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Diversity of Macro Invertebrates of the River Rwizi in Western Uganda: A Citizen Science-BioBlitz Approach

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Abstract

This study elucidates the pivotal role of citizen science-BioBlitz methodologies for rapid assessment of the macro-invertebrate taxa within the threatened River Rwizi of South-western Uganda. Utilizing a comprehensive mixed-methods approach, the investigation focused on six distinct river segments to demonstrate the efficacy of participatory citizen science-BioBlitz approaches conducted by experts, students and community volunteers. BioBlitz events included rigorous macro-invertebrate sampling at each of the selected sites along River Rwizi on nine occasions, incorporating collaborative taxonomic identification procedures involving experts, students, and the local community. Analyzing pollution concerns, diversity metrics, and community narratives yielded insights into river health and socio-ecological dynamics. A total of 43 macro-invertebrate families across 17 orders were documented with class Insecta dominating. Participants in BioBlitz events expressed predominantly positive sentiments, emphasizing satisfaction, education, and heightened awareness, besides negative sentiments rooted in historical mistrust. Intriguingly, the study unveiled an unforeseen trend in macro-invertebrate taxa richness, rising from upstream to urban sprawl and diminishing at peri-urban downstream sites. The study underscores the potential of citizen science-BioBlitz methodologies in advancing community science education and unraveling the intricate dynamics of threatened river ecosystems. The insights offered are invaluable for policymakers and conservationists seeking effective strategies to address challenges in the River Rwizi and comparable ecosystems.

Keywords

Diversity, Macroinvertebrates, Rwizi, Citizen-Science-BioBlitz 6

1. Introduction

Biodiversity, a crucial natural asset, faces ongoing threats due to anthropogenic activities, including land use change, invasive species introduction, pollution, and climate change [1]. Despite growing global recognition of the importance of biodiversity conservation, its decline persists. Public understanding of biodiversity varies widely, emphasizing the need for increased awareness and education [2].

The intricate ecosystems of rivers play a vital role in maintaining ecological balance, and understanding the diversity of macro-invertebrates within these water bodies is crucial for assessing overall environmental health [3] [4]. In the context of Western Uganda, the River Rwizi stands as a critical watercourse facing various environmental challenges, including anthropogenic influences, habitat modifications, and pollution [5] [6]. This study delves into the "Diversity of Macro-invertebrates of the River Rwizi in Western Uganda," employing a distinctive approach—the Citizen Science-BioBlitz method.

Rivers, being dynamic habitats, are susceptible to a myriad of stressors that impact the composition and abundance of macroinvertebrate communities [7] [8]. The River Rwizi, situated in Western Uganda, epitomizes such challenges, necessitating comprehensive research to understand and mitigate the impacts on its macroinvertebrate populations. Recent studies have highlighted the vulnerability of the River Rwizi to pollution from agricultural runoff and sedimentation, emphasizing the urgency of assessing and conserving its aquatic biodiversity [9] [10].

Community participation in biodiversity conservation and research, particularly through the citizen science model, is deemed a practical and effective strategy for enhancing public awareness and conservation education [11]. The citizen science approach, emphasizing experiential learning, facilitates active community involvement, resulting in substantial contributions to scientific knowledge and the generation of extensive global data on species occurrence and distribution. This engagement not only advances biodiversity research but also transcends traditional education, playing a crucial role in fostering broader public awareness. The emphasis on hands-on involvement in scientific endeavors within community-based biodiversity initiatives underscores its significance as a means of achieving effective biodiversity protection [12].

Overview of the Citizen Science Approach

Citizen science also referred to as participatory or community-based monitoring [13], involves volunteers actively participating in scientific research, contributing to data collection, monitoring sites, and engaging in the scientific inquiry process [14] [15]. Over the past two decades, the popularity of citizen science has grown significantly, driven by the increasing recognition among scientists of the advantages of involving volunteers [11] [13] [15] [16] [17]. The cost-effectiveness of citizen science data has particularly appealed to researchers, enabling the ex-

ploration of research questions with large spatial and temporal scales [18] [19] [20] [21] [22]. The participatory approach offers non-scientists the opportunity to contribute to scientific knowledge and decision-making, emerging as a promising and cost-efficient method for involving citizens in monitoring and conservation efforts [23].

