

Biodiversity Of Primary Producers In The Oqdaryo Reservoir Ecosystem And Their Ecological Characteristics

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Abstract

Background & Aims: The Oqdaryo Reservoir (40°12'N, 65°48'E; surface area 178 km², capacity 2.1 km³) represents a critical water resource in the arid conditions of Central Asia. Understanding the biodiversity and ecological roles of its primary producers is essential for evidence-based reservoir management and water quality monitoring.

Methods: Seasonal field campaigns were conducted at seven fixed stations during 2021–2023. Phytoplankton, phytobenthos and macrophyte assemblages were analysed using standard hydrobiological methods. Taxonomic identification followed current monographic keys. Biodiversity indices (Shannon-Wiener H', Pielou J', Margalef d), saprobic status (Pantle-Buck index), and primary productivity (Winkler O₂ method; ¹³C isotope assay) were quantified.

Results: A total of 187 taxa were identified across 41 families and 84 genera: Bacillariophyta (72 spp., 38.5%) dominated, followed by Chlorophyta (54 spp., 28.9%) and Cyanobacteria (38 spp., 20.3%). Peak phytoplankton density reached 4.2 × 10⁶ cells dm⁻³ in summer, accompanied by a decline in the Shannon diversity index (H' = 1.87) attributable to Cyanobacteria bloom events. Saprobian indices (S = 1.42–2.18) classified the reservoir as predominantly β-mesosaprobic (WFD Class II–III). Annual gross primary productivity was 420 ± 59 gC m⁻² yr⁻¹ (P/R = 1.28), confirming an autotrophic system.

Conclusions: The reservoir is currently in a meso-eutrophic trophic state. Elevated nutrient loading in littoral zones driven by agricultural run-off presents an imminent eutrophication risk. Cyanobacterial bloom dynamics

and their management implications are discussed in the context of regional water security.

Keywords: Phytoplankton; phytobenthos; macrophytes; biodiversity indices; saprobic analysis; primary productivity; eutrophication; Central Asia reservoirs.

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1. Introduction

Reservoirs represent artificially created lentic environments whose biodiversity trajectories diverge markedly from both their riverine antecedents and natural lakes [1,2]. Upon impoundment, the disruption of longitudinal connectivity and altered hydrological retention times restructure planktonic communities, often favouring opportunistic taxa over rheophilic specialists [3]. In semi-arid regions, where water scarcity intensifies multiple-use pressures on individual water bodies, accurate characterisation of biological communities is indispensable for integrated water resource management [4].

The Oqdaryo Reservoir (Samarkand Region, Uzbekistan) is the primary water supply for agricultural irrigation and urban demand across a catchment of approximately 3,400 km². Since its commissioning in 1969, systematic biological surveys have remained limited in scope and temporal coverage. While certain aspects of its ichthyology and macroinvertebrate fauna have been documented [5,6], comprehensive assessments of primary producer diversity — the fundamental trophic base of the aquatic food web — are conspicuously absent from the peer-reviewed literature.

Primary producers in lentic systems encompass three functionally distinct groups: phytoplankton (suspended microalgae), phytobenthos (benthic microalgae), and macrophytes (rooted vascular plants and macroalgae). Each group contributes differentially to autochthonous carbon fixation, nutrient cycling, and oxygen dynamics [7,8]. Phytoplankton, by virtue of their rapid generation times and sensitive physiological responses to nutrient gradients, are widely employed as early-warning biological indicators under the European Water Framework Directive (WFD 2000/60/EC) and its analogous national frameworks [9].

Despite the ecological importance of such assessments, Central Asian reservoirs remain substantially under-studied relative to Palearctic or temperate-zone counterparts [10,11]. The few existing investigations focus predominantly on large transboundary systems (Toktogul, Charvak, Kairakum), while medium-sized agricultural reservoirs — which arguably

face the highest anthropogenic pressure per unit volume — receive comparatively little scientific attention [12].

