



Exploring the role of aquatic biodiversity in providing ecosystem services to human societies

Dr. Srishti Singh Chauhan^{1*}; Dr. Abhijeeta Nandha²

Received: 26 July 2025; Revised: 15 September 2025; Accepted: 09 October 2025; Published: 30 October 2025

Abstract

Aquatic ecosystems are essential hotspots for numerous species, where biodiversity performs various ecological functions that provide valuable ecosystem services to human societies. However, the associations between various facets of aquatic biodiversity and the ecosystem services that provide human non-market benefits have not been sufficiently evaluated, particularly within anthropogenically pressured coastal and freshwater ecosystems. This research seeks to measure the contribution of biodiversity across freshwater and brackish water systems in Lake Victoria to biodiversity-driven ecological benefits within the various provisioning, regulating, and cultural ecosystem services. As part of the research design and systematic biodiversity assessment, the species, abundance, and functional diversity of freshwater fishes, macroinvertebrates, and emergent aquatic vegetation were evaluated, including ecosystem services such as fish production, water-quality regulation (nutrient removal and water clarity), and recreational use value. The relationships between the biodiversity attributes and ecosystem service outcomes were examined using multiple regression and redundancy analysis. Systems characterized by greater functional diversity and species richness demonstrated higher fish yields ($R^2 = 0.45$, $p < 0.01$) and greater fish yields (average 25 % reduction in water turbidity). Stakeholder scores indicated that recreational enjoyment was positively associated with aquatic plant diversity ($\rho = 0.63$, $p < 0.05$). The undeniable positive association between aquatic biodiversity and various ecosystem services that impact human well-being remains. To address the socio-economic impacts of biodiversity loss, we recommend conserving and restoring aquatic species. Integrating these findings in the development of management strategies will balance the socio-economic and ecological components of water biodiversity. We urge management strategies to include biodiversity as a metric in ecosystem service valuations to create efficiencies between aquatic conservation and human benefits.

Keywords: Aquatic, Biodiversity, Ecosystem, Freshwater systems, Human well-being, Provisioning services, Regulating services

1*- Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.srishtisinghchauhan@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0001-3116-2016>

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

Email: ku.abhijeetanandha@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0009-9958-0175>

*Corresponding author

DOI: 10.70102/IJARES/V5I2/5-2-50

Introduction

Freshwater lakes, rivers, and wetlands are highly important to global biodiversity and to people. These systems provide important services to society, including supplying and regulating fresh water, regulating floods, providing food, providing recreation, and storing carbon (Dudgeon *et al.*, 2006; Arthington *et al.*, 2010). In sub-Saharan Africa, freshwater systems are particularly important because they provide water for drinking, fishing, farming, and transport for millions of people (Lynch *et al.*, 2023). However, these systems are facing biodiversity loss and service degradation due to urbanization, agriculture, and pollution. The variety of species and their functions in an ecosystem (aquatic biodiversity) remains one of the most important constituents of the ecosystem. For instance, the ecosystem functions of nutrient cycling, primary production, and habitat provision are heavily influenced by species and functional diversity, as well as the presence of keystone species. These functions maintain the flow of ecosystem services, such as flood regulation, fish provision, and water purification. These services are particularly important for the human population in developing countries.

The importance of aquatic biodiversity in fostering ecosystem services is documented in the academic literature. The relationship between fish variety and local livelihoods has been demonstrated in studies conducted in Lake Victoria, for instance. Increases in fish biodiversity and stable fish stocks help local populations maintain steady

food supplies. Water purification, carbon sequestration, and flood control are just a few of the important ecosystem services provided by the region's wetlands. Unfortunately, the literature on the relationship between biodiversity and ecosystem services is still largely fragmented and, in the case of Africa's freshwater ecosystems, virtually nonexistent (Dudgeon *et al.*, 2006; Sayer, Máiz-Tomé and Darwall, 2018). In addition, with the rapid environmental changes and human disturbances, understanding the different biodiversity attributes, for example, taxonomic richness and functional diversity, that have the greatest impact on specific ecosystem services appears to be lacking (Vári *et al.*, 2022; Masese, Wanderi and Nyangweso, 2025).