Relatedly, a "BioBlitz" is a specific form of citizen science described as an intensive, short-duration event that brings together scientists, naturalists, and community members to identify and record as many species of living organisms as possible within a designated area during a specific period of time [17] [24] [25]. Typically, a BioBlitz involves a rapid field survey where volunteers aim to document as many species as possible in a defined location during a specific period, with its primary goal being to create a snapshot of biodiversity over a designated timeframe [26]. The BioBlitz concept, recognized for being good science, effective outreach, and enjoyable, has been widely employed worldwide to gather and share information about plants and animals in natural areas, particularly parks [26]. This collaborative and rapid biological survey involves various activities such as species identification, data collection, and documentation. Ballard *et al.* [27] found that BioBlitzes contribute more significantly to site and species management compared to other types of citizen science programs with positive conservation outcomes while Parker *et al.* [25] underscore how expert-led BioBlitzes generate conservation-relevant data, enhance research capacity, and establish working partnerships focused on conservation. They clarify how the term "BioBlitz" is not copyrighted and can be freely used, adapted, and modified by any group for their own purposes [25].

The application of a Citizen Science BioBlitz approach to the study of aquatic macro-invertebrates in the River Rwizi provides numerous justifications, offering benefits for both scientific research and community engagement. From a biodiversity assessment perspective, the BioBlitz serves as a rapid and comprehensive survey method, enabling the identification and documentation of a diverse array of aquatic macroinvertebrate taxa in the River Rwizi. The collected data, in turn, establishes a crucial baseline for understanding the current ecological health and diversity of the river ecosystem. Beyond scientific exploration, community engagement becomes a focal point, offering educational opportunities that foster environmental awareness and empower local citizens with knowledge and skills in scientific observation and environmental stewardship. Furthermore, the BioBlitz supports long-term monitoring, allowing the observation of temporal trends in macroinvertebrate populations, Thus, applying the Citizen Science BioBlitz approach to the study of aquatic macro-invertebrates in the River Rwizi not only contributes to scientific understanding but also engages and empowers local communities in environmental conservation efforts in line with the principles of citizen science, promoting collaboration between scientists and citizens for the benefit of both the environment and society.

The Citizen Science-BioBlitz approach, employed in this study, exemplifies a collaborative and inclusive methodology [11] [28]. By engaging both experts and

community volunteers, this approach not only facilitates the rapid assessment of macroinvertebrate taxa but also promotes community participation in scientific endeavors. As Western Uganda faces increasing environmental pressures, such a citizen-driven approach becomes instrumental in gathering valuable data on the macroinvertebrate diversity of the River Rwizi [17] [29].

The study investigates the potential of the citizen science-BioBlitz approach to document macro-invertebrates in rivers. This method complements traditional scientific data collection and contributes to the advancement of community science education. Community-based macro-invertebrate assessments, conducted in BioBlitz events, actively involve citizen scientists and the public in hands-on sampling activities. These events serve as a platform to raise awareness about the importance of clean water and the impact of human activities on aquatic ecosystems. The gathered data are valuable for river water resources management and conservation, recognizing macro-invertebrates as significant ecological indicators of environmental quality [30] [31] [32] [33]. Additionally, this approach creates educational and outreach opportunities, offering substantial support for effective conservation and management practices [33] [34] [35].

The study sets the stage for a detailed exploration into the macroinvertebrate diversity of the River Rwizi, emphasizing the unique Citizen Science-BioBlitz approach as a means to gather critical insights related to macroinvertebrate diversity, and the broader implications for both conservation efforts and community engagement in Western Uganda's riverine ecosystems.

2. Materials and Methods

2.1. Study Area and Sites

The River Rwizi catchment, located in South-western Uganda, is a crucial hydrological and ecological region facing various environmental challenges. Spanning approximately 8554.7 km^2, the catchment is situated between longitudes 30.21˚ E to 32.52˚ E and latitudes 0.24˚ S to 0.92˚ S, with an altitudinal range of 1300 to 2170 meters above sea level [36] [37]. The river, stretching about 55 km, meanders eastwards from the hilly terrain of the region, ultimately discharging into Lake Victoria.

