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Article

Hydroecological Distribution, Ecological Grouping and Practical Significance of Higher Aquatic and Riparian Plants in The Fishery Water Systems of Bukhara Region

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Abstract: In Bukhara region, fishponds, canals, collector drains, drainage ditches and terminal lakes are interconnected as a single anthropogenic-hydrological system, in which mineralization, water depth, flow regime and biogenic elements shape the distribution of higher aquatic plants. The aim of the study was a comprehensive assessment of the species composition, ecological grouping, relationship with hydrochemical conditions and practical significance for fisheries of higher aquatic and riparian plants in the water bodies of Bukhara region. The study area was divided into three hydrological blocks: fish farms connected to the Amu-Bukhara Canal and its branches; the Northern, Central and Southern collector-drainage systems; and large lakes and reservoirs. Field observations were conducted from April to October, and the main geobotanical records were made from May to September along permanent routes. At each point, water temperature, pH, transparency, substrate, shoreline moisture and available hydrochemical parameters were recorded; macrophytes were studied by photographic recording, herbarium collection and rake sampling. As a result, 98 species belonging to 26 families and 61 genera were recorded. The leading families were Poaceae (19 species), Cyperaceae (10 species), and Potamogetonaceae and Amaranthaceae (9 species each). According to the ecological classification, rooted submerged hydatophytes accounted for 17.35%, free-floating submerged hydatophytes for 4.08%, free-floating species for 4.08%, helophytes for 21.43%, hygrophytes for 17.35% and halophytes for 15.31%. Mineralization was 2.43±1.52 g/L in the relatively fresh inflow waters and 9.13±6.38 g/L in the collector-drainage and lake group. The proportion of submerged macrophytes was higher in shallow and relatively fresh water bodies, whereas the proportion of riparian and halophytic species increased in deep and mineralized lakes. The functional assessment revealed the role of macrophytes as a feed resource, phytoremediators, habitat substrate and biomass requiring management in cases of excessive growth. *Lemna gibba* and *Azolla caroliniana* were selected for biotechnological application. This approach provides a scientific basis for identifying floristic changes along the hydrological chain, interpreting water quality biologically and developing management measures based on the use of local macrophyte biomass as a resource.

Keywords: Bukhara region; higher aquatic plants; macrophytes; hydrological block; hydrochemistry; mineralization; ecological group; floristic diversity; fishpond; collector-drainage; phytoremediation; *Lemna gibba; Azolla caroliniana*; aquaculture.

Introduction

The efficient use of water resources in inland water bodies and aquaculture systems requires the integrated management of food security, water quality and biodiversity. Although the rapid development of global aquaculture has increased fish production, it has made the issues of feed resources, nutrient-rich wastewater and the reduction of anthropogenic pressure on natural water bodies even more pressing. Higher aquatic plants are a structural and functional component of aquatic ecosystems, and their distribution is determined by regional climate, hydrological regime, depth, light, mineralization, nutrients and substrate characteristics. Therefore, macrophytes have been regarded not only as a component of floristic diversity but also as bioindicators characterizing the ecological status of water bodies and as a manageable biological resource.

This issue is of particular importance in arid regions. Repeated economic use of water, collector-drainage flows, high evaporation and salinization create a strong hydrochemical gradient between water bodies. Under such conditions, fresh canal networks, fishponds, moderately mineralized drainage ditches and highly mineralized terminal lakes may coexist within a single area. International studies show that macrophyte composition is particularly sensitive to depth, water transparency, trophic status and salinity. However, floristic-ecological assessments in Bukhara region that encompass fishponds together with the canals supplying them, collector-drainage systems and receiving lakes as a single hydrological chain remain limited.

The research gap of the present study is associated precisely with this integrative approach: most local studies have described the hydrobiological status of individual lakes or water bodies, but changes in macrophyte composition along the water pathway "supply network → fishpond → outflow water → drainage ditch/collector → terminal water body" have not been generalized. It is also necessary to integrate the floristic list with ecological groups, water quality and functional value for fisheries.

