HELLENIC ORNITHOLOGICAL SOCIETY

IMBRIW-HELLENIC CENTRE FOR THE MARINE RESEARCH

Project: "Improving knowledge and increasing awareness wetland restoration in Attica region- EEA"

Intermediate report: Ecological water quality monitoring of Vourkari Lagoon

PROJECT PROMOTER

REGION OF ATTICA

FEBRUARY 2017

Please cite this report as: Markogianni V., Sigala K., Simboura N. and Dimitriou E., 2017. Intermediate report: Ecological water quality monitoring of Vourkari Lagoon. Improving knowledge and increasing awareness wetland restoration in Attica region- EEA. Hellenic Ornithological Society, Institute of Marine Biological Resources and Inland Waters- Hellenic Centre for the Marine Research.

Contents

1. Introduction

Estuaries and tidal lagoons are highly dynamic ecosystems and notable for their biological diversity and valuable ecosystem services such as decomposition of organic matter, nutrient recycling, nursery for fish species, and removal of pollutants. These particular features confer a high ecological value on coastal lagoons, that is acknowledged by European legislation in the Habitats Directive and the Natura 2000 network (European Commission, 2011). Many of these coastal systems are also characterized by intense human occupation, population growth and economic development, frequently leading to their significant transformation and degradation (Newton et al., 2014; Perez-Ruzafa et al., 2013 in Mateus et al., 2016). Most of these pressures are expected to be aggravated under the predicted climate change scenarios (Brito et al., 2012a; Lloret et al., 2008 in Mateus et al., 2016).

Coastal lagoons have been the subject of several studies addressing different biological components (Sakka Hlaili et al., 2006, 2008; Fertouna-Bellakhal et al., 2015, Zaaboub et al., 2014 in Béjaoui et al., 2017), sediment characterization (Zaaboub et al., 2015 in Béjaoui et al., 2017) and hydrodynamics (Harzallah, 2003; Béjaoui et al., 2008 in Béjaoui et al., 2017) which suggest that primary production in the lagoon results from highly dynamic exchanges between marine and continental inputs and the fluctuations of environmental factors (Béjaoui et al., 2017).

McGlathery et al. (2007 in Pereira Coutinho et al., 2012) have shown that the range of external nutrient loads both to coastal bays and to deeper estuaries is very similar. The enrichment of coastal water by nutrients may result in an enhanced algal biomass and/or the increase of the growth rate. This may lead to an undesirable disturbance of the balance of organisms and the quality of the water concerned, which is the central definition of eutrophication (CEC, 1991; Tett et al., 2007 in Pereira Coutinho et al., 2012).

High biomass decreases light availability, favoring among the primary producers the community that is most competitive for light, i.e., phytoplankton at the expense of macrophytes (Cebrian et al., 2014 in Leruste et al., 2016). This over-production causes a loss of diversity (Schramm, 1999; De Jonge and de Jong, 2002 in Leruste et al., 2016), habitat destruction and mortalities due to anoxia (Smith, 2006; Carlier et al., 2008 in Leruste et al., 2016). In 2000, The Water Framework Directive (WFD, 2000/60/EC) was established in Europe requiring member states to monitor the ecological and chemical quality state of water bodies and implement ways to achieve good status by 2021 (Cartaxana et al., 2009 in Leruste et al., 2016) by the assessment of the biological quality elements (BQEs). Efforts have been made in many parts of the world to combat eutrophication by reducing nutrient inputs from watersheds and initiate ecological restoration.

Divergent views about the number of lagoons in Greece exist. Heliotis (1988) identifies 37 lagoons, whereas a major wetland inventory lists 60 lagoons, covering an area of about 288 km^2 (approximately 14 percent of all Greek wetlands, Zalidis and Mantzavelas, 1994 in FAO, 2015). The main anthropogenic pressures to which coastal lagoons are subjected in Greece are agriculture, animal husbandry, dam constructions, water level alterations and overfishing. Vourkari Lagoon, is one of the four lagoons located in the Attica prefecture and very little is known about its ecological composition and water quality. The main aim of this study is to monitor and estimate its ecological status based on physicho-chemical and biological indicators, accompanied by the collateral monitoring of other key components, such as heavy metals, total organic carbon and total lipids and oils concentrations.