The upper catchment of the River Rwizi traverses' multiple districts, including Buhweju, Sheema, Bushenyi, Mbarara, Ntungamo, Isingiro, and Kiruhura, before it flows into Lake Mburo (**Figure 1**). This region experiences a bi-modal climate characterized by distinct wet seasons from March to May and September to November, providing essential rainfall for the river and the surrounding ecosystems [38]. The warm temperatures, ranging between 20˚C - 30˚C year-round, are attributable to the equatorial proximity of the area.

2.2. Site Selection

The site selection and delineation process occurred during district consultation workshops, relying on local land uses and identifying areas with potential pollution

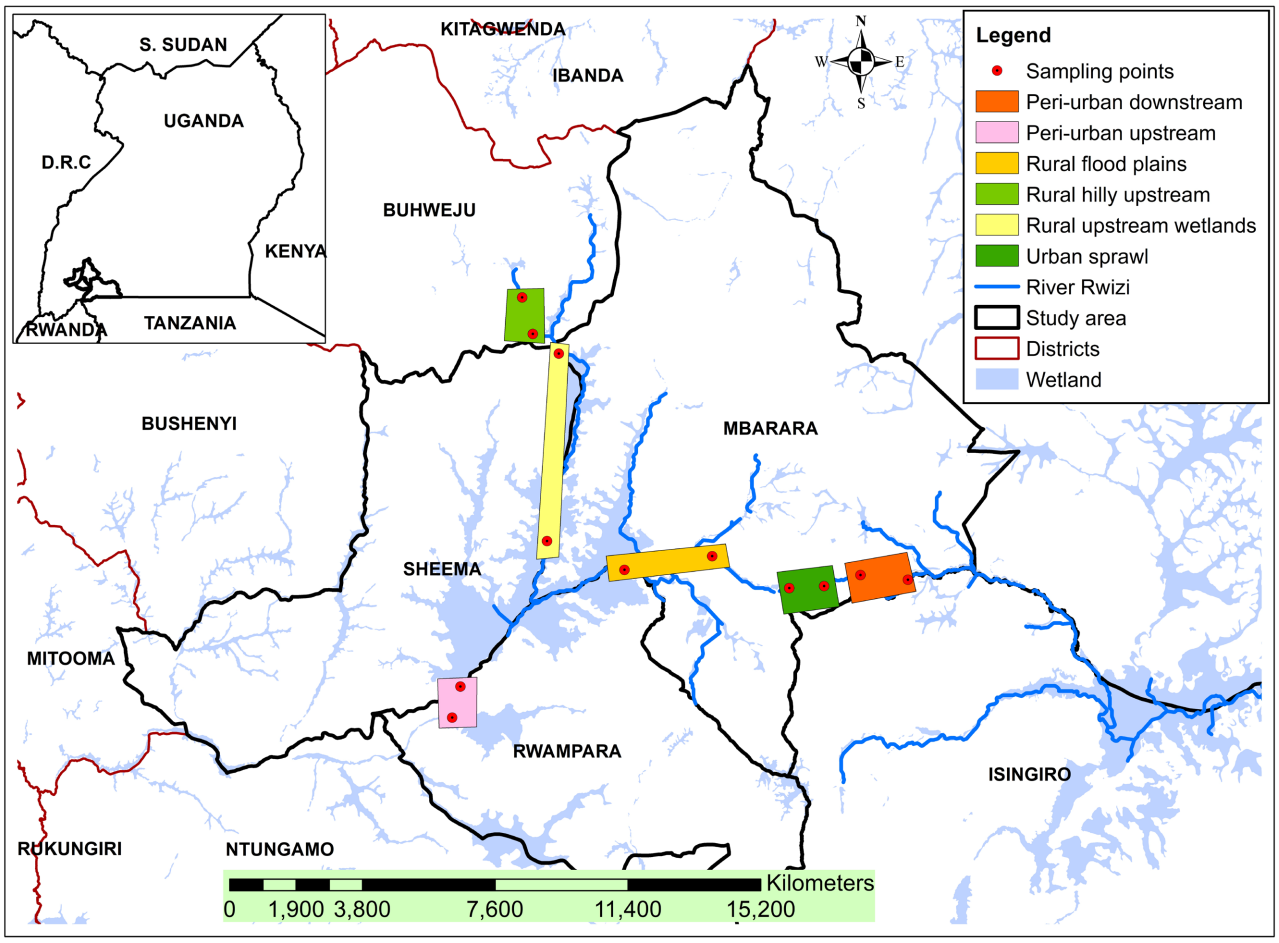

Figure 1. Study area and sampling site locations with pollution dissemination.

manifestations. Active community participation was encouraged, leading members to propose sampling sites based on their local knowledge, considering accessibility and proximity to the main River Rwizi. The main river was segmented to capture the diversity of the riverine environment. Strategically, twelve sites were chosen for macroinvertebrate sampling, with two data collection points designated for each river segment to account for variations along the segment's length (Figure 1). The selection aimed to balance representativeness across different segments, ensuring a comprehensive assessment of macroinvertebrate biodiversity within the River Rwizi watershed. This approach not only effectively involved the community in the research process but also nurtured a sense of ownership and collaboration, ultimately enhancing the scientific rigor of the study.

A mixed-methods approach for macroinvertebrate metrics and socio-ecological dynamics in the context of a citizen science BioBlitz research design that combined both quantitative and qualitative research methods was used in this study.

2.3. Community Engagement

Permission to conduct the research was obtained from district authorities, faci-

