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Evaluating the ecological restoration of a Mediterranean reservoir

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Abstract: The restoration of Lake's Karla environment and ecosystem is studied through the evaluation of its current status. Its drainage, in 1962, created a series of environmental problems and led to the local economy contraction. The Lake Karla reconstruction project has begun since 2000. The construction of a reservoir at the lowest part of Lake Karla watershed is among the parts of this project, which will be supplied from Pinios River and the runoff of the surrounding mountains. This newly re-established water body is considered a vital aquatic ecosystem as it is listed in the network of Natura 2000 and has been characterized as a Permanent Wildlife Refuge by Greek Law. The results indicate that the delay of implementation of Lake Karla reconstruction project, the violation of Environmental Terms and the lack of environmental policy are the most important cause of pressures.

Key words: ecosystem restoration, eco-technology, anthropogenic pressures, biodiversity

1. INTRODUCTION

Lake Karla (Thessaly, Greece) was considered one of the most important shallow lakes in Greece until 1962, where complete drying of the lake took place - creating more agricultural land - and is now being re-constructed, establishing a 'new' reservoir offering multi services (i.e social, economic and ecological sustainable development of the region). Prior to 1960's Lake Karla was considered one of the most important hydro-ecosystems in the region as it served as a natural reservoir providing water storage and recharge to groundwater. Accordingly the importance of restoring this water body and reversing the environmental conditions caused by manmade activities was considered of high importance by the European Union. The concept of the Lake Karla' restoration project is, probably, the first European project towards nature conservation following the eco-technological approach. The Karla's project has been recognized as an important opportunity for addressing the complex challenges in the hydro-ecological management in the main agricultural region of Greece with growing demand of freshwater, providing also the traditional and new services to the people.

In this paper we discuss the restoration approach of Lake Karla as well as the pressures and their causes that negatively affect the restoration process. This is achieved by evaluating the results of the monitoring and fieldwork programs that Management Body of Ecodevelopment Area of Karla – Mavrovouni – Kefalovriso – Velestino performs the years 2012-2013 funded by the European Union.

2. THE STUDIED SITE-DATA DESCRIPTION

2.1 The biogeographical context

Former Lake Karla occupied the lowest part of its natural basin and was considered as one of the most important wetlands in Greece until 1962. Surface runoff from the watershed and floodwaters of the Pinios River (discharging via the Asmaki ditch) supplied the lake with large quantities of freshwater. The river occasionally overflowed, and floodwaters rich in oxygen and nutrients drained into Karla. Much of the surrounding farmland was inundated when floodwaters were held in the lake, but today, the river is levelled to prevent flood damage. The climate of the area is typical continental with cold and wet winters and hot and dry summers. Mean annual precipitation in the lake's watershed is about 560 mm and is distributed unevenly in space and time. Mean annual potential evapotranspiration is about 775 mm and the mean annual temperature is 14.3 ºC (Vasiliades et al. 2009). The geological structure consists mainly of recent grains of various sizes originating from the lake's deposits. The decision for the complete drying of the lake in 1960s took place in order to create more land for agriculture and to avoid the flooding of the low elevation lands because of its surface area fluctuations.

2.2 The project design

Technical studies, recommended draining the lake via the Karla Tunnel and building a smaller reservoir instead of the natural lake for flood protection and for the revelation of agricultural fields. The re-constructed Lake Karla occupies the lowest part of the former Lake Karla. It lies between latitude 39º26′49′′S to 39º32′03′′N and longitude 22º46′47′′W to 23º51′50′′E and has a surface of 38 km^2. It is characterized by its shallow depth with a maximum water depth of 4.5 m and a mean depth of 2 m.

Among the targeted measures were: the establishment of riparian zones to control the diffuse agricultural pollution sources, the operation of a peripheral buffer zone for the elimination of the nutrients input, the establishment of habitats corridors to avoid the ecosystem fragmentation and to improve the re-habilitation, the re-operation of a controlled outlet to improve flushing effect minimizing the water retention time, the construction and operation of artificial wetland for the improving of water quality, the construction of fish ladders at Pinios pumping station, the re-organization and the modification of the agricultural strategy in the whole region according to agri-environmental friendly practices.

Finally, the restoration plan included the designation of the area as a protected Ecodevelopment area under the Natura 2000 network because of its biodiversity and the establishment of a Management Body which is responsible for the implementation of the restoration plan, the monitoring program, and the application of management principles taking into consideration the local socio-economic needs.