On this basis, the aim of the study was to assess the distribution patterns of higher aquatic and riparian plants in the fishery water systems of Bukhara region on the basis of hydrological and hydrochemical gradients, to classify them into ecological groups, and to determine their feed, phytoremediation and biotechnological potential for fisheries. The tasks included the delineation of hydrological blocks, seasonal monitoring along permanent routes, characterization of water quality, determination of species composition, comparison of ecological groups and cover, and screening of promising species. The practical aspect of the study consists in evaluating macrophytes not only as an element of biodiversity, but also as a means of natural purification of fishery waters, maintenance of habitat substrate, formation of a supplementary food base for herbivorous fish and management of excess biomass. Such a multifunctional approach is consistent with the principles of circular and resource-efficient water use in arid regions.

In recent years, aquaculture sustainability has been moving towards the principle of managing water resources, the feed base and waste nutrients within a single system. Naylor et al., analysing 20 years of global aquaculture development, showed that despite increased production efficiency, problems related to feed raw materials, water quality and the assessment of ecosystem services persist [1]. From this perspective, aquatic plants acquire a dual significance in fishery systems – as a component providing ecosystem services and as a source of renewable biomass.

The regional and global distribution of macrophytes is uneven. Murphy et al., summarizing global data on 3,457 aquatic macrophyte species, demonstrated substantial regional differences in species richness and endemism [2]. Alahuhta et al., analysing the macroecology of freshwater macrophytes, emphasized that local environmental factors – depth, water chemistry, hydrology and habitat structure – act as important filters even at large spatial scales [3]. Poikane et al., based on data from 539 European lakes, demonstrated the relationship between macrophyte composition and

ecological status and noted that the decline of submerged vegetation and the increase in free-floating plants are associated with trophic pressure [4].

Mineralization is a particular factor in arid and semi-arid regions. Kaijser, Kosten and Hering analysed the distribution of 46 aquatic plant taxa along a salinity gradient and showed that some species tolerate a very narrow chloride range, while others tolerate a broad one; *Stuckenia pectinata* was recorded among the species adapted to relatively high salinity [5]. Søndergaard et al., analysing submerged plant cover and species richness in 666 shallow lakes, identified chlorophyll-a, Secchi transparency and mean depth as strong predictors of macrophyte cover [6]. These results justify the need to assess the depth–transparency–mineralization gradient jointly under Bukhara conditions. Schneider et al. further showed that macrophyte mass development cannot always be explained by high nutrient levels alone, that hydromorphological stability and disturbance regime also play a major role, and recommended that ecosystem functions be assessed before mechanical removal [7].

The role of large riparian plants in water quality is also not uniform. Maucieri, Salvato and Borin, comparing phosphorus retention efficiency in microcosms with different macrophytes, demonstrated substantial functional differences between *Typha latifolia*, *Phalaris arundinacea*, *Phragmites australis* and other species [8]. Ng and Chan, examining *Spirodela polyrhiza* and *Lemna* systems in fish-farm wastewater, showed that macrophyte-based phytoremediation can be effective in reducing ammonia, nitrate, nitrite, phosphate, turbidity and suspended solids [9]. Paolacci, Stejskal and Jansen experimentally confirmed that *Lemna minor* can take up NH_4^+, NO_3^- and PO_4^{3-} in a medium resembling aquaculture wastewater [10]. Similarly, Iatrou, Kora and Stasinakis cultivated *Lemna minor* and *Lemna gibba* in secondary-treated wastewater and showed that biomass, protein and starch production depended on the nitrogen in the medium [11]. Ceschin et al. demonstrated species-specific differences in nitrate and phosphate bioaccumulation by *Lemna minuta* and *Lemna minor* [12]. In a recent review of duckweeds, Zhou et al. emphasized their capacity to remove nitrogen, phosphorus, organic pollutants and certain heavy metals while producing valuable harvestable biomass [13].

