



Plankton–Bird Coupling in an Urban Lake: Linking Trophic Micro-Indicators with Waterbird Guild Dynamics in Blue Bird Lake, Hisar

Kirti Beniwal, Researcher, Dept. of Zoology, NIILM University, Kaithal (Haryana)

Dr. Varsha Sharma, Assistant Professor, Dept. of Zoology, NIILM University, Kaithal (Haryana)

Abstract

Urban lakes are small but ecologically important ecosystems. Even when surrounded by human activities, they can support rich biodiversity, including plankton, fish, and waterbirds. This study examines the ecological connection between plankton communities and waterbird feeding guilds in Blue Bird Lake, Hisar (Haryana). The aim was to understand how small microscopic organisms (plankton) influence the distribution and seasonal patterns of birds at higher trophic levels. Seasonal sampling of water quality, phytoplankton, zooplankton, and bird diversity was conducted over one annual cycle. The results show that seasonal changes in nutrients and dissolved oxygen influence plankton abundance, which in turn affects fish availability and bird guild structure. Winter months showed the highest bird diversity, closely associated with increased zooplankton density and stable water conditions. The study concludes that plankton can act as early biological indicators of habitat quality and bird-supporting capacity in urban lakes. An integrated plankton–bird monitoring framework is suggested for sustainable lake management.

Keywords: Urban limnology, plankton diversity, waterbird guilds, trophic linkage, Blue Bird Lake, Hisar

1. Introduction

Freshwater lakes function as interconnected ecological systems in which physical, chemical, and biological components continuously influence each other. In India, small and medium-sized urban lakes are increasingly recognized as important biodiversity reservoirs despite facing rapid urban expansion. According to the Ministry of Jal Shakti (Census of Water Bodies, 2023), India has over 2.4 million water bodies, many of which are small lakes and ponds that support local ecosystems and livelihoods. However, urban lakes frequently experience nutrient inflow, surface runoff, untreated sewage discharge, and recreational pressure. These inputs alter water chemistry—particularly dissolved oxygen (DO), Biological Oxygen Demand (BOD), nitrates, and phosphates—thereby influencing biological productivity and habitat quality. Studies conducted across Indian urban lakes between 2015 and 2023 consistently show that moderate nutrient enrichment can enhance primary productivity, whereas excessive nutrient loading leads to eutrophication, oxygen depletion, and biodiversity decline.

Plankton form the base of aquatic food webs and act as sensitive indicators of ecological condition. Phytoplankton convert solar energy into organic matter through photosynthesis and are directly influenced by light availability, nutrient concentration, and temperature. Zooplankton feed on phytoplankton and serve as an essential energy link to fish and aquatic invertebrates. Field surveys in north Indian lakes (2018–2022) indicate that seasonal plankton abundance peaks during post-monsoon and winter when water transparency improves and dissolved oxygen stabilizes above 6 mg/L, creating favourable conditions for aquatic life. In contrast, monsoon runoff often increases turbidity and nutrient pulses, temporarily altering plankton composition. Such seasonal plankton fluctuations influence fish growth and insect availability, which ultimately affect higher trophic levels including birds.

Blue Bird Lake in Hisar (Haryana), located in a semi-arid agro-urban landscape, represents a typical north Indian urban freshwater system. Preliminary biodiversity surveys conducted by local ecological groups (2022–2023) recorded more than 60–75 bird species annually, including resident species such as egrets and cormorants and winter migrants like northern shovelers and common teal. Seasonal bird counts show peak abundance between November and February, coinciding with improved water quality parameters and increased zooplankton



density observed in winter sampling. Informal water-quality assessments during 2023 indicated dissolved oxygen levels ranging between 5.5–8.0 mg/L in winter and slightly lower values during summer, while nutrient levels showed moderate monsoon-driven increases. However, despite these observations, no integrated trophic-level study has systematically examined how plankton communities influence waterbird feeding guild distribution in this lake.

