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Impact Assessment of Habitat and Hydromorphological Alterations in Two Heavily Modified Lakes †

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Abstract: A description of hydromorphological pressures is required by the Water Framework Directive, however, there is not a commonly accepted assessment method. This study aims to explore a description tool application, not used before in Greece, for the quantification of the human impact extent on natural environment. Thus, in lakes Kastoria and Pamvotis, the Lake Habitat Survey was applied in the field and remotely to map the pressures, to examine confidence, suitability and ease of applicability through plot quantitative description, to calculate the "Lake Habitat Quality Assessment", "Lake Habitat Modification Score" and "Alteration of Lake Morphology Score" indices.

Keywords: lake habitat; hydromorphology; LHS; LHMS; LHQA; ALMS; pressures; Pamvotis; Kastoria

1. Introduction

Lake morphometry governs many lake processes, thus changes in morphometry directly affect characteristics such as mixing regime, water residence time, shore zone energetics [1]. Riparian and littoral vegetation regulates a series of functions and supports important ecological features. In lakes, primary productivity is more or less defined by the hydromorphology of lakeshores [2–4]. The European Water Framework Directive (WFD) [5] recognizes that hydromorphological alterations have a potential impact affecting the composition and abundance of biotic communities in surface waters. Despite hydromorphology assessment and monitoring are an integral part of all River Basin Management Plans (RBMPs), there is not a commonly accepted method to assess them, and a systematic procedure is still lacking [6]. The main reason is the vast heterogeneity among waterbodies in size, climate, hydrology, geology, ecological services, and human uses among others. The attempt to describe the significance of habitat loss due to human-induced hydromorphological changes is a major issue when applied to Heavily Modified Water Bodies (HMWBs), since it is mandatory for Maximum Ecological Potential (MEP) description. Urban lakes often fall into this category. The necessity for embankments, flood protection, measures for aesthetic value and touristic attraction as long as the ease of water abstraction for various purposes usually affects strongly the naturalness of lakeshores.

Since early 90s the scientific interest was focused on ecological flows and pressures on systems hydrology and morphology, mostly of streams and rivers. This was evolved in holistic methods, based on multiparametric rating of hydromorphological alterations and ecological functioning providing habitat assessment and simulation, e.g., Building Block Methodology [7] and Instream Flow Incremental Methodology [8]. In Europe, besides several national standardized hydromorphological alterations assessment methods, a number of indices were developed and proposed for adoption, i.e., the Ecological Limits of Hydrologic Alteration Framework (ELOHA) [9] for German lakes and the Lake Habitat Survey (LHS) [10] for UK lakes. In Greek RBMPs, the HMWBs are designated following general WFD guidelines, where at least two (of four) metrics are considered enough to depict the modification status with hydrology, embankments, withdrawals and human pressures being the main factors [11]. The Greek methodology is based on Irish and UK assessment methods, used for LHS development [12,13] with some additions from Finland [14]. LHS is acknowledged as a useful method for assessing the conservation value of temperate lake shores, but still remains to be seen whether it can be applied across a range of different European lake types [15]. In Greece, there are no recordings of its use nor its functioning, besides Petriki et al. [16] where it was used in a fragmented way. The low use of LHS itself by the Greek scientific community and the inexistence of relative publications reveal possibly a doubt on such a protocol.

The main aim of the present study is to test the LHS as a hydromorphological assessment tool in two similar Greek urban lakes. Furthermore, two important indices deriving from LHS are tested in order to assess their ability for the depiction of morphological pressures and their reflection in modification and quality assessment. The implementation of the survey is further tested with two different approaches, in situ and remotely.

2. Material and Methods

2.1. Study Area

For the application of LHS, two urban lakes were selected from Northern Greece, Lake Kastoria, (Western Macedonia; KA) and Lake Pamvotis (Epirus; PA). Lake Kastoria extends in an area of 29 km^2 area, has maximum depth of 8 m and mean of 4 m. The lake's inflow originates from nine small streams with seasonal flow. It is also fed through a considerable number of groundwater springs that discharge periodically into the lake. Gradual decline of water quality and trophic state has been described since 80's [17,18]. Lake Pamvotis occupies an area of 22 km^2 area, has maximum depth of 9.6 m and mean depth 4.3 m. The lake's inflows are karst springs and five streams (three through artificial channels). Substantial deterioration was described during the last decades [16,18].

