'Flower–Fish–Snails and Mussels–Birds' : A Novel Ecological Restoration Pathway for Beautiful Plateau Lake Wetlands and Its Application (Post-Print)

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Date: 2024-03-27T00:00:00+00:00

Abstract

Under the combined influence of human activities, climate change, and other factors, Yunnan plateau lake wetlands are facing varying degrees of water level decline, surface area reduction, and water quality pollution, with severe loss of native aquatic biodiversity and many native species becoming endangered or even extinct. Ecological restoration approaches implemented since the 1980s have predominantly utilized exotic species, inevitably introducing negative impacts of exotic species on plateau wetland ecosystems and native species. To address these issues, with support from relevant projects, this article proposes a new ecological restoration pathway based primarily on native flagship species–the "flower-fish-snail/mussel-bird" approach–and conducted experimental demonstrations in Dianchi Lake and Erhai Lake. Results demonstrate that this new ecological restoration pathway reconstructs the missing links in the energy flow chain of degraded lake wetland ecosystems, enhances overall ecosystem functionality, and enables eutrophication substances such as nitrogen and phosphorus in the water column to successfully leave the aquatic environment and reach land along two pathways: "algae-fish-bird (or human)" and "flower-fish-bird (or human)" . In the experimental areas, traditional precious Yunnan food ingredients such as Ottelia acuminata and golden-line fish were also harvested; the white-petaled, yellow-stamened Ottelia acuminata densely floating on the water surface forms a beautiful landscape characteristic of Yunnan plateau lake wetlands. Based on the experimental demonstration work in Dianchi Lake and Erhai Lake, and combined with the biodiversity characteristics and current status of various plateau lake wetlands in Yunnan, ecological restoration and management measures targeting different categories of wetland ecological conditions were proposed.

Full Text

An Innovative Restoration Mode "Macrophytes-Fishes-Benthons-Birds" Implemented in Aesthetic Plateau Wetlands

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Abstract

Affected by the combined impacts of human activities and climate change, Yunnan plateau lakes and wetlands face varying degrees of water level decline, surface area reduction, and water quality deterioration, with severe loss of indigenous aquatic biodiversity and many native species now endangered or extinct. Since the 1980s, ecological restoration efforts have predominantly employed alien species, inevitably introducing negative impacts on plateau wetland ecosystems and indigenous species. To address these challenges, supported by relevant projects, this study proposes an innovative restoration approach centered on indigenous flagship species—the "macrophytes-fishes-benthons-birds" model—and demonstrates its application in Dianchi and Erhai lakes. Results show that this new restoration pathway reconstructs missing links in the energy flow chains of degraded lake wetland ecosystems and improves overall ecosystem functionality, enabling nitrogen, phosphorus, and other eutrophic substances to leave the water along two routes: "algae-fish-bird (or human)" and "macrophytes-fish-bird (or human)." The demonstration areas also yielded traditional premium food ingredients such as *Ottelia* (macrophyte flowers) and golden-line fish, while the white-petaled, yellow-stamened *Ottelia* flowers densely floating on the water surface created a distinctive aesthetic landscape unique to Yunnan plateau lakes and wetlands. Based on the successful demonstrations in Dianchi and Erhai, and considering the biodiversity characteristics and current status of various plateau lake wetlands in Yunnan, this paper proposes targeted ecological restoration and management measures for different categories of wetland ecological conditions.

Keywords: plateau lakes and wetlands, indigenous flagship species, innovative restoration modes, "macrophytes-fishes-benthons-birds"

1. Major Challenges Facing Yunnan Plateau Lake Wetland Ecosystems

Yunnan, located at the eastern flank of the collision zone between the Indian subcontinent and Eurasian plates, possesses complex and diverse natural environments that have nurtured rich biodiversity. The province' s higher plants and vertebrate species account for 46.8% and 55.35% of China' s total, respectively, earning it the reputation as the "Kingdom of Flora and Fauna" [3]. Yunnan' s wetlands encompass 4 categories and 14 types, including rivers, lakes, and marshes, covering an area of 5,636 km^2 (1.05% of China' s total wetland area), with lake wetlands comprising 1,185 km^2 (21.03% of Yunnan' s wetland area) [4,5]. However, intensifying human activities and climate change have subjected Yunnan plateau lakes to varying degrees of impact, broadly categorized into two types: lakes with relatively good water quality but significantly declining indigenous fish species numbers and populations (e.g., Lugu Lake and Fuxian Lake), and lakes with deteriorating water quality reaching Class V or inferior Class V, where many indigenous fish species are endangered or completely disappeared from the lake (e.g., Dianchi, Xingyun Lake, and Qilu Lake).

