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Ecological restoration outcomes in Rwanda's Rugezi wetland: Biodiversity indices and food web recovery

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ABSTRACT

Wetlands play significant roles in the environment as filters of water, storehouses of carbon, flood-control zones, and habitat providers of wildlife- and they continue to be degraded. An example is Rugezi Wetland in north Rwanda: this is a Ramsar site that feeds into downstream lakes but was significantly degraded by both agriculture and drainage. This paper examines the progress of recent restoration there with an eye towards biodiversity and the structuring of the food web. A mixed-methods research approach was employed by the research team: systematic field surveys in and after the restoration, metrics of water quality (water nutrient concentrations, dissolved oxygen, turbidity) and maps of the habitats using GIS analysis were developed. They also tallied important figures of biodiversity (species richness, Shannon-Wiener index) and monitored the presence of the species in case of plants, birds, fish, amphibians, and invertebrates. Results show marked improvements post-restoration. The Shannon-Wiener index for wetland vegetation rose from ~1.0 to >2.0, and overall plant species richness increased (e.g. the return of diverse aquatic plants such as *Lemna* spp. and *Vossia* spp.). Bird species count climbed from 35 (in 2007) to 85 (in 2023), including recoveries of specialists like the Grey Crowned Crane (*Balearica regulorum*) and Shoebill (*Balaeniceps rex*). Fish populations (notably *Oreochromis* and *Barbus* spp.) rose from ~15,000 (in 2017) to 22,000 (in 2024), and invertebrate species richness expanded by 72 species. Hydrological and habitat restoration increased the open water area by ~12% and improved water quality: dissolved oxygen rose from ~4.2 to 7.8 mg/L, while nitrogen and phosphorus concentrations fell by ~56% and ~63%, respectively, reducing eutrophication risk. Illegal extraction of wetland resources declined, and over 3,500 community members adopted sustainable activities (beekeeping, ecotourism). The restoration of Rugezi Wetland has markedly enhanced biodiversity and strengthened food web interactions. Increases in diversity indices and higher trophic populations demonstrate recovery of ecological functions. Sustained conservation measures, including protection of habitat, invasive species control, and community engagement, will be essential to maintain these gains.

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INTRODUCTION

Wetlands are at the places of vital importance. They are amongst the most prolific ecosystems on the planet, filtering water, preventing floods, sequestering carbon dioxide and giving shelter to all manner of wildlife. Although they inhabit just a small part of the planet (around 6 %), they are more rapidly degrading than forests (Turner *et al.*, 2000). Global loss of wetland areas over the past century has reached 35 % (Turner *et al.*, 2000), something that has damaged biodiversity as well as disturbed the natural balance of ecosystems. By repairing broken wetlands, the clock will be reset on these losses.

These regions enhance the habitat by re-establishing proper water levels and plants and reintroduce additional animal and plant species (Davidson *et al.*, 2019). Restored wetlands usually demonstrate significantly enhanced biodiversity and ecological harmony, as compared with degraded wetlands (Zedler and Kercher, 2005).

African wetlands are likewise crucial for both biodiversity and human well-being, yet face intense pressures from agriculture, drainage, and climate change. Rwanda's Rugezi Wetland (Rugezi Marsh) exemplifies this. Situated at ~2,100 m elevation in northern Rwanda, Rugezi (6,735 ha) is a protected Ramsar site that functions as headwaters to Lakes Burera and Ruhondo (Gaspard *et al.*, 2022). It supports a rich assemblage of species, including globally threatened wetland birds (e.g. Grauer's Swamp-warbler *Bradypterus graueri*, papyrus warbler *Calamonastides gracilirostris*) and mammals such as the *Sitatunga antelope* (*Tragelaphus spekii*) (Gaspard *et al.*, 2022). However, before restoration, the marsh had been heavily drained for agriculture, leading to severe biodiversity loss and altered hydrology (Gaspard *et al.*, 2022). By the early 2000s, much of Rugezi was infested with invasive plants and degraded soil, and wetland specialist wildlife had declined dramatically.

Conservation efforts have been stepped up in Rugezi, a wetland in East Africa, since the late 2000s. Activists restored the dried-out ponds, installed the native plants (papyrus, sedges), and attempted to extirpate the invasive species. This was to be achieved by restoring natural water flow and multidimensional habitats. Even though professionals speculated that such measures would help enhance biodiversity and the general health of an ecosystem, they had yet to investigate the level of the project's effectiveness. A crucial question was whether restored diversity of species and trophic communities, communities connected through food webs, were in fact getting better.