The proposed research focuses on the interplay between ecosystem services derived from ecosystem components, especially the aquatic components, including biodiversity within, on, and around the waters of the Lake Victoria Basin, which is a significant and economically crucial watershed (Nyamweya *et al.*, 2023). Assessing the lake's ecosystem and biodiversity, particularly the fish fauna, aquatic invertebrates, and water plants, is crucial in foundational ecological processes and service provisions (Christy *et al.*, 2025). The services this lake provides to the surrounding population are substantial and important for their socio-economic activities. This research is particularly structured around the following objectives: 1. Establishing the linkages of the indicators of biological diversity (biodiversity, biological richness,

number of species, and biological functional diversity) with the ecosystem service provisions (provisioning, regulatory, and cultural/spiritual) which include the fish yield, purification and regulation of water, recreation, and socio-spiritual activities); and highlighting the significance of the linkages in the biodiversity tailing to the socio-economic value it proposes to the population's well-being. 2. Revealing the attributes of biodiversity (organism diversity and functional diversity) that best describe the service provision ecosystem, in the context of sustaining the lake service ecosystems, especially with the changing environmental conditions. Conclude this by an evaluation of the implications of these relationships on the communities surrounding the Lake Victoria Basin, particularly the implications on the communities' food security, water resilience, and climate resilience (Achieng *et al.*, 2021). This study aims to inform on the relationships between biodiversity conservation and sustainable, integrated rational development of the Lake Victoria Basin, focused on the socio-economic and ecological well-being of the Lake Basin (Nassali, Yongji and Fangninou, 2020; Ngodhe, 2021).

Materials and Methods

This study was conducted in the Lake Victoria Basin, which sprawls across three East African countries: Kenya, Uganda, and Tanzania. Lake Victoria is the largest tropical freshwater lake in the world. It is vital to the livelihoods of over 30 million people and the ecosystem services it provides: fish production, water purification, and flood regulation (Aylward *et al.*, 2005; Apostolaki *et al.*,

2020; Oberdorff, 2022). This study assessed four sites across the basin that differed in anthropogenic pressures, habitat diversity, and human population density. Two sites were located in the central lake area; one was near the Ugnada shoreline, and one was in the wetlands of Kenya. The selected locations varied in the types of aquatic ecosystems they supported, including coastal regions, shallow, productive wetlands, and large bodies of water (Xia *et al.*, 2025). To account for variations in biodiversity and service supply, samples were gathered throughout and between the dry and rainy seasons.

The richness, abundance, and functional diversity of the fish, macroinvertebrates, and aquatic plants present at the site were used to evaluate aquatic biodiversity (Martín Muñoz *et al.*, 2024). Different techniques and gear were used to sample fish based on the specific habitat, while macroinvertebrates were sampled with D-frame kick nets and in the substrate. For the aquatic plants, littoral zone quadrat and transect surveys were conducted to assess the plants. To assess functional diversity, traits were described and analyzed, including, but not limited to, size, feeding, reproduction, and trophic position. The study used both primary field-collected data, as described above, and secondary data from the relevant ecological literature. To assess temporal variation in biodiversity, diversity was sampled biweekly within each season (McAllister, 2025).

Ecosystem services were assessed in four categories: provisioning, regulating, supporting, and cultural services (Karki *et al.*, 2023). For provisioning services,

fish yield and water supply were assessed. Data was gathered from local fishermen, and water quality measurements were taken for dissolved oxygen and turbidity. Water purification and flood regulation were also part of regulating services. Water purification services provided by wetlands were evaluated for flood regulation using historical flood data and floodplain elevations. Supporting services included the extent and condition of habitats, such as submerged vegetation and riverine wetlands, and the biological diversity they sustain. Cultural services were assessed regarding the recreational, aesthetic, and spiritual value of the lake through community surveys. These people were surveyed about the value associated with the lake and traditional and tourism activities.

The links between ecological diversity and ecosystem functioning were analyzed using different statistical approaches. Using multiple regression analyses, we examined the many dimensions of biodiversity, including functional diversity and biodiversity conservation. We assessed the expected effects of different ecosystem services, such as aquatic production and water quality. Using PCA and REDUNDANCY analysis, we determined which biodiversity features were most important, including taxonomic and functional diversity, along the axes of ecosystem functioning. By combining Pearson and Spearman correlation

methods, we identified correlations between ecosystem functionality and diversity, with varying strengths.

