

Original Research

**INFLUENCE OF LITTORAL HABITAT CHARACTERISTICS ON
MACROINVERTEBRATE COMMUNITIES IN LAKE OHRID**

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Abstract

Lake Ohrid, one of Europe's oldest and deepest freshwater lakes, represents a unique ecosystem with high biodiversity and numerous endemic species. Its littoral zone comprises a variety of habitats - rocky, sandy and mixed substrates - whose physical and biological characteristics play a crucial role in macroinvertebrate communities. Macroinvertebrates are essential components of littoral ecosystems, contributing to nutrient cycling and food web functioning and are widely used as bioindicators of ecological status. This study analyses the influence of habitat characteristics and structural heterogeneity on the composition, density and diversity of macroinvertebrate fauna. Samples were collected across different substrate types and depth zones, and communities were assessed using the Shannon-Wiener diversity index, Simpson's dominance index and Pielou's evenness index, along with complementary ecological indices. Habitat heterogeneity and substrate type were identified as key factors in distribution and community stability. Comparative analysis highlighted local differences: locality Ohrid Bay showed greater ecological stability and endemic species presence, locality River Koselska (Daljan) showed limited diversity and sensitivity to disturbance, while locality HIO-Radozda profile had very good ecological status with sensitive taxa. These findings enhance understanding of habitat-organism interactions in Lake Ohrid and provide valuable data for ecological monitoring, biodiversity conservation and sustainable management of this exceptional lake ecosystem.

Keywords: biodiversity, bioindicators, habitat heterogeneity, ecological monitoring.

INTRODUCTION

Lake Ohrid is characterised by its high biodiversity and a remarkable number of endemic species, making it an important site for scientific research and sustainable resource management [1,2]. Its littoral habitats are highly heterogeneous, including rocky, sandy, habitats with submerged vegetation i.e., macrophytes, and mixed substrates with areas of mud and sand [3,4]. Physical and biological characteristics – such as substrate type, aquatic vegetation, water depth and flow conditions-strongly influence the distribution, abundance

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and composition of macroinvertebrate communities [5–9]. As integral components of the littoral ecosystem, macroinvertebrates contribute to nutrient cycling, organic matter decomposition and food web dynamics [7,10–12], while their sensitivity to habitat changes makes them reliable bioindicators for assessing the ecological status [13,14] of the habitat of interest. Investigating littoral habitat effects on macroinvertebrates in Lake Ohrid enhances understanding of ecosystem processes and provides essential data for monitoring, conservation and sustainable management of this unique lake [1,3,4,9].

MATERIALS AND METHODS

Field research was conducted at three localities around Lake Ohrid in North Macedonia: Ohrid Bay, River Koselska (Daljan) and profile HIO-Radozda (Figure 1). These sites were selected to represent different levels of anthropogenic pressure, substrate heterogeneity and availability of previous data. Ohrid Bay is located near the urban centre and is influenced by wastewater discharge, air pollution, tourism, and shoreline modification. Daljan, in the transitional zone affected by Koselska River, reflects external inputs of sediments and pollutants. Hydrobiological institute Ohrid-Radozda serves as a reference locality with the longest research history at Lake Ohrid, with extensive datasets for long-term ecological assessment.

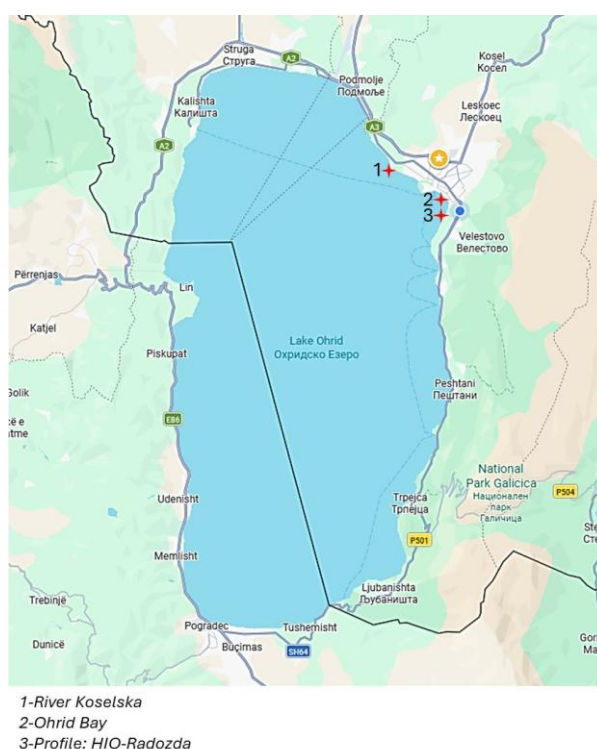


Figure 1 Location of the sampling localities in Ohrid Lake, Republic of North Macedonia

