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Water mite fauna (Acari: Hydrachnidia) as an indicator of the preliminary assessment of the effects of the remediation of Lake Jeziorko (Poland) using probiotic bacteria

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ABSTRACT

Sustainable restoration of eutrophic lakes remains a vital challenge, with probiotic bioremediation providing a non-invasive alternative to conventional chemical approaches. This study assesses the effectiveness of Effective Microorganisms (EM) technology in restoring Lake Jeziorko (Poland), using water mites (Hydrachnidia) as sensitive bioindicators of habitat change. During the monitoring period lasting a total of 35 months (samples were taken each time in July for three years) across littoral and profundal zones, collecting 9,739 water mite individuals from 38 species. Bathymetric analysis confirmed a decrease in bottom sediment thickness, which probably triggered a clear response in benthic fauna. Although the initial year showed a lake-wide increase in species richness, long-term trends reveal a split: littoral communities declined due to external nutrient inputs and cyanobacterial blooms, while profundal communities (dominated by typical lake taxa such as *Neumania limosa* and *Piona stjordalensis*) remained stable and showed signs of improved sediment oxygenation. These findings indicate that while probiotic bioremediation effectively conditions deep-water habitats and reduces sediment volume, it is not sufficient alone to counter external eutrophication pressures. Additionally, these studies indicate that profundal aquatic mite communities show a clear improvement in profundal conditions, while littoral water mites indicate that the ecological situation did not improve permanently.

KEYWORDS

Lake restoration, bioindicators, Hydrachnidia, probiotic bioremediation, profundal zone, sediment reduction

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INTRODUCTION

The assessment of the ecological condition of standing water bodies is a crucial element of environmental monitoring. Over the years, various methods have been used for this purpose, differing in the scope of analysed organisms, the level of detail, and data interpretation capabilities. In addition to physicochemical indicators, biotic methods are employed, often based on the analysis of benthic macroinvertebrate communities (Poikane *et al.* 2016). An example is the LMI (Lake Macroinvertebrate Index), a metric recommended by the Chief Inspectorate of Environmental Protection (European Commission 2003). It provides a synthetic tool for evaluating the ecological quality of lakes based on the composition of littoral benthic macroinvertebrates and allows comparison of various types of standing water bodies across the European Union (European Commission 2003).

While such methods are useful, because they identify organisms only to the family level, they do not always allow precise habitat quality assessments. Analyses based on broad taxonomic groups limit the ability to detect subtle environmental changes. Therefore, increasing attention is being paid to organism groups with well-understood ecological requirements, particularly those comprising both eurytopic and stenotopic species (Calapez *et al.* 2017; Kownacki and Szarek-Gwiazda 2022; Sadlak and Chrzan 2024). Water mites (Hydrachnidia) fall into this category and have long been used as bioindicators (Biesiadka and Kowalik 1991; Zawal 1996; Goldschmidt 2016) in assessing the ecological quality of lakes and other standing water bodies.

Growing anthropogenic pressure on aquatic ecosystems increases the importance of environmentally friendly restoration methods (Kurzaj 2016). Traditional interventions, such as sediment removal or the use of coagulants, can be costly and invasive, potentially disrupting natural biological processes (Gallardo *et al.* 2008; Svendsen *et al.* 2009; Goldschmidt 2016). An alternative approach is probiotic restoration, which involves the application of bacteria that support natural self-purification processes. This method contributes to the reduction of nutrients, improvement of sediment quality, and mitigation of cyanobacterial blooms (Kurzaj 2016). Evaluating the effectiveness of such interventions requires both physicochemical and biological analyses (Garg *et al.* 2022). Indicator organisms such as water mites are particularly valuable for tracking long-term changes in habitat quality and ecological conditions (Smith *et al.* 2010; Miccoli *et al.* 2013).

It was assumed that the structure of the water mite fauna before and after bioremediation would show significant differences, both in species composition and in the dominance structure of individual synecological groups, reflecting the improved condition of the lake. The most pronounced differences were expected in the deeper zones of the lake.

