Article

Monitoring of an urban lake in the Mediterranean coast after restoration measures

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Abstract: Urban lakes are artificial systems that accomplish many functions, such as storing rainwater, avoiding flooding of adjacent urban areas and supporting recreational activities. However, their intrinsic aesthetic value is usually reduced due to eutrophication problems and anoxia processes. The objective of this study is to present the results of the water quality monitoring of a small urban lake (11264 m^2 and 1.5 m average depth) in Tavernes de la Valldigna (Valencia, Spain) during summer 2016. The final aim is to determine the better parameters for monitoring urban lakes having into account budget restrictions. La Goleta lake has suffered repeated events of fish deaths and bad odors that cause the alarm of residents and tourists, especially in summer. Municipal authorities undertook a restoration project which first part was developed during the first semester of 2016. Surveillance monitoring should be financed by the Town Council, so limiting the monitored parameters to the most appropriate ones is key for guarantying long-term surveillance. The results of this study show the importance of macrophyte community in determining water quality and maintaining dissolved oxygen levels. Dissolved oxygen is a key parameter easy to measure and a good indicator of lake water quality evolution. Analytical methodologies must be adapted to the high organic matter content of these systems to avoid interferences.

Keywords: storm tank; water quality; nutrients, phytoplankton, macrophytes

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1. Introduction

Urban lakes have been described as smaller and shallower water bodies than natural lakes, with a larger ratio of watershed area to lake surface area [1]. This causes a greater exposition of urban lakes to human impacts. Eutrophication issues have been well studied in natural lakes and the effects of harmful algal blooms (HABs) have become a growing concern for water resources management. However, studies focussing on urban lakes are rare and scientits have pointed out the need of a deeper knowledge of their ecological dynamics to develop effective management strategies [1].

Cities benefit from internal urban ecosystems, such as urban lakes thanks to the ecosystem services that they offer [2]. Direct ecosystems services of urban lakes can be rainwater drainage, storing rainwater, water supply, recreational and cultural values. The locally generated ecosystem services have a substantial impact on the quality-of-life in urban areas [2]. To preserve these services we need to be sure that management strategies are effective, thus, we need effective monitoring programs able to detect relevant water quality changes.

Study area

La Goleta Lake is an urban lake located at Tavernes de la Valldigna town (Eastern Spain) (Figure 1). It works as storm tank that collects runoff of nearly 200,000 m^2 of urban area. Its current dimensions are 11,264 m^2 and 1.5 m average depth. For a complete description see [3]. This town is a very important touristic destination in the Spanish Mediterranean area. In fact tourism is one of the main economic activities in the area and is mainly based on residential development [4], it experiences an important population increase during summer. Since its construction in 1982, the lake has suffered repeated events of fish deaths and bad odours that cause the alarm of residents and tourists. So municipal authorities worried by the environmental health risk and the economic impact on tourism industry decided to undertake a restoration project. The first phase of the lake restoration was developed during the first semester of 2016. A closed circuit for recirculating water was built with element such as fountains and waterfalls to increase water aeration. Also, UV clarifiers were coupled to the recirculation system. For more details on these restoration measures see [3].

During construction of the recirculation system, the water level of the lake was lowered by pumping water to the sea. The penetration of sunlight to the bottom of the lake allowed the development of a benthic substrate dominated by the green algae *Chara* sp. It has been described that Characea occurs in shallow parts of lakes (0.5-2.5m), provided that water quality has sufficiently improved and enough light penetrates to the soil [5]. The observed recolonisation process was only possible due to very transparent circumstances during works. Other observed changes after restoration works was an important increase in the population of the little fish *Gambusia* sp. and the disappearance of mosquito larvaes. During this restoration works bigger fishes disappeared from the lake.