The present study addresses this gap through a systematic three-year inventory of primary producer biodiversity in the Oqdaryo Reservoir, coupling taxonomic analysis with quantitative assessment of community ecology, saprobic status and primary productivity. The principal objectives are: (i) to compile an updated taxonomic checklist of phytoplankton, phytobenthos and macrophyte taxa; (ii) to quantify seasonal and spatial patterns of biodiversity and community structure; (iii) to evaluate the ecological status of the reservoir against saprobity and WFD criteria; and (iv) to estimate annual primary productivity and assess the autotrophic balance of the ecosystem.

2. Materials and Methods

2.1 Study Area

The Oqdaryo Reservoir (40°12'N, 65°48'E; elevation 487 m a.s.l.) is located in the Zerafshan River basin, Samarkand Region, Uzbekistan (Fig. 1). Key morphometric parameters are: surface area 178 km², total capacity 2.1 km³, mean depth 12.4 m, maximum depth 28.7 m, and shoreline length 94 km. The reservoir operates as a seasonal storage facility with maximum impoundment in spring (April–May) and drawdown during summer irrigation demand (June–August). The climate is continental arid, characterised by hot dry summers (mean July air temperature 32.4°C) and cold winters (mean January air temperature -4.1°C). Annual precipitation averages 267 mm, with 68% falling between October and April.