The aim of this study was to evaluate the effectiveness of the probiotic restoration of Lake Jeziorko. The research focused on analysing the species composition, spatial distribution, and abundance and diversity of water mites. Observations were conducted across different lake zones over a 35-month period following the restoration procedure. The study also aimed to assess spatial differences in faunal responses to bioremediation, particularly between littoral and profundal zones.

MATERIAL AND METHODS

The active agent used in the bioremediation of Lake Jeziorko was the Aquamar Water Purification probiotic, which consists of a complex of microorganisms originally called effective microorganisms (EM). The EM mixture comprises approximately 80 species of microorganisms, including lactic acid bacteria, propionic acid bacteria, photosynthetic bacteria, nitrogen-fixing bacteria, yeasts, and actinomycetes, selected from the natural environment and from bacterial strains used in the dairy and cheese industries. Essentially, these microorganisms stimulate and accelerate the natural processes of organic and mineral matter circulation in the environment. However, the exact mechanism of this action is not fully understood. This probiotic was applied to Lake Jeziorko twice (September 2016 and September 2017), in the form of very fine granules, in a dose of 1000 kg of the preparation (AWP) distributed evenly over the entire, vegetation-free water surface, so as to cover the entire surface of the bottom of the reservoir, translating into a concentration of approximately 110 g of the preparation per 1 m^2 of the lake bottom surface.

A systematic study of 31 physicochemical indicators of the reservoir's water quality was conducted. The following changes were noted: increased water clarity, decreased chlorophyll a concentration, decreased BOD5, decreased COD-Mn and COD-Cr, and increased O2 concentration (Śmietana *et al.* 2018).

To assess the feasibility and effectiveness of restoring Lake Jeziorko (Poland) (Śmietana *et al.* 2018) by using probiotic bacteria, comprehensive studies of the aquatic fauna were carried out, with special emphasis on water mites (Hydrachnidia), which constitute a significant component of aquatic invertebrate communities. The research was conducted systematically and repeatedly over three key time sampling occasions: before the restoration treatment in July 2016; 11 months post-treatment in July 2017; and 23 months post-treatment in July 2018. Each research series lasted two days and was aimed to capture changes in the structure and abundance of organisms.

During each research phase, comprehensive analyses of benthic invertebrate communities were performed, with a clear distinction made between the lake's littoral and profundal zones to allow precise assessments of the treatment's impact on different habitats. The profundal zone is considered to be the depth of 1.5–2.0 m, where the entire bottom is covered with a thick layer of mud, and where, due to the very low transparency of the water (continuous cyanobacterial blooms), sunlight does not reach the bottom. Samples were collected three times (in July every year) from 26 designated monitoring sites, always from the same locations to enable reliable temporal comparisons. In the shallow littoral zone (0.2–0.8 m) samples were taken using a hydrobiological hand net from 11 research sites, from dipper part of littoral zone (0.9–1.3 m) samples were collected using both a dredge and innovative triangular light traps (Zawal 2018) exposed for 24 hours to capture a broad range species that are more difficult to using standard methods from 8 sites (Fig. 1). The samples were covered the full spectrum of available habitat types (helophytes, nympheids, elodeids, sandy bottom, muddy bottom) to ensure the representativeness of the data. In the profundal zone, samples were collected using both a dredge and triangular light traps from 7 sites.

