



Original Research Paper

Machine Learning Evaluation of Zooplankton Responses to Nutrient Enrichment

Dr. Akash Bhattacharya^{1*}, Dr. Aida Ventkat Rao Dora²

^{1*}Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.akashbhattacharya@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0003-0361-6652>

²Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.aidaventkatraodora@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0008-1572-6994>

Key Words	Abstract
Zooplankton, Nutrient enrichment, Freshwater ecosystem, Aquatic biodiversity, Water quality, Ecological assessment, Machine learning.	Zooplankton communities are an essential part of the ecosystem in terms of controlling energy flow, sustaining higher trophic level organisms, and reflecting environmental quality changes. Nutrient enrichment that results from agriculture effluents, sewage, and human activities creates a profound impact on fresh water ecosystems by altering the amount of nutrients present in the environment. Nitrogen and phosphorous enrichment may affect algal growth, oxygen content in the water, and the habitat, causing alterations in the number, biodiversity, and species composition of zooplanktons. The present research paper aims at studying zooplankton community response to nutrient enrichment by applying ecological assessment techniques assisted by machine learning methods. The results of the predictive analysis revealed that nutrient-related parameters played a significant role in defining the distributions of zooplankton communities. As for different applied techniques, the Random Forest model offered better opportunities for predicting by detecting the interactions between various ecological parameters. The results of the research showed that the process of nutrients enrichment leads to the change in the composition of the zooplankton community, which means that tolerant species dominate in poor environments. It was possible to show that machine learning-assisted assessment may be used as an additional tool for determining aquatic animal reactions.

* Corresponding Author's email: ku.akashbhattacharya@kalingauniversity.ac.in

Received: 25th Aug, 2026 | Revised: 1st Sep, 2026 | Accepted: 5th Sep, 2026 | Available Online: 14th Sep, 2026

(DOI): 10.70102/AEJ.2026.18.5s.35

Introduction

Zooplankton constitutes an important element of aquatic ecosystems since it represents a significant connection between the primary producers and higher-trophic level organisms such as fish. (Basak et al., 2025). Zooplankton controls energy transfer, helps in nutrient cycling, and quickly reacts to the changes in environment, which makes it useful biological indicators of the ecosystem state. Any zooplankton community change indicates changes in water quality, stability of the habitat, and the disturbance of aquatic ecosystems. (Giering et al., 2022).

Nutrient enrichment represents an important factor influencing the equilibrium of the aquatic ecosystem. Additional inputs of nitrogen and phosphorus into the water through agriculture, industry discharge, domestic sewage, and land use changes result in the acceleration of the eutrophication processes. Increased amounts of nutrients lead to algal blooms, alteration of oxygen levels, and food resources. These environmental changes affect the zooplankton community structure and species diversity. (Mao et al., 2023).

Some zooplankton have different reactions to nutrient enrichments. While some species are able to survive in high-nutrient habitats and thrive, the others tend to become extinct due to lack of oxygen. This is because of the effect of nutrient enrichment on aquatic organisms and the environment which is a signal of environmental degradation in the long term. Thus, the relation between nutrients and zooplankton response is

vital for maintaining the ecosystem. (Kruk et al., 2022).

Traditional ecological assessment methods usually depend on field observation and statistics. (Li et al., 2026; Shang et al., 2024; Thirunavukkarasu et al., 2026). However, aquatic ecosystems consist of many factors that interact with each other in complex ways and therefore require the analysis of multiple variables in order to find some hidden relations. Machine learning offers an approach that allows the analysis of numerous environmental factors at once. (Grillo et al., 2024; Begam et al., 2025; Narasimha Kumar et al. 2025).

For this research, an evaluation framework based on machine learning is used in order to understand the behavior of zooplankton in varying levels of nutrient enrichment. This involves the analysis of the effects of water quality indicators on the behavior of zooplankton and identifying critical ecological factors that impact their distribution. The findings of this study have important implications for assessing the health of aquatic ecosystems.