2. Methodology

2.1 Study area

The study was carried out at Vourkari Lagoon (37°58'47"N, 23°23'17''E), in Saronikos Gulf, western Attiki, Greece, a relatively shallow coastal wetland covering 3.0 km^2 (Figure 1). It is situated about 30 km to the east of the capital city of Athens, with Salamina Island delineating its easterly oriented mouth. The wetland is less than 6 m deep, and its main habitats include open water, intertidal mudflats, and a halophytic grassland dominated by Salicornia fruticosa and shrubby seablite - Suaeda vera (Margaris et al. 2004). The sediment in Faneromeni bay is silty sand (HCMR, 1998). Human activities within and around the Lagoon include aquaculture, boat fishing, housing, and industry. The latter 2 activities pose the most important threats in habitat losses through construction activities and pollution inflows (Liordos, 2010). The near by Elefsis bay has been characterized as an eutrophicated area of moderate or poor ecological quality (HCMR, 1998).

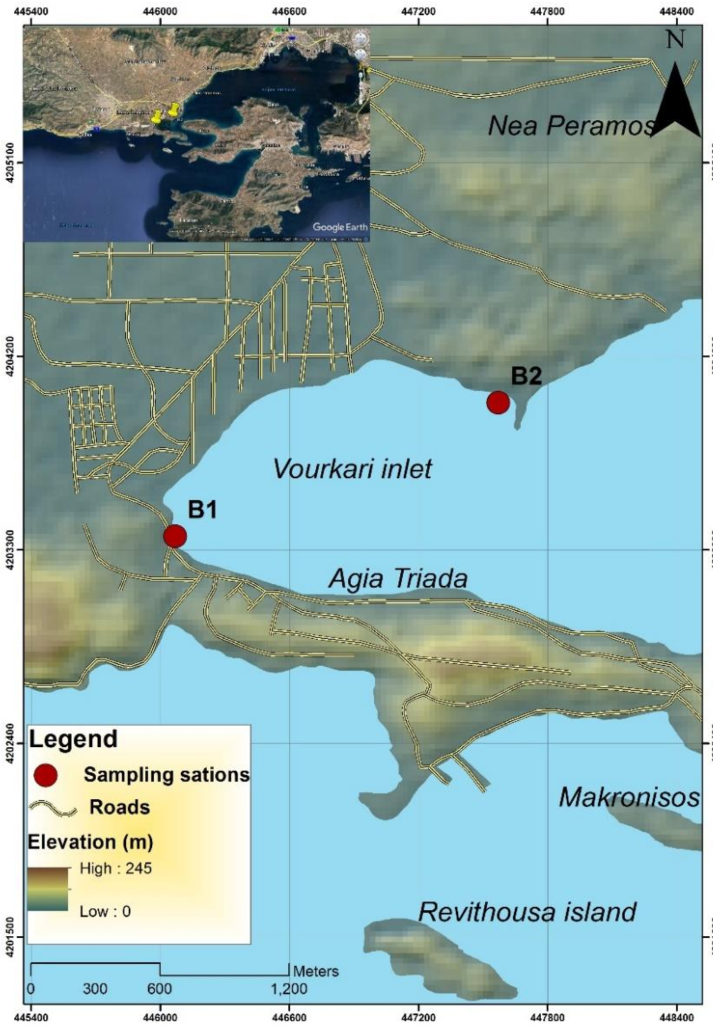

Figure 1. Vourkari inlet and sampling stations

2.2 Water Sampling

Field water samples for measurements of heavy metals, nutrients, total organic carbon (TOC), total lipids and oils and physico-chemical parameters were collected in November 2016 and January 2017, in two (2) stations (Figure 1). Those two stations were selected based on the anthropogenic pressures in the Vourkari Lagoon. A Portable instrument Horiba U-50 Multiparameter Water Quality Checker was used to measure water temperature, pH, electrical conductivity and dissolved oxygen concentration. Water samples were collected and transported to the HCMR laboratory for further analysis. To classify the physicochemical status of Vourkari's sites according to the dissolved oxygen concentrations, the Norwegian system was used (Cardoso et al., 2001; Table 1).