Therefore, the present research aims to bridge this ecological gap by combining seasonal limnological data (temperature, transparency, DO, BOD, nitrates, phosphates), plankton diversity indices, and structured bird guild surveys conducted over a one-year cycle (2022–2023). By linking micro-level trophic indicators with macro-level bird assemblages, the study seeks to provide scientifically grounded evidence that plankton dynamics can serve as predictive tools for understanding avian habitat suitability in urban lakes. In simple terms, this research investigates how microscopic life in the water ultimately shapes the visible bird diversity observed around Blue Bird Lake, Hisar.

1.2. Objectives of the Study

1. To analyse seasonal changes in physico-chemical parameters of Blue Bird Lake.
2. To examine phytoplankton and zooplankton diversity and abundance.
3. To classify waterbirds into feeding guilds and document seasonal variation.
4. To study the relationship between plankton abundance and bird guild distribution.
5. To propose a trophic linkage model for urban lake conservation.

2. Literature Review

Sekhon, Aulakh & Kler (2023) – Migratory Bird Use of Rural Wetlands

Sekhon and co-authors (2023) conducted seasonal surveys across rural wetlands to document migratory bird patterns and ecological guild dominance. Their findings showed that winter months recorded the highest species richness due to enhanced feeding opportunities created by stable shallow-water zones. The study emphasized that trophic productivity, influenced by seasonal nutrient pulses, determines habitat attractiveness for migratory guilds. The authors concluded that ecological monitoring should integrate habitat structure and seasonal productivity to understand bird dynamics. From a stopover ecology and habitat filtering framework, the research explained how migratory birds select wetlands offering optimal food-energy returns.

Sidhu, Sekhon, Aulakh & Kler (2021) – Village Ponds of Punjab

Sidhu and colleagues (2021) investigated the ecological importance of village ponds in Punjab for supporting waterbird diversity. Their research evaluated species richness, seasonal bird presence, and habitat quality across multiple rural ponds. They found that ponds with stable water levels and moderate nutrient productivity supported higher bird abundance, especially winter migrants. Though plankton were not directly quantified, the authors linked bird presence to aquatic productivity and prey availability, indicating bottom-up trophic influences. The study concluded that even small wetlands function as productive micro-ecosystems when trophic balance is maintained. Using landscape connectivity theory, the research argued that interconnected pond networks collectively sustain regional avian biodiversity.

Gadekar (2020) – Freshwater Zooplankton Baseline Study

Gadekar (2020) provided a baseline zooplankton diversity survey in Indian freshwater systems, emphasizing the need for reference datasets for ecological comparison. The study catalogued species richness across different trophic states and observed that lakes with moderate nutrient levels supported balanced plankton communities, while polluted lakes showed dominance by tolerant species. The research concluded that baseline micro-faunal inventories help detect ecological shifts before visible degradation occurs. Applying baseline monitoring framework theory, the author stressed the importance of long-term biological records in evaluating ecosystem resilience.



Sayasrao & More (2020) – Zooplankton as Early Warning Indicators

Sayasrao and More (2020) examined zooplankton diversity patterns in freshwater lakes and highlighted their sensitivity to nutrient enrichment and organic load. The study found that rotifer dominance increased in nutrient-rich conditions, indicating eutrophic tendencies. They argued that plankton communities provide early warning signals for trophic imbalance, which may later manifest as fish decline or reduced bird visitation. The research concluded that plankton-based indices are cost-effective tools for ecological monitoring. From an indicator-based environmental management theory, the authors proposed integrating plankton monitoring into wetland governance systems.

Yardi, Bharucha & Girade (2019) – Pashan Lake, Pune

Yardi, Bharucha and Girade (2019) examined ecological recovery patterns in Pashan Lake, Pune, after restoration interventions. Their study focused on water quality improvement, habitat restructuring, and avian diversity response in an urban lake system. Although plankton were not the primary subject, the research indirectly highlighted trophic linkages by demonstrating that improvements in habitat and nutrient balance resulted in changes in bird abundance and guild composition. The authors observed that piscivorous and insectivorous birds increased in areas where shallow-water productivity improved, suggesting that lower trophic productivity influences higher trophic use. The study concluded that bird assemblages serve as ecological response indicators reflecting underlying trophic functioning. From a socio-ecological systems and urban commons perspective, the lake's ecological condition was shaped by both biophysical processes and community-led governance efforts.

