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Nitrogen loading and natural pressures on the water quality of a shallow Mediterranean lake

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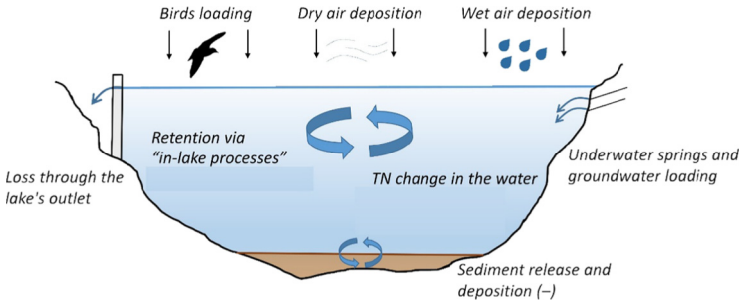
HIGHLIGHTS

- Total Nitrogen loading from natural sources is a potential pollution factor, especially in small wetlands
- Karstic aquifer flow in Koumoundourou lake catchment is the main factor for most of the nitrogen transfer n the lake
- Water pollutants models and mass budget estimations offer important information for the design of lake's restoration measures

GRAPHICAL ABSTRACT

TN mass budget in a Mediterranean Lake.



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ABSTRACT

The water quality of Koumoundourou Lake, a heavily modified, peri-urban, brackish and shallow lake near Athens, Greece, is under multiple stressors due to the industrial activities in the catchment area and natural pollution pressures. Although the broader area has undergone significant land use changes since the beginning of the 20th century converting it from rural to heavily industrialized, Koumoundourou Lake remained as one of the few habitats in Attica Region, for large numbers of aquatic birds. The water quality of the lake has been recently improved, which contributed to the increase of aquatic birds' population in the area and to the higher, in relation to the past, nitrogen inputs from natural sources. Therefore, a monitoring program has been implemented to assess the pollution pressure factors in the lake. A water quality model has been also used to simulate the lake's processes and estimate the nutrient mass budget focusing on the various nitrogen loading mechanisms (natural and anthropogenic). Based on the model output, the main polluting factor of the lake is the groundwater inflows. Aquatic birds affect slightly the lake's water quality, while the dry and wet atmospheric deposition contributes insignificantly to the total nitrogen loading.

1. Introduction

Coastal wetlands such as estuarine lakes and lagoons, dune swamps, mudflats, coastal floodplains, mangrove and saltmarsh swamps, have always been linked to financial and social development, since they support settlements, harbours, and agricultural activities; they provide food, fresh water and the means for trade and transport (Airoldi and Beck, 2007). The ecosystem services provided by coastal wetlands are indisputable. The provision of habitat, flood protection, erosion control, water purification, carbon sequestration, and opportunities for recreation and environmental and cultural education and research, are the most valued (Barbier et al., 2011). In the recent decades, coastal

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wetlands are often profoundly impacted by uncontrolled urbanization and industrialization, land use change, intensive cultivation and physical alteration of the environment (Vitousek et al., 1997) that affect their ecological integrity (Ehrenfeld, 2000). Nevertheless, even stressed and small wetlands remain an integral part of the developed landscape (Ehrenfeld, 2000) and often have a positive effect on their delivery, especially water quality, water regulation and biodiversity conservation (Blackwell and Pilgrim, 2011).

Additionally to the humanly imposed pressures, very often coastal wetlands are affected by natural processes, such as meteorological conditions and physical habitat change. Many surveys during the last years concerning the effect of aquatic birds on the water quality of lakes and other water bodies have led to the conclusion that there is a strong correlation between their population and nutrient concentrations (e.g. Manny et al., 1994; Mukherjee and Borad, 2001; Chaichana et al., 2010; Telesford-Checkley et al., 2017). On the other hand, atmospheric pollution has been recognized as one important factor affecting the water quality of freshwater bodies and coastal sea, while in some cases could lead to acidification of streams and lakes and toxic contamination of habitats (EPA, 2001). Although there are many natural sources of nitrogen compounds to the atmosphere (soil, wetlands, etc.), in the northern hemisphere and especially in heavily industrialized areas, the main source of nitrogen nowadays is considered to be anthropogenic (industrial combustion, vehicle traffic, emissions from intensive farming, waste lagoons; Guerzoni et al., 1999).

Under this scope, the natural and anthropogenic pollution loads to Koumoundourou Lake, a peri-urban, shallow, coastal lake were estimated, so as to investigate the role of each pressure type to the lake's water quality. The main pollution sources examined in the present effort were the aquatic bird excrements, the number of which during the last years has been increased, and the atmospheric dry and wet deposition that in such an industrialized area is expected to be intensified. The assessment of the relative significance of each pollution source to the total nitrogen (TN) of the waterbody can be achieved through the estimation of the TN mass budget of the lake (e.g. Scheider et al., 1979). For this purpose, hydrodynamic and aversions-dispersion models were employed and the main biogeochemical internal processes of the lake were simulated.