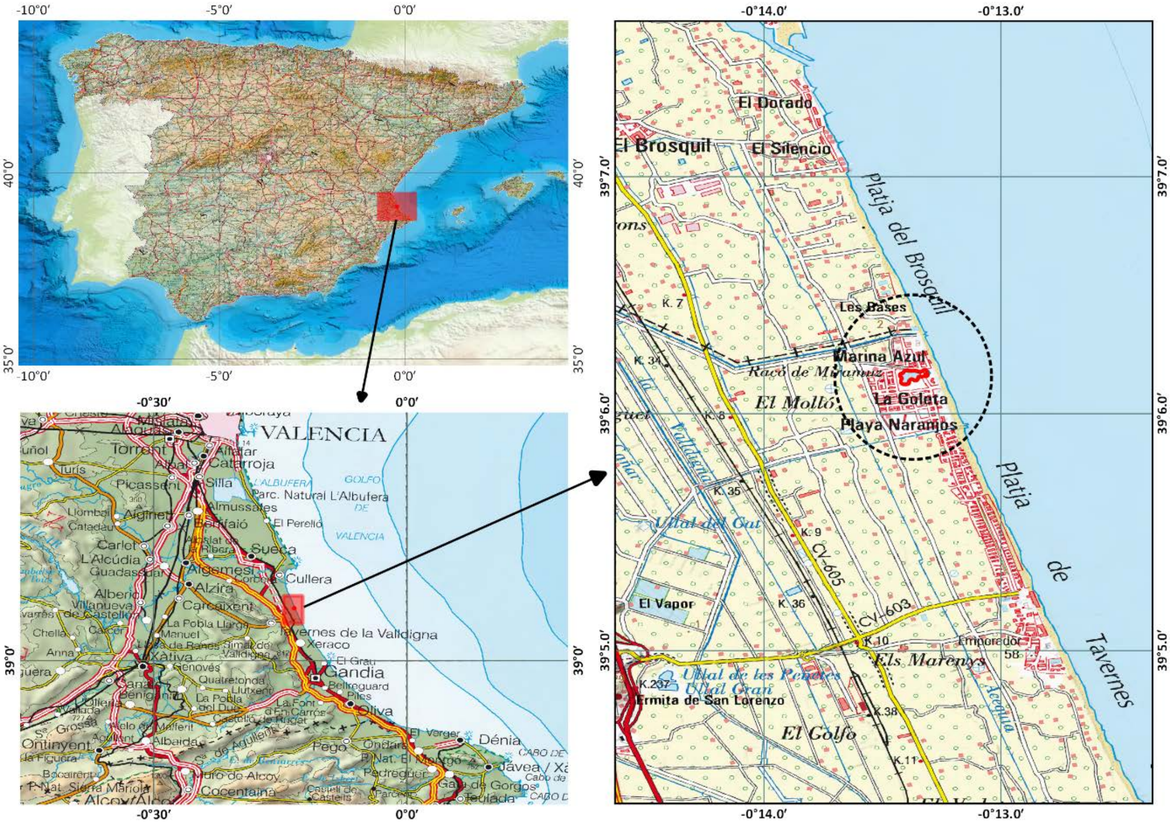

Figure 1 Location of the study area (La Goleta lake, Eastern Spain)

Aim of the work

The objective of this study is to present the results of the water quality monitoring of La Goleta lake (Valencia, Spain) measures from June to October 2016 after the implementation of the first phase of restoration. The final aim is to determine the better parameters for monitoring urban lakes having into account budget restrictions.

2. Results

La Goleta lake was usually sampled at the same hour between 9:00 and 10:00h a.m. The sampling frequency was biweekly, but was increased after precipitation events because of the well-known effect of the first flush. The first flush phenomenon has been defined as “the initial period of stormwater runoff during which the concentration of pollutants is substantially higher than during later stages” [6]. The enormous quantity of pollutants discharged in this period into the receiving waters has been identified as one of the leading causes of degradation in the quality of receiving waters [6]. In figure 2 we can observe the precipitation events during the study period.