Sampling was carried out seasonally during summer and autumn 2025 using the Multihabitat Transect Method for Benthic Material [15], following limnological protocols [10,11,16–20] and the EU Water Framework Directive [21]. Transects were established from the shoreline towards deeper zones, covering littoral, sublittoral and profundal habitats down to 150 m. At the locations Ohrid Bay and Daljan, three depth levels were sampled

corresponding to the lower limit of macrophyte vegetation. At HIO-Radozda profile, littoral sampling points (2 m, 5 m and 10 m) represented three consistent habitat types: sandy-muddy (sand-dominated), muddy-sandy (mud-dominated) with submerge vegetation and muddy substrate.

Macrozoobenthos samples were collected with a van Veen grab sampler (225 cm², 15 × 15 cm). Samples were preserved in 96% ethanol and transported to the laboratory, where they were analyzed under a binocular stereomicroscope. Identification followed standard freshwater invertebrates taxonomic keys [22–29]. Densities were expressed as the number of individuals per square meter (ind/m²).

RESULTS AND DISCUSSION

A total of 49 macrozoobenthos species belonging to eight taxonomic classes were recorded across the studied localities (Table 1). The highest diversity was observed at HBZ–Radozda (37 taxa), while Pristanishte had 24 taxa and Koselska River (Daljan) only 12.

Table 1 Macrozoobenthos composition at the Ohrid Lake

Class	Taxa (49)	Profile HIO-Radozda (summer 2025)	Ohrid Bay (autumn 2025)	River Koselska (Daljan) (autumn 2025)
Turbellaria	<i>*Dendrocoelum magnum</i> Stankovic 1969	+		
	<i>*Dendrocoelum maculatum</i> (Stankovic & Komarek, 1927)	+		+
Oligochaeta	<i>Limnodrilus hoffmeisteri</i> Claparède, 1862	+		
	<i>Pothamotrix hammoniensis</i> (Michaelsen, 1901)	+		
	<i>Eiseniella tetraedra</i> (Savigny, 1826)	+		
	<i>Tubifex tubifex</i> (Müller, 1774)	+	+	+
	<i>Criodrilus lacuum Hoffmeister, 1845</i>		+	
	<i>*Peloscolex stankovici litoralis</i> (Hrabě, 1931)		+	
	<i>*Rhynchelmis komareki typical</i> Hrabě, 1931		+	+
Hirudinea	<i>Erpobdella octoculata</i> (Linnaeus, 1758)	+	+	+
	<i>Glossiphonia maculosa</i> Sket, 1968	+	+	
	<i>Glossiphonia complanata</i> (Linnaeus, 1758)	+	+	
	<i>Glossiphonia pulchella</i> Sket 1968	+	+	
	<i>*Piscicola geometra</i> Linnaeus, 1761)	+		
	<i>*Dina krilata</i> Sket 1989	+	+	+
	<i>*Dina lepinja</i> Sket & Sapkarev, 1986	+		
	<i>*Dina lychnida</i> (Sket, 1968)	+		
	<i>*Dina profunda</i> Sket 1989	+		
	<i>*Dina svilesta</i> Sket 1989	+		
Gastropoda	<i>*Ginaia munda munda</i> (Sturany, 1894)	+		
	<i>*Xestopyrgula dybowskii</i> Poliński, 1929	+	+	
	<i>Theodoxus fluviatilis dalmaticus</i> (Linnaeus, 1758)	+		
	<i>*Gyraulus lychnidicus</i> Hesse, 1928	+		
	<i>*Gyraulus trapezoids</i> Poliński, 1929	+		
	<i>*Gyraulus albidus</i> Radoman, 1953		+	
	<i>*Chilopyrgula sturanyi</i> Brusina, 1896	+	+	
	<i>*Ancylus tapirulus</i> Poliński, 1929	+		
	<i>*Valvata stenotrema</i> Poliński, 1929		+	+
	<i>*Ochridopyrgula macedonica macedonica</i> (Brusina, 1896)		+	
	<i>*Ochridopyrgula macedonica charensis</i> Radoman, 1978	+	+	
	<i>*Ochridohoratia sturanyi</i> (Westerlund, 1902)		+	
	<i>*Radix relicta</i> Poliński, 1929		+	
	<i>*Pyrgohydrobia grochmalickii</i> (Polinski, 1929)			+
Bivalvia	<i>*Dreissena carinata</i> (Dunker, 1853)	+	+	+
	<i>Sphaerium corneum</i> Linnaeus, 1758	+	+	