litated by the District Chief Administrative Officers. The research team organized a one-day consultative workshop to introduce the project to security leaders, district political heads, and technocrats. This workshop served as a platform to disseminate the research concept and its objectives. The outcomes of these workshops were pivotal in publicizing the project to technocrats at the district level and establishing an entry point into the communities within the riparian zone of River Rwizi parishes. Subsequent introductions were made to extension workers, parish chiefs, and Local Councils.

The extension workers, parish chiefs, and Local Councils played crucial roles as focal points for community entry and engagement. They actively participated in the selection of participant volunteers for the Citizen-Science-BioBlitz activity. Furthermore, they guided the mobilization and recruitment processes of participants for data collection. Participation was restricted to individuals above 18 years old, and voluntary acceptance was sought from potential participants. Those who agreed underwent training in macro-invertebrate data collection methods. This training was particularly important in the context of deteriorating water quality, anthropogenic pollution, and the overall need for water conservation in the River Rwizi watershed.

To ensure the safety of participants, all necessary safety precautions were implemented, including strict adherence to the National Guidelines for Research involving Humans as Research Participants [39].

2.4. Citizen Science-BioBlitz Events

A guided bio-blitz sampling strategy was implemented to conduct an inventory of macro-invertebrates along selected sites of the River Rwizi. The lead team of bio-blitzers was composed of biologists from Mbarara University of Science and Technology (MUST), including expert lecturers, three technicians, two graduate students, and two trainees from the International Crane Foundation (ICF). The involvement of expert academic staff from MUST ensured scientific rigor and proficiency in the sampling process. Additionally, community volunteers, comprising 6 to 8 individuals from each of the 12 selected sites along the River Rwizi, actively participated in the bio-blitz events. The engagement of community volunteers not only expands the data collection capacity but also aligns with the principles of citizen science, enhancing community involvement in scientific research [11]. The collaborative effort between academic experts and community volunteers aimed to generate comprehensive data on macro-invertebrates.