This paper focuses on a dearth of empirical studies around wetland recovery by measuring change in biodiversity and trophic-level complexity within the Rugezi Wetland system due to the intervention.

Interventions are evaluated by a systematic field sampling program, together with metrics of diversity and ecological indicators, comparing the pre- and post-restoration situation. Its main goals were to (1) assess changes in biodiversity indices (species richness and diversity) following treatment, and (2) to follow through the cascade of the food web in the wetland ecosystem, starting with primary producers, then to top predators. The comprehensive species inventories coupled with habitat and water quality measurements can reveal the effect of the restoration of Rugezi on the ecosystem. These results have implications regarding wetland management in Rwanda and similar highland marshlands for the conservation policy and sustainable land-use project.

MATERIALS AND METHODS

Study area

The position of the Rugezi Wetland is in the northern part of Rwanda (Burera and Gicumbi Districts) at ~ 1 °21 '36 S 29 °50 '59 E, around 1800-2100 m altitude above sea-level. In 2005, the core area, covering an area of 6,736 ha, was inscribed as a Ramsar site (Gaspard *et al.*, 2022). A system of interconnected marshes, reed beds, riparian zones and shallow lakes characterises the wetland. It carries the run-off of Mount Muhabura and empties into Lake Ruhondo. There are papyrus (*Cyperus papyrus*), Typha, Miscanthus (*Miscanthus violaceus*), and an array of water plants. This habitat mosaic supports over 200 bird species, including a few amphibian (e.g. *Leptopelis kivuensis*, *Phrynobatrachus natalensis*), reptile (e.g. *Chamaeleo rudis*), mammal (e.g. *T. spekii*, otters), fish and invertebrate taxa among others. The biodiversity of the wetland and the size of the wetland had been diminished through anthropogenic drainage and cultivation before the restoration, favouring a single species culture of *Typha* and causing the invasiveness of other species, like water hyacinth (*Eichhornia crassipes*) (Gaspard *et al.*, 2022) (Fig. 1&2).

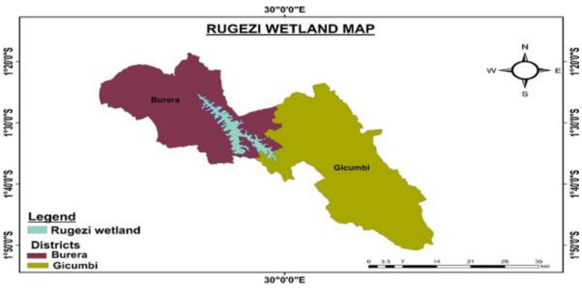

Fig. 1. Map showing the Rugezi map

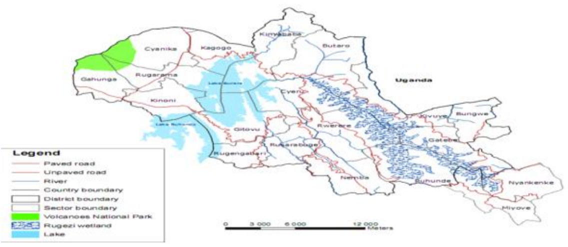

Fig. 2. Rugezi wetland watershed

Rugezi Wetland consists of freshwater marshes, riparian zones, and wetland vegetation dominated by papyrus reeds, sedges, and aquatic grasses. The wetland area is an ecological hotspot, supporting a rich variety of wildlife. Over 200 bird species have been documented, including endemic, migratory, and water-dependent birds, making it an important bird conservation area. The wetland also serves as a habitat for a range of amphibians, small mammals, reptiles, and various species of insects. Additionally, it supports a wealth of aquatic life, including fish species and water plants that contribute to the overall biodiversity.

Research design and data collection

As a pre- and post-restoration research, we utilised a mixed-experimental design. A total of 12 (each 20 m 20 m) field plots were marked across the wetland of which six plots underwent the restoration interventions with the other six nearby non-defected plots being used as control for the baseline values. Restoration treatments, including re-contouring drains, planting native wetland flora and invasive species removal were deployed in 2015-2016. The research included six survey rounds that included two pre-restoration (baseline surveys done early in the 2000s), one mid-restoration, and three post-restoration (the most recent in 2023). In every plot, presence and abundance of vegetation was quantified on plants, birds, amphibians, reptiles, mammals, fish and aquatic invertebrates were recorded. Community structure was measured by quadrats and transects and aquatic fauna was sampled by nets and traps. Water quality was monitored on-site and in the laboratory (UNILAK Environmental Laboratory): on-site parameters were pH, dissolved oxygen (DO), turbidity, nitrate-nitrogen, phosphate-phosphorus and total organic carbon. The GIS was used to measure open-water area on satellite imagery (2007 and 2023).