Koumoundourou Lake is a highly impacted wetland. Human interventions in managing the lake's morphology occurred since the antiquity, by hydrologically isolating the lake from the sea, while the communication between the lake and Elefsina Bay was accomplished through a channel (Dimitriou et al., 2012). The coastal embankment was reconstructed a few decades ago making the lake's separation from Elefsina Bay permanent, allowing outflows from the lake to the sea through a small discharge channel. Nowadays, after the implementation of a rehabilitation plan, the lake outflows were further regulated through an artificial weir, which was constructed in 1998 to raise the lake's water level and to prevent the inflow of polluted groundwater (Koutsomitros et al., 2001). This intervention to the hydrological conditions of the lake and also the implementation of legislative frameworks (e.g. EU Water Framework Directive, 2000/60/EC) have led to the gradual improvement of the lake's ecological status. Nevertheless, the artificial weir severely impacted the ecological integrity of the lake, since it led to: (a) the artificial decrease of water level fluctuations, (b) it led to the decrease of the water salinity, affecting the density of aquatic vegetation, and (c) the prevention in the free movement of fish species from and to the sea (Mentzafou et al., 2016). The decrease of the water salinity and the increase of the area occupied by common reed (*Phragmites australis*) and submerged macrophytes (*Chara corfuensis*, *Lamprothamnium papulosum*, *Potamogeton filiformis*, *Potamogeton pectinatus* and *Ruppia cirrhosa*) have also favored the bird population of the lake, by providing nesting habitat and food. It should be noted that the lake is often used by migratory birds for wintering, while the sanitary landfill of the Western Part of Attica Region and the Psyttaleia sewage treatment plant, in the close proximity, provide food abundance (Dimitriou et al., 2012).

2. Materials and methods

2.1. Study area

Koumoundourou Lake is a shallow, brackish lake lying on the east shore of Elefsina Bay, on the edge of Thriassion plain in western Attica (Fig. 1). The area of the small lake is about 146,500 m^2. The lake is recharged primarily by karstic underwater springs mainly at the northeastern part that discharge the calcareous mountains of Parnitha and Aegaleo (Paraschoudis, 2002). Its average depth is 1.0 m, while depths over 3.0 m are reached only locally at the northeast edge, close to the main spring's area (Dimitriou et al., 2012). The lake does not stratify and temperature and salinity parameters are rather uniformly distributed in the water column, apart from the northeast, deepest part of the lake (Papadopoulos et al., 2004).

Due to its location near Athens and the infrastructures in the wider area (road, highway and railway networks, Elefsina port), Thriassion plain was gradually industrialized and nowadays, practically, no cultivated land exists in this area. Northeast of Koumoundourou Lake an oil refinery is located in close proximity while north of the lake, a cement plant and industrial steel production units operate. Other important pollution pressures of the area include a military camp, immediately adjacent to the lake with fuel storage facilities for military purposes. Finally, at the northeastern part of Thriassion plain the sanitary landfill of the Western Part of Attica Region is located, which replaced the older landfill of Ano Liosia that operated from 1965 until 2007 (although it was considered saturated after 2004) without an impermeable membrane to prevent waste leakages (Dimitriou et al., 2012). This led to the contamination of groundwater and eventually of Koumoundourou Lake (Dimitriou et al., 2008).

2.2. Data collection and processing

The necessary bathymetric data collection of Koumoundourou Lake was implemented during a past effort by the scientific personnel of Hellenic Centre for Marine Research (HCMR; Roussakis, 2004).

Monitoring survey was conducted during the period April 2011–January 2012. The monitoring hydrochemical survey was bimonthly and water samples were analyzed for the determination of nutrients (nitrate, nitrite and ammonium) concentrations. Water level measurements were used to calculate the outflow from the lake towards the sea through the weir. The aquatic bird survey was conducted from observation points along lakeshores following the line transect and “look and see” method and the modified line transect survey (Bibby et al., 1993). The bird survey was implemented in eight (8) visits.

Detailed and high quality climatological data were available from Ano Liosia telemetric meteorological station (National Technical University of Athens-Centre for Hydrology and Informatics) and included air temperature, precipitation, relative humidity, wind speed and incoming solar radiation. Hourly potential evaporation *Et* from Koumoundourou Lake was calculated based on Penman (1948) equation.

The necessary data concerning the concentration of the main air pollutants (NO_2 and NO) in the wider area, were obtained from Elefsina station (National Network for the Control of Atmospheric quality and Pollution-NNCAP; Ministry of Environment and Energy).

Finally, the groundwater inflows through the underwater springs were indirectly calculated based on the water balance equation of the lake.

The details concerning the data collection and processing are listed in the Supplementary Material.