

Linkages between physicochemical status and hydromorphology in Greek lakes under WFD policy

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Abstract: The national monitoring network of waters in Greece, in the context of Water Framework Directive, has been operational since 2012. It comprises 50 lake water bodies, both natural and artificial (24 and 26 respectively). The aims of the study are i) to present the main features of Greek lakes; ii) to position them according to hydromorphological and physicochemical data from the first period of monitoring and iii) to investigate how the hydromorphological features influence water quality. Greek lakes are discerned in relation to hydromorphological aspects such as mean depth, volume, surface area, catchment area. Impacted and unimpacted lakes are separated when positioned along physical and chemical attributes, such as Secchi depth, TP and ion concentrations. The dataset covers a gradient of eutrophication, which seems to be the main anthropogenic pressure on lakes in Greece and probably one of the most widespread anthropogenic pressures on lakes across Europe. Catchment areas of the Greek lakes have undergone substantial agricultural, industrial, and urban development over recent years, leading to eutrophication and hydromorphological alterations. Management measures at a catchment scale aiming to control land uses would be needed in order to maintain and/or improve water quality in Greek lakes, supplemented by site-specific measures when appropriate. The monitoring network provides baseline data that will allow the assessment of status and trends of Greek lakes.

Key words: WFD, Greek lakes, hydromorphology, water quality

1. INTRODUCTION

The Water Framework Directive (WFD) foresees the operation of monitoring programmes for surface waters and groundwater in order to assess their ecological and chemical status (article 8). Comparable pan-European datasets, with hydromorphological, physicochemical and biological information are used to assess ecological status of surface waters and improve our knowledge on the structure and function of these ecosystems (Hering et al. 2010; Moe et al. 2013).

The complex geomorphology of Greece, the uneven distribution of precipitation and different regional demands for irrigation and drinking water are some of the characteristics that affect the hydromorphological features of Greek lakes (Zacharias 2002); this in turn strongly governs various ecosystem functions (Schindler and Scheurell 2002). According to Nöges (2009), nutrient inputs are profoundly affected by catchment and lake area through surface and groundwater drainage while nutrient retention, a fundamental property of every aquatic ecosystem, is linked to its geomorphological, hydrological, edaphic and biotic characteristics (Hansson et al. 2005). Furthermore, intensive agriculture activities, domestic and industrial inflows have changed the surface water distribution and use (Skoulikidis et al. 1998).

In line with WFD, Greece had to establish a national monitoring network (JMD 140384/2011); EKBY now operates the monitoring network for lakes in Greece, establishing baseline data to assess their ecological status and trends. The aims of the study are i) to present the main features of Greek lakes, ii) to position them according to morphological and physicochemical data from the first period of monitoring and iii) to investigate how the hydromorphological features influence water quality.

2. MATERIALS AND METHODS

2.1 Study area and data sets

The Greek National Water Monitoring Network for lakes comprises 50 water bodies, both natural and reservoirs. The heterogeneity of Greek geology, climate and topography has resulted in a lake dataset with a broad range of morphological, physical and chemical characteristics. Fifty-three stations have been established, 27 of which are subject to surveillance monitoring and 26 to operational. Most water bodies have one sampling station each, except transboundary lakes Megali Prespa, Mikri Prespa and Doirani, which have two sampling stations each (Figure 1).