1.1 Declining Trends in Lake Wetland Environment and Biodiversity

Yunnan' s first wetland resource survey in 2002 recorded 124 bird species, 432 fish species, 118 amphibian species, and 236 reptile species [6]. The second survey in 2012 documented 162 bird species, 587 fish species, 127 amphibian species, 94 reptile species, and 36 mammal species, including 237 Yunnan endemics (207 fish species) [7]. While this apparent biodiversity increase reflects improved survey depth and methodology, the situation for specific lakes remains alarming. Dianchi Lake, the largest inland lake on the Yungui Plateau located in Kunming, exemplifies these challenges. Before 1957, Dianchi harbored 23 fish species, including 12 endemics [8]. From 1958 onward, 36 introduced fish species dramatically altered the fish community composition. Since the 1960s, indigenous fish species declined from 26 to only 11, with just four species—silver whitefish, crucian carp, loach, and ricefield eel—now surviving in the lake [9].

Zooplankton communities have also shifted dramatically. Before 1960, protozoans dominated Dianchi' s zooplankton. By 1978, 61 protozoan species were recorded [10], and by 1985, total zooplankton reached 171 species (62 protozoans, 52 rotifers, 35 cladocerans, 22 copepods, and 6 other microfauna) [11]. However, dominant species shifted from clean-water to pollution-tolerant taxa. Phytoplankton showed similar patterns: 186 species were recorded before 1960, with charophytes as dominants; by 1985, species increased to 205 but were dominated by chlorophytes, while charophytes disappeared [12]; by 2019, some clean-water species reappeared locally, but overall species composition had deteriorated. Macroinvertebrates declined from 123 recorded species to only six by the late 1970s, with sensitive species like cnidarians, sponges, and the snail *Semisulcospira cancellata* going extinct [1]. By the 1980s, pollution-tolerant chironomid larvae and oligochaetes dominated, a pattern persisting through 2020–2021, while native species like *Margarya* snails and *Anodonta woodiana* became rare.

Aquatic vegetation coverage plummeted from 90% in the 1960s to 12.6% in the 1980s and only 1.4% after 2000. Species richness declined linearly from 44 species in 1957 to 30 in 1977 and 22 in 1997 [1,13]. Water quality deteriorated from Class I in the 1950s to Class III-IV in the 1970s, and to Class IV-inferior Class V by the 1990s. Although management efforts improved quality to Class V by 2016 and Class IV since 2019, these trends mirror the decline in aquatic biodiversity. Lake area also shrank historically, from 510 km^2 in the late Song/early Yuan dynasty to 410 km^2 by the late Yuan dynasty, with 38.8 km^2 reclaimed between 1938-1978 (12% of the 1938 surface area) [14]. Further reduction to the current 309 km^2 occurred after the 1980s, with water levels dropping from 1,886.94 m average (1988-2015) to a low of 1,885.93 m in 1989 before recovering to 1,887.42 m in 2014 after restoration projects [15].

1.2 Nutrient Removal Pathways in Plateau Lake Wetlands

Yunnan plateau lakes have small catchment areas, long water replacement cycles, and weak self-purification capacity. Under pristine conditions, native biodiversity enabled nitrogen and phosphorus accumulation to leave the water through two primary food chain pathways: (1) the "algae-fish-bird (or human)" route, where nutrients moved from algae to zooplankton to fish and shrimp, then to piscivorous birds or human harvest; and (2) the "macrophytes-fish-bird (or human)" route, where nutrients transferred from macrophytes like *Ottelia* to fish and then to birds or humans [Figure 1: see original paper]. However, environmental pollution, alien species invasion, and climate change have severely degraded these ecosystems, breaking key food chain links and blocking nutrient removal pathways. While pollution interception projects around lakes have gradually controlled external sources, reconstructing these food chains to restore nutrient removal pathways has become critical for plateau lake wetland restoration.

2. Previous Plateau Lake Wetland Restoration Modes and Their Limitations

Previous ecological restoration measures for internal pollution in Yunnan plateau lakes predominantly used alien species in three main modes: (1) silver carp and bighead carp for algae control, effective for algal blooms in inferior Class V water; (2) lakeshore restoration with reeds and willows, improving landscape aesthetics; and (3) water hyacinth mode, which reduced nitrogen and phosphorus but created severe negative impacts—covered waters became anoxic and lightless, eliminating fish, shrimp, shellfish, and aquatic plants. All three modes introduced alien species, causing unavoidable negative impacts on the unique plateau wetland ecosystems and indigenous species, with water hyacinth causing particularly severe ecological damage.

Recognizing these limitations, our team since 2004 has focused on utilizing native organisms for natural restoration, proposing the three-dimensional "macrophytes-fishes-benthons-birds" restoration mode. This approach combines indigenous flagship macrophytes (e.g., *Ottelia*), flagship fish (e.g., Dianchi golden-line barbel), and benthic animals (e.g., *Margarya* snails, *Anodonta woodiana*) to reconstruct broken ecological chain links and restore nutrient removal pathways. *Science* magazine featured this restoration mode as an important approach for restoring habitats and saving rare indigenous species in Southwest China plateau lake wetlands [17].