Rao et al. (2015) – Madduvalasa Reservoir, Andhra Pradesh

Rao and co-authors (2015) studied spatial variation in zooplankton communities across different zones of Madduvalasa Reservoir. They observed that shoreline stations with vegetation supported higher plankton diversity than open-water sites. This spatial heterogeneity suggested that microhabitat differences strongly influence trophic productivity. The study concluded that multi-station sampling provides a realistic understanding of ecological structure. Through patch dynamics theory, the reservoir was interpreted as a mosaic of productive and less-productive zones influencing overall biodiversity patterns.

Karuthapandi, Rao & Xavier (2013) – Zooplankton and Trophic Condition Study

Karuthapandi and colleagues (2013) evaluated zooplankton composition in relation to water quality and trophic state in a South Indian freshwater system. Their research demonstrated that balanced zooplankton communities corresponded with moderate nutrient levels, while eutrophic conditions led to reduced diversity and bloom-forming dominance. They emphasized that zooplankton act as a functional bridge between primary producers and higher trophic levels. The study concluded that trophic-state assessment should integrate plankton structure analysis for accurate ecosystem evaluation. Under functional bioindicator theory, plankton communities were positioned as central regulators of aquatic food-web stability.

Koli & Muley (2012) – Tulshi Reservoir, Maharashtra

Koli and Muley (2012) conducted a seasonal assessment of zooplankton communities in Tulshi Reservoir. Their findings showed that plankton density peaked in winter when water temperature stabilized and transparency improved. During monsoon, turbidity reduced plankton productivity due to limited light penetration. The research highlighted that aquatic ecosystems function through seasonal pulses that reorganize food webs. The study concluded that understanding plankton seasonality is crucial for predicting fish and avian feeding opportunities. From a seasonal pulse theory perspective, lake ecosystems were described as dynamic systems structured by cyclical environmental forces.

Donar & Reddy (2012) – Nipani Reservoir, Karnataka

Donar and Reddy (2012) investigated zooplankton diversity and seasonal variation in a freshwater reservoir of Karnataka. Their research identified multiple zooplankton groups, including rotifers, cladocerans, and copepods, which fluctuated according to nutrient levels



and seasonal temperature variation. They reported that zooplankton diversity declined during periods of high organic pollution and increased during stable post-monsoon conditions. The authors concluded that zooplankton act as sensitive bioindicators of trophic status and water quality. Using trophic linkage theory, the study explained how micro-level plankton shifts can influence fish populations and indirectly affect higher consumers such as waterbirds.

3. Study Area

Blue Bird Lake is located in Hisar district, Haryana, in a semi-arid climatic zone. The lake has shallow margins, open water areas, and patches of aquatic vegetation. It receives seasonal rainfall during monsoon and experiences high summer temperatures. Surrounding land use includes urban settlement, recreational space, and agricultural areas.

4. Materials and Methods

Sampling Period

Field observations were conducted over one year covering:

- Summer
- Monsoon
- Post-monsoon
- Winter

Water Quality Analysis

The following parameters were measured seasonally:

- Temperature
- Transparency
- pH
- Dissolved Oxygen (DO)
- Biological Oxygen Demand (BOD)
- Nitrate and Phosphate concentration

Plankton Collection and Identification

Water samples were filtered using plankton nets. Samples were preserved and examined under a compound microscope. Plankton were identified up to genus level using standard identification keys. Diversity indices were calculated to assess ecological balance.

Bird Survey

Birds were recorded using transect and point-count methods during early morning hours. Species were grouped into feeding guilds:

- Carnivorous (fish eaters)
- Insectivorous
- Omnivorous
- Herbivorous

Data Analysis

Correlation analysis was performed to examine relationships between plankton abundance and bird guild density.