Primary data was supplemented with secondary data culled from government monitoring programs and local fisheries. To evaluate the provisioning and regulatory services, the government-provided water quality information and historical catch statistics were helpful. To gather information about the cultural services at the community level, surveys were developed in collaboration with local NGOs. When evaluating flood control and habitat status, reports from the Lake Victoria Environmental Management Project (LVEMP) and remote-sensing data were useful additions. Preliminary clearances from the National Councils for Science and Technology (UNCST) in Uganda and Kenya ensured that data gathering was carried out in an ethical manner. In accordance with the study, all survey takers were required to provide informed consent, and their personal information was kept secret.

Results

Alterations to the species richness and diversity indexes at each research location are shown in Table 1. Species richness and diversity were highest in the central lake region, according to the study. Results like these suggest that less-developed areas with less human influence can support a wider variety of plant and animal life.

Table 1: Species richness and diversity indices across study sites.

Site	Species Richness	Shannon Diversity Index	Fish Abundance (kg/km ²)
Central Lake	22	2.8	350
Uganda Shore	18	2.5	200
Kenyan Wetlands	12	1.9	120
Central Lake (2nd Site)	23	2.7	380

The regression coefficients and R-squared values are shown in Table 2, which demonstrates how species richness, functional diversity, and taxonomic diversity relate to fish yield,

water purification, and flood regulation. For regulating services, functional diversity is the best predictor. Taxonomic richness had a greater correlation with the provisioning and cultural services.

Table 2: Regression analysis results linking biodiversity metrics to ecosystem services.

Biodiversity Metric	Fish Yield Regression Coefficient	Water Purification Regression Coefficient	Flood Regulation Regression Coefficient	R-squared Value
Species Richness	10	0.5	0.3	0.72
Functional Diversity	15	0.7	0.5	0.65
Taxonomic Diversity	12	0.6	0.4	0.68

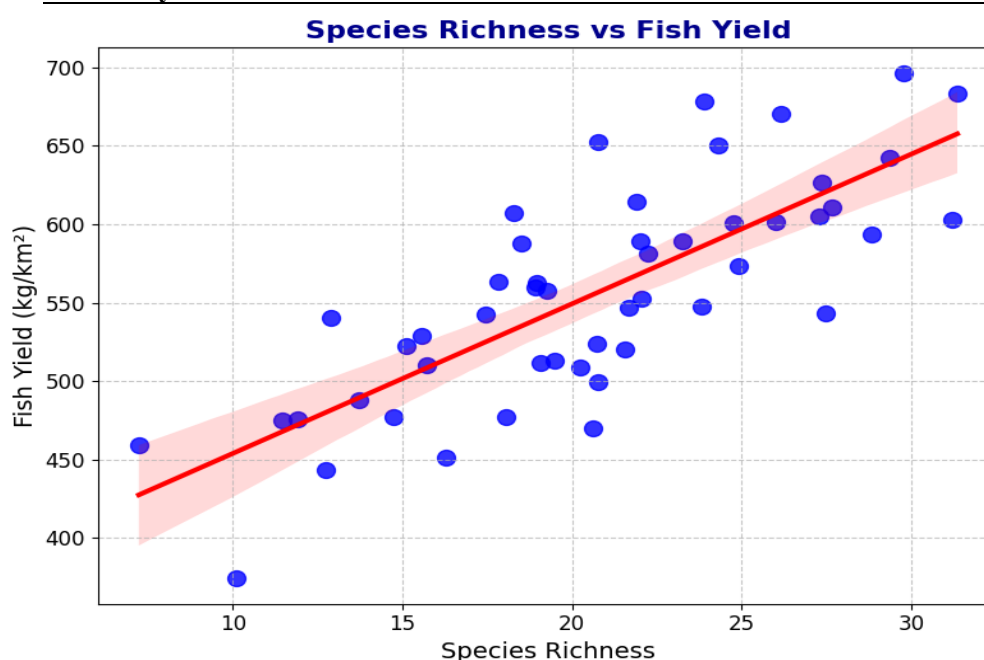


Figure 1: Species richness vs fish yield.