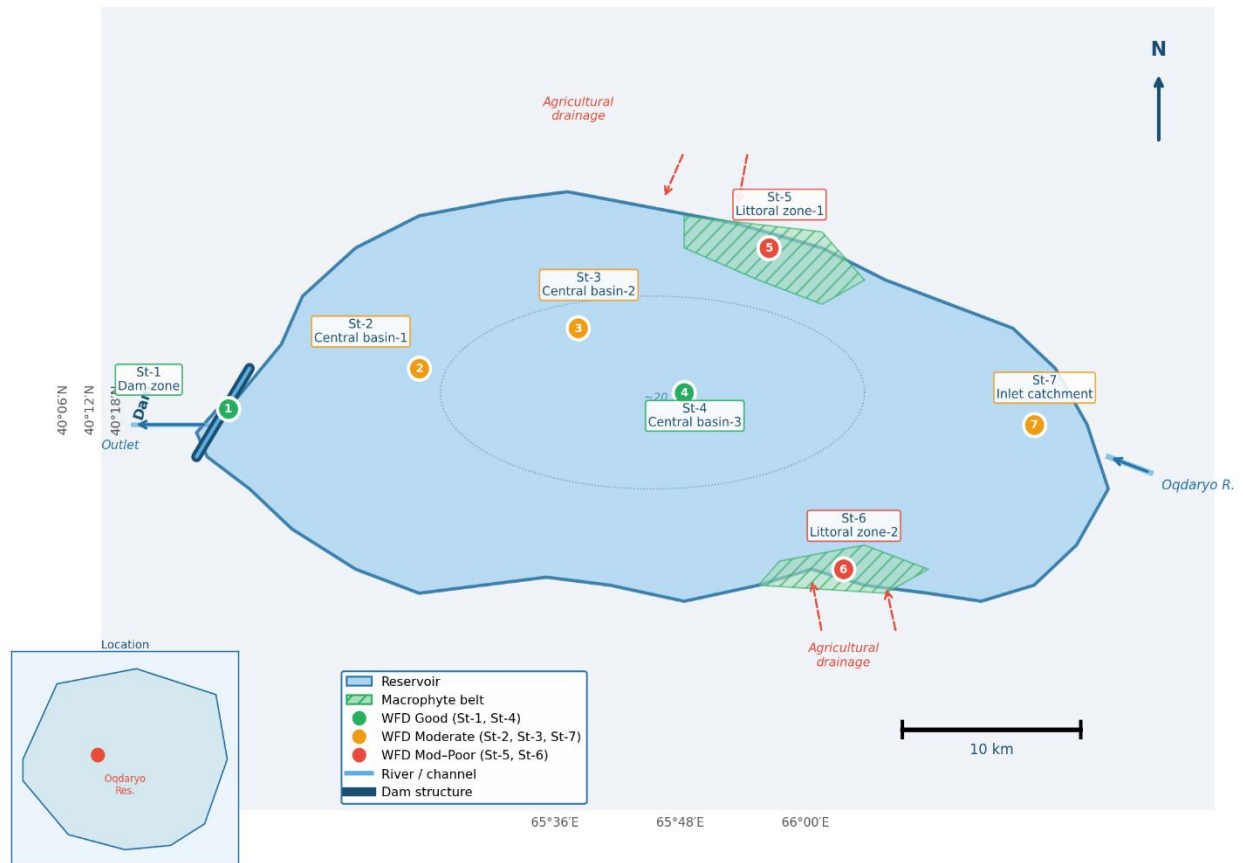


Fig. 1. Location of Oqdaryo Reservoir and positions of seven permanent monitoring stations (St-1 to St-7) used during the 2021–2023 seasonal survey campaigns.

Colour coding indicates WFD ecological status class (green = Good; orange = Moderate; red = Moderate–Poor). Hatched areas denote macrophyte belt extent along the littoral margin. Inset: position of the reservoir within Uzbekistan.

2.2 Sampling Design

Seven permanent monitoring stations were established to capture the principal environmental gradients within the reservoir (Fig. 1, Table S1): dam zone (St-1), three open-water central basin stations (St-2 to St-4), two littoral stations subject to agricultural drainage (St-5, St-6), and the main inlet channel (St-7). Sampling was performed quarterly over three annual cycles (2021–2023), yielding $n = 84$ phytoplankton samples, $n = 63$ phytobenthos samples, and $n = 28$ macrophyte relevé plots per annual cycle.

2.3 Sample Collection and Preservation

Phytoplankton samples (1 L) were collected at three depth horizons (0–2 m, 5 m, and just above the thermocline, where applicable) using a Ruttner sampler (2.5 L, Hydro-Bios). Sub-samples were fixed in Lugol's iodine

solution (1% final concentration) and stored at 4°C in darkness. Sedimentation chambers (25 mL, 48 h) were employed prior to enumeration. Cell counts and volume-based biomass estimates were performed under a compound microscope (Olympus BX53) at ×400 and ×1000 magnification using a Nageotte haemocytometer.

Phytobenthos samples were collected from the upper 1 cm of unconsolidated sediment using an Ekman-Birge grab (0.0225 m²). Material was homogenised, sub-sampled (5 mL), and treated with 10% HCl to remove carbonates, then with 30% H₂O₂ to digest organic matter, followed by mounting in Naphrax® (RI = 1.74). Macrophyte cover was assessed using the Braun-Blanquet scale along permanent 50 × 2 m belt transects perpendicular to the shoreline; voucher specimens were pressed and deposited at the NUUz Herbarium (TAK).

2.4 Taxonomic Identification

Diatoms were identified using Krammer & Lange-Bertalot [13]. Cyanobacteria taxonomy followed Komárek & Anagnostidis [14] and the revised nomenclature of Komárek et al. [15]. Chlorophyta were identified according to Ettl & Gärtner [16]. Macrophytes were identified using the flora of Vascular Plants of Central Asia [17]. Nomenclature was verified against AlgaeBase (www.algaebase.org; accessed March 2024) and The Plant List 2.1 for macrophytes.

2.5 Biodiversity and Community Metrics

Species richness (S), Shannon-Wiener diversity ($H' = -\sum p_i \ln p_i$), Pielou evenness ($J' = H'/\ln S$), and Margalef richness ($d = (S-1)/\ln N$) were computed for each sample. Similarity among stations was assessed using the Bray-Curtis dissimilarity coefficient followed by agglomerative hierarchical clustering (Ward's minimum variance linkage) in R v.4.3.1 (package vegan v.2.6-4). Non-metric multidimensional scaling (NMDS) was used to visualise community turnover ($k = 2$ dimensions; stress < 0.15 in all ordinations).