5. Data Analysis and Interpretation

5.1 Seasonal Variation in Physico-Chemical Parameters

Table 1. Seasonal Mean Values of Water Quality Parameters

Parameter	Summer	Monsoon	Post-Monsoon	Winter
Temperature (°C)	32.4	29.1	24.3	16.8
Transparency (cm)	38	24	46	52
pH	8.3	7.8	8.1	7.9
DO (mg/L)	4.6	5.8	6.4	7.2
BOD (mg/L)	5.9	4.8	3.6	2.9
Nitrate (mg/L)	1.92	2.84	1.56	1.21
Phosphate (mg/L)	0.82	1.14	0.63	0.48

Water temperature was highest in summer (32.4°C) and lowest in winter (16.8°C), reflecting the semi-arid climate of Hisar. Transparency declined sharply during monsoon (24 cm) due to runoff and suspended particles. Dissolved Oxygen (DO) was lowest in summer (4.6 mg/L) when high temperature increased biological oxygen demand, and highest in winter (7.2 mg/L), indicating better oxygen conditions.

Nitrate and phosphate levels peaked during monsoon due to agricultural runoff and surrounding land-use influence. Higher BOD in summer (5.9 mg/L) suggests organic loading stress during low-water conditions. Winter showed improved ecological balance with lower nutrients and higher oxygen.

This confirms Objective 1 — Blue Bird Lake exhibits strong seasonal limnological fluctuation typical of urban semi-arid lakes.

5.2 Phytoplankton and Zooplankton Diversity

Table 2. Seasonal Plankton Density (Mean Organisms/Litre)

Group	Summer	Monsoon	Post-Monsoon	Winter
Phytoplankton	1480	1920	1350	980
Zooplankton	720	860	1040	1180
Shannon Index (H')	1.84	1.62	2.11	2.34

Phytoplankton density peaked during monsoon (1920 org/L) due to nutrient enrichment from runoff. However, diversity index (H') was lowest in monsoon (1.62), indicating dominance by fewer tolerant genera (e.g., cyanophytes). Zooplankton density increased steadily from summer to winter, reaching maximum in winter (1180 org/L). This reflects improved water clarity and balanced productivity. Higher Shannon index in winter (2.34) indicates more stable ecological conditions. Balanced plankton structure during winter supports higher trophic levels.

This fulfills Objective 2 — plankton abundance and diversity fluctuate seasonally, with winter showing highest ecological stability.

5.3 Seasonal Bird Guild Distribution

Table 3. Seasonal Bird Guild Density (Individuals per Survey)

Guild	Summer	Monsoon	Post-Monsoon	Winter
Carnivorous	42	48	63	95
Insectivorous	36	40	58	72
Omnivorous	28	31	36	49
Herbivorous	18	22	26	33
Total Species	28	32	41	58

Bird abundance and species richness peaked in winter (58 species). Carnivorous guild showed highest increase in winter (95 individuals), coinciding with high zooplankton and improved fish prey availability. Insectivorous birds increased during post-monsoon and winter, possibly due to improved invertebrate emergence linked to plankton productivity. Summer recorded lowest bird density due to high temperature, lower DO, and reduced prey availability.

This confirms Objective 3 — bird guild structure varies strongly with season, especially winter migratory influx.

5.4 Correlation between Plankton Abundance and Bird Guild Density

Table 4. Pearson Correlation Coefficient (r)

Relationship	r-value	Significance (p<0.05)
Zooplankton vs Carnivorous Birds	0.81	Significant
Zooplankton vs Insectivorous Birds	0.74	Significant
Phytoplankton vs Herbivorous Birds	0.63	Moderate
Phytoplankton vs Carnivorous Birds	0.52	Moderate
BOD vs Bird Diversity	-0.69	Significant Negative



Strong positive correlation ($r = 0.81$) between zooplankton and carnivorous birds confirms trophic linkage. As zooplankton density increased, carnivorous bird numbers also increased. Negative correlation between BOD and bird diversity (-0.69) indicates that pollution stress reduces avian richness. Phytoplankton showed moderate relationship with herbivorous guild, suggesting indirect food-web connections.

This fulfills Objective 4 — clear statistical evidence supports plankton–bird coupling.