Table 1. Dissolved Oxygen Classification System (Cardoso et al., 2001).

(Cardoso et al., 2001)		High	Good	Moderate	Poor	Bad
Dissolved Oxygen	mg/l	> 9	> 6.4 and < 9	> 4 and < 6.4	> 2 and < 4	< 2

2.3 Benthic samples and Ecological Quality Status assessment

From each station two replicated samples were collected, using a Box Corer, of 0,03m^2 (Figure 2). The samples were sieved with sea water through a 1mm mesh, fixed in neutralized formalin (4%) and stained with Rose Bengal, so as to facilitate the sorting effort. Macroinvertebrates were sorted, identified to species level where possible (in a few cases a higher taxonomic level was used, due to the bad preservation of the animal and/or missing of important for the taxonomy parts of the body etc.), and counted.

Figure 2: Sieved sediment from station 1 (left) and sediment from station 2 (right)

Ecological Quality Status assessment was based on the methods suggested by European Water Framework Directive. According to the soft bottom benthic invertebrates MED_GIG intercalibration, the Bentix biotic index (Simboura & Zenetos, 2002) is used for the Eastern Mediterranean coastal waters and the multivariate M-AMBI index (Muxika et al., 2007) for the transitional waters. Moreover, biodiversity, abundance and the percentage of tolerant and sensitive species are included in the tools proposed for the description of benthic communities' status (No 477/2010/EU/ 2010).

Hence, in the present study, we calculated indices of biodiversity, abundance and biotic indices. Abundance/m^2, number of species (S), Pielou's evenness (J) (Pielou, 1969) and Shannon-Wiener diversity index (log_2 basis) (Shannon & Weaver, 1963) were used. The above-mentioned calculations were made using Primer statistical package.

M-AMBI index (Borja et al, 2000) has been proposed from the Mediterranean Intercalibration team for the transitional body waters (Reizopoulou et al., 2016). In transitional ecosystems it has been proved that biotic indices are not very efficient, since these ecosystems naturally host many tolerant and opportunistic species adapted to the natural stress of the environment (highly variable salinity etc.). M-AMBI combines AMBI with Shannon diversity index and species richness. Hence, it is more suitable for these kinds of ecosystems. For the calculation of the M-AMBI the free software (http://www.azti.es) has been used.

MED_GIG intercalibration exercise for transitional ecosystems does not include hypersaline lagoons. So, in the present study we used the reference values and the boundaries that are inferred in MED-GIG for other types of lagoon and in decent references (AMBI=0.05, H=4 και S=50) (Reizopoulou et al., 2016; Simboura & Reizopoulou, 2008).

Bentix (Simboura and Zenetos, 2002) is based on the ecological model of Grall και Glemarec (1997), that uses the relative contribution of tolerant and sensitive taxa weighting the percentages in an ecologically relevant way. The Bentix index applies to all kind of marine soft bottom benthic data. That's kind of indices are not influenced by the sampling effort, the type of the habitat and the taxonomic level of the analysis. Moreover, Bentix has been tested and evaluated in Greek ecosystems and for different pollution types (Simboura & Zenetos, 2002; Simboura et al, 2007). However, a refinement of the upper limits of the scale is required in the case of habitats which are considered physically stressed (e.g. muddy habitats). In this case the nature of the substratum favors the accumulation of organic matter. Furthermore, the circulation regime in muddy, sheltered bays and the morphological conditions naturally favor the accumulation of nutrients and the stratification of the water column. Thus, the benthic fauna is normally dominated by some tolerant species, reducing the Bentix index even if the conditions are undisturbed by human activities. Bentix is the officially calibrated biotic index for Greece coastal waters (GIG, 2013) and it is the one used for the evaluation of the ecological quality according to Water Framework Directive (2000/60). For the calculation of the index we used the Bentix Add-In free software (www.hcmr.gr).