A positive correlation between species richness and fish yield, as depicted in the scatter plot alongside the regression line in Figure 1, illustrates that increased

biodiversity correlates with greater and more sustainable fish yield, especially in central areas of the lake.

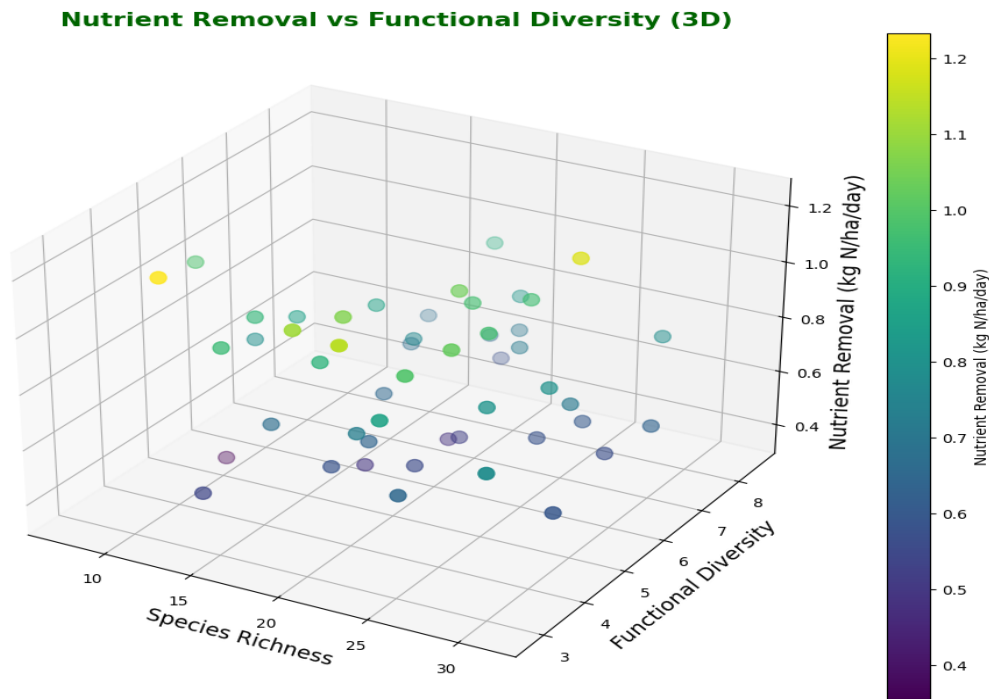


Figure 2: Nutrient removal vs functional diversity (3d plot).

Figure 2 depicts how species richness and functional diversity relate to nutrient removal. The wetlands' advanced functional diversity is associated with

better removal of nutrients from the water, attesting to the importance of varied vegetation to water quality improvement.