2.1 Demonstration in Dianchi Lake

Since 2003, restoration focus has shifted from the lake body to the lakeshore zone, initiating large-scale wetland reconstruction to restore ecosystem functions [16]. Our demonstration showed that indigenous macrophytes like *Ottelia* and benthic animals like *Anodonta woodiana* effectively purify Dianchi' s water, with efficacy correlating with species density [Figure 2: see original paper]. Artificial propagation and release of indigenous fish such as Dianchi golden-line barbel reestablished stable populations of species previously extinct in the lake. Restoration of macrophytes, benthos, and fish provided food and habitat for waterbirds, increasing avian diversity. The harvested *Ottelia* flowers and golden-line fish represent traditional premium food ingredients whose economic value can offset restoration costs, while the dense white and yellow flowers create a unique aesthetic landscape. International academic journal *Science* specifically reported on this three-dimensional restoration mode, recognizing it as a vital pathway for restoring plateau lake wetland ecosystems and rescuing endangered indigenous species [17].

2.2 Demonstration in Eryuan East Lake Wetland, Dali

Eryuan County, located at the northern source of Erhai Lake along bird migration routes, plays a crucial role in Erhai' s ecosystem health. We implemented the "macrophytes-fishes-benthons-birds" mode in East Lake, substituting Dali schizothoracin as the flagship fish while maintaining the same macrophytes and benthic shellfish [Figure 3: see original paper]. From 2019–2023, a 20 hm^2 demonstration area was established through replanting *Ottelia* and other macrophytes, and releasing indigenous fish (Dali schizothoracin) and benthic shellfish (*Anodonta woodiana* and *Margarya*). Results showed over 90% survival of macrophytes with vigorous growth, and over 80% survival of fish and benthos. Compared with control areas, phytoplankton and zooplankton diversity increased by over 80% [FIGURE:4, FIGURE:5], and waterbird populations increased by over 50%. This demonstrates that the "macrophytes-fishes-benthons-birds" mode significantly enhances aquatic biodiversity, ecosystem integrity, and functionality.

3. Expanding the New Wetland Restoration Pathway

Based on successful applications in Dianchi and Erhai, and considering the biodiversity characteristics and current status of Yunnan plateau lakes, we propose categorizing lakes into three types for targeted restoration [Figure 6: see original paper].

3.1 Ecological Conservation for Healthy Lakes

For lakes with well-preserved native species and good water quality (Class I-III), such as Fuxian, Erhai, and Lugu, we recommend "macrophytes-fishes-benthons-birds" rehabilitation focusing on restoring the two nutrient removal pathways. Fuxian Lake, being deep with limited shallow littoral zones, relies primarily on the "algae-fish" pathway; restoration should emphasize releasing *Anabarilius grahami*, Fuxian golden-line barbel, and algae-grazing native species like *Spinibarbus yunnanensis* and *Acrossocheilus yunnanensis*. For Erhai, protection of existing macrophyte communities is paramount, prohibiting herbivorous fish like grass carp, removing decaying plants, and restoring lakeshore zones while promoting native macrophytes like *Ottelia* and native fish like Dali schizothoracin and five endemic *Cyprinus* species. Lugu Lake should strictly control alien fish stocking while protecting native macrophytes like *Ottelia acuminata* and promoting three endemic schizothoracin species. Effective protection and restoration of endemic species will help restore original habitats and reconstruct traditional plateau lake fisheries and ecological cultures (e.g., Fuxian' s "waterwheel fishing").

3.2 Ecological Restoration for Moderately Degraded Lakes

For lakes where most native species have disappeared and water quality is poor (Class IV–inferior Class V), such as Dianchi, Qilu, Xingyun, Chenghai, and Yilong, restoration should primarily use algae-filtering silver carp and bighead carp, supplemented by "macrophytes-fishes-benthons-birds" restoration to enable nutrient removal through both pathways. In Dianchi, besides silver carp and bighead carp, suitable littoral areas should be planted with *Ottelia* and pondweeds, while releasing native fish (Dianchi golden-line barbel, *Acrossocheilus yunnanensis*, silver whitefish, Kunming schizothoracin) and native benthos (*Margarya* snails, *Anodonta woodiana*). Qilu Lake should similarly combine primary silver carp/bighead carp with littoral planting of red-line grass and Qilu *Ottelia*, releasing endemic fish (Qilu carp, bighead carp) and benthos (*Anodonta woodiana*). Xingyun Lake should focus on silver carp/bighead carp while enhancing recovery of native fish (Xingyun whitefish, bighead carp) and benthos (*Margarya* snails, *Corbicula fluminea*, *Palaemon modestus*).

3.3 Ecological Recovery for Severely Degraded Lakes

For Yangzonghai Lake, contaminated by heavy metals, the priority is heavy metal removal. The primary approach should be proliferating heavy metal-adsorbing benthic shellfish (*Anodonta woodiana*, *Cipangopaludina chinensis*, *Corbicula fluminea*), as shells adsorb and sequester heavy metals during growth. This should be supplemented by lakeshore restoration and stocking of native algae-grazing fish (*Spinibarbus yunnanensis*, *Acrossocheilus yunnanensis*). For lakes in other regions, this "macrophytes-fishes-benthons-birds" framework can be adapted based on water quality, native species preservation status, and artificial propagation potential to select key species, repair broken ecological chain links, restore nutrient removal pathways, and promote healthy wetland ecosystem development.

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Note: Figure translations are in progress. See original paper for figures.