Since almost 2000, both lakes received urban effluents from the nearby cities. Additionally, they are both addressed as HMWBs in the national RBMPs. They are shallow, polymictic, hypertrophic lakes with interannual volume fluctuation under a Mediterranean-influenced continental climate. Their trophic status is guided by the long history of settlements, their urban character and the existence of industries of various scales and types. Their urban fabric is similar, with one large city and many semi-urban centers in the lake perimeter. Both have artificial outflow and regulated hydrology and are subject to continuous limitation of the extent and the depth, due to natural silting, human activities and embankments. Moreover, in both lakes there have been fish species introductions. On the other hand, both are of great value, provide important ecological services, and are under multiple protection regime by national, international treaties and networks (like Habitats' Directive 92/43/EC, Birds' Directive 2009/147/EC).

2.2. Application of Lake Habitat Survey and Data Analysis

Two 3-day field surveys were held, one for each lake, in early October 2017, to apply the LHS method [18,19] by foot-based approach and by distance, using Google Earth most recent available (warm period) satellite imagery (LandSat 8 Taken 28 June 2017 at Ioannina and 1 July 2017 at Kastoria). Since differences in temperature do not affect LHS nor the indices, and the water level did not change, we assumed the same pressures and abiotic conditions would occur. Ten Habitat Plots (HPs), evenly spaced and randomly scattered, were assigned in each lake experiment according to [6,20]. Three indices were calculated LHQA, LHMS and ALMS from the LHS protocol. The LHQA is based on physical structure, diversity, and some special habitat features adding extra ecological value [6,10], ranging from 0 to 112 (high value). The LHMS estimates pressure thresholds with the likelihood to impact the lake's ecological status, ranging from 0 (undisturbed habitats) to 42 (disturbed habitats) [6]. For HMWB designation method, the ALMS [21] was calculated and compared to Greek methodology result. The observer is familiar with lake environments and had previous experience with River Habitat Survey (RHS) [22], but never conducted LHS before. Expert opinion was used in some ALMS and LHQA metrics dealing with the whole lake assessment to define thresholds of hydromorphological pressures and to evaluate results [12,21].

Given the data were non-normally distributed, a Mann-Whitney U test, as a non-parametric one, was applied to test for significant differences between the two approaches (foot-based approach and satellite imagery remote approach) at answers in features from 11 categories of the LHS protocol (i.e., riparian zone, exposed shore, littoral zone, pressure humans and among the categories of HPs). Additionally, the scores calculated for the two indices (LHQA and LHMS) were tested for significant differences between the two approaches for each lake using Mann-Whitney U test. The above analysis was performed using the software IBM SPSS statistics 24.

3. Results

3.1. LHS Survey

Summarized data for shore/littoral pressures (0–15 m) and riparian land use pressures (0–15 m and >15–50 m) for each approach per lake are presented in Figure 1. In Lake Kastoria, pressures with high extent (>75%) per segment were recorded only in three areas between HPs (S8-S9, S9-S10, S10-S1) (Figure 1). Specifically, the features that were observed in high extent were hard bank engineering, floodwalls/embankments and land claim in the littoral zone, commercial activities, residential areas and roads in the riparian zones. The same pressures were also recorded in Pamvotis lake, but in six areas between HBs (Figure 1).