Table 1 continued

Amphipoda	* <i>Gammarus ochridensis abyssalis</i> Karaman 1931	+		
	* <i>Gammarus ochridensis</i> (Schäferna, 1926)	+		+
	<i>Gammarus roeselii triacanthus</i> Gervais, 1835	+	+	
	* <i>Gammarus stankokaramani</i> Karaman, 1976	+		
Isopoda	<i>Asellus aquaticus</i> (Linnaeus, 1758)	+	+	
	* <i>Proasellus gjorgjevici</i> f. <i>typicus</i> (Karaman, 1933)	+		+
	* <i>Proasellus remyi</i> f. <i>Nudus</i> (Karaman, 1953)	+		
	* <i>Synurella longidactylus</i> Karaman, 1929	+		
Insecta	<i>Chironomus plumosus</i> (Linnaeus, 1758)	+	+	+
	<i>Sialis lutaria</i> (Linnaeus, 1758)	+		
	<i>Baetis</i> sp. Leach, 1815	+		
	<i>Ischura</i> sp. Charpentier, 1840		+	
	<i>Polypedilum pedestre</i> (Meigen, 1830)		+	
	<i>Leptocerus</i> sp. Brewster, 1815			+
Total number of taxa (49)		37	24	12

*The symbol asterisk denotes endemic species

Endemic species (marked with asterisk: *), particularly among Gastropoda, Amphipoda and Hirudinea, highlight the exceptional biological value of Lake Ohrid. Gastropoda were the most species-rich group (14), followed by Hirudinea (10), Oligochaeta (7), Insecta (6), Amphipoda and Isopoda (4 each), while Turbellaria and Bivalvia were represented by two species each.

At HIO-Radozda, the highest total density was observed at 100 m (5475 ind/m²), dominated by *Tubifex tubifex* (3750 ind/m²). Shallow zones (1–5 m) were characterised by lower densities and a greater contribution of Insecta, while deeper zones were dominated by Oligochaeta, Amphipoda and Isopoda (Table 2). At intermediate depths (10–50 m) increased contributions of *Chironomus plumosus* and *Dreissena carinata* were observed in areas with shell accumulations and silted substrates [13]. Profundal zones were dominated by *Tubifex tubifex* and *Synurella longidactylus*, reflecting adaptation to fine, organically enriched sediments with low oxygen availability.

Table 2 Macrozoobenthos density (ind/m²) by depth and substrate type at the HIO–Radozda profile

Depth (m)	Bottom facies	Turbellaria	Oligochaeta	Hirudinea	Gastropoda	Bivalvia	Amphipoda	Isopoda	Insecta	Total density (ind m ⁻²)	Number of taxa
1	Fine sand with mud and vegetation		100	100			100	0	175	475	5
2	Black sand with mud		275	100			25	0	25	300	5
5	Mud with Chara and ashy shells		50	25	25	375	300		275	0	6
10	Shell zone			75		250			150	1050	4
15	Shell zone	50	425	200	100	450	100	75	475	1875	14
20	Shell zone		125	175	75	500	450	300	75	1700	9

Table 2 continued

30	Sand, mud and shells	225	225	50	850	250	400	175	2175	10
50	Mud	300	150	325		375	1000		2150	8
70-80	Mud with sand	825	25			575	25	25	1475	7
100	Mud	4050	50			1250	125		5475	7
150	Mud	75	25			100	125		325	4

Other species with high densities included *Proasellus gjorgjevici f. typicus* (1000 ind/m²), *Dreissena carinata* (800 ind/m²), *Gammarus ochridensis abyssalis* (775 ind/m²) and *Sphaerium corneum* (500 ind/m²). These results point to a stable, resilient benthic community under favourable hydrological conditions, with clear vertical and substrate-related heterogeneity in sustaining Lake Ohrid's benthic biodiversity.

Figure 2 shows a clear change in the composition and density of the benthic fauna with increasing depth and substrate type at the Ohrid Bay locality. The highest total density was observed at 10 m, where Gastropoda and Amphipoda dominated, indicating favorable conditions in mud with shells and *Chara*. The total lowest density was recorded at 20 m, where the simplified fauna is associated with mud and *Dreissena* shells.