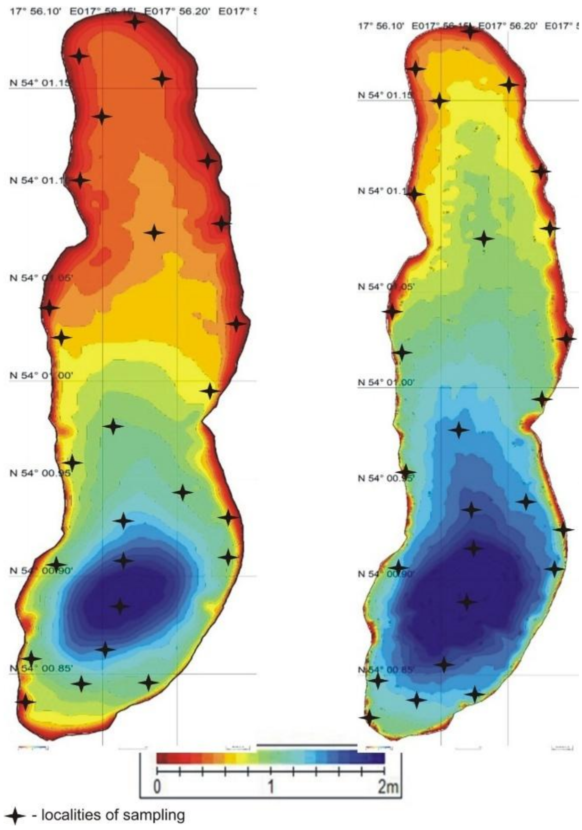

Figure 1. Decrease in sediment thickness and localities of sampling.

RESULTS AND DISCUSSION

Over the three-year monitoring period of Lake Jeziorko (2016–2018), a total of 9,739 water mite individuals (Hydrachnidia), representing 38 species, were collected. The fauna was dominated by a small group of taxa: *Limnesia maculata* (18.8%), *Piona conglobata* (16.3%), *Forelia liliacea* (11.3%), and *Unionicola aculeata* (10.8%), which together accounted for over 57% of the entire community (Table 1). Such high dominance by a few species may indicate limited habitat heterogeneity and a disturbed ecosystem structure (Goldschmidt 2016).

Table 1. Comprehensive summary of the water mite fauna (Hydrachnidia).

Species	2016		2017		2018		Total		ecological status**
	No.	dom.* (%)	No.	dom. (%)	No.	dom. (%)	No.	dom. (%)	
Arrenurus affinis			1	0.02			1	0.01	tyrphophilus species
A. biscissus					1	0.05	1	0.01	lake species
A. bruzelii	2	0.06					2	0.02	small water bodies species
A. crassicaudatus	69	2.15	114	2.56	56	2.69	239	2.45	lake species
A. falciger	41	1.28	12	0.27	3	0.14	56	0.58	tyrphophilus species
A. globator	3	0.09	30	0.67			33	0.34	small water bodies species
A. latus	5	0.16					5	0.05	lake species
A. maculator	1	0.03					1	0.01	small water bodies species
A. perforatus			2	0.04			2	0.02	lake species
A. sinuator	78	2.43	92	2.07	15	0.72	185	1.90	small water bodies species
Arrenurus sp.	17	0.53	5	0.11	7	0.34	29	0.30	
Brachypoda versicolor	75	2.34	140	3.15	62	2.98	277	2.84	lake species
Eylais extendens		0.00	6	0.13			6	0.06	small water bodies species
Forelia liliacea	459	14.30	609	13.70	36	1.73	1104	11.34	lake species
F. variegator					2	0.10	2	0.02	small water bodies species
Hydrachna globosa	7	0.22	39	0.88	28	1.34	74	0.76	small water bodies species
Hydrodroma pilosa	63	1.96	195	4.39	172	8.25	430	4.42	small water bodies species
Hygrobates longipalpis	21	0.65	49	1.10	6	0.29	76	0.78	lake species
Limnesia connata	3	0.09	1	0.02	1	0.05	5	0.05	lake species
L. maculata	636	19.82	817	18.38	378	18.14	1831	18.80	small water bodies species
L. marmorata			23	0.52			23	0.24	small water bodies species
Limnesia sp.	4	0.12	1	0.02	6	0.29	11	0.11	small water bodies species
Limnochares aquatica	3	0.09	5	0.11	2	0.10	10	0.10	tyrphophilus species
Mideopsis orbicularis	85	2.65	53	1.19	17	0.82	155	1.59	lake species
Neumania deltoides	3	0.09		0.00	51	2.45	54	0.55	small water bodies species
N. limosa	165	5.14	53	1.19	52	2.50	270	2.77	lake species
N. vernalis	1	0.03	2	0.04	1	0.05	4	0.04	small water bodies species
Oxus ovalis			1	0.02			1	0.01	lake species
Piona alpicola			23	0.52			23	0.24	tyrphophilus species
P. coccinea	241	7.51	421	9.47	121	5.81	783	8.04	small water bodies species
P. conglobata	146	4.55	941	21.17	499	23.94	1586	16.29	small water bodies species
P. imminuta			4	0.09	6	0.29	10	0.10	lake species
P. neumani	8	0.25			1	0.05	9	0.09	small water bodies species
P. nodata					1	0.05	1	0.01	astatic water species
P. pusilla	2	0.06	29	0.65	2	0.10	33	0.34	lake species
P. rotundoides	44	1.37	5	0.11			49	0.50	small water bodies species
Piona sp.	333	10.38	308	6.93	112	5.37	753	7.73	small water bodies species
Piona stjordalensis	103	3.21	149	3.35	198	9.50	450	4.62	lake species