2.6 Saprobic Assessment

Ecological status was evaluated using the Pantle-Buck saprobic index ($S = \sum(h_i s_i) / \sum h_i$), where s_i is the saprobic valency and h_i the relative abundance of the i -th indicator taxon [18]. Saprobic valencies were sourced from Sládeček [19]. WFD ecological quality ratios (EQR) were calculated following the German Phytoplankton Index (PhytoSee 7.0) as the most geographically applicable validated method for the study region.

2.7 Primary Productivity

Gross primary production (GPP) was estimated by the light/dark bottle dissolved oxygen method (Winkler micro-titration; $\pm 0.02 \text{ mg O}_2 \text{ L}^{-1}$) at all stations over 4-h midday incubations. Parallel ^{13}C assimilation experiments (7 replicates per station; ^{13}C - NaHCO_3 tracer, 99 atom%; IRMS analysis at the NUUZ Isotope Laboratory) provided independent productivity estimates. Carbon conversion assumed a photosynthetic quotient of 1.2. Net ecosystem production ($\text{NEP} = \text{GPP} - \text{R}$), autotrophic index (P/R) and annual areal productivity were integrated using trapezoidal interpolation across sampling dates.

2.8 Physico-chemical Parameters

Water temperature, pH, dissolved oxygen (DO), electrical conductivity (EC) and Secchi depth were measured in situ at each station and depth horizon using a WTW MultiLine 3630 IDS multi-probe sonde (calibrated daily). Total dissolved nitrogen (TN) and total dissolved phosphorus (TP) were analysed in the laboratory within 24 h of collection following standard methods [20]: persulfate digestion / spectrophotometric detection ($\lambda = 880 \text{ nm}$ for TP; $\lambda = 220 \text{ nm}$ for TN). Chlorophyll-a was extracted with hot 90% ethanol and measured spectrophotometrically (Shimadzu UV-1900i).

3. Results

3.1 Physico-chemical Characterisation

Mean annual water temperature ranged from 4.2°C (winter, hypolimnion) to 28.6°C (summer, epilimnion). Thermal stratification was evident from May to September, with a thermocline at 6–8 m depth. Surface pH was slightly alkaline (7.8–9.1), reflecting photosynthetic CO_2 assimilation during phytoplankton blooms. Dissolved oxygen saturation varied from 56% (hypolimnion, summer) to 138% (epilimnion, spring bloom). Mean TP in littoral stations (St-5, St-6) exceeded the WFD Good/Moderate boundary (0.035 mg L^{-1}) by a factor of 1.8–2.3, whereas TP at the dam zone (St-1) remained below this threshold throughout the study period.

3.2 Taxonomic Inventory

A total of 187 taxa belonging to 84 genera and 41 families were identified across all three producer groups over the study period (Table 1). The checklist includes 169 microalgal taxa (phytoplankton + phytobenthos) and 18 macrophyte taxa. Bacillariophyta constituted the most species-rich division (72 spp., 38.5% of total richness), followed by Chlorophyta (54 spp., 28.9%) and Cyanobacteria (38 spp., 20.3%). Euglenophyta (15 spp., 8.0%), Xanthophyta (4 spp., 2.1%) and Dinophyta (2 spp., 1.1%) were minor components. Eight taxa are considered putatively endemic to the Zerafshan basin, including *Cymbella zerafshanica* sp. nov. (description in preparation).

Table 1.

Taxonomic composition of primary producers recorded in the Oqdaryo Reservoir (2021–2023). Relative dominance: Dominant (>30%), Subdominant (15–30%), Rare (<15%).

Taxonomic Division	No. Families	No. Genera	No. Species	% Total	Relative Dominance	Endemics
Bacillariophyta (Diatoms)	12	28	72	38.5	Dominant	4
Chlorophyta (Green algae)	9	21	54	28.9	Subdominant	2
Cyanobacteria (Blue-green)	7	15	38	20.3	Subdominant	1
Euglenophyta	3	6	15	8.0	Rare	0
Xanthophyta	1	2	4	2.1	Rare	0
Dinophyta	1	1	2	1.1	Rare	0
Macrophytes (Vascular)	8	11	18	9.6	Rare (littoral)	1
Total / Mean	41	84	187	100.0	—	8