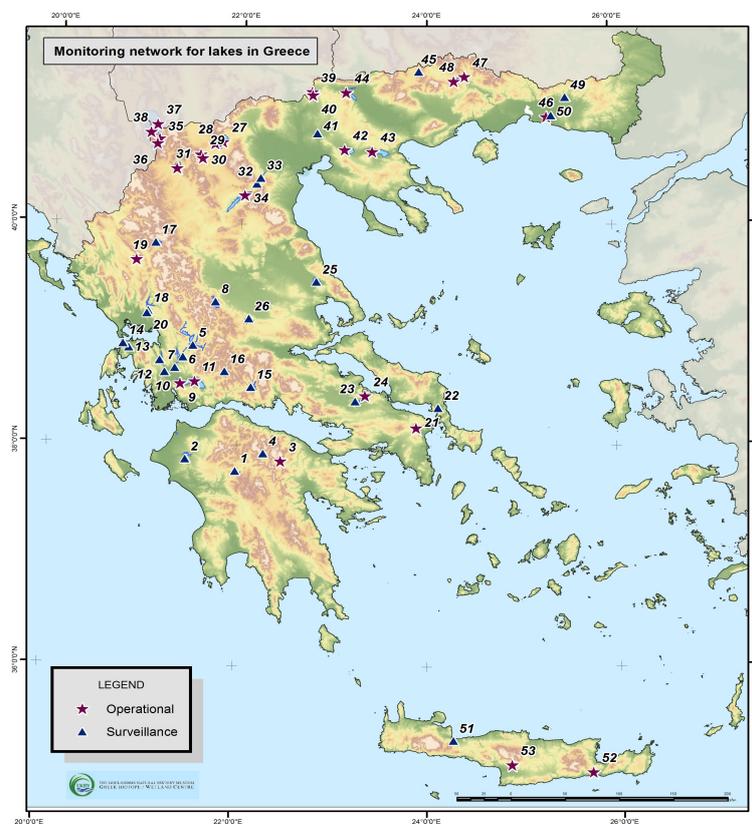


Figure 1. Monitoring network for lakes in Greece.

Physicochemical features were measured seasonally and each month during growing season (May to October). Samples were taken from euphotic zone [2,5xSecchi Depth (SD)]. In particular: Transparency was measured with a Secchi disc. Temperature, pH, oxygen, conductivity and Total Dissolved Solids were measured with portable meters from ThermoScientific instruments. Filtrations for Chlorophyll *a* measurements were carried out through Whatman GF/F glass-fiber filters and Chlorophyll *a* was estimated using standard methods (APHA 2012). Analyses for Na⁺, K⁺, Cl⁻ and SO₄⁻ were carried out with the use of Ion Chromatography (ISO 14911 1999, ISO 10304-01 2009). Analyses of Total Phosphorus (TP) were carried out in unfiltered water using ascorbic method following persulfate digestion (APHA 2012). Data used for this study were taken from samplings carried out in 2015. To estimate the catchment area impact on water bodies, the Schindler's ratio was calculated as the ratio between the catchment and the surface area to lake volume (Stefanidis and Papastergiadou 2012). Intensive agriculture was measured as the sum of the Corine Land Cover categories corresponding to a high potential impact from agricultural activities, such as arable land (including irrigated land), permanent crops (with associated annual crops), vineyards, orchards, olive groves and complex cultivation patterns. Morphological parameters of transboundary lakes were estimated including data from sharing countries.

2.2 Statistical Analysis

All statistical analysis, including Boxplots, Pearson's Correlations and Principal Component Analysis (PCA), was conducted using R Statistical Software (R Core Team 2014).

Data analysis was performed only in stations sampled for at least two months over growing season. Very shallow natural lakes Koroneia, Saltini, Pikrolimni, Stymfalia and Dystos were excluded from analysis, due to either outlier values or lack of data caused by drought. Values below the quantification limit were replaced with the value of quantification. Variables were tested for skewness and log transformed when needed. Correlation Analysis was conducted in order to elucidate possible relationships between parameters. PCA was used to interpret the major patterns of variation within the data and ordinate the lakes with respect to selected hydromorphological and physicochemical variables.

3. RESULTS

Correlation analysis between TP and Schindler's Ratio revealed a significant relationship ($p < 0.05$), as the two variables were positively correlated in both reservoirs and natural lakes ($r = 0.45$ and $r = 0.41$, respectively) (Table 1). The relationship between TP and Mean depth was statistically significant in both cases ($p < 0.01$) and the r values confirmed the strong negative correlation between the two variables.

Table 1. Pearson correlation between TP, Schindler's Ratio and Mean Depth

	Natural Lakes (n=20) LogTP	Reservoirs (n=23) LogTP
LogSchindler's Ratio	0.41*	0.45*
LogMeanDepth	-0.60**	-0.79**

* significant at $p < 0.05$, ** significant at $p < 0.01$

Boxplots in Figure 2 show TP and Chlorophyll a data (growing season mean) plotted against Intensive Agriculture and Population Density groups. Intensive agriculture activities affirmed their high impact on TP loading in water bodies, both reservoirs and natural lakes. Population density showed the same positive relationship with TP, as expected.

PCA revealed the ordination of Greek natural lakes in two PCs, with eigenvalues above one ($\lambda_1 = 3.11$ and $\lambda_2 = 1.42$, respectively), which captured 91.51% of total variance (Figure 3). All variables had high scores on the major PCA axis I, with lake volume standing out and negatively correlated with the axis. The second axis was positively associated with Schindler's ratio and catchment area. In reservoirs, the two first axes captured 81.94% of total variance, with lake volume and catchment area, being strongly correlated with PC1 whereas PC2 was only affected by Schindler's ratio.