* dominance; ** after Cichocka (1998).

Table 1. Continued.

Species	2016 No.	2016 dom.* (%)	2017 No.	2017 dom. (%)	2018 No.	2018 dom. (%)	Total No.	Total dom. (%)	ecological status**
Piona stjordalensis	103	3.21	149	3.35	198	9.50	450	4.62	lake species
P. variabilis	62	1.93	33	0.74			95	0.98	small water bodies species
Pionides ensifer			1	0.02			1	0.01	astatic water species
Unionicola aculeata	525	16.36	282	6.34	246	11.80	1053	10.81	lake species
U. figuralis					2	0.10	2	0.02	lake species
larvae	4	0.12					4	0.04	
Total	3209		4446		2084		9739		

* dominance; ** after Cichocka (1998).

The nature of the water mite fauna before and after the application of bacteria showed no clear differences. Some differences emerged in the form of increased overall species richness and abundance in the first-year post-application, which regressed in the following year. In 2016, before bioremediation, 27 species were recorded, and the community was dominated by small-water body species typical of eutrophic, unstable aquatic environments. In 2017, a year after the application of probiotic bacteria, the number of species increased to 30, with a rise in the abundance of lake-typical taxa (e.g., *Piona stjordalensis*, *Brachypoda versicolor*, *Arrenurus crassicaudatus*), suggesting local improvements in sediment quality and oxygen conditions (Zawal 1996; Goldschmidt 2016). However, in 2018, although the number of species returned to 27, a decrease in total abundance and the appearance of species characteristic of astatic waters (e.g., *Piona nodata*) was observed, possibly indicating increasing habitat instability due to eutrophication (the parameters: water clarity, chlorophyll a concentration, BOD5, COD-Mn and COD-Cr, and O2 concentration; after improvement in 2017, returned to close to the original values as in 2016 (Śmietana *et al.* 2018) and cyanobacterial blooms (Biesiadka and Kowalik 1991). The 2018 drop in abundance mainly affected mites in the shallow littoral, probably coinciding with increased nutrient inflow from nearby agriculture farm and intense cyanobacterial blooms during a hot, sunny summer. These blooms likely caused diurnal oxygen fluctuations and localized pH increases, adversely affecting littoral water mite populations. Consequently, lake species associated with shallow littoral habitats declined, while those in deeper zones remained stable or increased. Species such as *Neumania limosa*, *Unionicola aculeata*, and *Piona stjordalensis* increased in deeper areas, benefiting from more stable oxygen and pH conditions. Despite the overall drop in abundance, the percentage share of lake species remained stable. Small-water body species showed a slight decline in 2017, stabilizing in 2018 (Figs 2–4).