Data on the nutritional value of aquatic plant biomass in aquaculture are also expanding. Minich and Michael, in a systematic review and meta-analysis covering 58 studies, showed that aquatic plants have been used in live, dried and pelleted forms in various fish species and noted that inclusion levels in the range of 15–30% were associated with positive results in many trials [14]. For *Azolla*, Yohana et al. analysed protein, amino acids, vitamin and mineral composition and antinutritional factors, emphasizing that the optimal inclusion level differs depending on the *Azolla* species and the fish species [15]. Rahmah et al., by partially incorporating *Azolla* biomass grown in aquaculture wastewater into the diet of *Pangasius*, demonstrated the practical feasibility of the chain "wastewater treatment → biomass production → return to feed" [16]. Arora, Nandal and Chaudhary summarized the multifunctional potential of *Azolla* in terms of rapid growth, nitrogen fixation, bioremediation and use as a feed raw material [17]. Bujak and Bujak interpreted the *Azolla*–*Nostoc azollae* symbiosis as a "superorganism" model based on continuous biological nitrogen fixation and linked this property to the mechanism by which *Azolla* biomass is formed even in nitrogen-poor environments [18].

Recent feeding trials reinforce this approach. Song et al. showed that diets supplemented with duckweed affect growth, muscle composition, and antioxidant and immune parameters in grass carp, indicating the potential of moderate inclusion levels [19]. Banik et al. studied the effect of *Lemna minor* supplementation on carbohydrate metabolism in *Ctenopharyngodon idella* and showed that duckweed can be evaluated not only as a protein source but also as a functional feed component [20]. The 2025 systematic review by Betanzo-Torres et al. noted that *Phragmites*, *Typha* and other macrophytes are among the most frequently used groups in aquaculture wastewater treatment, but that studies integrating water treatment with biomass/resource production are still insufficient [21]. Tang et al. showed that nitrogen removal in constructed wetlands depends not only on direct plant uptake but also on rhizosphere microorganisms and nitrification–denitrification processes [22].

Thus, three lines of macrophyte research are well developed in the international literature: ecological indication and habitat filters, phytoremediation of wastewater, and the use of duckweed and the aquatic fern *Azolla* as feed in aquaculture . However, data on the simultaneous assessment of floristic composition, hydrochemistry and functional value, integrating canals, fishponds, collector-

drainage systems and terminal lakes in an arid region as a single hydrological chain, are limited. The present study was aimed precisely at filling this gap using Bukhara region as an example.

Materials and Methods

The study area encompassed hydrologically interconnected water bodies in Bukhara region. The area was divided into three main blocks: (I) the Amu-Bukhara Canal and its major branches, together with the fishponds and outflow drainage ditches located along them; (II) the Northern, Central and Southern collector systems, the major drainage ditches discharging into them and the fish farms connected to these networks; (III) large water bodies such as Dengizkul, Zamonbobo, Khadicha, Qoraqir, Ayoqogitma, Devkhona, Zikri, Qumsulton, Tudakul and Shurkul, together with the fishery facilities hydrologically or economically connected to them. The main conceptual chain was formulated as "canal, collector, large water body → fishpond → pond outflow water → drainage ditch, collector".

Field observations were conducted from April to October; the main geobotanical surveys were repeated along the same permanent routes in May, June, July, August and September, in accordance with the active vegetation period of macrophytes. At each station, the biotope was described from the shore towards open water in standard ecological zones: highly moist riparian soils, highly moist saline soils, the shoreline zone, the shallow littoral zone, the water surface and the submerged zone.

At each observation point, water temperature, pH, water transparency, bottom substrate characteristics and riparian soil moisture were recorded. The bottom substrate was described as sandy, silty, clay-silt, detrital or mixed, and the water flow as stagnant, slow-flowing or flowing. Rapid field measurements of NH_4^+, NO_3^- and PO_4^{3-} were performed with portable test kits. The hydrochemical data summarized from the sources were divided into two functional groups: relatively fresh inflow and canal waters, and the collector–drainage–terminal lake group.

The species composition of macrophytes was recorded along permanent routes. At each point, the higher aquatic and waterside plants encountered were entered in a field notebook, their habitat and distribution status were recorded, and photographs were taken. Herbarium specimens were prepared for species difficult to identify precisely in the field. Specimens were collected by hand and with a rake-type plant sampler on shores and in shallow areas, in a special wading suit where water depth permitted, and from a boat or motorboat in large and deep water bodies. For each specimen, the water body, route point, date, biotope, water depth, position of the plant relative to the water level and dominance status were recorded.