5.5 Proposed Trophic Linkage Model for Urban Lake Conservation

The findings of the study indicate that Blue Bird Lake functions through a bottom-up trophic regulation mechanism in which seasonal nutrient input plays a central role in structuring the entire food web. During the monsoon season, runoff from surrounding urban and agricultural areas increases the concentration of nutrients such as nitrates and phosphates in the lake. This nutrient pulse stimulates phytoplankton growth, leading to higher primary productivity. As phytoplankton biomass increases, zooplankton populations also expand because they feed directly on phytoplankton. In the post-monsoon and early winter seasons, this increased zooplankton availability supports higher populations of aquatic insects and small fish. These organisms serve as prey for carnivorous and insectivorous waterbirds, resulting in a noticeable increase in bird abundance and guild diversity during winter. Thus, the seasonal pathway can be understood as nutrient input leading to phytoplankton growth, followed by zooplankton expansion, fish and invertebrate rise, and finally an increase in bird populations. However, this productive trophic cascade operates effectively only within ecological limits. When nutrient loading exceeds a threshold, especially under conditions of high biological oxygen demand (BOD), phytoplankton communities may shift toward cyanobacterial dominance. Such excessive blooms reduce water transparency and lower dissolved oxygen levels during decomposition, weakening trophic stability. Under these stressed conditions, zooplankton diversity declines, fish experience oxygen stress, and bird richness decreases due to reduced prey availability and deteriorating habitat quality. Therefore, nutrient balance is critical for maintaining ecological stability in the lake.

The study further indicates that winter represents the most stable trophic window in Blue Bird Lake. During this season, dissolved oxygen levels are relatively higher due to lower temperatures, plankton diversity remains balanced without harmful dominance, and water transparency improves. These conditions support greater fish and invertebrate availability, which in turn attracts a higher richness of resident and migratory birds. Overall, the ecological interpretation suggests that Blue Bird Lake's avian diversity is closely linked to micro-level trophic processes. Maintaining nutrient control, preventing excessive organic loading, and preserving habitat heterogeneity are essential for sustaining trophic balance and long-term urban lake conservation.

6. Results and Discussion

Results

The seasonal assessment of water quality in Blue Bird Lake revealed clear climatic influence on physicochemical conditions. During summer, water temperature was highest due to intense heat in the semi-arid region of Hisar, leading to moderate concentration of nutrients and slight reduction in dissolved oxygen levels. In the monsoon season, heavy surface runoff from surrounding urban and agricultural areas increased suspended solids, resulting in lower transparency and slight nutrient enrichment. However, winter recorded comparatively higher dissolved oxygen and more stable water chemistry because of lower temperatures and reduced microbial decomposition rates. Nutrient concentrations showed a moderate rise during monsoon due to inflow, but they remained within tolerable ecological limits during most of the study period. The plankton community structure reflected these seasonal water-quality shifts. Phytoplankton were mainly dominated by green algae (Chlorophyceae) and diatoms (Bacillariophyceae), which are typical indicators of moderately productive freshwater systems. The highest phytoplankton diversity was observed during post-monsoon and winter seasons when water clarity improved and light penetration supported balanced



photosynthetic activity. Zooplankton communities, particularly rotifers and cladocerans, showed peak abundance in winter, likely due to improved water stability and increased phytoplankton availability as food. In contrast, monsoon season exhibited fluctuating plankton density because increased turbidity and suspended particles disturbed light penetration and habitat conditions. Waterbird diversity followed a distinct seasonal pattern. The highest species richness was recorded in winter due to the arrival of migratory birds. Carnivorous and insectivorous guilds were dominant in shallow and productive zones where fish, insects, and aquatic invertebrates were abundant. Herbivorous birds were mainly concentrated along vegetated margins where aquatic plants and macrophytes were available. During summer, bird richness declined because of elevated temperature, reduced water depth, and lower prey visibility. This indicates that habitat suitability in Blue Bird Lake is strongly influenced by seasonal water availability and trophic conditions.

Statistical analysis further supported the trophic linkage hypothesis. A positive correlation was observed between zooplankton abundance and carnivorous bird density, suggesting that increased secondary productivity enhances prey availability for higher trophic levels. A moderate association was also found between phytoplankton productivity and herbivorous guild presence, particularly in vegetated zones. Dissolved oxygen showed a positive relationship with overall bird richness, indicating that better water quality supports higher biodiversity. Conversely, periods of elevated BOD and nutrient spikes were associated with reduced presence of sensitive bird species, highlighting that excessive organic loading weakens trophic stability. Overall, the results confirm that seasonal plankton dynamics significantly influence bird guild distribution through bottom-up ecological regulation. The study confirms that plankton communities play an important role in shaping bird assemblages in urban lakes. When plankton diversity is balanced and nutrients remain within moderate limits, the food web remains stable. This stability supports fish and insect populations, which attract bird guilds.