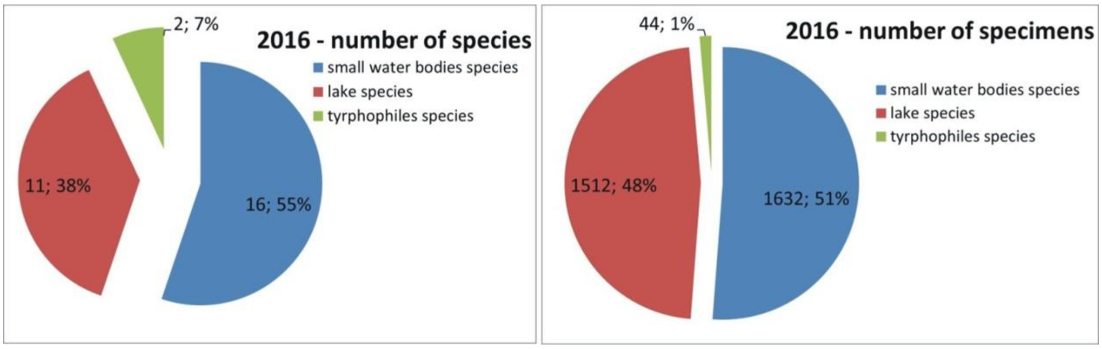

Figure 2. Share of various synecological groups of water mites in Lake Jeziorko in 2016.

Analysis of the vertical distribution of water mites showed a slight decrease in species and individuals at depths of 1.3–2 m and a significant increase at 1.2 m in the first-year post-application. In the second year, there was a marked increase at 0.5 m and a modest rise in species and individual counts at 1–2 m (Fig. 5).

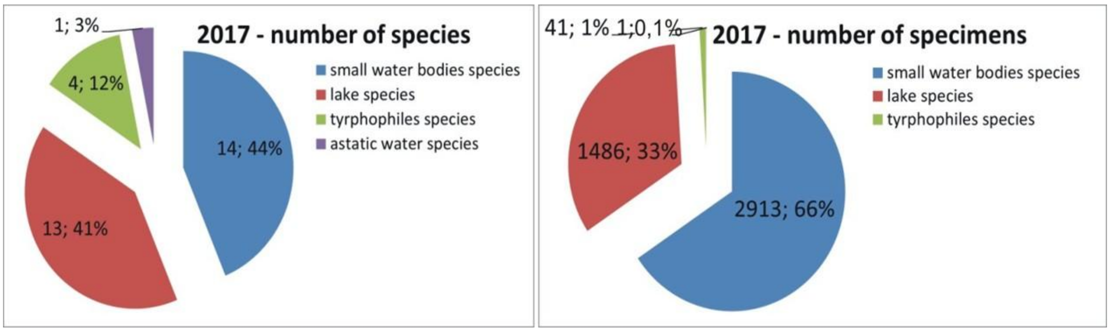

Figure 3. Share of various synecological groups of water mites in Lake Jeziorko in 2017.

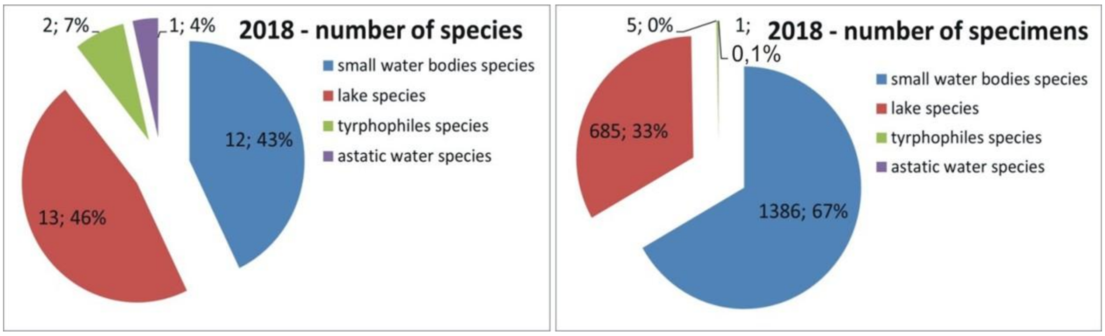

Figure 4. Share of various synecological groups of water mites in Lake Jeziorko in 2018.