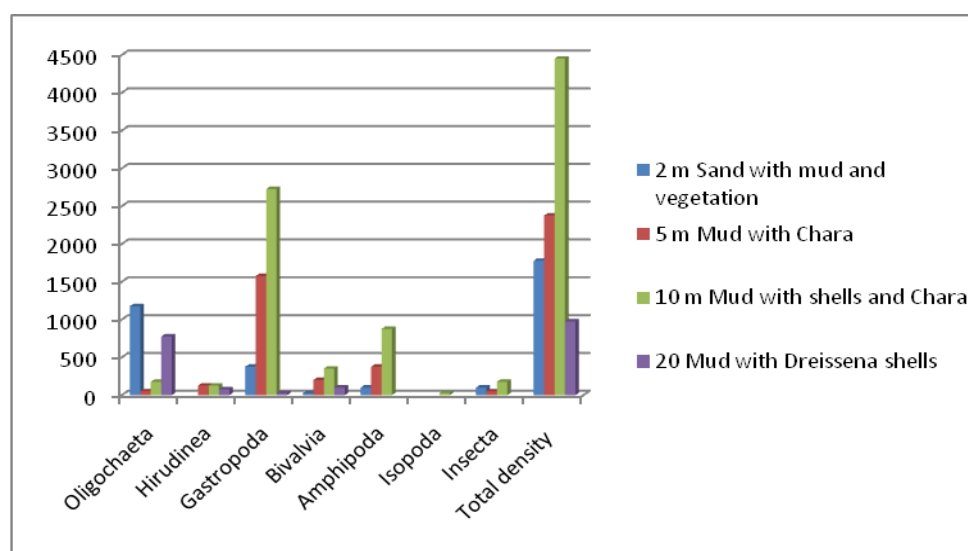


Figure 2 Density (ind/m²) of macrozoobenthos by depth and substrate type at the Ohrid Bay

At Ohrid Bay, 24 taxa were registered (Table 3). The highest species richness and density occurred at 5 m on a muddy bottom with *Chara*, where 14 species were identified. Endemic gastropods such as *Ohridohoratia sturanyi* reached 2325 ind/m² at 10 m depth. The community showed clear vertical zonation with diverse assemblages in shallow zones and reduced diversity at 10 m due to unstable sediments. The highest benthic density was observed at 2 m, where a mixed substrate of sand, mud and submerged vegetation supported diverse taxa, mainly Bivalvia and Gastropoda (Figure 2).

Koselska Reka (Daljan) showed only 12 taxa, shaped by detritus-rich substrates and organic enrichment (Figure 3). At 10 m, benthic fauna were absent, reflecting unfavorable conditions, while at 20 m density increased again, dominated by Oligochaeta and Gastropoda typical of muddy habitats with shells with notable contributions from Bivalvia and

Amphipoda. Diversity was low, with sensitive species absent at depth and tolerant forms dominant. In contrast, Ohrid Bay was more stable, supporting higher diversity due to muddy facies, charophytes and endemic gastropods.

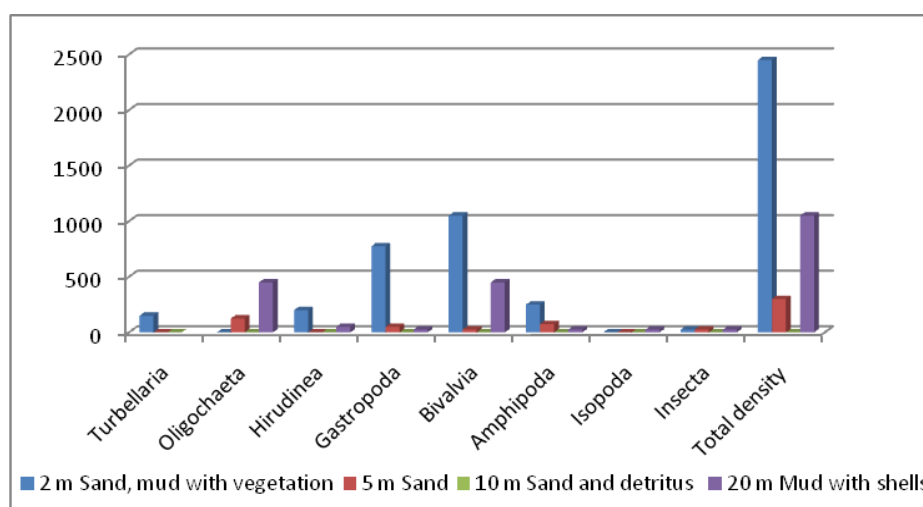


Figure 3 Density (ind/m²) of macrozoobenthos by depth and substrate type in Daljan