2.5. Citizen Science-BioBlitz Training

The training process commenced with an orientation for the Mbarara University of Science and Technology (MUST) team, providing them with a comprehensive understanding of the natural history of the River Rwizi, emphasizing the significance of aquatic biodiversity, and elucidating the socio-ecological role of macro-invertebrates in aquatic environments. This foundational knowledge is aimed at facilitating experiential learning, community science education, and research

purposes. Subsequently, the team conducted a field reconnaissance as part of a pilot study to validate the most suitable sampling sites along the river. This involved a detailed description of the sites, incorporating input from community participants. During this phase, team members were introduced to the technical procedures involved in the collection and treatment of samples, as well as the utilization of protocols and taxonomic guides for the identification of aquatic macro-invertebrates. This preparation phase was crucial to orient the team and equip them with the necessary skills to subsequently train local community volunteers for participatory citizen Science-BioBlitz surveys. The overarching goal was to determine the macro-invertebrate assemblages for each identified river segment.

The sampling strategy implemented in this study encompassed nine sampling sessions at each designated site between January and July 2023, with a focus on macroinvertebrate organisms. Utilizing a modified D-frame metal sieve with a prescribed mesh size of 5 mm, the sampling adhered to well-established macrobenthos sampling protocols [40]. Various methods, including scoops, dips, or sweeps, were employed along the littoral river bank areas recognized as the most productive habitats for macro-invertebrates. To maintain data accuracy, organisms were meticulously rinsed by sweeping them against the flowing river water current, with any debris and non-macro-invertebrates, such as fish, released back into the water. The collected macro-invertebrates underwent further processing, involving hand-picking from the sieve using forceps or brushes. Subsequently, they were spread on a white sheet of absorbent paper for participatory taxonomic identification and counting. This detailed and systematic approach aimed to provide a representative understanding of the macroinvertebrate taxa present in the River Rwizi.

The macroinvertebrate sampling and identification procedures were conducted by adhering to standardized techniques to ensure accuracy and reliability. Citizen scientists and volunteers, equipped with prior training, skillfully carried out hands-on sampling using essential equipment like D-nets, trays, and containers for the systematic collection of macroinvertebrate specimens. Following the guidelines established by USEPA [41], samples were methodically composited for each entire site and subsequently pooled for a comprehensive analysis spanning different river segments.

The taxonomic identification and verification processes were collaborative efforts involving university experts and students, guided by identification guides [42]. During the verification stage, the team actively engaged the community, fostering a culture of shared learning and collaboration. Unidentified taxa, meticulously preserved in 70 percent ethanol, were transported to the laboratory for further processing and rigorous identification. This systematic collection and identification procedure were replicated for additional samples randomly gathered at various locations during one-hour sampling sessions.

In the laboratory, the utilization of stereo microscopes and hand lenses facilitated the observation of finer details for taxonomic identification, specifically at

the family taxon level. The specifications and justifications for family taxa were grounded in established studies and aligned with USEPA [41] protocols, as well as guidelines from Fry [42]. It is noteworthy that this comprehensive approach considered the inherent taxonomic challenges associated with the absence of published identification guides for aquatic macrobenthos in East Africa [43]. Collectively, this rigorous methodology ensured a thorough understanding of the macroinvertebrate taxa present in the River Rwizi.

2.6. Community Reflection and Feedback on BioBlitz Experiences

Community participants were actively encouraged to provide feedback and reflections on their BioBlitz experiences. Surveys and interviews were conducted to capture qualitative data on community perceptions, satisfaction, and awareness. The study employed an open citizen science method, fostering natural discussion, to collect feedback from participants about their individual and collaborative BioBlitz experiences. The primary aim was to investigate shifts in awareness, knowledge, and attitudes towards aquatic biodiversity. Narratives capturing the emotional dimensions of BioBlitz events were documented. Community participants' BioBlitz experiences were opportunistically gathered from their narratives during or after field sampling. The analysis categorized these experiences as positive (supportive of BioBlitz participation) or negative (critical or unsupportive).

2.7. Data Analysis

Thematic content analysis was conducted to characterize the typologies of pollution concerns in selected riparian areas along specific river segments of the River Rwizi. This involved the integration of community observations and narratives, capturing various types and sources of river pollution and degradation as unanimously agreed upon by the community through group consensus.