Winter season provides ideal ecological conditions—moderate temperature, higher dissolved oxygen, and improved water clarity—leading to increased plankton productivity and higher bird diversity.

Urban pressures, if unmanaged, may disrupt this trophic linkage by causing eutrophication or oxygen depletion. Therefore, plankton monitoring can serve as an early ecological warning system before visible bird decline occurs.

Discussion

The findings of this study show that Blue Bird Lake behaves like a typical urban freshwater ecosystem where seasonal climate and nutrient inflow control overall ecological balance. The lake does not remain ecologically constant throughout the year; instead, its physical, chemical, and biological conditions change with seasons. Summer heat increases water temperature and creates moderate stress conditions, while monsoon runoff brings nutrients and suspended materials into the lake. Winter, however, provides relatively stable and balanced conditions with higher dissolved oxygen and improved water clarity. These seasonal changes form the foundation upon which biological communities respond. Plankton communities, being the base of the aquatic food web, showed clear seasonal patterns. When nutrients increased during monsoon, phytoplankton density rose, but diversity did not always increase proportionally. In contrast, winter conditions supported more balanced and stable plankton diversity. Zooplankton, which depend on phytoplankton as food, increased gradually toward winter. This indicates that ecological stability is not simply about high productivity but about balanced productivity. A stable plankton community supports better food availability for higher trophic levels. Waterbird diversity also followed seasonal ecological patterns. The highest richness and abundance were observed in winter, especially among carnivorous and insectivorous birds. This suggests that improved lower trophic productivity indirectly benefits bird populations. When plankton and aquatic invertebrates increase, fish and insect availability also improve, attracting birds to the lake. During



summer, harsh temperature and lower oxygen conditions reduce habitat suitability and prey availability, resulting in comparatively lower bird richness. Overall, the study confirms that Blue Bird Lake functions through a bottom-up ecological process where changes at the micro level (water quality and plankton) influence higher organisms such as birds. The lake remains ecologically stable when nutrients are balanced and oxygen levels are adequate. However, excessive nutrient loading or organic pollution may disturb this balance and reduce biodiversity. Therefore, maintaining water quality and monitoring plankton communities are important for sustaining bird diversity and long-term urban lake conservation.

7. Conclusion

The present study clearly establishes that Blue Bird Lake functions through an interconnected trophic system in which lower-level ecological processes influence higher organisms such as birds. Seasonal changes in nutrient input and water quality parameters regulate phytoplankton growth, which in turn determines zooplankton abundance. This cascading effect moves upward in the food chain, influencing fish and aquatic insect availability and ultimately shaping the distribution and density of different bird feeding guilds. The results demonstrate that plankton diversity is not only a measure of lake productivity but also an indicator of ecological balance. Similarly, bird guild composition reflects the availability of trophic resources and habitat quality within the lake ecosystem.

The study also highlights that dissolved oxygen levels and controlled nutrient concentrations are essential for maintaining trophic stability. When nutrients remain within moderate limits, the lake supports balanced plankton communities, adequate prey populations, and higher bird richness. However, excessive nutrient loading or increased biological oxygen demand can disrupt this stability and weaken the food-web structure. Therefore, integrated monitoring of plankton communities and waterbird guilds can serve as a practical ecological tool for urban lake conservation. By linking micro-level indicators with visible biodiversity patterns, such an approach can strengthen wetland management strategies and help sustain long-term ecosystem health in urban freshwater systems.

8. Conservation Recommendations

The findings of this study suggest that conservation of Blue Bird Lake should move beyond simple beautification or periodic cleaning and instead focus on maintaining ecological processes that sustain trophic balance. Since plankton form the base of the food web and directly influence bird guild distribution, conservation planning must integrate limnological monitoring with avifaunal assessment.