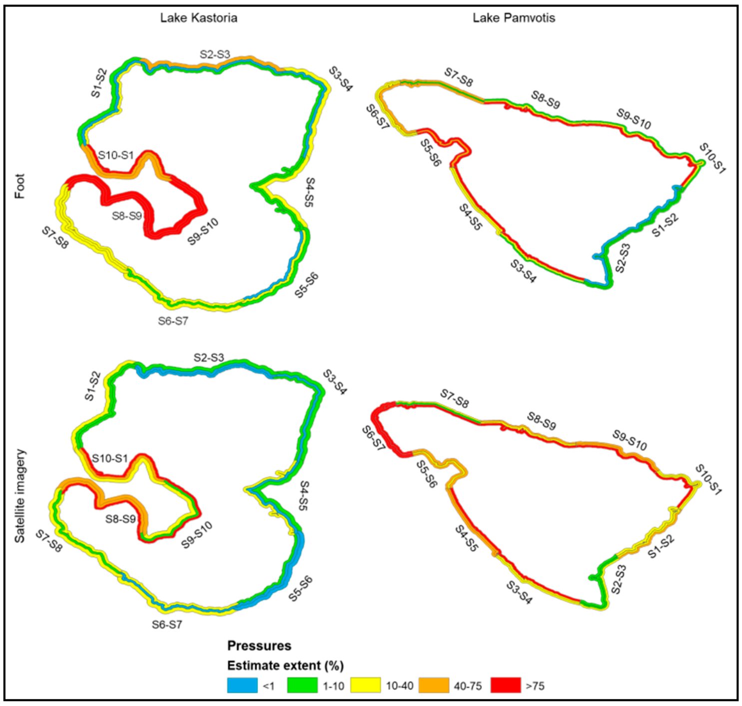
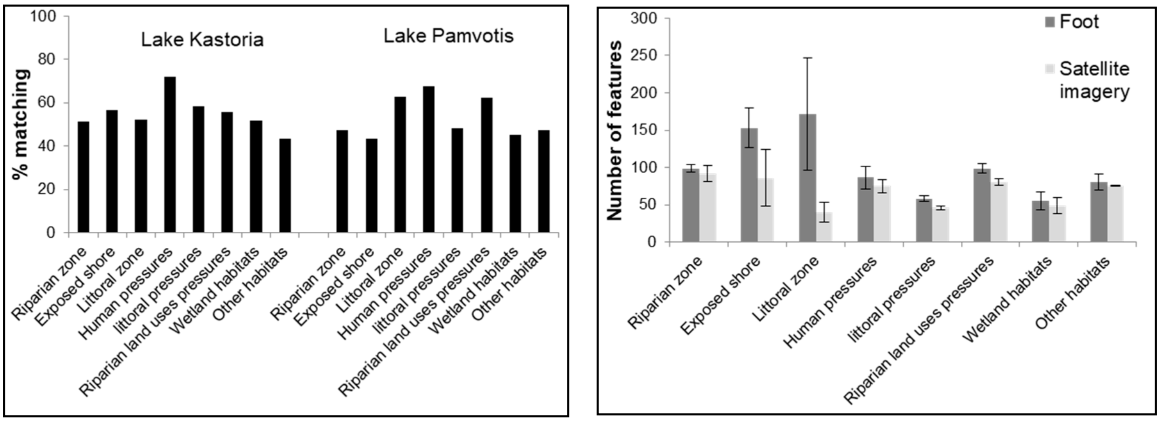


Figure 1. Estimate extent (%) of littoral and riparian (0–15 m and 15–50 m) land uses pressures in each area between HPs from two different approaches (foot-based approach and satellite imagery) in lakes Kastoria and Pamvotis.

Mann-Whitney U test between the two approaches (foot-based approach and satellite imagery) in Lake Kastoria showed that there were differences in the 24% (26 records) of the cases (Table 1).

However, in Lake Pamvotis, the same analysis revealed less (5% of the cases, i.e., 6 records) statistically significant differences than in Lake Kastoria (Table 1). The percentage of matching entries for each section of the LHS survey between foot-based approach and satellite imagery approaches is illustrated in Figure 2.



(**a**) (**b**)

Figure 2. (**a**) The percentage of entries for each section of the LHS survey that were matching between the foot-based approach and satellite imagery approaches in each lake; (**b**) Comparison of the average number of recorded features observed between the two approaches (foot-based approach and satellite imagery) per section.

Table 1. Significant differences between approaches (foot-based approach and satellite imagery) according to Mann-Whitney U test. HP: Habitat Plot, S: Station.

Feature	Lake Kastoria	Lake Pamvotis
Exposed shore	S10: U = 16, $p = 0.036$	S1: U = 8, $p = 0.019$
Littoral zone		S9: U = 21, $p = 0.023$
Human pressures	S2: U = 273, $p = 0.020$	
Littoral pressures	All HPs $p < 0.05$, apart from S2, S4	S2: U = 0, $p = 0.007$
Riparian land use pressures (0–15 m)	S1-S2: U = 0, $p = 0.007$ S10-S1: U = 10.5, $p = 0.013$	
Riparian land use pressures (15–50 m)	All HPs $p < 0.05$, apart from S4-S5, S6-S7, S8-S9 and S9-S10	
Wetland habitats (0–15 m)	S8-S9: U = 1.5, $p = 0.038$	
Wetland habitats (15–50 m)		S7-S8: U = 0, $p = 0.025$
Other habitats (0–15 m)	S2-S3: U = 0, $p = 0.002$; S3-S4: U = 1, $p = 0.005$; S4-S5: U = 2, $p = 0.006$; S5-S6: U = 0, $p = 0.002$	
Other habitats (15–50 m)	S3-S4: U = 4.5, $p = 0.024$; S5-S6: U = 2, $p = 0.004$; S8-S9: U = 6, $p = 0.044$	S2-S3: U = 2, $p = 0.046$; S7-S8: U = 2.5, $p = 0.028$