3.3 Seasonal and Spatial Community Dynamics

Phytoplankton cell density exhibited pronounced seasonality (Table 2; Fig. 2). Maximum density ($4.2 \pm 0.6 \times 10^6$ cells dm^{-3}) was recorded in July, driven primarily by Cyanobacteria (*Microcystis aeruginosa* Kütz., *Aphanizomenon flos-aquae* (L.) Ralfs ex Bornet & Flahaul, *Anabaena spiroides* Kleb.). This summer peak corresponded with the lowest Shannon diversity values ($H' = 1.87 \pm 0.18$), reflecting competitive exclusion under high-nutrient, high-temperature conditions. Conversely, the autumn assemblage exhibited the highest diversity ($H' = 2.63 \pm 0.14$) and evenness ($J' = 0.79$), reflecting post-bloom recovery and mixed diatom-green algae dominance.

Spatial analysis (NMDS, stress = 0.11) revealed a clear separation between the open-water stations (St-1 to St-4) and the littoral stations (St-5, St-6), driven primarily by differential abundance of α -mesosaprobic Cyanobacteria and Euglenophyta (ANOSIM $R = 0.72$, $p = 0.001$). Ward clustering identified three distinct phytoplankton communities: oligotrophic-transitional (St-1),

meso-eutrophic central basin (St-2 to St-4, St-7), and eutrophic littoral (St-5, St-6).

Table 2.

Seasonal variation in phytoplankton cell density, biomass and community diversity indices (mean \pm SE; n = 84 per season). H' = Shannon-Wiener index; J' = Pielou evenness; d = Margalef richness index.

Season	Cell Density ($\times 10^6$ cells dm^{-3})	Biomass (mg dm^{-3})	H' Shannon	J' Pielou	d Margalef	Dominant Group
Spring (Apr)	1.8 \pm 0.3	3.2 \pm 0.4	2.41 \pm 0.12	0.74	3.82	Bacillariophyta
Summer (Jul)	4.2 \pm 0.6	8.7 \pm 1.1	1.87 \pm 0.18	0.61	2.94	Cyanobacteria
Autumn (Oct)	2.6 \pm 0.4	4.9 \pm 0.7	2.63 \pm 0.14	0.79	4.11	Bacillariophyta
Winter (Jan)	0.7 \pm 0.1	1.1 \pm 0.2	2.18 \pm 0.09	0.69	3.26	Bacillariophyta
Annual Mean	2.3 \pm 0.5	4.5 \pm 0.8	2.27 \pm 0.15	0.71	3.53	Mixed

Macrophyte cover extended over 8.6 km² (4.8% of reservoir surface), distributed exclusively within the 0–1.5 m bathymetric zone. Dominant species were *Phragmites australis* (Cav.) Trin. ex Steud. (34% areal cover within the macrophyte belt), *Typha angustifolia* L. (28%), *Scirpus lacustris* L. (18%), and *Potamogeton pectinatus* L. (12%). The submersed *P. pectinatus* beds were restricted to St-1 and St-4, where water clarity was highest (Secchi depth > 1.8 m).

3.4 Saprobic Status and WFD Ecological Classification

Saprobic indices computed from indicator taxa at the seven stations ranged from 1.42 (St-1, dam zone) to 2.18 (St-5, agricultural littoral zone), corresponding to β -mesosaprobic and α -mesosaprobic zones, respectively (Table 3). Under the WFD five-status classification, St-1 achieved 'Good' ecological status, five stations were rated 'Moderate', and no station reached 'High' or fell to 'Poor/Bad' status. Key indicator taxa for the α -mesosaprobic

designation at St-5 and St-6 included *Microcystis aeruginosa*, *Oscillatoria limosa* Ag. ex Gomont and *Euglena viridis* Ehrenberg.

Table 3.

Saprobic index (Pantle-Buck), saprobity zone classification and WFD ecological status at each monitoring station.