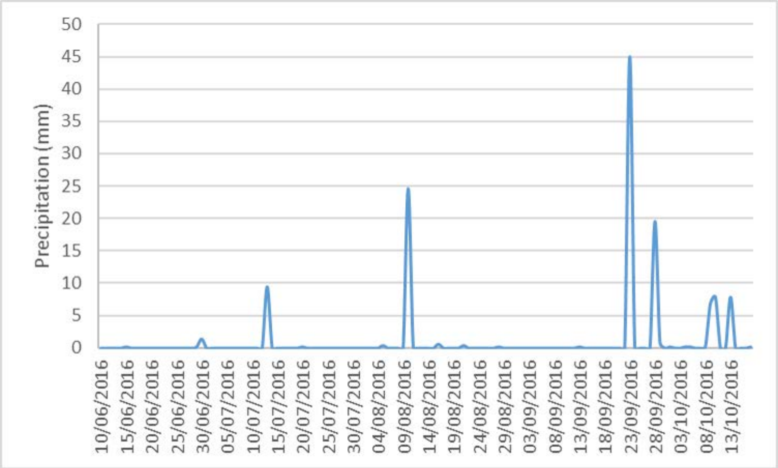

Figure 2 Precipitation chart during study period. Data source: http://riegos.ivia.es/datos-meteorologicos

2.1. Physical and chemical parameters

Temperature ranged from 30.5 to 22.1 ºC, the lowest temperature was observed during the October 2016 samplings. Conductivity varied between 2.27 and 5.09 mS, the lowest values were observed on October after the cumulative rain of September and October. Average evaporation in this area during the study period was 4.3 mm according to meteorological data from the Tavernes de la Valldigna station (source: http://riegos.ivia.es/datos-meteorologicos). Dissolved oxygen minimum observed value was 1.06 mg/L and the maximum value was 8.32 mg/L. The percentile 40 of dissolved oxygen was 4.2 mg/L, meaning that 40% of the measures were lower. Ammonia concentration ranged between non-detectable concentrations (< 0.01mg/L) to a maximum of 0.14 mg/L. To avoid toxicity problems ammonia concentration should be lower than 0,05 mg/L [7]. This value was exceeded 3 times on June 14, October 10 and October 17. Dissolved inorganic nitrogen (DIN) ranged from 0.04 to 0.46 mg/L. Dissolved inorganic phosphorus (DIP) varied between 0.001 and 0.037 mg/L, dissolved silicate (DSi) between 0.14 and 1.31 mg/L and total phosphorus (TP) between 0.02 and 1.16 mg/L. In order to better define potential nutrient control, we compared nutrient ratios between DIN, DSi and DIP concentrations with Redfield ratios (Si:N:P = 16:16:1). DIN was he potentially most deficient nutrient for phytoplankton growth during nearly all of the study period. Chemical oxygen demand (COD) and Biochemical oxygen demand (BOD_5) measured on samples taken on October 17 were 36 and 3 mg/L respectively.

2.2. Phytoplankton abundance and composition

Total chlorophyll *a* (Chl-*a*) concentration ranged from 1.1 to 18.9 µg/L.

In summer campaigns (June to August) the pico and nano phytoplankton composition were dominated by *Monoraphidium* sp. and nanoplanktonic flagellates identified as *Cryptomonad* sp. Other taxa like *Tetraedron* sp. and *Closterium* sp. belonging to Chlorophyceae were also identified as well as *Cyclotella* sp (diatoms) although in a lower cell density. On the other hand, the microplankton composition correspond to different genera of dinoflagellates like *Scrippsiella* sp., *Alexandrium* sp. *Gonyaulax* sp. and *Gymnodinium* sp. and to centric diatoms such a *Navicula* sp., *Amphora* sp. and some pennate like *Pseudonitzchia* sp. The phytoplankton richness and diversity in this season was that corresponding to natural ecosystems (Shannon index of 2.5).

In autumn campaigns (October) only two taxon were the most abundant in plankton composition, the chlorococcal species of *Chlorella* (78%) and *Scenedesmus* (17%). Dinoflagellates, diatoms and Cryptophyceae taxons represented less than 5% with a Shanon index of 1.