Ecological grouping was adapted to Bukhara conditions based on the principles of Sculthorpe's life forms of aquatic plants, Cook's approach to aquatic and wetland plants and the wetland habitat classification of Cowardin et al. Four main criteria were applied in the classification: the position of vegetative organs relative to the water level, the type of attachment to the substrate, the hydrological regime and substrate salinity. As a result, 10 ecological groups coded A–J were established.

The numbers of species, genera and families were calculated from the floristic list; the share of ecological groups was expressed as a percentage using the formula $n/N \times 100$. The leading families were ranked by species number. For comparisons between water bodies, the free-floating (C), submerged (A+B), helophyte–amphiphyte (E+F) and riparian (G–J) blocks were used. The practical significance for fisheries was evaluated on the basis of literature data and field observations in four functional categories: forage biomass; phytoremediation; habitat and spawning substrate; and biomass requiring management when forming excessive cover (Fig. 1).

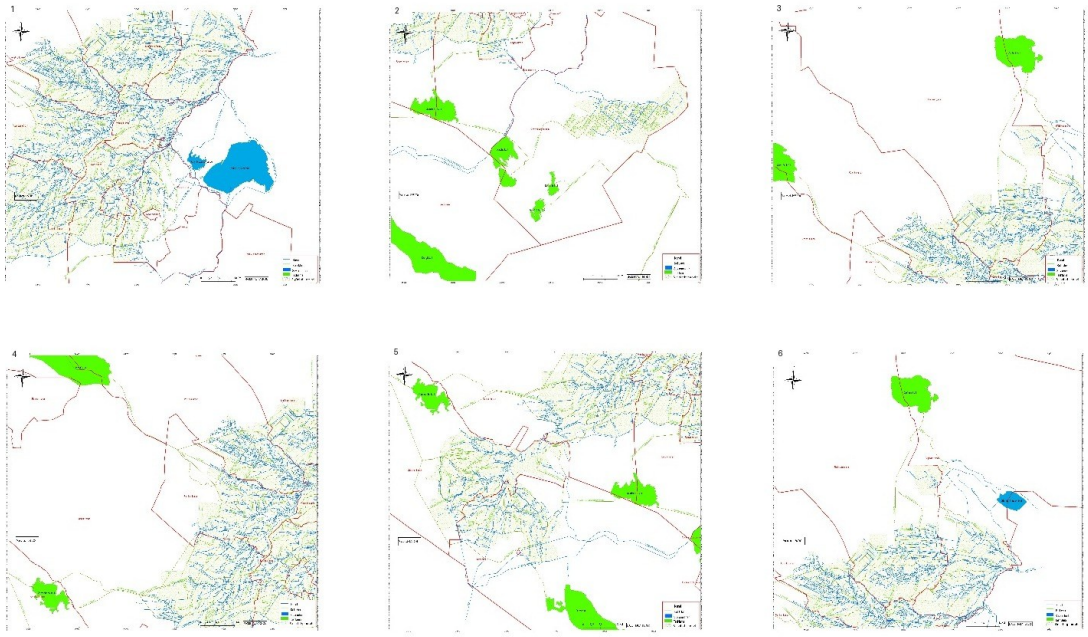


Figure 1. Route-based map of the study area divided into hydrological blocks. 1 – north, 2 – south, 3 – southeast, 4 – southeast, 5 – northwest, 6 – east.

Results

Hydrochemical generalization revealed a sharp mineralization gradient between water bodies. In the group of relatively fresh waters of irrigation ditches, canals and fish-farm inflows, pH was 7.00±0.71, mineralization 2.43±1.52 g/L, Cl^- 417.15±221.25 mg/L and SO_4^{2-} 540.30±458.49 mg/L. In the group of collector drains, drainage ditches, terminal and large lakes, mineralization rose to 9.13±6.38 g/L, with Cl^- amounting to 3012.68±3683.61 mg/L and SO_4^{2-} to 3734.61±2805.19 mg/L. This difference indicated an increase in water salinity in the canal–collector–lake direction (Tables 1 and 2).