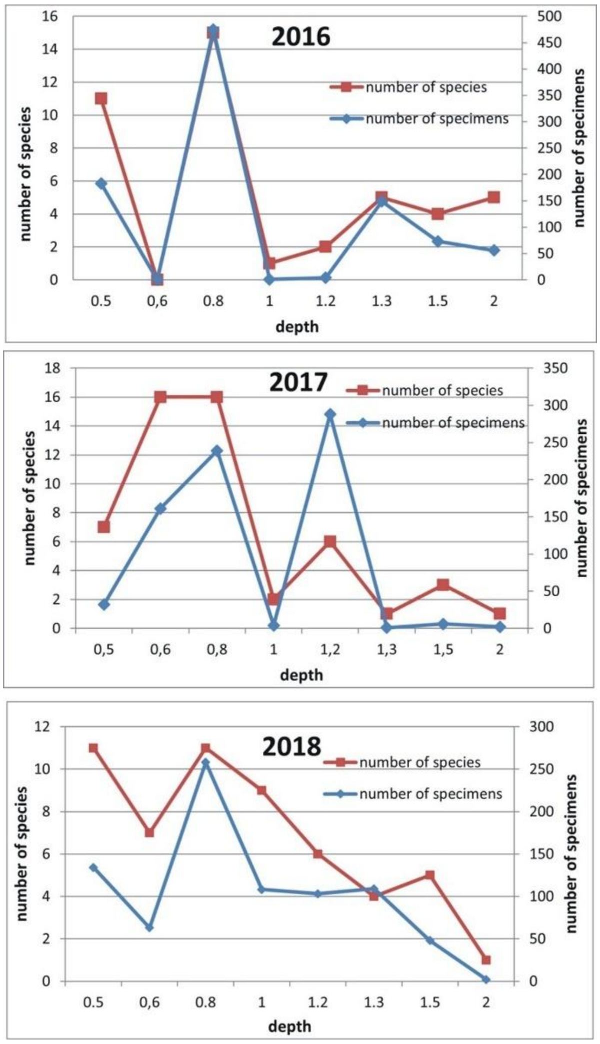

Figure 5. Vertical distribution of water mites (Hydrachnidia) in Lake Jeziorko before bacterial application (2016), 11 months (2017), and 35 months (2018) after application.

The distribution of water mites along the profile of lakes has been studied many times, and in addition to the analysis of the number of water mites at different depths (Viets 1930, 1931; Biesiadka 1972, 2003), the influence of such parameters as habitat type (Pieczyński 1964; Kowalik 1977, 1984; Davids *et al.* 1994), food availability (Davids *et al.* 1994) and physical and chemical parameters of water (Kowalik 1984; Bagge 1989; Rieradevall and Gil 1993) was also studied.

The minor scale of differences makes definitive conclusions difficult. However, the observed increases in species abundance and richness in the first year, particularly among lake species linked to sandy bottoms (psammophilous – associated with a sandy bottom) (Svendsen *et al.* 2009), may indicate improved oxygen conditions.

CONCLUSION

The study demonstrated that probiotic bioremediation in Lake Jeziorko contributed to localized ecological improvements, particularly in deeper zones. The most significant effects were observed in the first year after treatment, with increased species diversity and a higher proportion of the lake taxa. These changes suggest improved oxygen conditions and sediment quality, affirming the initial effectiveness of bioremediation. Although the positive trend was not sustained lake-wide in 2018—with some regression in the littoral zone due to cyanobacterial blooms—the deeper-zone fauna remained stable and resistant to adverse changes. The lake species such as *Neumania limosa*, *Unionicola aculeata*, and *Piona stjordalensis* maintained their populations, indicating lasting habitat improvement potential.

The findings confirm that microbiological bioremediation alone is insufficient to counteract excessive nutrient input and eutrophication effects. However, it can support restoration efforts, especially as part of a broader ecosystem recovery program. The results emphasize the need for ongoing monitoring and nutrient input reduction. Combining bioremediation with such measures may ensure lasting water quality improvements.