3. Discussion

Conductivity was relatively high and was attributed to high evapotranspiration rates (4.3 mm) and proximity to the sea (sea breeze). Decreases in conductivity occurred after precipitation events. Dissolved oxygen was a critical parameter of water quality, with concentrations below 4.3 mg/L 40% of the times studied. The effect of oxygen depletion was observed on fishes living in the lake, *Gambusia* sp., which were observed staying at the most shallower depth. However, no mortality was observed. Ammonia levels reached toxic concentrations for fishes three times, but again no mortality was observed. Previously reported fish mortalities affected big fishes such as *Mugil cephalus*. *Gambusia* sp. can tolerate a wide range of conditions [8] and that may be the cause of no observed mortality even after low oxygen and high ammonia conditions. These fish can be highly beneficial to humans through controlling mosquitoes, which is an important feature given the tiger mosquito plague that is now expanding on Mediterranean areas. Tough these fish may have negative impacts on other species with which they interact, such as the *Valencia hispanica* or *Aphanius iberus*, these species are not present in this artificial water body, so the advantages outweigh the disadvantages of their presence at La Goleta lake. *Chara* sp. dominant in the benthic substrate prefer low oxygen waters, and played an important role in DO levels. The lowest oxygen levels were observed early in the morning due to nocturnal respiration.

Nitrogen was the potentially most deficient nutrient for phytoplankton growth during most of the study period according to Redfield ratio. This Mediterranean area suffers from high nitrate levels due to agricultural activity [9]. However, the lake watershed is urban [3] so agriculture is not an important source of nitrate. Phosphorus levels were also high and usually it was not the main potentially limiting nutrient. Phosphorus is present in first-flush, however, aquatic birds excretion can be considered the main source of both nitrate and phosphorus. The estimated proportion of nitrate to phosphorus in aquatic birds faeces is 2.1 [10], which can explain phosphorus not being limitant. This organic matter accumulated in the sediment can produce a high diffusive flux to the water column, as it has been observed for both ammonia and phosphorus during summer seasons in other urban lakes [11]. Silica levels were high because the lake is adjacent to a sandy beach, so silica potentially limiting circumstances were scarce.

Chemical oxygen demand (COD) and Biochemical oxygen demand (BOD_5) were determined to measure the amount of organic compounds in water. BOD estimates biodegradable organic matter, while COD is less specific, since it measures everything that can be chemically oxidized. La Goleta lake reduced values of BOD_5 indicates that there is an important fraction of non-biodegradable compounds. This has been related with the source of water from first-flush which is rich in hydrocarbons and oils [6]. In this area, also we can find pesticides that are used in the in the garden surrounding the lake. The presence of organic matter in the water column conditioned the choice of the nitrate analysis method. Brucine methodology was chosen because APHA methods were not appropriate for waters enriched by organic matter.

The dominant phytoplankton groups are characteristic of shallow water bodies, in mixed and nutrient enriched conditions. In this sensitive Mediterranean ecosystem where the water temperature is not a limitant factor an increase in nutrient content yields bloom-forming cells reducing the plankton diversity and performing a bottom-up control. Although during the whole study period there are species sensitive to forming blooms (*Pseudonitzchia* sp., *Alexandrium* sp., etc), only when nutrient load increases, for instance after precipitation events, this occurs.

In this study we have focused on water quality after the first phase of La Goleta lake restoration measures. We consider that the most appropriate parameters that shoud be mid-term monitored are dissolved oxygen, ammonia and total chlorophyll *a*. These variables are easy to measure and the information that they give us for water lake management very important. We also think that monitoring phytoplankton blooms is clue as fish mortalities that could not be explained by oxygen depletion or ammonia toxicity could be due to phytoplankton toxins. [12] monitored cyanobacteria blooms and the associated cyanotoxin production for 14 months on a monthly basis in an urban lake. However, we believe that this frequency may be not enough due to the high temporal variability that characterizes phytoplankton. So, we recommend to the management authorities (the Council in this case) to analyse phytoplankton when a bloom is detected by high chlorophyll *a* levels. [1] suggested to monitor chl *a* and TP concentrations as the most critical water quality variables for eutrophic lakes. We recommend for urban lake monitoring the diagnosis of the main limitant nutrient, because this can strongly influence the phytoplankton composition and abundance. At present, La Goleta lake shows a higher potential limitation of nitrate rather than phosphate limitation.