Table 1. Generalized hydrochemical characteristics of relatively fresh waters of irrigation ditches, canals and fish-farm inflows

Parameter	Overall mean, M ± SD
pH	7.00 ± 0.71
Mineralization, g/L	2.43 ± 1.52
Cl^-, mg/L	417.15 ± 221.25
SO_4^{2-}, mg/L	540.30 ± 458.49
O_2, mg/L	—
BOD_5, mg O_2/L	—
NH_4^+, mg/L	0.57 ± 0.57
NO_2^-, mg/L	0.052 ± 0.045
NO_3^-, mg/L	6.30 ± 0.28
PO_4^{3-}, mg/L	—
Fe, mg/L	—
Suspended solids, mg/L	16.00 ± 1.41

Table 2. Generalized hydrochemical characteristics of water in collector drains, drainage ditches, terminal and large lakes

Parameter	Overall mean, M ± SD
pH	7.42 ± 0.67
Mineralization, g/L	9.13 ± 6.38
Cl^-, mg/L	3012.68 ± 3683.61
SO_4^{2-}, mg/L	3734.61 ± 2805.19
O_2, mg/L	6.38 ± 1.52
BOD_5, mg O_2/L	5.06 ± 4.81
NH_4^+, mg/L	1.44 ± 1.31
NO_2^-, mg/L	0.066 ± 0.063
NO_3^-, mg/L	6.53 ± 4.48
PO_4^{3-}, mg/L	0.267 ± 0.423
Fe, mg/L	1.52 ± 4.56
Suspended solids, mg/L	42.46 ± 30.53

The floristic inventory recorded 98 species belonging to 26 families and 61 genera. The species-to-genus ratio was 1.61, and 41 genera (67.2%) were monotypic. Poaceae was the largest family with 19 species (19.39%), followed by Cyperaceae with 10 species (10.20%), Potamogetonaceae and Amaranthaceae with 9 species each (9.18%), Polygonaceae with 6 species (6.12%) and Typhaceae with 5 species (5.10%). This structure indicates that, in addition to aquatic and riparian biotopes, the flora of saline moist shores was also included within the scope of the study (Table 3).

Table 3. Share of leading families in the aquatic and riparian flora of Bukhara region

Family	Number of species	Share, %
Poaceae	19	19.39
Cyperaceae	10	10.20
Potamogetonaceae	9	9.18
Amaranthaceae	9	9.18
Polygonaceae	6	6.12
Typhaceae	5	5.10
Other 20 families	40	40.82
Total	98	100.00

By ecological group, A – rooted submerged hydatophytes comprised 17 species (17.35%), B – free-floating submerged hydatophytes 4 species (4.08%), C – free-floating hydatophytes 4 species (4.08%), D – rooted hydrophytes with floating leaves 1 species (1.02%), E – helophytes 21 species (21.43%), F – amphiphytes 5 species (5.10%), G – hygrophytes 17 species (17.35%), H – mesohygrophytes 10 species (10.20%), I – halophytes 15 species (15.31%) and J – mesophytic/ruderal shoreline species 4 species (4.08%). Among the major functional blocks, true aquatic plants (A–D) accounted for 26.53%, helophytes–amphiphytes (E+F) for 26.53%, moist-shore species (G+H) for 27.55%, halophytes for 15.31% and ruderal species for 4.08% (Table 4).

Table 4. Distribution of higher aquatic and riparian plants by ecological group

Code	Ecological group	Number of species	Share, %
A	Rooted submerged hydatophytes	17	17.35
B	Free-floating submerged hydatophytes	4	4.08
C	Free-floating hydatophytes	4	4.08
D	Rooted hydrophytes with floating leaves	1	1.02
E	Helophytes	21	21.43
F	Amphiphytes	5	5.10
G	Hygrophytes	17	17.35
H	Mesohygrophytes	10	10.20
I	Halophytes	15	15.31
J	Mesophytic/ruderal shoreline species	4	4.08
—	Total	98	100.00

The environment–plant relationship revealed a spatial sequence of ecological groups. Groups A–B depended on the underwater light regime and substrate, group C on low flow and wave exposure, group D on water-level stability, groups E–F on the shallow littoral zone and water-level fluctuations, groups G–H on shoreline moisture, and group I on saline substrate [23]. The presence of halotolerant aquatic species such as *Stuckenia pectinata*, *Zannichellia palustris* and *Ruppia* cf. *maritima* was associated with highly mineralized biotopes (Table 5).