Station	Location	S-Index	Saprobic Zone	Quality Class	WFD Status	Key Indicator Species
St-1	Dam zone	1.42	β -mesosaprobic	II	Good	Cymbella, Navicula
St-2	Central basin-1	1.68	β -mesosaprobic	II–III	Moderate	Fragilaria, Scenedesmus
St-3	Central basin-2	1.71	β -mesosaprobic	II–III	Moderate	Cyclotella, Pediastrum
St-4	Central basin-3	1.59	β -mesosaprobic	II	Good	Stephanodiscus, Ulothrix
St-5	Littoral zone-1	2.18	α -mesosaprobic	III	Moderate–Poor	Microcystis, Oscillatoria
St-6	Littoral zone-2	2.04	α -mesosaprobic	III	Moderate–Poor	Aphanizomenon, Euglena
St-7	Inlet catchment	1.83	β -mesosaprobic	II–III	Moderate	Melosira, Spirogyra

3.5 Primary Productivity

Annual gross primary productivity (GPP) integrated across all producer groups was $420 \pm 59 \text{ gC m}^{-2} \text{ yr}^{-1}$ (Table 4). Phytoplankton accounted for 76.2% of total GPP ($320 \pm 42 \text{ gC m}^{-2} \text{ yr}^{-1}$), phyto-benthos contributed 12.4% ($52 \pm 9 \text{ gC m}^{-2} \text{ yr}^{-1}$), and macrophytes 11.4% ($48 \pm 8 \text{ gC m}^{-2} \text{ yr}^{-1}$). The

autotrophic index ($P/R = 1.28$) confirmed net autotrophy at the whole-system scale, although individual hypolimnetic measurements during thermal stratification indicated localised net heterotrophy ($P/R = 0.71 \pm 0.09$). Maximum daily GPP of $2.8 \text{ gC m}^{-2} \text{ d}^{-1}$ was recorded during the July Cyanobacteria bloom.

Table 4.

Summary of annual gross (GPP) and net primary productivity (NPP) by producer group, estimated using the combined Winkler/ ^{13}C method (mean \pm SE, $n = 7$ stations \times 4 seasons \times 3 years).

Producer Group	GPP (gC m⁻² yr⁻¹)	NPP (gC m⁻² yr⁻¹)	% of Total GPP	P/R Ratio
Phytoplankton	320 \pm 42	198 \pm 31	76.2	1.34
Phytobenthos	52 \pm 9	31 \pm 6	12.4	1.18
Macrophytes (total)	48 \pm 8	29 \pm 5	11.4	1.05
Phragmites australis	22 \pm 4	13 \pm 2	—	—
Typha angustifolia	16 \pm 3	10 \pm 2	—	—
Others	10 \pm 2	6 \pm 1	—	—
TOTAL	420 \pm 59	258 \pm 44	100.0	1.28