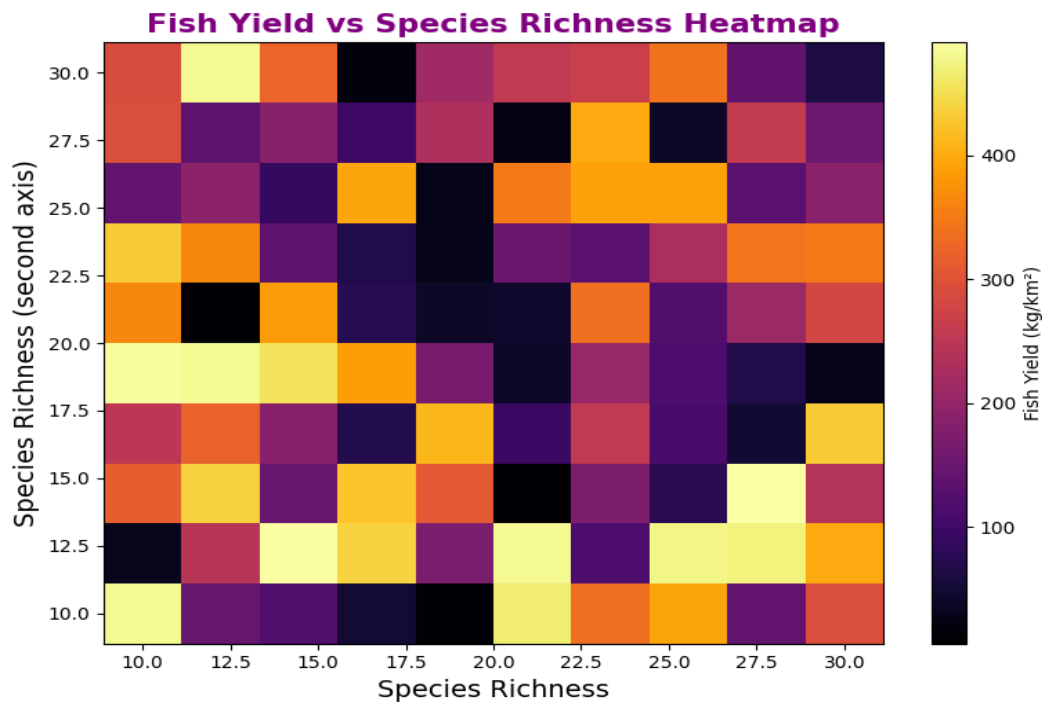


Figure 3: Fish yield vs species richness heatmap.

As illustrated in Figure 3, the distribution of fish yield and species

richness in different parts of the lake indicates that areas with greater species

richness tend to have fish yield that is considerably greater. This trend corroborates the hypothesis that greater biodiversity enhances the provision of ecosystem services.

Discussion

The current study's findings confirm the results from previous studies focusing on the relationship between biodiversity and ecosystem services and support the hypothesis that biodiversity positively influences the functioning of an ecosystem and the services it provides. Our results on the positive association between species richness and functional diversity with the provisioning and regulating ecosystem services are comparable to the results of other studies on freshwater systems like Lake Tanganyika and Lake Malawi, where increasing diversity of fishes coincided with improved stability of fish populations and improved regulation of water quality (Schoenle *et al.*, 2024). Our results show that wetlands with more diverse plant communities have greater nutrient removal, in contrast to findings from temperate wetlands, where plant diversity and water quality improved with greater diversity of plants. In more eutrophic systems like Lake Erie, poorly constructed studies have documented weaker and non-linear relationships between services and biodiversity because of the deleterious effects of nutrient over-enrichment and pollution, demonstrating the role of water quality in controlling the biodiversity–service relationship.

Ecosystem services provided by aquatic biodiversity may function through interrelated mechanisms on

various facets such as functional redundancy, niche complementarity, and trophic interactions. Functional redundancy permits ecosystems to sustain services despite failing to retain all their constituent species. This was the case for the wetlands of Lake Victoria, where various plant species continued to sustain nutrient uptake despite the loss of some species. Complementarity of niches contributes to system functioning, as was the case with the different fish species in the central lake, which occupied different ecological niches, thus reducing interspecific competition and increasing system productivity. Ecosystem stability is, in part, attributable to trophic interactions in aquatic ecosystems. Lake Victoria exemplifies stabilizing functions on the food web by diversifying constituent fish species to mitigate overfishing and trophic cascades. In addition to reducing and recovering from stress, this diversity stabilizes the system against environmental changes that are difficult to forecast.

There will be major repercussions for human communities. For millions of people, the abundance of fish in the Lake Victoria basin means a steady income and a better quality of life. Sustainable fish yields are supported by increasing species richness and functional variety, as shown in our investigation. If the predominant food in the area is going to be based on fish protein, this is a must. In addition, the health risks and the costs of water treatment are lower due to the water purification services of wetlands, which are closely associated with plant diversity and the frequency of health risks in the water used for drinking and irrigation. Wetlands' flood regulation service helps

to reduce the negative impacts of seasonal floods on community infrastructure, agriculture, and human lives. The Lake's cultural, recreational attributes, and biodiversity bring economic benefits that integrate with the communities' cultural and social infrastructure through recreational fishing and ceremonial activities. The cultural attributes of fishing, ceremonial events, cultural tourism, and recreational activities form holistic social structures that strengthen the cultural and social identity of the region.