2.3 The post-monitoring program

A monthly monitoring program of water quality took place from January 2012 to July 2013 in three sampling stations (Fig. 1). The European Directives (i.e the Water Framework Directive and the Habitat Directive) were used as guidelines for the applied methodology, with respect to the characterization of the water body and for the assessment of its status. More details about the sampling and monitoring methodology concerning nutrients (Dissolved Inorganic Nitrogen, DIN, Total Phosphorus, TP), turbidity (Secchi depth), Chlorophyll-a as a proxy of algal biomass have been described in detail and published by Sidiropoulos et al. (2012) and Chamoglou et al. (2014). Also, monthly lake level was recorded throughout the years 2012, 2013. In the present paper the hydrological regime and the eutrophication trends are discussed under the light of the pressures and the undertaken measures.

3. RESULTS

The design of the restoration project and the establishment of the protected area have been addressed the increase of the provisional services as well as the promotion of regulating services and yet, the re-establishment of the cultural services delivered in the wide area named: Eco development Area of Karla-Kefalovriso-Mavrovounio-Velestino (Fig. 1).

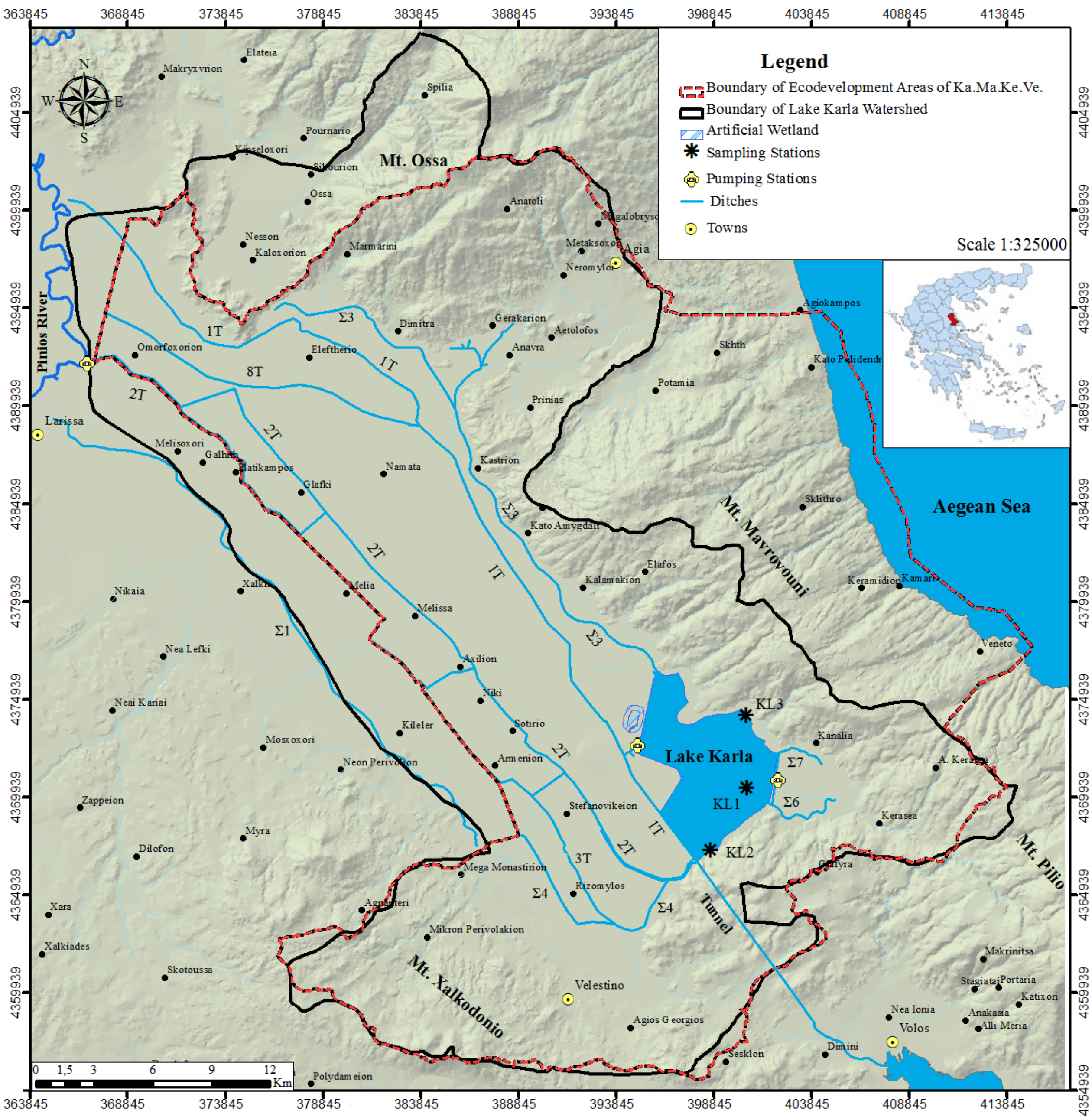

Figure 1. Map of Eastern Thessaly showing the boundaries of Lake Karla Watershed and Ecodevelopment Area. The monitoring stations (water quality) are also depicted.