Regular seasonal monitoring of plankton and water quality is essential. Sampling of physicochemical parameters such as dissolved oxygen, BOD, nitrates, phosphates, transparency, and temperature should be conducted at least four times a year (summer, monsoon, post-monsoon, and winter). Along with this, phytoplankton and zooplankton diversity indices should be calculated to detect early signs of imbalance, such as cyanobacterial dominance or sudden decline in zooplankton abundance. Continuous monitoring will help identify stress conditions before visible ecological damage occurs.

Control of nutrient inflow during monsoon is particularly important because runoff from surrounding agricultural fields and urban areas increases nitrate and phosphate concentrations. Establishing vegetative buffer strips around the lake boundary can reduce nutrient and sediment entry. Proper drainage planning, sediment traps, and filtration zones can further minimize nutrient pulses. Preventing direct sewage discharge and ensuring that any inflow passes through preliminary treatment systems will reduce organic loading and prevent eutrophication.

Protection of shallow productive zones is another critical recommendation. The study indicates that shallow and vegetated margins support high plankton productivity, invertebrate growth, and bird feeding activity. These areas should not be concretized or excessively cleared for recreational infrastructure. Maintaining aquatic macrophytes in controlled proportion helps stabilize sediments, support herbivorous birds, and provide shelter for fish



and insects. Habitat heterogeneity—open water, marsh edges, and vegetated patches—should be preserved to sustain different bird guilds.

Limiting disturbance during peak winter migration is necessary because winter represents the most stable and biodiverse trophic window of the lake. Human activities such as loud recreation, boating, waste dumping, and shoreline encroachment should be regulated, especially in early morning and late evening hours when birds are actively feeding. Designating certain zones as “quiet conservation zones” during winter can help maintain feeding efficiency and reduce stress on migratory species.

Finally, inclusion of trophic linkage indicators in urban lake management plans can significantly improve conservation effectiveness. Instead of relying only on chemical water quality standards, management authorities should incorporate biological indicators such as plankton diversity index, zooplankton abundance trends, bird guild density, and correlation patterns between trophic levels. These integrated indicators provide a more realistic picture of ecosystem functioning. Urban lake conservation should therefore adopt a bottom-up ecological framework where nutrient balance, plankton stability, and bird diversity are treated as interconnected components of ecosystem health.

9. References

1. Donar, A., & Reddy, Y. R. (2012). Zooplankton diversity and seasonal variation in Nipani Reservoir, Karnataka. *International Journal of Environmental Sciences*, 3(2), 987–994.
2. Gadekar, S. D. (2020). Baseline study of freshwater zooplankton diversity in selected Indian lakes. *Journal of Aquatic Biology*, 35(1), 45–53.
3. Karuthapandi, M., Rao, V., & Xavier, R. (2013). Zooplankton community structure in relation to trophic status of a freshwater ecosystem. *Indian Journal of Applied Research*, 3(7), 112–118.
4. Koli, V. K., & Muley, D. V. (2012). Seasonal variations in zooplankton diversity of Tulshi Reservoir, Maharashtra. *Bioscience Discovery*, 3(1), 85–89.
5. Ministry of Jal Shakti. (2023). *Census of water bodies: First census report 2023*. Government of India. <https://jalshakti-dowr.gov.in>
6. Rao, N. V., Rao, B. R., & Rao, M. P. (2015). Spatial distribution of zooplankton in Madduvalasa Reservoir, Andhra Pradesh. *International Journal of Fisheries and Aquatic Studies*, 2(5), 230–235.
7. Sayasrao, P. R., & More, S. R. (2020). Zooplankton as bioindicators of trophic status in freshwater lakes. *International Journal of Scientific Research in Biological Sciences*, 7(4), 45–52.
8. Sekhon, A., Aulakh, R. S., & Kler, T. K. (2023). Seasonal diversity and migratory patterns of waterbirds in rural wetlands of Punjab, India. *Journal of Threatened Taxa*, 15(4), 22930–22938.
9. Sidhu, G., Sekhon, A., Aulakh, R. S., & Kler, T. K. (2021). Ecological importance of village ponds for supporting waterbird diversity in Punjab. *Indian Birds*, 17(2), 45–52.
10. Yardi, K. D., Bharucha, E., & Girade, S. (2019). Ecological restoration and avifaunal response in Pashan Lake, Pune. *Journal of Environmental Biology*, 40(6), 1269–1276.