Materials and Methods

The present study employs an ecological assessment framework for the investigation of the role of nutrients on zooplankton in freshwater ecosystems. Ecological assessment involves the evaluation of water quality features, nutrient levels, and zooplankton features to assess the state of aquatic ecosystems in regard to changes that occur due to changes in environmental disturbances. Environmental factors that correspond to nutrient level and habitat

conditions were assessed alongside zooplankton community features to detect patterns that correspond to ecological changes. Machine learning-assisted analysis was utilized as a supplementary tool in detecting the connection between environmental variability and zooplankton behavior.

The observation of zooplankton was employed in the assessment of the effects of environmental disturbances on zooplankton communities. Changes in species composition, abundance, and diversity caused by habitat changes were detected in regard to nutrient enrichment. The presence of dominant and sensitive zooplankton taxa was analyzed in terms of their reaction to environmental changes.

Evaluation of ecological factors for the aquatic environment has been carried out based on critical parameters that affect the survival and presence of zooplankton. Some of the nutrient-related parameters include the levels of nitrogen and phosphorus, while some of the other

factors include the levels of dissolved oxygen, temperature, pH, and chlorophyll-a.

The relationship between the environmental factors and the reactions of zooplankton have been assessed using machine learning approaches. Various ecological factors have been considered at once for classifying the habitat and zooplankton community changes. Various predictive models have been compared to interpret the relationship between the conditions of nutrients and biological responses.

Results and Analysis

Influence of Nutrient Enrichment on Zooplankton Communities

Enrichment in nutrients had an important role in influencing the community structure of zooplanktons via changes in the environmental factors and feeding conditions. High nutrient content led to growth of algae, which influenced the feeding environment and structure of the zooplankton.

Table 1: Influence of Environmental Factors on Zooplankton Community Response

Environmental Factor	Ecological Effect	Zooplankton Response
Nitrogen concentration	Increased nutrient availability and algal productivity	Increase in tolerant species abundance
Phosphorus concentration	Promotes eutrophic conditions	Changes in community composition
Dissolved oxygen	Determines habitat suitability	Reduced diversity under low oxygen conditions
Temperature	Influences metabolic activity	Seasonal population variation
Chlorophyll-a	Represents primary productivity	Affects food availability



Original Research Paper

Places that had moderate level of nutrients were found to have a higher number of zooplanktons because of better availability of food, while places having high nutrients levels had poor ecological quality owing to low oxygen and stressful habitat conditions. It was found that nutrient tolerant zooplankton dominated under the enriched condition, while sensitive zooplankton were found in fewer numbers. Table 1 indicates that nutrient conditions and related water quality factors collectively influence zooplankton distribution patterns and ecosystem stability.

Machine Learning-Based Assessment of Zooplankton Responses

The machine learning-assisted analysis was conducted to reveal possible patterns of

interaction between environmental variables and the zooplankton communities' response to it. In the context of the analysis, the models used several ecological variables to understand the impact of nutrient enrichment on zooplankton population and the quality of their habitat. It was shown that all models could provide reliable predictions of ecological patterns but the Random Forest model was more effective due to its ability to perform complex analysis of multiple environmental variables interaction.

Thus, the higher prediction capability of the models suggests that the variables related to nutrients (particularly, nitrogen, phosphorus, and dissolved oxygen), are crucial for understanding the state of zooplankton communities.