The study confirmed the high bioindicative value of aquatic mites, especially those inhabiting the deeper zones of lakes, which proved to be more stable and reliable in assessing ecological quality. Because the littoral zone is characterized by greater changes than deeper water zones, littoral species are characterized by greater euthyropicity and therefore do not respond as clearly to environmental changes. Deep-water species better reflected the actual state of the ecosystem and the effects of reclamation activities, being less susceptible to short-term environmental fluctuations that strongly affect littoral fauna. Therefore, analyzing deep-zone water mite communities should be a standard element of lake ecological monitoring, especially for water bodies undergoing bioremediation or other restoration interventions.

The restoration model combining bioremediation with water mite-based bioindication can be successfully applied to other lakes with similar morphometric features, sediment characteristics, and trophic levels. The study results underscore the importance of spatial and bathymetric differentiated analysis in evaluating restoration effectiveness. Differences in the response of littoral and profundal fauna highlight the need to consider vertical environmental gradients and hydromorphological features of lakes when planning conservation and restoration measures.

Lake restoration should adopt an interdisciplinary approach, integrating biological, chemical, and hydrotechnical methods. It is also crucial to address the entire catchment system through reducing anthropogenic pressures and implementing preventive measures to curb nutrient and pollution inflows. Only then can lasting improvements in water quality and the stabilization of lake ecosystems be achieved.

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زیاگان هرناهای آبزی (Acari: Hydrachnidia) به عنوان شاخصی برای ارزیابی مقدماتی اثرات اصلاح دریاچهٔ جزیورکو (لهستان) با استفاده از باکتری‌های پروبیوتیک

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چکیده

احیای پایدار دریاچه‌های غنی از مواد مغذی همچنان چالشی حیاتی است و زیست‌پالایی پروبیوتیکی جایگزینی غیرتهاجمی برای رویکردهای شیمیایی مرسوم ارایه می‌دهد. این مطالعه اثربخشی فناوری میکروارگانیسم‌های مؤثر (EM) را در احیای دریاچه جزیورکو (لهستان) با استفاده از هرناهای آبزی (Hydrachnidia) به عنوان شاخص‌های زیستی حساس تغییر زیستگاه ارزیابی می‌کند. در طول دوره نظارت که در مجموع ۳۵ ماه طول کشید (نمونه‌ها هر بار در ماه ژوئیه به مدت سه سال گرفته شد) در مناطق ساحلی و عمیق، ۹۷۳۹ هرنای آبزی از ۳۸ گونه جمع‌آوری شد. تجزیه و تحلیل ژرفاسنجی، کاهش ضخامت رسوبات کف را تأیید کرد که به احتمال باعث واکنش واضحی در جانوران کف‌زی شد. اگرچه سال نخست افزایش غنای گونه‌ای در سراسر دریاچه را نشان داد، روندهای بلندمدت نشان‌دهنده یک شکاف است: جوامع ساحلی به دلیل ورودی‌های مواد مغذی خارجی و شکوفایی سیانوباکتری‌ها کاهش یافتند، در حالی که جوامع عمیق (که تحت سلطهٔ گونه‌های معمول دریاچه مانند *Neumania limosa* و *Piona stjordalensis* بودند) پایدار ماندند و نشانه‌هایی از بهبود اکسیژن‌رسانی رسوبات را نشان دادند. این یافته‌ها نشان می‌دهد که اگرچه زیست‌پالایی پروبیوتیکی به طور مؤثر زیستگاه‌های آب‌های عمیق را بهبود می‌بخشد و حجم رسوبات را کاهش می‌دهد، اما به تنهایی برای مقابله با فشارهای خارجی ناشی از تغذیه‌گرایی کافی نیست. افزون بر این، این مطالعات نشان می‌دهد که جوامع کنه‌های آبزی عمیق، بهبود آشکاری را در شرایط عمیق نشان می‌دهند، در حالی که کنه‌های آب‌های ساحلی نشان می‌دهند که وضعیت اکولوژیکی به طور دایم بهبود نیافته است.

واژگان کلیدی: احیای دریاچه، شاخص‌های زیستی، Hydrachnidia، زیست‌پالایی پروبیوتیکی، منطقهٔ عمیق، کاهش رسوبات

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