3. Results

3.1 Physicochemical parameters

The water temperature of Vourkari Lagoon ranged typically for the season, between 8.16 (B1, 01/2017) and 16.3 ^{o} C (B2, 11/2016), with an average value of 12.52 ^{o} C (Table 2). According to pH measurements, the Vourkari water is basic with values ranging from 7.2 (B1, 01/2017) to 8.23 (B2, 11/2016), and an average value of 7.66 (Table 2). Dissolved oxygen concentrations are sufficient and ranged from 5.03 (B2, 01/2017) to 9.2 mg/L (B1, 11/2016), with an average value of 7.58 mg/L, which characterizes the average water quality as good since it is greater than 6.4 mg/L and lower than 9 mg/l (Cardoso et al., 2001; Table 1). Values of electrical conductivity ranged from 55,300 (B2, 01/2017) to 64,800 μS/cm (B1, 11/2016), with an average value of 59,425 μS/cm (Table 2).

Table 2. Descriptive statistics of physicochemical parameters measured

Parameter	Units	N	Minimum	Maximum	Mean	Std. Dev.
pH	-	4	7.20	8.23	7.66	0.519
T	^{o}C	4	8.16	16.3	12.52	3.72
D.O.	mg/l	4	5.03	9.2	7.58	1.79
Salinity	ppt	4	35.8	43.1	38.98	3.37
Electr. Conductivity	μS/cm	4	55,300	64,800	59,425	4,209.8

3.2 Total Organic Carbon (TOC)

Total Organic Carbon concentration constitutes a significant indicator for characterizing the water suitability for various anthropogenic uses. According to the Official Journal of the Hellenic Republic (892/2001), TOC concentrations should not present major differences between the repeated samplings. At this study, TOC measurements of Vourkari Lagoon are considered low (Table 3) but further sampling campaigns should be conducted to verify this indication. The evaluation of the ecological quality based on benthos, requires the use of a combination of several indices, including TOC, while according to the general model, the increase of organic carbon leads to a reduction of species diversity and an increase of species abundance, as a result of the dominance of few opportunistic species. In parallel, the total biomass is decreased.

Table 3: TOC concentrations measured in November 2016 at Vourkari inlet.

Sampling stations	TOC (mgC/L)
B1	0.1
B2	0.12

3.3 Ecological Quality Status assessment based on benthos

In total, 104 macroinvertebrate individuals belonging to 18 species were identified. Most of the species found are classified as opportunistic, of r-strategy, usually observed in protected coastal areas and in organically-enriched environments (Pearson & Rosenberg, 1978). Polychaeta was the most abundant taxonomical group (~ 46%), followed by Crustacea (~ 33%) and Molluscs (~ 13%). The full species list with their abundance per station are provided in the appendix.

In the first station the polychaeta *Hediste diversicolor*, an euryhaline species, indicative of disturbance (physical or technical, Simboura & Nicolaidou, 2001) is the most abundant species (29%). In the second station the most abundant species is the crustacean *Microdeutopus gryllotalpa* (34%), a typical species for transitional ecosystems (Nicolaidou et al., 2005).

Generally, biodiversity found in both stations is low. Station B2 presented higher number of species and number of individuals. Hence, Shannon diversity was also higher (Table 4). Since B2 is located in the outer part of the bay, having better communication with the rest of the Saronikos Gulf, it is logical to have higher diversity and better ecological quality.

According to the samples taken, zoobenthic communities of the area present low number of species and low diversity. This may be due to the substrate type, which is fine, the various types of pollution and in addition it reflects the physical instability conditions.