With regard to the physicochemical aspects, the two principal components of the PCA explained 84.04% of the data variance, in natural lakes (Figure 4). The first axis ($\lambda_1 = 2.13$) was driven mainly by electrical conductivity and sodium and less by calcium ions. The second axis was associated with Secchi depth and TP, revealing a clear gradient from deep, clear water bodies to shallow more impacted ones. The same gradient was evident in reservoirs, as TP and Secchi depth were the principal drivers of the second axis, with the former being now the strongest one. Electrical conductivity, sulphate and sodium ions were the most influential parameters of axis 1, separating the two reservoirs from Crete, T.L. Faneromenis and T.L. Bramianon. One reservoir, T.L. Pournariou is separated from the others, as it is highly associated with calcium ions.

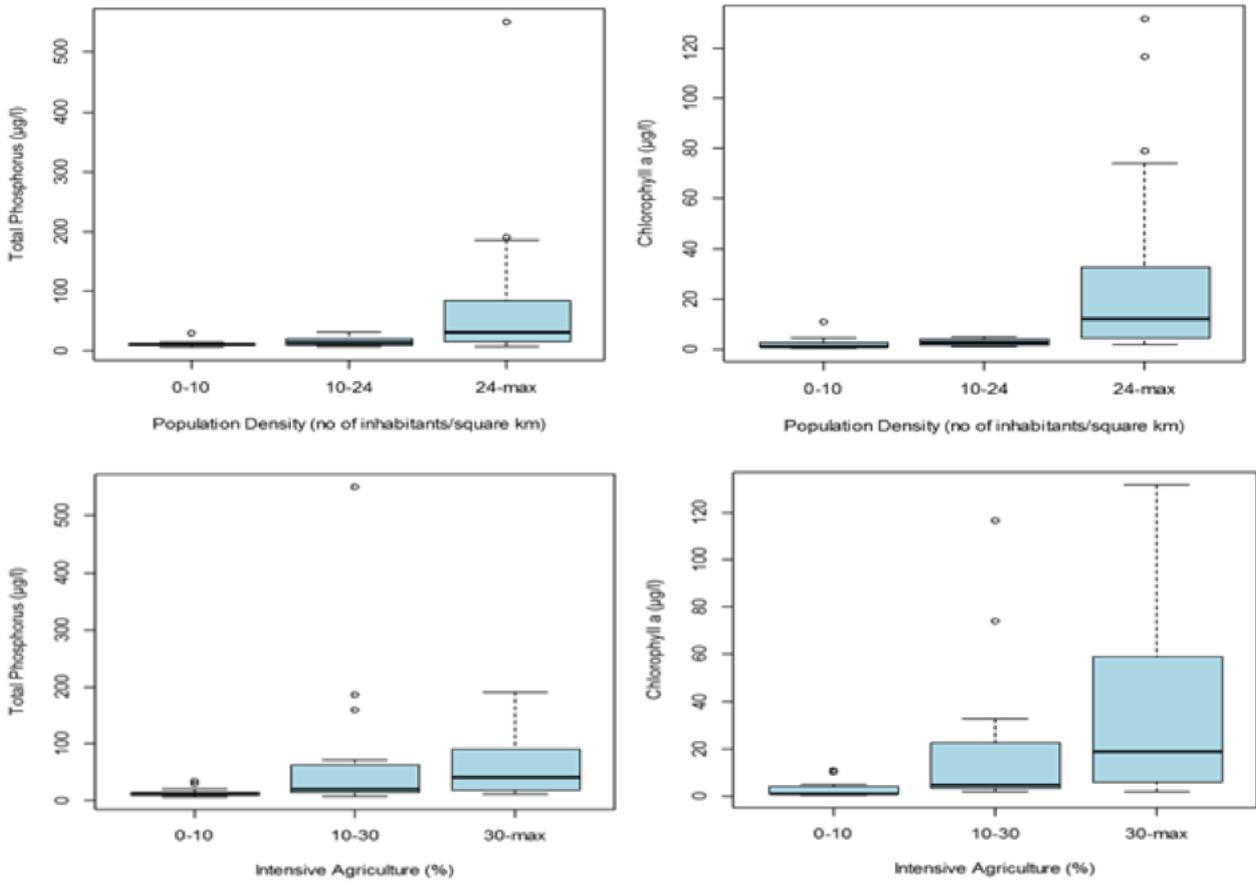


Figure 2. Boxplots of Intensive Agriculture and Population Density groups in relation to TP and Chorophyll a.