Quantitative analysis involved computing the composition and abundance of invertebrate orders and families within specific river segments and sample sites. Paleontological Statistics Software (PAST) was employed for this purpose

The Shannon-Wiener Diversity Index (H') was used to measure taxonomic diversity by considering both the variety of taxa and their even distribution. The Dominance Diversity Index (D) was also calculated to assess the abundance of dominant taxa in a community. Additionally, pair-wise Sorensen indices of similarity (S) were determined to explore the connections between taxa at different sites within river segments or across multiple sites. The Sorensen Coefficient (SC) calculator [44] was employed to compute similarity quotients based on species presence, enabling the comparison of species composition between different communities.

3. Results

Typology of factors leading to riparian degradation and pollution of River Rwizi

The reconnaissance survey conducted along River Rwizi aimed at identifying and categorizing various study sites. The findings, summarized in Table 1, reveal a spectrum of activities and factors contributing to environmental degradation and aquatic pollution, particularly in wetland and riverbank areas.

Taxonomic composition of macro-invertebrates identified in River Rwizi

The study identified a total of 43 macroinvertebrate families belonging to 17 orders (Table 2). The dominant group was Class Insecta, encompassing seven orders, with dragonflies and damselflies (Odonata) emerging as the richest and most abundant order, constituting 18.6% of the total count [n = 839]. Hemiptera (true bugs] and Ephemeroptera (mayflies) each exhibited occurrence above 10% following Odonata. There were only a few Trichoptera, accounting for only 2.74% frequency.

Table 1. Typology of factors leading to riparian degradation and pollution of River Rwizi.

STUDY SITES	Factors leading to riparian degradation and pollution
Rural, Hilly Upstream (RHU)	This segment, located in Buhweju, captures the ecological conditions and human influences typical of rural, hilly terrains. It encompasses hill erosion, agrochemical use, seasonal flooding, wetland degradation, and disposal of alcohol distillation waste.
Rural Upstream Wetlands (RUW)	Positioned in the lower Buhweju-Sheema stretch, this site delves into rural upstream wetlands, offering insights into wetland ecosystems. Dynamics include upstream wetland degradation, riparian cultivation, agriculture, road run-off, and livestock grazing.
Rural Flood Plains (RFP)	In Mbarara district, this segment characterizes rural flood plains, addressing wetland degradation, riparian cultivation, inundations, eutrophic flood pools, water hyacinth, fecal contamination from livestock grazing, river bank erosion, siltation, sedimentation, and sand mining.
Peri-Urban Upstream (PUU)	In Mbarara district, this segment characterizes rural flood plains, addressing wetland degradation, riparian cultivation, inundations, eutrophic flood pools, water hyacinth, fecal contamination from livestock grazing, river bank erosion, siltation, sedimentation, and sand mining.
Urban Sprawl (USP)	Within Mbarara district, this segment represents the peri-urban upstream region, exploring the transitional zone between rural and urban influences. It encompasses soil excavation, wetland degradation, riparian cultivation, eucalyptus tree farming, urbanization, gully erosion, waste dumping, and abattoir discharge.
Peri-Urban Downstream (PUD)	Situated at the Mbarara-Isingiro interface, this segment characterizes the peri-urban downstream region, capturing river dynamics during its transition from urban to rural influences. Issues involve cumulative urban waste discharges, degradation, riparian cultivation, livestock impact, river bank erosion, siltation, sedimentation, gully erosion, eucalyptus tree farming, and plastic pollution.

Table 2. Taxonomic composition of macro-invertebrates identified in River Rwizi.

Phylum	Class	Taxon	No. of families	Frequency	% families	% Frequency
Annelida	Oligochaeta	Opisthopora	1	2	2.33	0.24
Arthropoda		Odonata	8	314	18.60	37.43
		Hemiptera	6	180	13.95	21.45
		Ephemeroptera	4	99	9.30	11.80
		Coleoptera	5	47	11.63	5.60
		Trichoptera	3	23	6.98	2.74
		Diptera	2	4	4.65	0.48
		Hymenoptera	1	1	2.33	0.12
	Malacostrica	Decapoda	3	41	6.98	4.89
		Amphipoda	1	3	2.33	0.36
Cnidaria	Ceriantharia	Ceriantharia	1	1	2.33	0.12
Mollusca		Veneroida	1	15	2.33	1.79
		Unionida	1	2	2.33	0.24
	Gastropoda	Gastropoda	3	69	6.98	8.22
		Neotaenioglossa	1	24	2.33	2.86
		Architanioglossa	1	2	2.33	0.24
Platylminthes	Turbellaria	Turbellaria	1	12	2.33	1.43
All Taxa	**5**	**17**	**43**	**839**	**100**	**100**