Runoff from the watershed exerts significant influence on urban lakes and thus inflow nutrient reduction is critical for the control of eutrophication [1]. Thus, the second phase of La Goleta lake restoration measures will target pollutants and organic matter inflow. Sediments are an internal nutrient source that will be also targeted, the mitigation with macrophytes such as vetiver is planned. After second phase of restoration measures sediments quality will also be monitored. Degraded features of water quality include high accumulation rates of oxygen-demanding reduced by products of anaerobic metabolism on sediments [e.g., methane (CH_4) and hydrogen sulfide (H_2S) [13]. These products can be a net carbon source to the atmosphere with a net effect on greenhouse gas emission [14]. The disturbance caused to residents by bad odours is one of the recurrent claims to the Council, as it may happen in any other urban lakes, so we recommend to monitor the levels of this gasses too.

4. Materials and Methods

Water samples were taken at the 2 sampling points shown in Figure 2. These points were selected after diagnosis sampling of the lake [3]. Only one water sample was collected at 0.05 m depth in each point, representative of the whole water column due the lake shallowness. Water samples were collected in 2 L polyethylene bottles. A subsample of 250 mL was removed for phytoplankton cell counts. Water samples were kept in a cool box (4 ºC) and transported to the laboratory. Temperature, conductivity and dissolved oxygen were determined in situ by means of a data logger PCE-PHD 1.

Figure 3 Sampling points at La Goleta lake

At the laboratory, the water samples were divided into several equal parts, following the conservation procedures suggested by [15]. The samples were filtered through 0.45 µm cellulose acetate membrane filters for nutrient and chlorophyll *a* analyses.

Chlorophyll *a* content was determined with the trichromatic method based on visible spectroscopy [15], using [16] equations to obtain the concentration. Pigment extraction was performed with acetone 90%.

The following nutrients were analysed in all the samples: nitrate, ammonium, dissolved inorganic phosphorus (DIP), dissolved silicate (DSi) and total phosphorus (TP). Nutrients were analysed colorimetrically using the methods of [17]. Nitrate was analysed using the Brucine Method [18]. Dissolved inorganic nitrogen (DIN) was calculated as the sum of nitrate, nitrite and ammonium. Chemical oxygen demand (COD) and Biochemical oxygen demand (BOD_5) were analysed once to estimate organic pollution of water.

In order to analyse the phytoplankton communities both epifluorescence and Uthermhol microscopic counting methods were used. Epifluorescence was used to identify the pico and nanoplanktonic cells size [19]. Samples contained in 250 mL glass bottles were fixed with glutaraldehyde until reaching a final concentration of 2% [20]. Samples were filtered with Millipore GTTP membranes (pore size 0.2 µm). Finally, a cover glass was placed on top of the filter [21]. The counts were performed by epifluorescence microscopy [22] with a Leica DM 2500, using the 100×-oil immersion objective. A minimum of 300 cells was counted and at least 100 cells of the most abundant species or genera were counted with an error under 20% [23]. Uthermhol was used for micro and macroplanktonic cell size. Phytoplankton samples were fixed with formaldehyde, concentrated according to UNE EN15204:2006, based on [24], and qualitatively examined under a LEICA DM IL inverted microscope. The Shannon-Weaver index (H') was calculated according to [25]

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Conflicts of Interest: “The authors declare no conflict of interest."

Abbreviations

The following abbreviations are used in this manuscript:
Harmful algal blooms (HABs)
American Public Health Association (APHA)
Dissolved oxygen (DO)
Dissolved inorganic nitrogen (DIN)
Dissolved inorganic phosphorus (DIP)
Dissolved silicate (DSi)
Total phosphorus (TP)
Chemical oxygen demand (COD)
Biochemical oxygen demand (BOD_5)
Chlorophyll *a* (Chl-*a*)

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