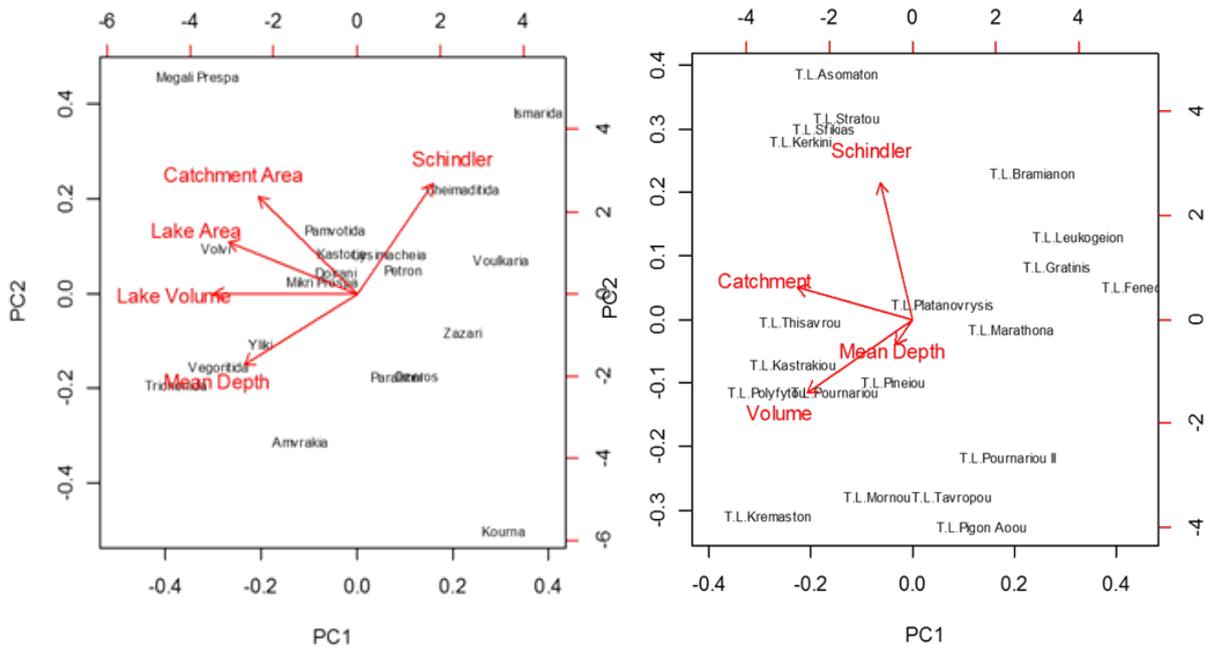


Figure 3. PCA biplots of selected morphological variables in Greek lakes dataset.

natural lakes. A gradient of increasing TP along the second component, separate clear reservoirs and deep natural lakes with high Secchi depth from shallow, impacted lakes with low Secchi depth. This describes the sensitivity of shallow lakes to resuspension process and further to nutrient loading. Urban lake Pamvotida, along with lakes Zazari, Cheimaditida and Lysimacheia are clustered on the top left quadrant of the plot, highly associated with TP. Nutrient loading is the result of household wastewater inputs and intense agriculture activities (Skoulikidis et al. 1998). Specifically, regarding the urban lakes, as lakes Pamvotida and Kastoria, it is well documented that they tend to receive high nutrient loads and show higher trophic status than non-urban ones (Naseli-Flores 2008); thus site-specific mitigation measures should be implemented. Water bodies, Kourna and Amvrakia, are positioned together on the bottom left of the plot, as they are highly associated with calcium, with the latter also related with sulphates. In Amvrakia, a hard water lake, several studies have been reported high concentrations of these ions, mainly due the presence of gypsum of the surroundings (Danielidis et al. 1995; Skoulikidis et al. 1998).

Findings suggest that intervention at a catchment scale aiming to control land uses would be needed in order to maintain and/or improve water quality in Greek lakes, supplemented by site-specific mitigation measures when appropriate. The sustainable and cost-effective management of Greek lakes requires a proper understanding of the relationships between morphometry and physicochemical variables. Continuous surveys would be useful in providing long-series data to be able to link hydromorphology and physicochemical conditions to ecological processes and biological responses.

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