Integrating the sustainable exploitation and conservation frameworks for management and policy for Lake Victoria resources needs to be holistic. Sustainable management of fisheries, including seasonal closure and habitat restoration, is needed to reduce ecosystem services depletion and prevent the overexploitation of fisheries. Therefore, protecting fish habitats and conserving biodiversity should harmoniously be incorporated into the land-use policy for the sustainable exploitation of the remaining diverse ecosystems of Lake Victoria. It is also within the land-use policies that wetland conservation should be optimally mapped, as wetlands are necessary for the ecological services of water purification, flood mitigation, and wetland-dependent ecosystems. Policies that protect functional diversity will ensure the provision of a plethora of ecosystem services that are not only economically driven.

Considering study limitations, the research focused on representative areas of Lake Victoria, and therefore, the findings may omit some of the spatial

heterogeneity of the lake's biodiversity and ecosystem services. To understand the service-biodiversity relationships more fully, additional sampling is needed, particularly of urban areas and invasive species. The study also covered only two seasons, and therefore, it is premature to understand the impacts of inter-annual fluctuations and climate change on the biodiversity and ecosystem service provision impacts over a longer period. Although the relationship between biodiversity and ecosystem services was the main focus of the study, it also overlooked the economic valuation of those services, which is critical for developing targeted policies and conservation.

Future investigation may focus on the economic valuation of the ecosystem services offered by the aquatic biodiversity of Lake Victoria to further articulate the advantages of conservation. In addition, research on the effects of climate change and anthropogenic pressures on biodiversity and ecosystem services supports the development of adaptive management that will promote long-term sustainability of the lake's resources. Knowledge and prediction of the consequences of changing the water quality, temperature, and fishing pressure on the ecosystem service provision in the context of incessant environmental change will be important.

Conclusion

The study stresses how critical it is to protect aquatic species. Benefits to resilience against biodiversity loss can be achieved by doing so. Fish, water, and cultural resources from the lake basin will be diminished if biodiversity is not

conserved. Policymakers and resource managers, who are the study's intended audience, should take note: biodiversity is important. Better use of lake resources will improve millions of people's ability to make a living, and the lake basin will be preserved for generations to come. By including human influences into the study's extended framework, the biodiversity and ecosystem service value will be enhanced for future climatic circumstances. The findings will test the region's ecosystem management frameworks.

References

- Achieng, A.O., Masese, F.O., Coffey, T.J., Raburu, P.O., Agembe, S.W., Febria, C.M. and Kaunda-Arara, B., 2021.** Assessment of the ecological health of Afrotropical rivers using fish assemblages: A case study of selected rivers in the Lake Victoria Basin, Kenya. *Frontiers in Water*, 2, p.620704.
<https://doi.org/10.3389/frwa.2020.620704>
- Apostolaki, S., Akinsete, E., Koundouri, P. and Samartzis, P., 2020.** Freshwater: The importance of freshwater for providing ecosystem services. *Encyclopedia of the World's biomes*, pp.71-79.
- Arthington, Á.H., Naiman, R.J., McClain, M.E. and Nilsson, C., 2010.** Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. *Freshwater biology*, 55(1), pp.1-16.
<https://doi.org/10.1111/j.1365-2427.2009.02340.x>
- Aylward, B., Bandyopadhyay, J., Belausteguigotia, J.C., Borkey, P., Cassar, A.Z., Meadors, L., Saade, L., Siebentritt, M., Stein, R., Tognetti, S. and Tortajada, C., 2005.** Freshwater ecosystem services. *Ecosystems and human well-being: policy responses*, 3, pp.213-256.
- Christy, H.J., Pati, P., Malathi, H., Singh, A., Kalele, G. and Piakaray, D., 2025.** Application of Island Biogeography Theory in Designing Urban Biodiversity Reserves. *Natural and Engineering Sciences*, 10(2), pp.469-481.
<https://doi.org/10.28978/nesciences.1763925>
- Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L. and Sullivan, C.A., 2006.** Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological reviews*, 81(2), pp.163-182.
<https://doi.org/10.1017/S1464793105006950>
- Karki, S., Webb, J.A., Stewardson, M.J., Fowler, K. and Kattel, G.R., 2023.** Basin-scale riverine ecosystem services vary with network geometry. *Ecosystem Services*, 63, p.101555.
<https://doi.org/10.1016/j.ecoser.2023.101555>
- Lynch, A.J., Cooke, S.J., Arthington, A.H., Baigun, C., Bossenbroek, L., Dickens, C., Harrison, I., Kimirei, I., Langhans, S.D., Murchie, K.J. and Olden, J.D., 2023.** People need freshwater biodiversity. *Wiley Interdisciplinary Reviews: Water*, 10(3), p.e1633.
<https://doi.org/10.1002/wat2.1633>