Table 5. Relationship of higher aquatic plants with environmental factors

Ecological code	Ecological group	Occurrence in the aquatic environment	Main determining factor	Typical location in the Bukhara system
A	Rooted submerged hydatophytes	In clear or moderately clear, permanent, slow- or moderately flowing water; silty-sandy bottom	Light: distribution depth is limited by water transparency. Nutrients are taken up from bottom sediments via roots.	Canals, collectors and ponds; shallow parts of lakes
B	Free-floating submerged hydatophytes	In still, wind-sheltered water rich in biogenic elements	Rootless; nutrients are taken up directly from the water through the entire body surface.	Ponds; calm corners and shores of lakes
C	Free-floating pleustophytes	In still or very slow-flowing, warm, eutrophic water (high in nitrogen and phosphorus)	Currents and waves carry them away, hence calm water is required. Nutrients are absorbed directly from the water.	Ponds, stagnant sections of drainage ditches, collector outfalls
D	Rooted hydrophytes with floating leaves	In slow-flowing water with a stable level, 0.5-2 m deep	Roots are in the bottom and leaf blades on the water surface; hence sharp water-level fluctuations and strong waves are unfavourable.	Calm sections of canals and collectors; ponds

Ecological code	Ecological group	Occurrence in the aquatic environment	Main determining factor	Typical location in the Bukhara system
E	Helophytes	In the shallow littoral zone (approximately 0–1.5 m), on silty bottoms rich in organic matter	Aerenchyma supplies oxygen to roots in anoxic sediment. Tolerant of water-level fluctuations.	Collector banks, shallow littoral of lakes, pond margins
F	Amphiphytes	In the zone of periodic water-level fluctuations: on temporarily flooded and drying shores	Capable of forming both aquatic and terrestrial forms	Drained pond bottoms; water-level fluctuation zone of lakes.
G	Hygrophytes	On very moist, periodically flooded soils (groundwater approximately 0–0.5 m)	Adapted to permanent soil water saturation and short-term flooding.	Slopes of drainage ditches, toes of embankments, lake shores
H	Mesohygrophytes	On moderately moist shores (groundwater approximately 0.5–1.5 m)	Moisture-demanding but intolerant of prolonged flooding.	Canal and collector embankments, pond dykes
I	Halophytes	On the shores of highly mineralized water bodies, on soils salinized by evaporation	Outcompeted by other species in non-saline environments.	Dengizkul, Ayoqogitma and collector shores, solonchaks
J	Mesophytic-ruderal species	Farther from the water, in disturbed (anthropogenic) sites	Dependent not on moisture but on soil disturbance and low competition.	Spoil heaps from canal dredging, along irrigation ditches

Comparison across water bodies showed that the share of submerged species was higher in the shallow and relatively fresh Lake Qoraqir, whereas the share of riparian species increased in deeper and more highly mineralized systems such as Dengizkul, Devkhona and Ayoqogitma. According to the source data, the submerged group A+B accounted for 23.5% in Qoraqir, 18.9% in Khadicha, 15.6% in Devkhona and 8.7% in Dengizkul. Conversely, the riparian group G–J increased to 50.0%, 54.7%, 60.0% and 75.4%, respectively [24]. This sequence should be interpreted not solely in terms of mineralization, but jointly with depth, water transparency, hydroperiod and the proportion of littoral area (Table 6).

Table 6. Comparative parameters of the macrophyte flora of water bodies in Bukhara region

Water body (source)	Species (families)	Main species	Free-floating, C	Submerged, A+B	Helophyte and amphiphyte, E+F	Riparian, G–J
Bukhara regional system, total: canal–	98 (26)	*Phragmites australis*, *Typha angustifolia*, *Stuckenia*	4 species (4.1 %)	21 (21.4 %)	26 (26.5 %)	46 (46.9 %)