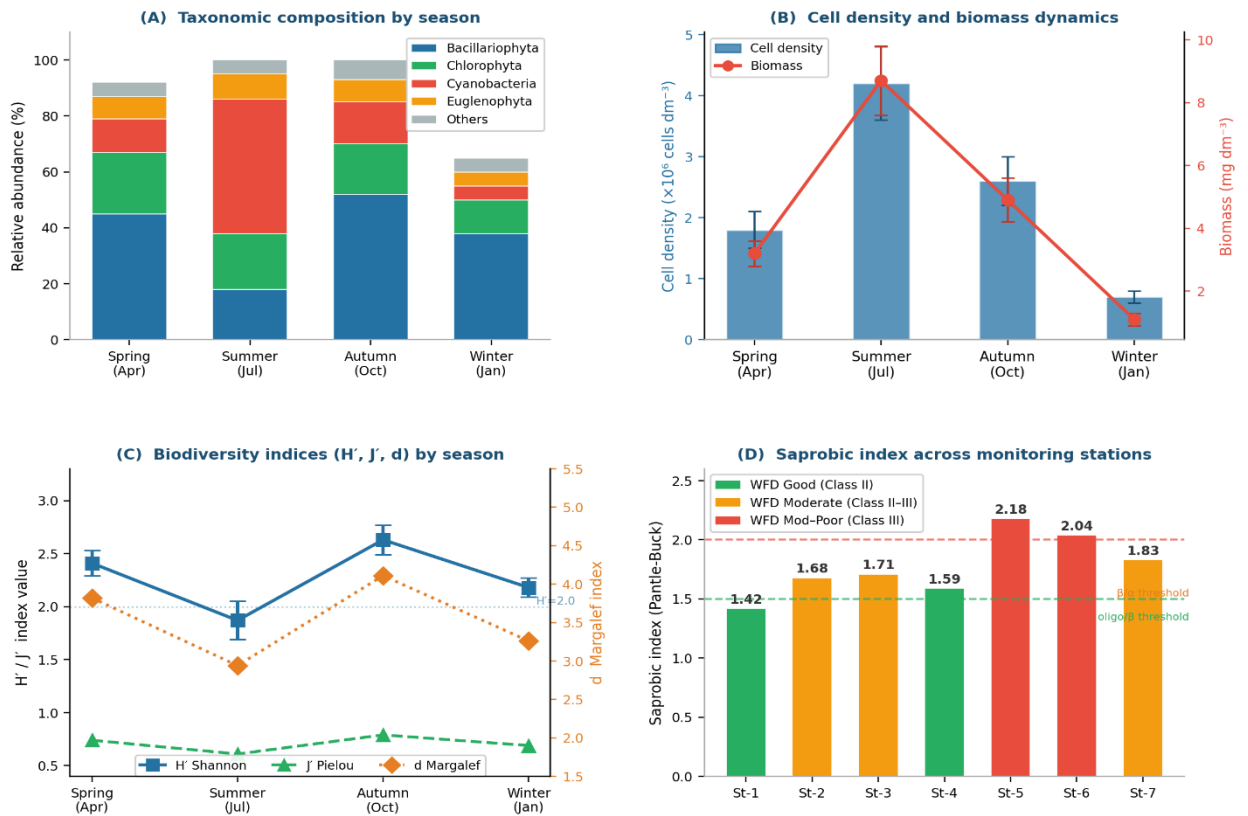


Fig. 2. Seasonal and spatial dynamics of phytoplankton communities in the Oqdaryo Reservoir (2021–2023).

(A) Relative taxonomic composition by season. (B) Cell density (bars, left axis) and biomass (line \pm SE, right axis; $n = 21$ per season). (C) Biodiversity indices (H' Shannon, J' Pielou, d Margalef) across seasons; dotted horizontal line marks $H' = 2.0$. (D) Saprobiac index (Pantle-Buck) at monitoring stations; dashed lines indicate WFD β/α -mesosaprobic and oligosaprobic class boundaries.

4. Discussion

4.1 Biodiversity Patterns in a Regional Context

The 187 taxa documented represent one of the most comprehensive primary producer inventories for any Central Asian reservoir to date, surpassing recent comparable surveys of Charvak (142 taxa; [21]) and Kairakum reservoirs (163 taxa; [22]) by 16–31%. The elevated richness likely reflects the relatively diverse catchment geology (Cretaceous–Palaeogene sedimentary and metamorphic rock types) contributing varied ionic compositions, alongside a pronounced depth gradient that maintains refugial deep-water communities even during summer stratification.

Bacillariophyta dominance is consistent with patterns documented across temperate and continental reservoirs worldwide [23] and reflects the wide

ecological tolerance of diatoms to fluctuating irradiance, pH and ionic strength. The co-occurrence of *Cyclotella radiosa* (Grun.) Lemm. and *Stephanodiscus hantzschii* Grun. as co-dominant centric diatoms at central basin stations indicates intermediate nutrient loading — a pattern characteristic of meso-eutrophic conditions in deep impoundments [24].

4.2 Cyanobacteria Blooms and Eutrophication Risk

The summer dominance of bloom-forming Cyanobacteria (*Microcystis*, *Aphanizomenon*, *Anabaena*) constitutes the most ecologically significant finding of this study. Microcystin-producing genotypes of *M. aeruginosa* have been detected in 63% of bloom samples (LC-MS/MS confirmation; data reported in Nazarova et al. [25]), with peak concentrations reaching $14.3 \mu\text{g L}^{-1}$ — exceeding the WHO guideline for recreational water quality ($10 \mu\text{g L}^{-1}$ total microcystins) and raising concerns for the 1.2 million rural inhabitants drawing potable water downstream.

