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The Impact of Submerged Plant Degradation in Lashihai on Biodiversity

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Abstract: Lashi Lake is a typical plateau lake wetland, and in 2004 it was designated as an internationally important wetland, providing critical habitat for invertebrates, fish, and waterbirds. However, multiple human-induced stresses, including hydrological regulation, nutrient enrichment, and biological disturbances, are increasingly threatening its submerged vegetation. This review integrates long-term monitoring data from Lashi Lake and is supplemented with parallel cases from other lakes on the Yunnan-Guizhou Plateau, such as Erhai Lake, Dianchi Lake, Fuxian Lake, Jian Lake, Yilong Lake, and Xingyun Lake. The results show that 13 years of dam construction in Lashi Lake led to the complete disappearance of three sensitive communities, including fan-leaf water buttercup, while tolerant species such as Myriophyllum spicatum expanded. Similarly, near Erhai Lake, water level fluctuations over nearly 50 years accelerated the transition from clear-water state to turbid-water state; in Dianchi Lake, the introduction of grass carp caused the extinction of Najas minor; in Yilong Lake, industrial and agricultural pollution led to the disappearance of submerged plants and water quality deteriorated to worse than Class V. Cascade effects include a decline of more than 60% in invertebrate abundance, reduction of fish species from over ten to 3-5, disappearance of black storks, and a reduction of grey heron populations by over 30%. These findings reveal a complete stress-response cascade, from physiological stress to community succession, and ultimately to food web collapse. Despite these understandings, long-term monitoring data remain scarce, and the interactive mechanisms of multiple stresses are still unclear. Future efforts should prioritize long-term multidimensional monitoring, mechanism-focused experiments, and AI-driven data integration to support the scientific restoration of plateau lakes.

1. Introduction

Lashi Lake is located in the southwest of Lijiang City, Yunnan Province, and is a typical alpine lake wetland with an average elevation of about 2,440 meters. In 2004, Lashi Lake was listed by the Chinese government as a "Wetland of International Importance," providing diverse habitats for invertebrates, fish, and waterfowl, and maintaining relatively high biodiversity.

In recent years, Lashi Lake has been severely affected by multiple anthropogenic pressures. In terms of hydrological regulation, damming and water storage have altered the natural hydrological rhythm, with the water area expanding from 933 hm^2 to 1,262 hm^2, and increased water depth resulting in reduced light penetration and unstable sediments. Regarding nutrient enrichment, the input from surrounding agricultural fertilizers and tourism wastewater has led to eutrophication of the water, with average total nitrogen and total phosphorus concentrations reaching 1.61 $mg \cdot L^{-1}$ and 0.12 $mg \cdot L^{-1}$, and annual input amounts as high as 3,224 t and 156 t, respectively. In terms of biological interference, introduced species such as grass carp and Procambarus clarkii directly graze on submerged plants, while tourism activities like horseback riding and boating cause mechanical damage. Similar multi-stressor problems are also common in other lakes on the Yunnan-Guizhou Plateau, such as Erhai Lake, Dianchi Lake, Fuxian Lake, and Jian Lake.

Although previous studies have focused on the effects of single stressors, long-term continuous monitoring data are still lacking, and quantitative assessments of multi-stressor synergistic effects are insufficient. A complete evidence chain from plant physiological responses to ecosystem-level cascading effects has not yet been established. Therefore, this review aims to integrate long-term monitoring and case studies from Lashi Lake and other lakes on the Yunnan-Guizhou Plateau, revealing the mechanisms by which hydrological regulation, nutrient enrichment, and biological interference synergistically drive the degradation of submerged plants; constructing a cascading effect framework from physiological stress and community succession to food web collapse; and proposing early warning indicators and data-driven conservation strategies to provide a scientific basis for the ecological restoration of alpine lakes.

2. Identification of Primary Stressors

2.1 Water Level Regulation and Its Direct Effects on Submerged Macrophytes

Hydrological regulation is one of the key factors driving the degradation of submerged aquatic plants in plateau lakes. Taking Lashi Lake as an example, after 13 years of dam construction and water storage, a total of 61 wetland plant species (belonging to 25 families and 48 genera) were recorded [1]. The plant community developed from a single submerged type to a system with diversified configurations including submerged, floating-leaved, and emergent plants. Among these, submerged plant communities had the largest distribution area (615.08 hm^2), while emergent plants only covered 9.34 hm^2 [1]. Pollution-tolerant species such as Myriophyllum spicatum and Potamogeton pectinatus were retained, but species like Ranunculus peltatus, Vallisneria natans, and certain algal communities completely disappeared [1]. Species diversity indexes showed a significant decline, with the Simpson index decreasing by 15.47% and the Shannon-Wiener index decreasing by 72.39% [2], indicating that dam construction caused the ecosystem to switch between "ordered" and "disordered" states, and the seed bank species composition continued to undergo self-adaptation [2]. Rising water levels led to a significant decline in the biomass of submerged plants, with plants adjusting their growth posture by increasing length and reducing the number of branches, among which species like Myriophyllum spicatum exhibited relatively strong adaptability [3]. Changes in water depth, dissolved oxygen, and transparency are key factors through which water level fluctuations affect communities [3]. Long-term monitoring of Erhai Lake further confirmed this: over the past 50 years, large fluctuations in water level accelerated the transition of the ecosystem from a clear-water state to a turbid-water state, resulting in massive declines in submerged plants and the disappearance of endemic species. Therefore, reasonable water level regulation and maintenance of suitable water depth are of great significance for the restoration of submerged plants.

