found molluscs, such as *Planorbis umbilicatus* (Müller), *Lymnaea peregra* (O. F. Müller), *L. lagotis* Schrank, *Ancylus latus* Edwards, *Succinea megalonixia* Bourg, dragonflies, auch as *Anax formosus* V. d. Lind., *Agrion tenellum* Dev., *A. elegans* V.

d. Lind., *Crocothemis erythraea* Brullè, and a large number of *Platycnemis pennis* Pall., a species living on floating plants. Other interesting records include the bird *Ardeola ralloides* Scopoli, the amphibian *Bombinator igneus* Merr. and the reptilian *Tropidonotus natrix* L.

Among fishes, in the Monticchio lakes were found the endemic bleak, the carp (*Cyprinus carpio* L.), the European perch (*Perca fluviatilis* L.), the black bass (*Micropterus salmoides* Lacépède), the Italian chub (*Squalius squalus* L.), the tench (*Tinca tinca* L.), the catfish (*Ameiurus melas* Rafinesque), *Rutilus aula* Bonaparte, the eel (*Anguilla anguilla* L.), the crucian carp (*Carassius carassius* L.) and the western mosquitofish (*Gambusia affinis* Baird and Girard). In LP, Spicciarelli and Mirauda (2015) also found alien species, such as the brown trout (*Salmo trutta* L. *morpha fario*), and some specimen of Japanese *koi* and white carps.

DISCUSSION

To understand the response of lake ecosystems to anthropogenic pressure and global change, the best approach is the long-term (multi-decadal) collection of limnological data with uniform protocols of sampling and analysis, such as those obtained for Lake Maggiore (Morabito *et al*., 2005), Lake Constance (Häse *et al*., 1998) or Lake Geneva (Tadonléké *et al*., 2009). However, for a relevant number of lakes, a series of short-term episodic studies were carried out in the past, frequently by different authors, using different methods. Frequently, such studies predate the starting of regular series of data collection. For example, in Italy studies on Lake Maggiore (Baldi *et al*., 1953), Garda (D'Ancona *et al*., 1961) or Trasimeno (Moretti, 1958) were carried out far before the start of the long-term ecological studies currently running (Morabito *et al*., 2018).

Lakes Monticchio are an example of lakes for which a large number of studies exist, frequently unpublished or difficult to find. They were mostly carried out independently, with no effort to obtain comparable data among them. In this paper, we try to assess if this kind of studies can be used to infer the trophic history of these lakes.

From the different studies, it emerges that the main effect of increase in human activities starting in the 1960's was eutrophication due to sewage discharge from the touristic infrastructures. The ecological quality of lakes affected by eutrophication can be best described by their phytoplankton, macrophyte or phytobenthos communities (Kelly *et al.* 2016). In the case of phytoplankton, different studies used sampling methods leading to results impossible to compare. The more recent studies, which used sampling by bottles and the Utermohl (1952) method, showed that the most abundant phytoplankton species are small-size cyanobacteria, such as *Woronichinia naegeliana*, *Microcystis aeruginosa* or *Aphanocapsa delicatissima*. These species were lost from the samples in the older studies, which used nets to collect phytoplankton. Furthermore, they were not considered by Musacchio (1981-1982) and Marano and D'Aprile (1991), who neglected in the algal counts the so-called "nanoplankton", *i.e.* the smaller cells.

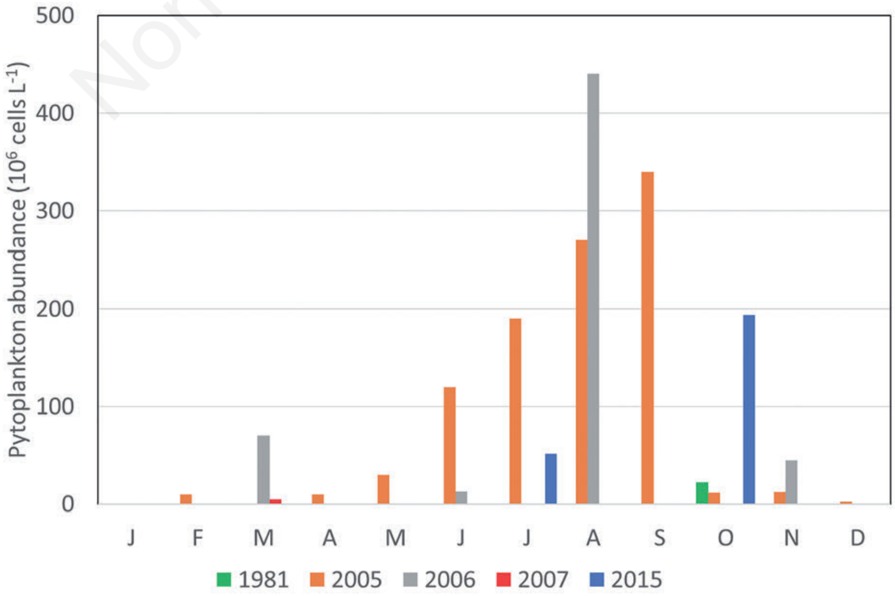

Fig. 9. Total phytoplankton abundance between 1981 and 2015 in Lago Grande from January to December.