In the former Lake Karla, there was no a natural surface outlet of the aquatic system Pinios River-Lake Karla, while it is thought that discharge took place through a system of karstic sinkholes of Mavronouni Mountain to Pagasitikos Gulf (Fig. 1). Nowadays, this discharge has been avoided with the creation of a non flow embankment, where the new reservoir meets the kartsic structures of Mavrovouni Mountain. So, the new Lake Karla is supposed to be drained artificially, by means of a tunnel (Fig. 1) to the Pagasitikos Gulf, which – at present - is closed and operates only in emergency situations. Thus, water losses from Lake Karla are through evaporation, withdrawals for irrigation and recharge to the aquifer.

Figure 2 demonstrates the water level fluctuation in Lake Karla during the years 2012 and 2013. It comes clear that the water level in the new reservoir was always lower than lowest ecological limit (+46.4 m), except once, on the 11/06/2012. This happens because the reservoir receives less water inputs since 2012 both from its basin because of unfinished works, and from Pinios River due to an interruption in their connection but also due to the withdraws before the river inflows the reservoir. During the winter period, precipitation feeds the lake while, at the moment, the Karla reservoir experiences intra-annual water level fluctuations due to the bad and unsustainable management of the inflows from Pinios river.

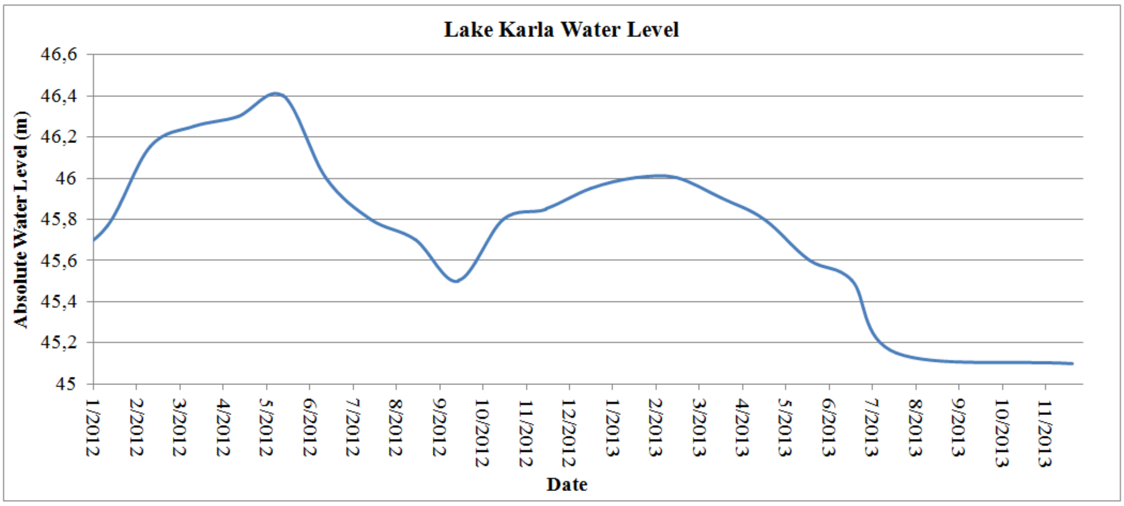

Figure 2. Water lever fluctuation of Lake Karla for the years 2012 and 2013.