Water body (source)	Species (families)	Main species	Free-floating, C	Submerged, A+B	Helophyte and amphiphyte, E+F	Riparian, G–J
collector–lake–pond [this study]		*pectinata*, *Potamogeton crispus*, *Ceratophyllum demersum*[1]				
Lake Qoraqir [Qobilov, 2020]	34 (16)	*P. australis*, *T. angustifolia*, *Schoenoplectus triqueter*, *Potamogeton* spp., *Myriophyllum spicatum*	1 (2.9 %)	8 (23.5 %)	8 (23.5 %)	17 (50.0 %)
Lake Khadicha [Raximov, 2025]	53 (22)	*P. australis*, *T. angustifolia*, *T. latifolia*, *P. perfoliatus*, *C. demersum*	4 (7.5 %)	10 (18.9 %)	10 (18.9 %)	29 (54.7 %)
Lake Devkhona [Toshov, 2021]	45 (21)	*P. australis*, *T. angustifolia*, *P. perfoliatus*, *M. spicatum*	2 (4.4 %)	7 (15.6 %)	9 (20.0 %)	27 (60.0 %)
Dengizkul [Shodmonov, 2022]	69 (24)	*P. australis*, *T. angustifolia*, *P. perfoliatus*, *M. spicatum*, *Najas marina*	0 (not recorded)	6 (8.7 %)	11 (15.9 %)	52 (75.4 %)
Lake Ayoqogitma [Shamsiyev, 2023]	67 (22)	*P. australis*, *M. spicatum*, *S. pectinata*, *Typha minima*	—	Total aquatic species: 17 (25.4 %)	—	50 (74.6 %)

From the fisheries perspective, the flora was evaluated in four functional directions. Soft pleustophytes and hydatophytes were regarded as a feed resource for herbivorous fish; *Lemna*, *Azolla*, *Phragmites*, *Typha* and other species as nutrient-assimilating phytoremediators; submerged macrophytes as habitat and spawning substrate for fish and invertebrates; and excessively dense cover as an object of management that adversely affects water exchange and the oxygen regime. Not all 98 species of the field list were included in the experiments. Based on the criteria of growth rate, ease of biomass harvesting, nutritional value, uptake of biogenic elements and adaptation to local conditions, *Lemna gibba* and *Azolla caroliniana* were selected as the principal biotechnological species (Table 7).

Table 7. Functional categories of macrophytes in the fishery system

Functional category	Main representatives	Significance for fisheries	Management approach
Forage biomass	*Lemna gibba*, *Lemna minor*, *Azolla caroliniana*, *Potamogeton crispus*, *Stuckenia pectinata*, *Najas marina*	Potential source of plant biomass for herbivorous fish and feed formulations	Controlled propagation, harvesting, drying and safety analysis
Phytoremediators	*Lemna* spp., *Azolla* spp., *Phragmites australis*, *Typha* spp., *Schoenoplectus* spp.	Binding of nitrogen, phosphorus and certain pollutants in biomass/rhizosphere	Water quality monitoring; separation of phytoremediation biomass from feed biomass
Habitat and substrate	*Potamogeton* spp., *Myriophyllum* spp., *Ceratophyllum* spp., *Najas* spp.	Shelter and substrate for fry, periphyton and invertebrates	Maintenance of optimal cover
Species forming excessive cover	*Phragmites australis*, *Typha* spp., *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Potamogeton crispus*	May adversely affect water exchange, fishing and the oxygen regime	Selective mechanical harvesting; no complete removal

Discussion

The results obtained for Bukhara region show that assessing macrophytes separately by water body type is insufficient. The overall flora of 98 species was formed through the complementarity of canal, pond, collector, drainage ditch and lake biotopes. This is consistent with the role of local habitat and hydrological factors in shaping macrophyte diversity at large scales, as noted by Alahuhta et al. The difference between 34–69 species in individual lakes and 98 species in the entire system indicates that hydrological networks and anthropogenic water bodies make an independent contribution to floristic diversity [25].

The hydrochemical gradient is logically consistent with the distribution of ecological groups. Mineralization in the collector-drainage and lake group, reaching 9.13±6.38 g/L, is several times higher than the 2.43±1.52 g/L in fresh inflow waters. Kaijser et al. showed that salinity is a strong selective factor in the distribution of aquatic macrophytes and that certain species, such as *Stuckenia pectinata*, are tolerant of high chloride conditions [26]. The 15.31% share of halophytes in Bukhara also reflects the influence of evaporative salinization around water bodies and of the collector-drainage regime on the shoreline flora.