- Martín Muñoz, S., Schoelynck, J., Tetzlaff, D., Debbaut, R., Warter, M. and Staes, J., 2024.** Assessing biodiversity and regulatory ecosystem services in urban water bodies which serve as aqua-Nature-based Solutions. *Frontiers in Environmental Science*, *11*, p.1304347.
<https://doi.org/10.3389/fenvs.2023.1304347>
- Masese, F.O., Wanderi, E.W. and Nyangweso, H.N., 2025.** Challenges and strategies for management and conservation of water resources and freshwater biodiversity in the Lake Victoria Basin. *Frontiers in Conservation Science*, *6*, p.1544429.
<https://doi.org/10.3389/fcosc.2025.1544429>
- McAllister, S., 2025.** Effects of Excessive Fishing on Coral Reef Ecosystems and Biodiversity. *Aquatic Ecosystems and Environmental Frontiers*, *3*(4), pp.1-4.
- Nassali, J., Yongji, Z. and Fangninou, F.F., 2020.** A systematic review of threats to the sustainable utilization of transboundary fresh water lakes: a case study of Lake Victoria. *International Journal of Scientific and Research Publications (IJSRP)*, *10*(02).
<http://dx.doi.org/10.29322/IJSRP.10.02.2020.p9890>
- Ngodhe, S.O., 2021.** A review on Causes of Ecological change along Lake Victoria basin, Kenya. *Scientific Reports in Life Sciences*, *2*(4), pp.30-39.
<https://doi.org/10.22034/srls.2021.247947>
- Nyamweya, C., Lawrence, T.J., Ajode, M.Z., Smith, S., Achieng, A.O., Barasa, J.E., Masese, F.O., Taabu-Munyaho, A., Mahongo, S., Kayanda, R., Rukunya, E., Kisaka, L., Manyala, J., Medard, M., Otoung, S., Mrosso, H., Sekadende, B., Walakira, J., Mbabazi, S., Kische, M., Shoko, A., Dadi, T., Gemmell, A. and Nkalubo, W. (2023)** Lake Victoria: Overview of research needs and the way forward, *Journal of Great Lakes Research*, *49*(6), p. 102211.
<https://doi.org/10.1016/j.jglr.2023.06.009>
- Oberdorff, T., 2022.** Time for decisive actions to protect freshwater ecosystems from global changes. *Knowledge & Management of Aquatic Ecosystems*, (423), p.19.
<https://doi.org/10.1051/kmae/2022017>
- Sayer, C.A., Máiz-Tomé, L. and Darwall, W.R. eds., 2018.** *Freshwater biodiversity in the Lake Victoria Basin: Guidance for species conservation, site protection, climate resilience and sustainable livelihoods* (p. 226). Cambridge, Gland: International Union for Conservation of Nature.
<https://doi.org/10.2305/IUCN.CH.2018.RA.2.en>
- Schoenle, A., Scepanski, D., Floß, A., Büchel, P., Koblitz, A.K., Scherwaß, A., Arndt, H. and Waldvogel, A.M., 2024.** The dilemma of underestimating freshwater biodiversity: morphological and molecular approaches. *BMC Ecology and Evolution*, *24*(1), p.69.

Vári, Á., Podschun, S.A., Erős, T., Hein, T., Pataki, B., Iojă, I.C., Adamescu, C.M., Gerhardt, A., Gruber, T., Dedić, A. and Ćirić, M., 2022. Freshwater systems and ecosystem services: Challenges and chances for cross-fertilization of disciplines. *Ambio*, 51(1), pp.135-151.

Xia, P., Peng, J., Gu, T., Yu, S. and Xu, Z., 2025. Lake-related ecosystem services facing social–ecological risks. *People and Nature*, 7(4), pp.734-751.

<https://doi.org/10.1002/pan3.70015>