3.1 Water quality / eutrophication

In Figure 3, the monthly variation of the key- eutrophication parameters (Nitrate-N, Ammonia-N, Total Phosphorous) along with the Secchi depth (SD) and Chlorophyll-a are presented. The water quality variables and the nutrients dynamics, are thought to be strong predictors of the trophic status. With regard to nutrient concentrations, Nitrate-N was always the most important form, in terms of percentage contribution, in the Dissolved Inorganic Nitrogen pool, exhibiting higher values during the summer months while Ammonium-N ranged from 0.009 mg/lt (June 2012) to 0.511 mg/lt (June 2013). Also, mainly the first year of sampling period, Ammonia-N concentrations were found a lot times above the value of 0.2 mg/lt, which is the limiting value for fish intoxication, according to the European Directive (2006/44). Total Phosphorus (TP) fluctuated between 0.004 mg/lt (March 2013) and 0.461 mg/lt (April 2012) appearing also high values during the warm months. The peak value of TP coincides with high inflows by the drainage channel located at the southeast part of the lake (Management Body Report 2012). Chlorophyll- α ranged between 6.19 mg/cm^3 (January 2012) and 403.58 mg/cm^3 (August 2012), with higher values recorded during the warmer months indicating a strong hypertrophication. The new reservoir did not appear any clear phase during the monitoring period as the Secchi depth ranged between 0.19 and 0.5 m reflecting its turbid character.

3.2 Pressures and mitigation measures

In Table 1 the main pressures affecting the new reservoir are presented along with the relevant measures undertaken, the ecosystem's state and the associated impacts on its goods and services. Pressures were separated in five categories while some of the relevant measures were implemented to a percentage up to 50% while the implementation of other did not started at all. Restoration measures in order to avoid flooding, to cover irrigation needs and to establish the hydrological regime make up the 50% of all implementations measures and they are purely mechanical measures. The eco-engineering, "green" measures (Table 1, in bold) mainly addressing the habitat conservation and the nutrient's retention did not yet implemented.

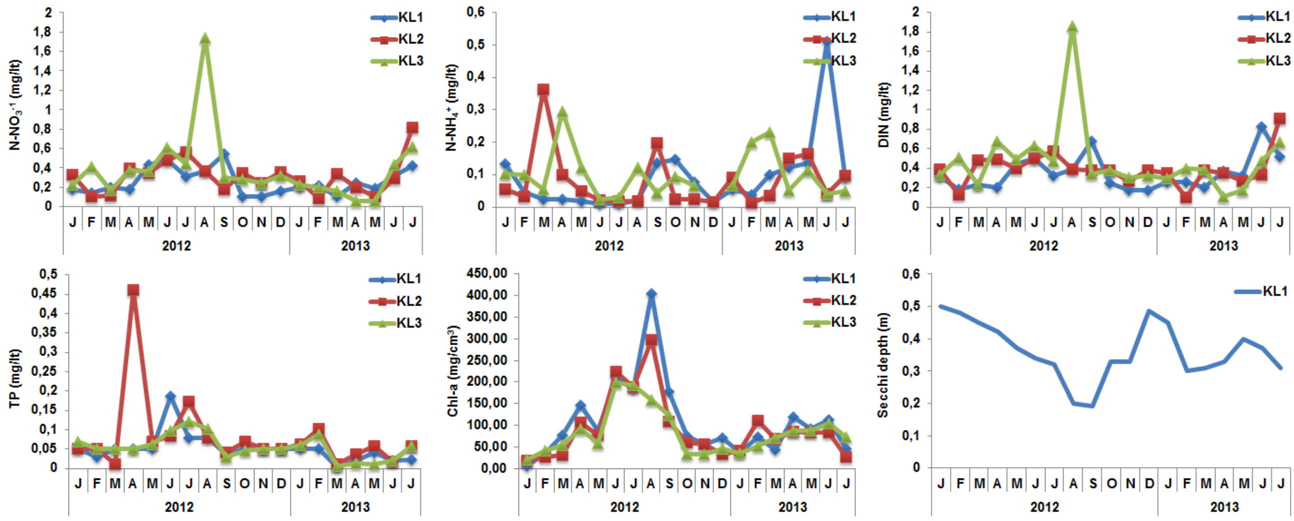

Figure 3. Monthly variation of Nitrate-N, Ammonia-N, Dissolved Inorganic Nitrogen, Total Phosphorus, Chl-α, Secchi Depth during the sampling period (January 2012 - July 2013).