The decline of submerged macrophytes in deep and mineralized lakes is interpreted as a multifactorial process. Søndergaard et al. identified Secchi transparency, depth and chlorophyll-a as strong predictors of submerged cover [27]. In the Bukhara system, mineralization, together with depth and water transparency, may limit light penetration to the bottom, the rooting substrate and species-specific osmotic tolerance. Therefore, the observed comparative differences should not be attributed to nutrients or salinity alone.

The function of macrophytes in fisheries is also twofold. Moderate cover increases the structural complexity of the aquatic environment, creating habitat for periphyton, benthos and juvenile fish; excessive cover, by contrast, may restrict water exchange and degrade the oxygen regime through the decomposition of organic matter at the end of the growing season. Therefore, the management objective should not be the complete elimination of macrophytes, but the maintenance of functional cover and

the selective harvesting of excess biomass. The multi-country experience of Schneider et al. likewise shows that there is no single universal removal strategy against macrophyte mass development [28].

From the phytoremediation perspective, Bukhara collector waters and fishery wastewater can be regarded as a nutrient source for macrophyte biomass cultivation. It has been experimentally confirmed that *Lemna* and other free-floating species transfer mineral nitrogen and phosphorus from aquaculture wastewater into biomass. Large helophytes, in turn, participate in long-term water purification processes through the root–rhizosphere system. However, biomass that has accumulated pollutants during phytoremediation cannot be used directly as feed; for feed biomass, heavy metals, microbiological safety and nutritional composition must be monitored separately [29].

The selection of *Lemna gibba* and *Azolla caroliniana* is based on the intersection of ecological and technological criteria. Duckweeds propagate rapidly by vegetative means, are easily harvested from the water surface and can reassimilate aquaculture waste nutrients . *Azolla*, in turn, is capable of biological nitrogen fixation owing to its symbiosis with *Nostoc azollae*. Recent feed studies indicate that the partial inclusion of duckweed and *Azolla* is promising for a number of fish species. Therefore, under Bukhara conditions, the chain "wastewater nutrients → controlled macrophyte biomass → safety and biochemical analysis → feed component" is a scientifically justified direction for the next experimental stage [30].

Conclusion

The canals, fishponds, collector-drainage systems and terminal lakes of Bukhara region, as an interconnected anthropogenic-hydrological system, form a single ecological gradient of macrophyte distribution; In the study system, 98 species of higher aquatic and riparian plants belonging to 26 families and 61 genera were recorded; Poaceae, Cyperaceae, Potamogetonaceae and Amaranthaceae were the leading families by species number; In the ecological classification, true aquatic plants (A–D) accounted for 26.53%, helophytes–amphiphytes for 26.53%, moist-shore species for 27.55%, halophytes for 15.31% and ruderal species for 4.08%; The increase in mineralization from relatively fresh inflow waters towards collector-drainage systems and terminal lakes was accompanied by a change in macrophyte composition; in deep and mineralized water bodies the share of submerged species decreased, while that of riparian species increased; In the fishery system, macrophytes performed four main functions: feed resource, phytoremediator, habitat/spawning substrate and biomass to be managed in the case of excessive development; Owing to their rapid propagation, ease of harvesting, nutrient uptake and feed potential, *Lemna gibba* and *Azolla caroliniana* were selected as the most suitable species for subsequent biotechnological experiments.To maintain an identical seasonal monitoring protocol and an identical panel of hydrochemical parameters at permanent GPS stations in each hydrological block; To monitor mineralization, pH, dissolved oxygen, NH_4^+, NO_2^-, NO_3^- and PO_4^{3-} in parallel with macrophyte cover, and to include EC and heavy metals where possible; To manage the cover and biomass of shallow submerged macrophytes selectively rather than eliminating them completely, and to harvest mechanically the excess biomass that interferes with fishing and water exchange; To separate technologically the biomass grown for phytoremediation from feed biomass, and to test the biomass intended for feed for heavy metals, microbiological safety and proximate composition; To continue separate pilot experiments on the controlled clonal propagation, semi-continuous harvesting and production of dried biomass of *Lemna gibba* and *Azolla caroliniana* in wastewater discharged from fishponds; At the next stage, to establish a station-level raw database for testing water quality–macrophyte cover relationships by Spearman correlation or appropriate multivariate analysis.

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