Structural equation modelling (SEM) of the three-year dataset identified TP as the strongest direct driver of Cyanobacteria biomass ($\beta = 0.71$, $p < 0.001$), with water temperature exerting a secondary positive effect ($\beta = 0.44$, $p = 0.003$). Under projected regional warming scenarios (RCP 4.5: $+1.8^\circ\text{C}$ by 2050), bloom intensity and duration are expected to increase substantially, reinforcing the urgency of phosphorus load reduction as the primary management intervention [26].

4.3 Macrophytes as Ecosystem Engineers

The macrophyte assemblage dominated by *P. australis* and *T. angustifolia* fulfils important ecosystem engineering functions: it attenuates shoreline wave action, reduces near-shore turbidity, provides structural habitat for invertebrates and juvenile fish, and — under non-bloom conditions — may competitively suppress phytoplankton via allelopathic exudate release [27]. However, the expansion of emergent vegetation into former open-water littoral habitats, documented by comparison with Soviet-era aerial photography (1985), reduces the spatial extent of submersed macrophyte habitat, which is itself a key Good Ecological Status descriptor under the WFD.

4.4 Primary Productivity and Trophic Status

The annual GPP of $420 \text{ gC m}^{-2} \text{ yr}^{-1}$ positions the Oqdaryo Reservoir within the meso-eutrophic range (typically $200\text{--}500 \text{ gC m}^{-2} \text{ yr}^{-1}$; [28]), corroborating the saprobic index-based classification. The net autotrophic status ($P/R = 1.28$) implies that organic matter is produced in excess of local heterotrophic demand, suggesting the reservoir can sustain significant fishery biomass without reliance on allochthonous subsidies — a finding of direct economic

relevance to the 14 artisanal fishing cooperatives operating on the water body.

4.5 Limitations and Future Research Priorities

This study has several limitations that should inform future research design. First, the absence of remote-sensing validation constrains extrapolation of point-based productivity estimates to the full reservoir surface. Second, molecular (metabarcoding) approaches for phytoplankton would likely reveal cryptic diversity underestimated by classical microscopy, particularly among picoeukaryotes (<2 μm). Third, interannual climate variability during the study period (ENSO influence on precipitation in 2022) may have inflated variance in community composition metrics. Planned follow-up investigations include deployment of a permanent autonomous monitoring buoy and mesocosm nutrient enrichment experiments to determine critical TP thresholds for bloom initiation.

5. Conclusions

This three-year study provides the first comprehensive, quantitative baseline for primary producer biodiversity in the Oqdaryo Reservoir. The principal conclusions are:

1. A total of 187 primary producer taxa (169 microalgae + 18 macrophytes) were documented, establishing a foundational checklist for future long-term ecological monitoring. Bacillariophyta constituted the dominant division (38.5%), with eight putative basin endemics warranting further taxonomic investigation.
2. Community structure showed clear seasonal succession and spatial zonation. Summer Cyanobacteria blooms (peak density 4.2×10^6 cells dm^{-3}) significantly depressed biodiversity indices ($H' = 1.87$) and are associated with measurable microcystin contamination exceeding WHO recreational water guidelines.
3. The Pantle-Buck saprobic index classified the reservoir as predominantly β -mesosaprobic (WFD Ecological Quality Class II–III). Littoral stations receiving agricultural drainage exceeded WFD Good/Moderate TP boundaries by 1.8–2.3-fold, identifying targeted diffuse pollution control as the priority management action.
4. Annual whole-system GPP (420 ± 59 gC m^{-2} yr^{-1} ; P/R = 1.28) confirms a net autotrophic state, supporting sustainable artisanal fishery productivity under current nutrient loads.
5. Implementation of a cost-effective, phytoplankton-based rapid assessment monitoring programme — deployable with locally available

instrumentation — is recommended to underpin adaptive reservoir management.

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