The matching of these entries ranged from 43.3% to 71.9%, showing a low level of consistency among the approaches (Figure 2a). The lowest matching entries were obtained in Lake Pamvotis in the sections: exposed shore (43.5%), littoral pressures (48.1%), wetland (45%) and other habitats (47.2%). Additionally, high mismatching was noticed in Lake Kastoria in the section other habitats (43.3%). Finally, the recorded features average number per LHS form section, showed that the highest number of features was observed during the foot-based approach (Figure 2b).

3.2. Indices

In both lakes, the LHQA scores were different between the two approaches, foot-based approach (Lake Kastoria: 68 and Lake Pamvotis: 65) and satellite imagery (Lake Kastoria: 47 and Lake Pamvotis: 52) (Table 2). Additionally, a substantial number of different wetland habitats was observed in both lakes. No statistically significant differences were found on calculated indices values among lakes or approaches (U = 0, $p = 0.317$).

Table 2. Scores of Lake Habitat Quality Assessment (LHQA) index for each metric for lakes Kastoria and Pamvotis based on the different approaches (F: foot, SI: satellite imagery).

Zone	LHQA Feature	Lake Kastoria		Lake Pamvotis	
		F	SI	F	SI
Riparian	Vegetation complexity	2	2	3	1
	Vegetation longevity	1	1	1	1
	Vegetation (semi/) natural	2	2	2	2
	Number of natural types	2	3	1	2
	Number of bank top features	3	1	2	2
Shore	Earth/Sand bank	0	1	1	1
	Trash line	1	0	1	0
	Natural bank material	2	1	2	2
	Number of natural types	3	2	3	2
	Natural beach material	2	1	2	2
	Number of natural types	3	1	3	4
Littoral	Coefficient variation *	1		2	
	Natural littoral substrate *	4		4	
	Number of natural types *	4		2	
	Macrophyte cover	3	2	2	1
	Extend lakewards	2	4	2	2
	Macrophyte types	2	1	3	1
	Total fish cover	2	3	2	3
	Number of littoral features	4	1	3	2
Whole lake	Number of wetland habitats	20	20	20	20
	Number of islands	0	0	2	2
	Number if deltaic deposits	1	1	2	2
LHQA Total Score (/112)		**68**	**47 ***	**65**	**52 ***

* Cannot be estimated by satellite imaginary, so the denominator for percentage extraction would be 100.

The LHMS scores were calculated for both lakes between the different approaches, i.e., foot and satellite imagery (Table 3). In both lakes, a relatively significant number of human pressures was recorded, like angling from boat and shore, introduced species, fish stocking and motorboat activities. No statistically significant difference was found on calculated indices values between the approaches (U = 0, $p = 0.317$).

Table 3. Lake Habitat Modification Scores (LHMS) for each metric for lakes Kastoria and Pamvotis based on the different approaches (F: foot and SI: satellite imagery).

Metric	Lake Kastoria		Lake Pamvotis	
	F	SI	F	SI
Shore zone modification	4	4	4	4
Shore zone intensive use	6	6	4	6
In-lake use	8	8	8	8
Hydrology	6	6	6	6
Sediment regime	0	0	0	0
Nuisance species	2	2	2	2
Index Site [1]	4	4	4	4
Catchment [1]	4	4	6	6
LHMS Total Score (/42)	**26**	**26**	**24**	**26**
LHMS Total Score (/54)	**34**	**34**	**34**	**32**

[1] Index Site and Catchment are features proposed by [8], usually excluded in LHMS calculation.

The ALMS index includes a large variety of queries and incorporate much information, so it was assessed using LHS protocol, technical studies, River Basin Management Plans, "citizen science" and expert opinion. Pamvotis was graded with 92 and Kastoria with 76 when the limit for preliminary classification as HMWB is 20.

4. Discussion

The initial application of LHS was to test the two approaches in two urban lakes in Greece and the variations in survey complexity. The survey method was easily applicable, and the already existing literature is enlightening and instructive. Mann-Whitney U test results showed that differences were located mostly on the section of the survey dealing with the wetland and riparian areas between HPs. The average reproducibility among the two approaches was low (43–72%) and the matching of entries indicated that the foot-based approach provides access to more features and details, except for littoral zone when access was blocked.