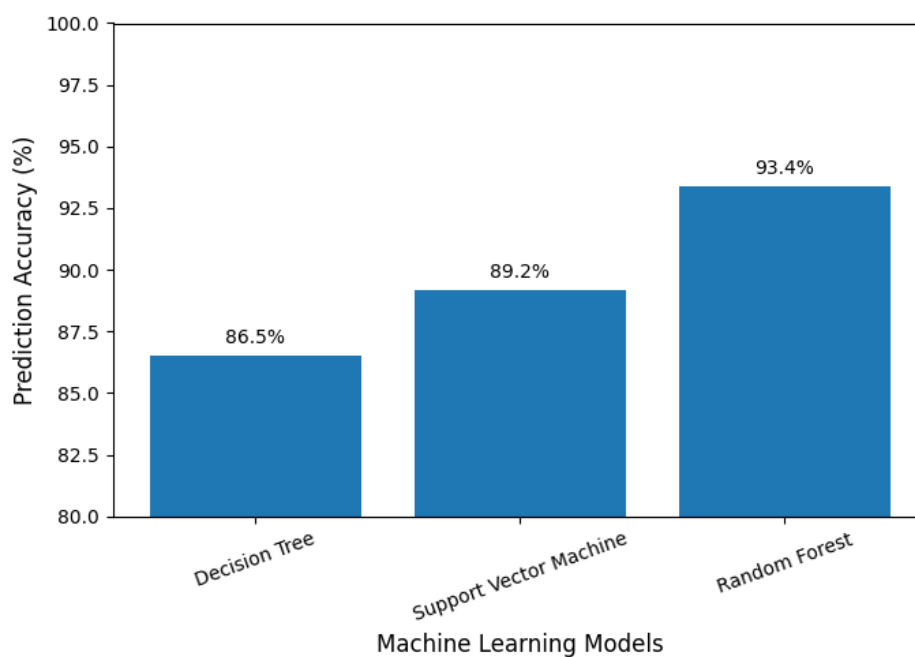


Figure 1: Zooplankton Prediction Accuracy



Original Research Paper

Figure 1 shows that the Random Forest model has the highest prediction accuracy and is therefore suitable for analyzing ecological interactions involving nutrient enrichment and zooplankton.

Environmental Factors Influencing Zooplankton Variation

Factors such as the availability of nutrients and water quality impacted the change in the community of zooplankton. Nutrients such as nitrogen and phosphorous had an important impact on the distribution of zooplankton species, while dissolved oxygen and temperature had an influence on survival.

Discussion

Nutrient enrichment is an ecological feature that impacts zooplankton communities because it changes the water quality and conditions of habitats. The results showed that increased levels of nutrients could positively affect food resources of organisms due to increased primary productivity, while excessive accumulation could disrupt the balance in the ecosystem and cause decreased availability of oxygen and change the species composition in the ecosystem.

Zooplankton responses to different ecological features were found to be important in terms of assessing the state of the ecosystem. Increased tolerance of species to nutrient-rich environment is an indication of ecological stress, while decreased diversity of the species is an indication of habitat degradation. Therefore, monitoring of

zooplankton is very important in order to detect any disturbances in the ecosystem related to nutrients.

The machine learning-assisted assessment greatly facilitated the interpretation of complex relationships between different ecological features and zooplankton variations (Ramadoss, S., & A. Kumaravel, 2025). By studying all of the ecological features simultaneously, predictive approaches helped identify the drivers of zooplankton community changes. Nonetheless, ecological observations are still vital in order to understand biological and ecological processes.

Overall, the study shows that integrating ecological assessment with predictive analysis can improve freshwater ecosystem monitoring. The approach can support conservation strategies by identifying vulnerable aquatic environments and guiding nutrient management practices for maintaining biodiversity and ecosystem stability.

Conclusion

In this research, responses of zooplankton towards nutrient enrichment were analyzed with assistance of machine learning ecological approach. It was found that nitrogen, phosphorus, dissolved oxygen, and temperature had considerable influence on the variation of zooplankton communities. Prediction helped to establish some significant associations between environmental factors and the response of aquatic animals, which provided better prediction with the help of the Random Forest algorithm. These findings proved the importance of the usage of

* Corresponding Author's email: ku.akashbhattacharya@kalingauniversity.ac.in

Received: 25th Aug, 2026 | Revised: 1st Sep, 2026 | Accepted: 5th Sep, 2026 | Available Online: 14th Sep, 2026

(DOI): [10.70102/AEJ.2026.18.5s.35](https://doi.org/10.70102/AEJ.2026.18.5s.35)

zooplankton as indicators of ecological state and possibilities of predictive tools in monitoring the biodiversity of freshwaters.