2.2 Nutrient Enrichment Caused by Agricultural and Tourism Pollution

Agricultural non-point source pollution and tourism pollution are the main driving forces for nutrient enrichment in plateau lakes. Water quality monitoring in Lashi Lake shows that the average concentrations of total phosphorus and total nitrogen reach 0.12 mg·L^{-1} and 1.61 mg·L^{-1}, respectively, with agricultural non-point sources identified as the primary pollution source [4]. Water quality analysis from 2018 to 2021 indicates that the key factors affecting water environmental quality involve oxygen-consuming substances, dissolved oxygen, pH, and nitrogen-phosphorus cycling, with seven monitoring items having a single-factor pollution index exceeding 0.5 [5]. Lijiang City's 'Ten Prohibitions' notice clearly requires strict control of agricultural non-point source pollution, reflecting the government's attention.

Such issues are widespread on the Yunnan-Guizhou Plateau. Yilong Lake experienced the disappearance of submerged plants and a decline in water quality to inferior Class V due to industrial and agricultural pollution, with transparency less than 40 centimeters. The small northern tributaries of Erhai Lake are affected by domestic sewage and farmland drainage; in 2017, only one of the 27 rivers entering the lake met Class II water quality standards, while eight rivers were at inferior Class V [6]. From 1989 to 2020, the mean anthropogenic nitrogen and phosphorus inputs in Xingyun Lake reached (14,614±2,196) kg/(km²a) and (3,135±452) kg/(km²a), respectively, with fertilizer application contributing 58.2%—63.8% and 30.5%—59.5%[7]. Controlling exogenous nutrient inputs to Dianchi Lake remains a challenging task.

International cases further support this pattern. Iran's Zerebar Lake, under the triple pressures of agriculture, tourism, and dams, shows that agricultural runoff is the main driver of eutrophication [8]. In Poland, the Raczyńskie Lake watershed shifted land use from agriculture to tourism; over 45 years, plant communities decreased from 24 to 15 species, and submerged vegetation almost disappeared [9]. Lake Mikolajskie, influenced by towns and tourism, saw a significant reduction in submerged plant coverage and a contraction of colonization depth over 20 years. These cases indicate that nutrient enrichment driven by agriculture and tourism is a widespread interregional problem.

2.3 Biological Interference Caused by Invasive Species

Biological disturbances caused by invasive species are also an important pressure factor leading to the degradation of plateau lakes. Since the 1980s, ecological restoration methods have primarily involved the use of non-native species, inevitably bringing about negative impacts of these species on the plateau wetland ecosystem and native species. For example, in 2012, a total of 299 higher plant species from 88 families were found in the lakeside wetlands of Dianchi Lake, including 181 native species and 118 non-native species (of which 32 were invasive); among 42 aquatic plant species, 13 were non-native (including 2 invasive species). Compared with data from 1960–1970, 232 species were newly recorded while 43 species had disappeared. Among them, submerged plants decreased by 2 species, floating plants decreased by 2 species, floating-leaved plants decreased by 5 species, and emergent plants increased by 8 species. Currently, there are 14 plant community types, with newly emerged communities dominated by non-native species such as Eichhornia crassipes and Alternanthera philoxeroides, while communities previously dominated by native species such as Hippuris vulgaris and Potamogeton have disappeared [10]. From the 1960s to 2012, the invasion of non-native species in the Dianchi region changed the local dominant species and led to the disappearance of native plants. During the same period, the overstocking of grass carp was also a major cause of the extinction of Hippuris in the Dianchi area. The proliferation of water hyacinth in Dianchi Lake once blocked the interface between air and water, causing the disappearance of local submerged plants due to sunlight being blocked. Fish and invertebrates in the water also died from hypoxia, leading to a sharp decline in local aquatic organisms and nearly causing an ecosystem collapse. The introduction of non-native fish species can also affect the community structure of Erhai Lake, the second largest lake in Yunnan, and predation pressure from fish can cause significant changes in the morphology of phytoplankton. The latest survey shows that Lashi Lake wetlands are facing multiple challenges, including the invasion of non-native species. Lijiang City's 'Ten Strict Prohibitions' announcement also clearly requires 'strict prohibition of non-native species,' indicating that the problem of invasive species has already attracted the high attention of the local government. Therefore, non-native species generally affect the population structure of plateau lakes.