The survey utilised four standard biodiversity indices: species richness (S), Shannon-Wiener diversity (Atkins, 1997), Simpson dominance index (D) and evenness (E) in describing vegetation, avian, ichthyofauna, amphibian and invertebrate communities at a restored wetland. These calculations were done in each of the Trophic Groups that were defined, they were the Primary producers (Aquatic plants, phytoplanktons), Primary consumers (Herbivores, zooplanktons), Secondary consumers (Carnivorous fish, insectivores, small predators), Tertiary consumers (Top avian and mammalian predators), and the decomposers (Earthworms, detritovorous fishes, shrimps). Temporal patterns in each Trophic Group were compared pre- and post-restoration using paired t-tests, and all analyses were done in R and Excel.

RESULTS

Wetland habitat and water quality

After hydrologic restoration, the hydrological balance and the quality of habitats of Rugezi was improved to a considerable extent (Fig. 3). Remote-sensing and field mapping data confirm that reflooding has reclaimed an area of about 12 % of the previous open water area of the site. Correspondingly, vegetative cover was ~40 % higher than baseline values, composed primarily of native macrophytes (papyrus, sedges, *Lemna* and *Vossia* mats). These changes were accompanied by increases in soil moisture and water-table levels in the treatments, maintaining low levels in the untreated controls and increases in biomass in the two areas (data not shown). There was a significant improvement in water-quality indicators as well. There was an average increase in post-restoration dissolved oxygen of 7.8 mg/L (in comparison to 4.2 mg/L before treatment), indicating improved aeration (Table 1). Mean pH was stabilised away from acidity (6.8→7.4). Nitrate-N declined by ~1mg/L to 1.1mg/L, and phosphate declined by ~0.8mg/L to ~0.3mg/L (Table 2); these trends indicate less n- and p-nutrient loading. The values of turbidity decreased to 12 NTU, and the suspended sediment concentration reduced by about 36 %. Taken together, all these findings suggest that this aquatic habitat has been made less eutrophic and more apt to support a wider group of biota.

Table 1. Key ecological indicators and habitat parameters before(pre) and after(post) Rugezi wetland restoration

Metric	Pre-restoration	Post-restoration (2023)	Change
Plant Shannon diversity index (H′)	1.0 (2007)	>2.0 (2023)	+≥1.0
Bird species richness	35 species (2007)	85 species (2023)	+50 species
Fish population (*Oreochromis*, *Barbus*)	~15,000 individuals (2017)	~22,000 (2024)	7,000
Sitatunga antelope population	200 (2017)	260 (2024)	60
Invertebrate species count	Low diversity (<some dozens)	+72 species	+72 species
Dissolved oxygen (mg/L)	4.2 (2007)	7.8 (2023)	3.6
Nitrate (mg/L)	2.5 (2007)	1.1 (2023)	-1.4
Phosphate (mg/L)	0.8 (2007)	0.3 (2023)	-0.5
Open water area	Reduced (2007)	+12% (2023)	12%

Table 2. Water quality parameters in Rugezi wetland before and after restoration (WHO recommended ranges shown)

Water quality parameter	Before (2007)	After (2023)	WHO guideline
pH	6.8	7.4	6.5–8.5
Nitrate (mg/L)	2.5	1.1	≤1.0
Phosphorus (mg/L)	0.8	0.3	≤0.5
Turbidity (NTU)	25	12	≤5

Wetland before

After restoration

Fig. 3. Rugezi wetland before and after restoration

Biodiversity and community indices

Restoration led to strong gains in biodiversity indices across multiple taxa. Plant community diversity (Shannon index) increased from ~1.0 to >2.0, reflecting both higher species richness and evenness. Before restoration, the marsh was dominated by a few common species (*Typha*, *Microcystis* blooms), yielding low diversity (Simpson's index ~0.9). Post-restoration, the flora became more varied: at least 7–10 aquatic plant species were recorded (e.g. *Papyrus*, *Cyperus latifolius*, *Miscanthus violaceus*, *Phragmites* spp., *Lemna* spp., *Vossia* spp.), and vegetation cover notably expanded.