Table 4: Number of species (S), number of individuals (N/m^2), Pielou's eveness (J) and Shannon diversity (H) per station

Station	S	N	J	$H(log_2)$
B1	9	750	0.742	2.353
B2	11	983	0.685	2.369

According to M-AMBI, ecological quality at both stations is moderate (Table 5). Bentix show that in B2 station the ecological quality is moderate, while in B1 station is poor. Hence, Bentix gives more "severe" results than M-AMBI. That result was expected, as Bentix was invented and used in coastal ecosystems. In contrast, M-AMBI is most used in transitional ecosystems, which are physically stressed.

Table 5: M-AMBI, Bentix, and EQS for each station

Station	**M-AMBI**		**Bentix**			
	value	EQS	Sensitive species %	Tolerant species %	value	EQS
B1	0.438	Moderate	2.22	97.78	2.09	**Poor**
B2	0.479	Moderate	13.56	86.44	2.54	**Moderate**

4. Conclusions-Discussion

Transitional ecosystems are characterized by sharp variations of the physico-chemical and hydro-morphological conditions, on a daily and seasonal level, that typically result to a mosaic of different habitats (Nicolaidou et al, 2005). Due to the high variability of environmental parameters (ex. salinity, dissolved oxygen O_2, temperature e.t.c.), these ecosystems are considered as naturally stressed. Thus, the species that inhabit such environments have been adapted to such variabilities and are resistant to the changes of environmental conditions (Elliott & Quintino, 2007). Therefore, the management of such ecosystems is complex, because the effects of the anthropogenic activities on the ecosystem, are often the same as those caused by the natural disturbance occurring in these environments ('The estuarine Quality Paradox' Dauvin, 2007; Elliott & Quintino, 2007).

Due to the water circulation and the physically stressed environment, the ecological quality was expected not to be good. Moreover, in such ecosystems, the seasonal variation is high. According to previous studies from HCMR in stations near our study area (Loutropirgos – Nea Peramos and Faneromeni), ecological quality was found moderate and poor (HCMR, 2009; Simboura et al., 2016). Further studying of biological and other key parameters for ecological quality assessment of Vourkari Lagoon will result in a better understanding of its ecological status and functioning that will facilitate the optimal management, protection and restoration of this ecosystem.

The case study area is undergoing a legal process to receive official protection through a Presidential Decree and this is a positive action if will be completed soon. Moreover, several other activities could improve the ecological status of the Lagoon, such as:

1) The hydrological restoration of the Lagoon through the removal of man-made constructions (eg roads) that obstruct freshwater from entering the Lagoon
2) The continuous water quality monitoring will act as an early warning system and will discourage potential polluters to impact the Lagoon
3) Targeted legal investigations to apply the polluter pays principle
4) Environmental education activities in the Lagoon with the active participation of local schools
5) Eco-touristic infrastructure establishment for bird-watching

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Appendix

Table. 1: Number of individuals per m^2 and % percentage of species in each station. Most abundant species are highlighted.

Species	**Number of individuals/m^2**		**% species percentage**	
	B1	**B2**	**B1**	**B2**
Abra alba	17	0	2	0
Abra sp. juv	117	0	16	0
Capitella capitata	0	17	0	2
Cerastoderma glaucum	0	17	0	2
Chironomidae sp.	117	0	16	0
Fabriciinae sp.	17	0	2	0
Hediste diversicolor	333	200	44	20
Loripes lacteus	0	67	0	7
Lumbrineris latreilli	0	17	0	2
Microdeutopus gryllotalpa	100	467	13	47
Modiolus barbatus	0	17	0	2
Monocorophium sp.	0	17	0	2
Naineris laevigate	0	117	0	12
Neanthes acuminata	0	33	0	3
Parapionosyllis sp.	17	0	2	0
Pettiboneia urciensis	0	17	0	2
Dipolydora flava	17	0	2	0
Syllis prolifera	17	0	2	0