On the contrary, data from the last two studies (Ceccanti *et al*., 2007; Spicciarelli and Mirauda, 2015) are fully comparable and show a relevant seasonal pattern in phytoplankton abundance, with large differences between monthly values (Fig. 9). This pattern leads to the conclusion that, even using the same methods for sampling and analysis, comparing phytoplankton abundance in different years is only possible if the full seasonal pattern has been covered, possibly with monthly, or even more frequent, sampling.

Macrophytes have also been frequently used to assess lake ecological status. For example, Pall and Moser (2009) proposed a multi-metric index based on vegetation density, macrophyte maximum growing depth (MMGD), presence of characteristic zonation, abundance of more or less tolerant species and similarity of species composition to that found in "reference", pristine lakes.

In particular, MMGD has been shown to be a lake trophic indicator. For example, on the basis of a large data set including 757 European lakes, Søndergaard *et al.* (2013) investigated the ability of MMGD to be used for evaluating lake trophic status. They found a good correlation between MMGD and Secchi disc depth, but weaker correlation between MMGD and nutrient concentration. In spite of its considerable year-to-year variability, they suggest that MMGD can be used as a trophic indicator for clear water lakes deeper than 4-5 m, such as Monticchio lakes.

The difficulty in finding a good correlation between nutrients and MMGD may be due do the large heterogeneity of the used data set. In fact, evaluating a long time series of MMGD data from a single lake, May and Carvalho (2010) found that changes in MMGD in Loch Leven (Scotland) reflected changes in phosphorus load from its catchment. Furthermore, relevant increases in MMGD during lake recovery from eutrophication has also been documented (Hint *et al*., 2013).

Historical record of MMGD dating back to late 1800 or early 1900 are available for a number of lakes around the world (Spence, 1982), including both Lakes Monticchio (Forti and Trotter 1908). They can then be used to infer reference conditions for these lakes, and to evaluate their trophic evolution, avoiding the difficulty in comparing Secchi disk depth related to the strong seasonal variability of this metric, presenting high values in winter when algal population are less abundant, as shown by the high value in February 2005 reported in Tab. 1.

Using this approach, May and Carvalho (2010) related MMGD to the nutrient input in Loch Leven (Scotland), inferring the history of its eutrophication and re-oligotrophication and showing that MMGD in 2006 was close to the value measured in 1905, indicating almost complete lake recovery.

In other lakes, old studies on macrophyte did not report MMGD. For example, Nimemeier and Hubert (1986) reviewed changes in macrophyte community due to eutrophication in Clear Lake (Iowa, USA), reporting a decrease in species number and a shift from submerged to emergent species, but they estimated a reduction of the photic zone from 4 m in 1951 to 0.8-1.5 m in 1981 on the basis of the Secchi disk depth.

In this international context, and as in Loch Leven, in the Monticchio lakes a comparison between macrophyte data collected in the early 1900s and in recent times was possible. Similar data are probably available in old records for other lakes that can allow to extend this exercise, giving information on their history.

CONCLUSIONS

An accurate analysis of the studies carried out on the Monticchio lakes allowed us to show the effect of the strong human impact affecting them in the second half of the 20th century. Their biological response was very different, because of the difference in water chemistry driven by their different morphology and hydrology. In LG, nutrient input leaded to algal blooms, cyanobacterial dominance, low water transparency and a strong decrease in MMGD, while in LP the relevant input of Fe^{2+} by underground springs (see Table 2) caused P concentration to stay very low, leading to low algal biomass and in increase in water transparency and MMGD.

This paper underlines the importance and the limits of evaluating old studies and grey literature to infer ecosystem history and reference condition. Among the limnological parameters, MMGD resulted the more reliable indicator of trophic status, being relatively independent from sampling methods and seasonal pattern. Phytoplankton abundance and composition would have been a valuable indicator, if a standard protocol have been followed, and frequent (*e.g.*, monthly) samples collected.

Irregular studies carried out with different and non-comparable approaches, such those carried out in Lake Monticchio, may give important hints about lake history, but they cannot replace regular sampling with well-defined protocols, such those used in the long-term ecological research (LTER) network.

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Corresponding author: renato.spicciarelli@unibas.it

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