Faunal richness likewise recovered. Amphibian surveys documented ~13 species in 2023 (e.g. *Hyperolius viridiflavus*, *Amietia* sp., *Afrixalus fulvovittatus*), up from very few in the degraded state. Reptile observations (e.g. Elliot's chameleon *Trioceros ellioti*, Lacertid *Adolfus africanus*) roughly doubled in diversity. Small mammal diversity increased (from ~10 to 20 rodent/insectivore species detected). Overall vertebrate species richness rose from ~110 to ~138 by 2024 (counting multiple taxa).

The most dramatic change was in bird diversity. Total wetland bird species rose from 35 in 2007 (pre-restoration) to 85 by 2023. Many waterbird and papyrus specialist species returned. For example, counts of the Grey Crowned Crane (*Balearica regulorum*) grew from ~300 to ~1,293 individuals; the Shoebill (*Balaeniceps rex*) rose from ~5 to ~17 (Table 1). Migratory ducks and other waterfowl also became more abundant. The increase in avian diversity contributed strongly to overall ecosystem diversity.

Aquatic and semi-aquatic consumer populations also recovered. Fish counts (primarily tilapia and barbs) rose from ~15,000 (2017) to ~22,000 (2024), driven by improved habitat and water quality. Invertebrate surveys showed a net gain of ~72 macroinvertebrate taxa (including aquatic insects and crustaceans), indicating far richer food resources than before.

Together, these changes yielded higher community evenness and resilience. Shannon indices for birds and fish approached or exceeded 2.0 post-restoration (versus <1.0 pre-restoration), and Simpson's indices decreased, reflecting more balanced species assemblages.

Food web and trophic recovery

The restoration's impact on the wetland food web was substantial. Primary producers (plants and phytoplankton) formed a more complex base. Where once only a few dominant reeds prevailed, post-restoration surveys found diverse vegetation patches. This supported larger primary consumer populations: herbivorous insects and zooplankton increased by ~50-55%, and herbivorous birds (e.g. Crested Coot *Fulica cristata*) increased by ~50%. *Sitatunga antelope*, an important marsh grazer, rose from ~120 to ~260 individuals as papyrus stands expanded. Even insectivorous bat populations (e.g. African pipistrelle) grew ~4-fold, benefiting from richer insect prey (Fig. 4).

Secondary consumers (small predators) also rebounded. Freshwater fish that feed on insects and plankton doubled or more in abundance. Amphibians showed notable recoveries: the *Hyperolius marmoratus* frog went from ~800 (early 2000s) to ~1,400 (2024), and *Leptopelis kivuensis* from ~350 to ~675. The Elliot's chameleon population rose from ~200 to ~360. Overall, secondary-trophic species richness increased by ~20-30%. At the tertiary level, top predators saw the largest proportional gains. Populations of predatory waterbirds recovered dramatically (as above, cranes and shoebills). Other large wetland birds (e.g. African Spoonbill) *Platalea alba*, White Pelican *Pelecanus onocrotalus*) also increased two- to three-fold. These predators now have more stable food bases. Decomposer communities likewise flourished: earthworm densities climbed from <50 to ~150 per m², and detritivorous shrimp rose from ~2,000 (2017) to ~2,820 (2024), reflecting healthier soils and organic matter cycling (Fig. 5&6).

Leptopelis kivuensis *Trioceros ellioti*

Fig. 4. Secondary consumers (small predators) *Leptopelis kivuensis* frog and Elliot's Chameleon (*Trioceros ellioti*)

Grey crowned crane Shoebill species

Fig. 5. Tertiary consumers: Grey crowned crane and shoebill species, RWCA, 2024

Fig. 6. Diverse avian species thriving in the Rugezi Marsh ecosystem, RWCA, 2023)

Food web and trophic interactions

A schematic description below summarises the most common trophic interactions in Rugezi Wetland, and highlights how, in a bottom-up restoration attempt, the interventions have trickled up along food chains (Fig. 7).