References

- [1] Basak, Jayanta Kumar, Sanjay Saha Sonet, Rahnumazzaman Rumman, Bhola Paudel, Sumaya Akter, Tapash Kumar Sarkar, and Mohammed Mafizul Islam. "Application of Machine Learning Models for Zooplankton Abundance Prediction in Ponds of Southeastern Coastal Regions in Bangladesh." *Environmental Monitoring and Assessment* 197, no. 8 (2025): 893.
- [2] Begam, G. Safiya, and W. Aisha Banu. "Recommendations for Using Transparent Deep Learning in Aquaponics to Detect Nutrient Deficiencies Using CNN and Grad-CAM." *Journal of Wireless Mobile Networks Ubiquitous Computing and Dependable Applications* 16, no. 1 (2025): 258–268.
- [3] Giering, Sarah L. C., Phil F. Culverhouse, David G. Johns, Abigail McQuatters-Gollop, and Sophie G. Pitois. "Are Plankton Nets a Thing of the Past? An Assessment of in Situ Imaging of Zooplankton for Large-Scale Ecosystem Assessment and Policy Decision-Making." *Frontiers in Marine Science* 9 (2022): 986206.
- [4] Grillo, Marco, Stefano Schiaparelli, Tiziana Durazzano, Letterio Guglielmo, Antonia Granata, and Falk Huettmann. "Machine Learning Applied to Species Occurrence and Interactions: The Missing Link in Biodiversity Assessment and Modelling of Antarctic Plankton Distribution." *Ecological Processes* 13, no. 1 (2024): 56.
- [5] Kruk, Marek, Anna Maria Goździewska, and Piotr Artiemjew. "Predicting the Effects of Winter Water Warming in Artificial Lakes on Zooplankton and Its Environment Using Combined Machine Learning Models." *Scientific Reports* 12, no. 1 (2022): 16145.
- [6] Li, Binbin, Qiuhua Li, Heng Wang, Ting Wu, Xiaochuan Song, Jinjuan Li, and Yongxia Liu. "Explainable Machine Learning and Causal Inference Reveal Habitat-Specific Environmental and Functional-Trait Drivers of Zooplankton Biodiversity in a Karst River–Reservoir System." *Ecological Indicators* 190 (2026): 115445.
- [7] Mao, Zhigang, Yong Cao, Xiaohong Gu, Qingfei Zeng, Huihui Chen, and Erik Jeppesen. "Response of Zooplankton to Nutrient Reduction and Enhanced Fish Predation in a Shallow Eutrophic Lake." *Ecological Applications* 33, no. 1 (2023): e2750.
- [8] Narasimha Kumar, S., L. U. Yang, R. Mahesh, U. Goyal, S. Farhan, T. Jadhav, and S. Thakur. "Machine Learning-Driven Quality Control in Additive Manufacturing of Aerospace Components." *International Academic Journal of Science and Engineering* 12, no. 4 (2025): 45–55.
- [9] Ramadoss, S., and A. Kumaravel. "Prediction of Toxic-Metabolic Disorders at Emergency Conditions Using Multi-

- Label Classification in Machine Learning.” *Archives for Technical Sciences* 2, no. 33 (2025): 801–818.
- [10] Shang, Jiahui, Yi Li, Wenlong Zhang, Xin Ma, Haojie Yin, Lihua Niu, Longfei Wang, and Jinhai Zheng. “Supervised Machine Learning for Understanding and Predicting the Status of Bistable Eukaryotic Plankton Community in Urbanized Rivers.” *Water Research* 266 (2024): 122419.
- [11] Thirunavukkarasu, Subramani, Poovazhagi Rajendran, Andrew Gift Watts, Clémence Epinoux, Juan-Carlos Molinero, Bo-Kai Liao, and Jiang-Shiou Hwang. “Use of Artificial Intelligence (AI) in Meso-Zooplankton (Copepod) Research: Applications, Advances and Future Perspectives.” *Limnologica* (2026): 126352.