Table 3 Ecological status of the localities according to the indices

2025	Spring		Autumn
Indices	HIO-Radozda	Ohrid Bay	River Koselska (Daljan)
N (ind/m ²)	17700	9575	3800
Number of species, S	37	24	12
Shannon & Weaver H	5.18	3.93	3.22
Margalef d	19.07	10.05	5.31
Pielou e	0.82	0.73	0.75
Simpson c	0.06	0.11	0.15
ASPT	7.41	4.2	4.6

* Yellow -medium polluted waters; Green-slightly polluted waters; Blue -clean unpolluted waters.

*ASPT (Average Score Per Taxon) Blue - high ecological status; Yellow -moderate ecological status.

Ecological indices confirmed these patterns (Table 3): HBZ–Radozda showed very good ecological status (ASPT 7.41), Ohrid Bay moderate stability with higher diversity (ASPT 4.2), and River Koselska (Daljan) slightly higher tolerance to enrichment (ASPT 4.6). The study demonstrates high structural and functional diversity of macrozoobenthic communities in Lake Ohrid, with clear vertical zonation and strong dependence on substrate type and macrophyte presence. These findings confirm the lake's biological complexity and ecological stability [1–4,14,30].

The highest diversity was recorded within Hirudinea, with significant contributions from Gastropoda and Amphipoda, indicating diverse microhabitats and favorable conditions for organisms with varying ecological requirements. Similar dominance patterns in littoral and sublittoral zones have been reported previously [10], emphasizing the importance of stable substrates and macrophyte communities for benthic fauna development. In contrast, homogeneous and organically enriched facies, such as muddy bottoms or detritus-dominated sediments, support simplified communities dominated by taxa tolerant to low oxygen concentrations and unstable conditions, such as *Tubifex tubifex*. These findings align with

previous studies indicating that substrate structure and vertical zonation are key factors determining the spatial organisation of macrozoobenthos in deep lakes [12,31,32].

The highest biodiversity was observed within *Chara tomentosa* meadows, underscoring the importance of macrophytes as structural engineers of benthic habitats. Charophytes provide shelter, stabilize substrates, and increase surface complexity, thereby enabling the coexistence of diverse taxa. This observation aligns with previous studies emphasizing the central role of macrophytes in maintaining benthic diversity in oligotrophic and mesotrophic lakes [5,6].

The Ohrid Bay locality demonstrates higher diversity and ecological stability, largely due to the presence of muddy facies and macrophytes, as well as the continuous occurrence of endemic gastropods. River Koselska (Daljan) is characterized by organic enrichment and unstable sediments, resulting in reduced diversity and the absence of sensitive taxa at greater depths. This contrast illustrates how substrate instability and anthropogenic pressures can negatively affect benthic macroinvertebrate communities, leading to simplified assemblages dominated by tolerant species [7–9,33]. In littoral zones, moderate densities and the dominance of Oligochaeta, Hirudinea and Amphipoda, together with a lower abundance of Insecta, are consistent with dynamic hydrological conditions and greater exposure to physical disturbance.

Overall, vertical zonation observed in Lake Ohrid's macrozoobenthos underscores the importance of substrate heterogeneity and macrophyte presence in maintaining ecological stability. The high ASPT values at HIO–Radozda confirm a very good ecological status, while the contrasting conditions at Ohrid Bay and River Koselska emphasize the need for continuous monitoring is essential to safeguard the lake's exceptional biodiversity.

CONCLUSION

This study confirmed littoral habitat heterogeneity on the composition, density and diversity of macrozoobenthic communities in Lake Ohrid. Structurally complex habitats, particularly charophytes meadows, supported the highest biodiversity and ecological stability, while homogeneous and organically enriched substrates sustained simplified communities dominated by tolerant taxa such as *Tubifex tubifex*.

Comparative analysis revealed clear differences among localities: Ohrid Bay maintains stable, diverse communities with endemic species; Koselska River (Daljan) is constrained by organic enrichment and unstable sediments; and HIO–Radozda is characterized by very good ecological status with sensitive taxa. These results highlight the exceptional ecological value of Lake Ohrid and emphasize the need for continuous monitoring and adaptive management to safeguard its biodiversity.

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