An increased and broader basis is now reflected in earlier primary producers- papyrus, sedge, emergent aquatic plants, and phytoplankton, which previously showed a more diverse plant ShannonWiener extent, changing to >2.0 (Kubwimana *et al.*, 2025; Concorde, 2025). This increase at the base has resulted in larger and more evenly distributed assemblages of primary consumers (zooplankton, detritivores, freshwater shrimp, herbivorous fishes, and grazing birds), supporting ~55 % greater zooplankton densities and significant increases in herbivorous fish abundance (an increase of almost 50 thousand individuals, to ~22,000 in total) and Sitatunga numbers. Secondary consumers, including insectivorous fishes, amphibians, small predatory birds and bats, and in parallel, there is an increase in water quality (dissolved oxygenation which increased ~4.2 and ~7.8 mg L -1; decrease in nitrate, phosphate) and growth of open-water and vegetated habitat, which have led to the re-establishment of species richness and functional connectivity (Kubwimana *et al.*, 2025). Taken collectively, the diagram illustrates the re-woven robust food web where high primary production and higher habitat architecture hallmark the concomitant increases in consumer biomass and predatory densities to index functional restoration of the Rugezi Wetland ecosystem (Table 3).

Table 3. Food web

Producers (Primary)	Primary consumers (Herbivores/Detritivores)	Secondary consumers (Small predators)	Tertiary consumers (Large predators)	Apex and decomposers (Top predators / nutrient recyclers)
Papyrus, Sedges, Aquatic plants Phytoplankton (↑ vegetation diversity post-restoration)	Zooplankton Freshwater shrimp Herbivorous fish (*Tilapia*, *Barbus*) Herbivorous birds (Crested Coot) *Sitatunga* (marsh grazer)→ (consume producers)	Insectivorous fish Amphibians (frogs) Small predatory birds Bats (insectivores) → (consume primary consumers)	Large predatory fish Predatory birds (Shoebill, Spoonbill) Grey Crowned Crane (omnivorous elements) → (consume secondary consumers)	Otter (*Aonyx capensis*) Other mammalian predators Decomposers: earthworms, microbes, detritivorous fish (Receive energy from all lower levels; recycle nutrients)

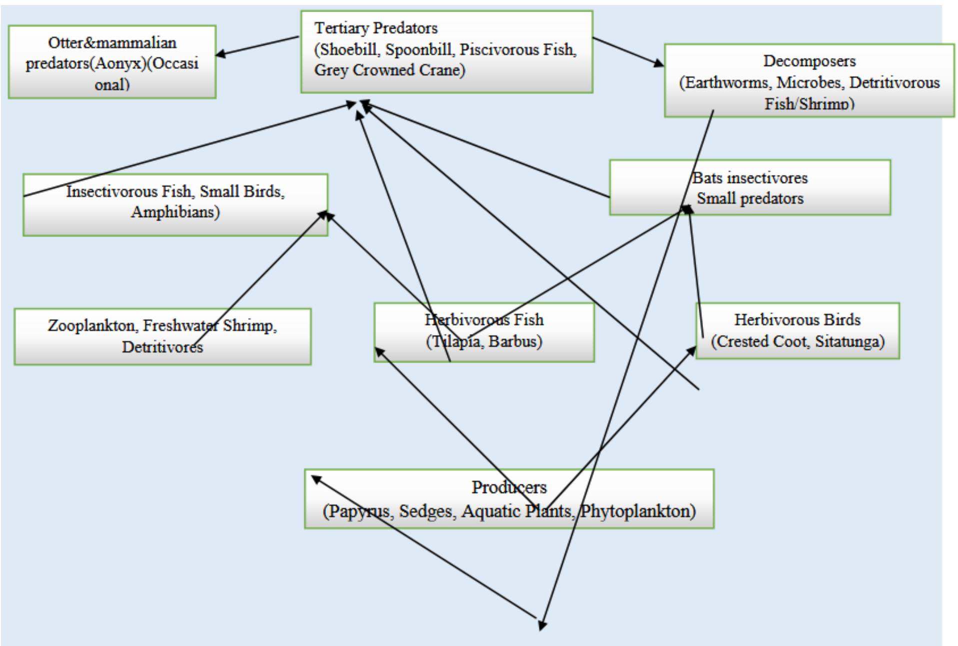

Fig. 7. Rudezi wetland foodweb

The arrows shows the flow of energy (Predator to prey)

Producers (Primary)

Main components: Papyrus (*Cyperus papyrus*), sedges, emergent aquatic plants, phytoplankton.

Status: Diversity (Shannon H') rose from ~1.0 to >2.0 after restoration; vegetation cover increased (~+40%).

Role: Provide habitat structure, primary production, and detrital inputs that sustain the food web.