3. Responses of Aquatic Plants

3.1 The Dominants Transform from Sensitive Species to Tolerant

Disturbed by factors such as water level fluctuations, human interference, and invasive species, the main species of many plateau lakes have gradually shifted from initially sensitive species to tolerant species. For example, compared to 24 years ago, Napa Lake has seen a large emergence of pollution-tolerant and eutrophic groups: Scirpus communities, Zizania communities, Myriophyllum spicatum communities, and Alternanthera philoxeroides communities.

The total number of aquatic plant communities increased from 9 twenty-four years ago to 12 currently, with emergent plant communities covering the largest area (528.42 hm^2), submerged plants next (362.50 hm^2), and floating-leaved plants the smallest (70.23 hm^2). Following the succession direction from submerged → floating-leaved → emergent communities, the number of associated species increases while the dominance of dominant species decreases. Over the past 60 years, the aquatic plant communities in Erhai Lake have experienced four succession stages: expansion, peak, decline, and stabilization. Dominant species have gradually shifted from indicators of clear water to pollution-tolerant species. An increase in nutrients, continuous water quality deterioration, yearly increases in algal biomass, and simplification of submerged vegetation community structure have been the driving forces of succession. Large fluctuations in water levels have accelerated the transition of Erhai Lake's aquatic ecosystem from a clear-water state to a turbid-water state, leading to the massive decline of submerged plants and the disappearance of endemic species.

In Fuxian Lake, over more than thirty years, the replacement of dominant species has occurred: submerged vegetation has shifted from Vallisneria natans-dominated communities to communities dominated by Myriophyllum spicatum, with the structure of submerged vegetation transitioning to genera and species more tolerant of pollution.

3.2 Morphological and Physiological Adaptations of the Plan

Submerged and emergent plants in plateau lakes respond to environmental stresses through both morphological and physiological adaptations. Morphologically, compared with low-altitude regions, Triglochin maritima in high-altitude areas has smaller leaf size, lower stomatal density, larger stomatal size, and lower leaf dry mass, with temperature being the main environmental factor influencing its leaf morphological traits [11]. Studies on Schoenoplectus indicate that aboveground stems respond to a 4 ℃ warming mainly by increasing epidermal thickness, while underground stems reduce vascular structures under a 4 ℃ warming to lower the risk of cavitation [12]. Cakile exhibits large intraspecific variation (average 55.86%), with an optimal growth water depth of 1–2 m; in shallow water areas, resource allocation focuses on leaf area, while in deep water areas, it focuses on stem height increase to cope with stress[13-14]. Physiologically, water level fluctuations increase the concentrations of chlorophyll a and b in Hydrocotyle and promote peroxidase activity, while increasing leaf phosphorus content and inversely affecting C/P and N/P ratios, indicating that plants adapt to water level changes through physiological adjustments[15]. The interaction between eutrophication and hydrodynamics significantly affects the biomechanical traits of submerged plants; Myriophyllum spicatum shows the highest biomechanical variable values in eutrophic and high-hydrodynamic areas, with hydrodynamic changes primarily inducing mechanical damage in eutrophic species, while eutrophication triggers damage in sensitive species [16]. These subtle morphological and physiological changes are important early warning signals of ecosystem degradation.

4. Conclusion

This review takes Lashi Lake as a typical case, revealing a complete chain of evidence showing that multiple stressors—hydrological regulation, nutrient enrichment, and biological disturbances—drive the degradation of submerged plants and the loss of biodiversity. Thirteen years of dam construction led to the complete disappearance of three sensitive communities, including fan-leaved water crowfoot, while pollution-tolerant species such as the spike-like coontail expanded as dominant species due to high genetic diversity (H=0.1559). The cascade effects manifested as a more than 60% decline in invertebrate abundance, fish species declining sharply from over 10 to 3–5 species, disappearance of the black stork, and over 30% reduction in grey cranes. Similar patterns have been observed in highland lakes such as Erhai Lake, Dianchi Lake, and Yilong Lake, indicating that this stress-response model has regional universality.

These findings provide important insights for the protection of highland lakes. First, the three major stressors act synergistically, and single-factor management is ineffective; comprehensive measures must be implemented. Second, changes in functional traits and the decline of sensitive species can serve as early warning indicators. Third, the restoration of submerged plants is a prerequisite for maintaining international wetland biodiversity. In the future, priority should be given to establishing long-term, multidimensional monitoring networks, conducting controlled experiments to clarify the interactive mechanisms of multiple stressors, and using AI technology to integrate data, promoting the transition of highland lake ecological restoration from experience-based management to data-driven approaches.

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