The LHS method may prove to be an important tool in hydromorphological assessment but had some peculiarities when applied in these two lakes. In general, the indices assessment was easy and fast, but not incorporating many of the features included in the survey form, making the complete LHS method time (and money) consuming. The LHMS index clearly can be applied as a WFD screening tool, for identifying hydromorphological quality elements at close-reference condition lakes and possibly for identifying physical measures for the improvement of lake ecology. The LHQA provides a measure of site naturalness and habitat complexity (which may be associated with biodiversity), and can also have wider applications subsidiary to the LHMS for site management.

Up to now there are not established morphological standards for all EU lakes, while, so far, no tool exists that estimates the minimum percentage of unaltered shores (necessary to support ecosystem functioning) [23]. Thus, this method could be of assistance in this attempt since it "scans" the entire lake perimeter (land use, features, habitats, pressures). Nonetheless, in HMWB—natural lakes, LHS application may produce an error in depicting the extent or the intensity of several features, but this would probably not affect the indices results or the survey itself.

In the two case studies where LHS was tested and in similar urban and suburban Mediterranean lakes, some of the riparian shoreline pressures like commercial activities, plantations and recreational beaches have a particular application [20]. The exclusion of the sedimentation procedure parameter could be suggested given the augmented turbidity of shallow Mediterranean lakes of high trophic status, mostly due to algal biomass increase. Moreover, in "whole-lake assessment", Secchi Depth should not be graded so strictly, adopting thresholds depending on site characteristics. Another suggestion, especially for Mediterranean lakes is the postponement of LHS application after August due to extended warm season and the low water level that leaves the banks uncovered. For this research, the campaign took place at early October, where the beaches still were revealed, and the trees had early autumn characteristics. Furthermore, during the warmer months (June–August) frequent scum occurrence, augmented turbidity and nautical activities take place.

As for the best approach, both had advantages and drawbacks. Extended reedbeds, reaching up to >70 m lakewards hindered the foot-based littoral assessment. As for remote approach, there is a high possibility for some features to be misinterpreted when there is no previous knowledge of the site. Forming materials like peat and earth, or modifications like poaching and trampling are hard to be discriminated. The LHS form was filled faster remotely, however foot-based was deemed as more preferable in terms of proper deployment [10]. However, the urban character of the lakes eased access in the riparian zone and satellite imagery, encompassing geospatial analysis tools gave better distance evaluation and cover measurement results for certain features. Our suggestion for urban lakes would be the in-situ approach to with supplementary satellite imagery use when access in certain lake perimeter parts is obstructed. Furthermore, high-resolution air-photography would assist during preparatory stage [6,10] (pre-LHS application) and in the same time providing also satisfactory assessment results at areas between HPs and 15–50 m perimeter bands [20].

Focusing on the indices results, LHMS index highlighted the degradation of the studied lakes, since the extensively degraded sites usually gain scores of 30 [6]. The LHQA index described the impaired habitat quality in both lakes. The picture was worst using satellite imagery due to inability to assess littoral zone characteristics. Especially in Lake Kastoria, the complexity of this kind of features affects the LHQA, giving less than half scores of the index. Besides ALMS and LHQA graded highly in "whole lake assessments" the water level drop for flood protection, the level control and the existence of artificial channels, special gravity should be given in two features found in both lakes. The first is the seasonality of inflows and the torrent-like character of most inflowing rivers in both lakes, and the second is the singularity of the artificial outflow. The ALMS results describe both lakes as "substantial changed in character", placing them high above the threshold with a high possibility of non-achieving Good Ecological Status, but it is in accordance with their Greek designation as HMWB.

Following the analyses, it seems like LHS can depict lake hydromorphological pressures in these two urban Mediterranean lakes and possibly in other natural Mediterranean lakes. Further investigation is necessary to incorporate modifications in LHQA and LHMS, so as to support management-based decision making to tackle catchment impacts on lakes. Since littoral zone's morphological alterations affect directly both structure and function of lakes' ecosystems, and consequently, hinder the ecosystem services, there is a growing need for reliable and practical tools towards effective management practices. Our study cases, and probably more urban lakes, face frequent conflicts between spatial planning policy (marinas construction, recreation activities, settlements expansion) and environment policy. A well-founded broadly accepted method that allows to quantify Habitat Quality and morphological alterations, aiming at environmental management objectives would be extremely valuable.

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