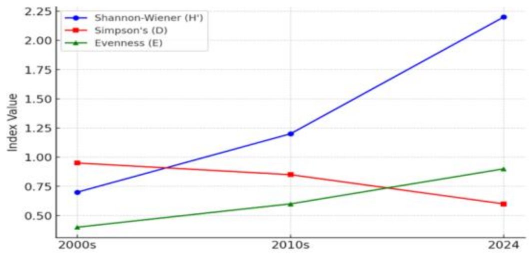

Fig. 8. Biodiversity indices over time in Rugezi wetland

Primary consumers (Herbivores and detritivores)

Main components: Zooplankton, freshwater shrimp, herbivorous fishes (*Tilapia*, *Barbus*), herbivorous birds (Crested Coot), *Sitatunga*.

Status: Zooplankton +55%; shrimp and herbivorous fish increased (fish ~+63%); Sitatunga population rose (200→260).

Role: Transfer plant-derived energy to higher trophic levels; important for nutrient cycling.

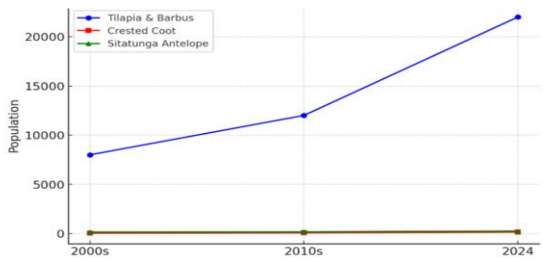

Fig. 9. Primary consumer populations overtime in Rugezi Wetland

Secondary consumers (Small predators)

Main components: insectivorous fish, amphibians (*Hyperolius* spp., *Leptopelis* spp.), small predatory birds, bats.

Status: Amphibian and insectivore populations increased substantially, supporting more predators.

Role: Control herbivore/insect populations and connect energy flow to tertiary consumers.

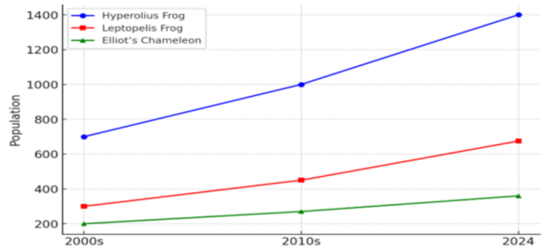

Fig. 10. Secondary consumers over time in Rugezi wetland

Tertiary consumers (Large predators)

Main components: Large predatory fish, predatory/wading birds (Shoebill, Spoonbill), Grey Crowned Crane.

Status: Significant recovery-Grey Crowned Crane to ~1,293 individuals; Shoebill sightings increased (10→17).

Role: Regulate prey populations and indicate wetland health; sensitive to habitat change.

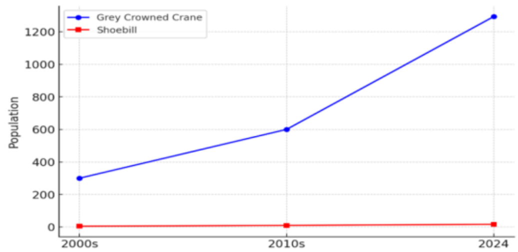

Fig. 11. Tertiary consumers over time in Rugezi wetland

Apex and decomposers

Main components: Otter (*Aonyx capensis*), mammals, earthworms, microbes, detritivorous fish/shrimp.

Status: Decomposer densities (earthworms, detritivores) rose; otter and mammalian predator presence were more regularly observed post-restoration.

Role: Recycle nutrients, close energy loops, and sustain long-term productivity.

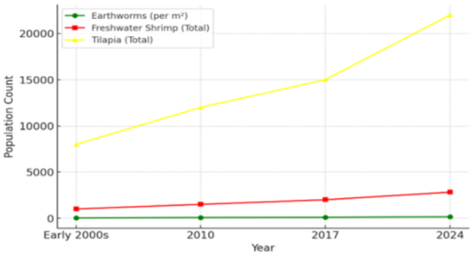

Fig. 12. Decomposers over time at Rugezi Wetland

DISCUSSION

Empirical evidence collected throughout the rehabilitation of Rugezi wetland and even after its recovery show that there has been tremendous recovery of the ecological system. The tracked improvements in the biodiversity indicators, i.e., over 100 percent growth in the plant Shannon index and widening peak diversity of species by more than two dozen genera, confirm earlier discoveries that a change in hydrological landscape and the structure of physical habitat can significantly enhance biodiversity growth (Zedler and Kercher, 2005; Davidson *et al.*, 2019). In parallel, the >100 percent rise in bird species richness also provides additional support that global treating wetlands indeed promotes waterbird populations and endemic fauna (Marnn *et al.*, 2025; Davidson *et al.*, 2019). The increased biomass of fish and invertebrates is the other indication of the improved productivity of ecosystems and water quality after the interventions (Davidson *et al.*, 2019).