Table 1. Main pressures, mitigation measures, implementation level during the restoration project on Lake Karla

Pressure	Restoration measure	Implementation status	Impacts
Flooding	Implementation of flood protection and mountainous water projects and of collectors /Diversion of flooded water into the reservoir with the pumping stations operation	**60%** *Constructed*: Reservoir and pumping stations *Non constructed:* Collectors and mountainous water projects	Damage to agricultural crops and infrastructures, removal of soil making the land barren
Point & Diffuse pollution sources	Treatment of inflow water to the reservoir, improvement of water quality / **Establishment of riparian zones, operation of a peripheral buffer zone, construction and operation of artificial wetland**	**0%** No project or tool has been implemented.	Deterioration of water quality, eutrophication, pressure on biota, changes in the structure and function of the water body, sedimentation, elimination of ecosystem services.
Habitat fragmentation	**Tree planting project, creation of land corridors, buffer zones.**	**10%** Failure on planting growth, incomplete establishment of corridors.	Habitat loss due to ineffective implementation, habitats isolation, impacts on flow energy, impacts on ecosystem services.
Hydromorphological alterations	Restoration of hydrological balance, rehabilitation of groundwater. Creation of a 38 km^2 water body and supplement channels.	**50%** *Constructed*: Reservoir *Non constructed:* Water distribution projects	Negative hydrological balance of Lake Karla Watershed, continuous degradation of water resources, soil salinization, desertification, land subsidence.
Human needs (irrigation)	Creation of the main reservoir and distributing irrigation channels	**50%** Incomplete construction of irrigation channels	Not implementation of social needs, no withdrawals.

4. DISCUSSION AND CONCLUSIONS

Lake Karla, in terms of typology (according the WFD) is considered as an artificial lake, and furthermore, as a highly modified water body. Based on the available dataset, historical data and expert judgment we could argue that the lake Karla experiences a long eutrophication period with signals of hypertrophication.

The environmental conditions of the new reservoir have not improved in spite of the undertaken measures. The new reservoir is characterized as eutrophic with the frequent occurrence of algal blooms dominated by cyanobacteria (Chamoglou et al. 2014). A reduced water transparency due to organic material and plankton, along with the presence of frequent algal blooms (*Anabaena* sp., *Aphanizomenon* sp.) reported by Ananiadis (1956), suggests that the lake has been eutrophic since at least the 1950s. Nutrient pollution and associated eutrophication of the new reservoir threaten the ecological integrity and the services provided to the local community.

At present, Lake Karla has an extremely high water retention time since there is no outflow (Chamoglou et al. 2014) thus shaping the biological communities (Stabouli et al. 2012), while the phosphorous in- lake concentrations are very far to maintaining even the mesotrophic conditions in a Mediterranean water body (Meerhof et al. 2012).

Regarding Lake Karla, restoration measures addressing the balancing of the hydrological regime are not yet finalized.

With increasing warming in the whole area (Loukas et al. 2014) it may be more difficult to fulfil the suggested ecological state targets of the lake, without undertaking additional efforts to reduce nutrient loading to levels lower than the present-day expectations. Although nutrient loading is, generally, expected to decline in warm Mediterranean area because of the low precipitation and lower runoff, however much higher concentrations are currently observed due to increased evapotranspiration leading to high concentrations in the remaining water (Jeppesen et al. 2014).

To conclude, the "alarming" current status of Lake Karla ecosystem is a synergy of three factors:

1. Decline of Environmental Terms of the project (Ministry of Environment, Planning and Public Works 2000) and failures in the planning of the project. According to the Environmental Terms the scheduled wetland, (in the west part of the reservoir,) ought to be constructed firstly thus filtering the inflows. Yet, the water level of reservoir has never been over the lowest ecological stage (+46.4 m) that the Environmental Terms commands. The artificial wetland which will upgrade the water quality has not been operated yet thus there is a nutrient rich inflow into reservoir.
2. The great delay of the Lake Karla project implementation leading to a hysteresis of the ecological restoration of the site. That was revealed from the two year monitoring of physicochemical parameters which indicated the eutrophic character of the reservoir aided by the fact that is still under the filling process. The only work that has been completed is the construction of the reservoir, the pumping stations and the water transfer project from the Pinios river. The collectors, who will supply the reservoir with flushing water from the surrounding mountainous area, have not been constructed yet. Irrigation work, which will act as an “outflow” thus enhancing flushing, is still uncompleted. Therefore there is no doubt that the new lake is far from an equilibrium stage which could be support its function.
3. Lack of environmental policy due to fragmentation of responsibilities, and further due to competent authorities dealing with water management where in some cases their responsibilities overlap. Moreover, due to the fact that the active involvement of the local communities is very weak, the increased participation in the whole basin management decisions by a wide range of stakeholders has been widely advocated by the Management Body of Lake Karla.

The re-constructed Lake Karla will success to regain its multiple functional role only if we respect the characteristics of the former Lake Karla in relation to present environmental and socioeconomic needs. An integrated watershed management approach should be developed rather than focusing only on the lake itself. Conservation of the “new” lake requires protection of watershed at ecosystem basis.

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