Importantly, the recovery across all trophic levels indicates that the wetland's ecological functions have rebounded. Top-down and bottom-up processes appear re-established: abundant primary producers underpin larger herbivore and predator populations. This aligns with restoration ecology theory, which predicts that reintroduction of natural water regimes and native plants will reweave disrupted food-web interactions (Hobbs and Harris, 2001). The return of specialist fauna (e.g. *Sitatunga*, papyrus warblers) suggests the marsh is regaining its pre-degradation ecological character.

Improved water quality with increase in the concentration of dissolved oxygen and a decrease in the nutrient load has played a central role of biochemical recovery at the study site. These ameliorations reduced algal bloom and provided nutrient levels favorable to aquatic life. At the same time, illegal habitat exploitation decreased and sustainable livelihoods-based beekeeping and ecotourism increased indicating that community-based management is strengthening ecological gains. Rolling out multi-pronged intervention package, akin to these initiatives, has also reinforced the resilience of wetlands in similar settings in other locations (Zedler and Kercher, 2005).

These findings support the Rwandan wetland policies, not to mention the Ramsar Convention conservation goals, in general (Davidson *et al.*, 2019). The success stories expressed in reversed ecology indicate restoration efforts coupled with protection efforts create reversals to decades of destruction. It is important to continue with monitoring to ensure that the sustained recoveries made continue to be lasting.
It would be possible to analyse genetic diversity in critical populations and determine the place of the wetland in the regional biodiversity networks in subsequent analysis.

CONCLUSION

Restoration of Rugezi Wetland has produced clear and measurable ecological benefits. Re-establishing hydrological regimes, removing invasives, and replanting native wetland vegetation increased habitat complexity and expanded vegetated and open-water areas. These habitat improvements were accompanied by improved water quality (notably higher dissolved oxygen and reduced nitrate and phosphate concentrations), a substantial rise in plant diversity (Shannon H′ from ≈1.0 to >2.0), and marked increases in faunal abundance and richness, including zooplankton, macroinvertebrates, fish, amphibians, and wetland birds. Trophic integrity has been substantially restored: primary-producer gains produced bottom-up effects that increased primary consumers and rippled upward to secondary and tertiary consumers (e.g., larger populations of predatory fish and wading birds), demonstrating a re-woven, more resilient food web. Social outcomes accompanied ecological gains: reductions in illegal extraction and the adoption of alternative livelihoods (beekeeping, ecotourism) strengthened local stewardship. Collectively, these results indicate that targeted wetland restoration in Rugezi has successfully recovered ecosystem structure and function and improved the wetland's capacity to deliver ecosystem services.

RECOMMENDATIONS

To the local community

1. Local communities should actively participate in conservation programs to ensure the sustainability of wetland restoration efforts.
2. Alternative sustainable livelihoods, such as beekeeping and ecotourism, should be encouraged to reduce dependence on wetland resources.
3. Awareness campaigns should be conducted to educate community members on the importance of wetland conservation and responsible resource use.
4. Farmers should adopt sustainable agricultural practices, such as buffer zone farming and organic fertilizers, to minimize nutrient runoff into the wetland.
5. Community-based monitoring programs should be established to help track environmental changes and report illegal activities.

To the government

1. The government should enforce strict policies and laws to protect Rugezi Wetland from encroachment, poaching, and pollution.
2. Investment in wetland management infrastructure, including improved hydrological control systems, should be prioritized.
3. Law enforcement agencies should be strengthened to prevent illegal harvesting of papyrus and other wetland resources.
4. Financial support should be provided for local conservation initiatives and community-led restoration programs.
5. Research institutions and environmental organizations should be supported in conducting long-term ecological monitoring of the wetland.

To the future researchers

1. Investigating the long-term impacts of wetland restoration on carbon sequestration
2. Assessing the socioeconomic benefits of wetland restoration
3. Evaluating the role of wetlands in mitigating flood risks

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