The presence of Odonata, Ephemeroptera, Coleoptera, and Trichoptera, considered less pollution-tolerant taxa [45], seemingly indicates clean water conditions. However, water quality assessment practices have predominantly relied on the diversity and abundance of Ephemeroptera, Plecoptera, and Trichoptera (EPT) as sensitive indicators to alterations in water quality, specifically in response to pollutants and habitat changes [46] [47] [48] [49]. A thriving EPT population is indicative of good water quality, while a decline suggests potential pollution or habitat degradation. Therefore, the absence of Plecoptera, recognized as the most sensitive taxon among EPT to changes in water quality [48], and the presence of a few Tricoptera (2.74% frequency) make it impractical to draw conclusive judgments about the water quality of the River Rwizi solely based on EPT. Accordingly, the evaluation of other water quality parameters is necessary to provide a comprehensive assessment.

Table 3 presents taxa richness, abundance, and composition of macro-invertebrates along River Rwizi allowing for a comprehensive understanding of the diversity and distribution of macroinvertebrate species across different segments.

Table 3. Taxa richness, abundance and composition of macro invertebrates at various segments of River Rwizi.

Taxa	RHU	RUW	RFP	PUU	USP	PUD	Grand Total
Order Amphipoda					**1**	**2**	**3**
Amphipoda					1	2	3
Order Architanioglossa					**1**	**1**	**2**
Viviparidae					1	1	2
Order Coleoptera	**3**	**1**	**11**	**14**	**12**	**6**	**47**
Dryopidae				1			1
Gyrinidae	1		7	9	8	3	28
Hydraenidae	2	1	3	2	4		12
Hydrophilidae			1	2		1	4
Scirtidae						2	2
Order Decapoda	**17**	**9**	**1**	**2**	**6**	**5**	**40**
Palaemonidae					1		1
Potamonautidae	17	9	1	2	5	5	39
Order Decapoda						**1**	**1**
Atyidae						1	1
Order Diptera	**1**	**2**			**1**		**4**
Chironomidae	1				1		2
Muscidae		2					2
Order Ephemeroptera	**28**	**10**	**16**	**9**	**25**	**11**	**99**
Baetidae	16	3	5	3	3	4	34
Caenidae	3	1	1	2	6	2	15
Heptageniidae	9	4	9	4	16	5	47
Leptophlebiidae		2	1				3
Order Gastropoda		**16**	**22**	**23**	**5**	**3**	**69**
Ampullariidae		8	11	10	2	1	32
Lymnaeidae					1	1	2
Planorbidae		8	11	13	2	1	35
Order Hemiptera	**7**	**17**	**32**	**47**	**41**	**36**	**180**
Belastomatidae		7	11	14	14	15	61
Corixidae	3	1	4	11	2	2	23
Gerridae	4	1	1		1		7
Hydrometridae			2	4	3		9

Continued

Naucoridae		7	11	14	21	14	67
Nepidae		1	3	4		4	12
Aphelocheiridae						1	1
Order Hymenoptera	1						1
Syrphidae	1						1
Order Neotaenioglossa	9	9			1	5	24
Thiaridae	9	9			1	5	24
Order Odonata	57	38	64	36	59	60	314
Aeshnidae	7	1	13	9	9	13	52
Calopterygidae	11	8	7	6	11	11	54
Chlorocyphidae	7	8	10	7	9	11	52
Coenagrionidae	14	2	4	5	3	3	31
Gomphidae	9	5	12	5	15	8	54
Lestidae	6	8	11	2	4	9	40
Libellulidae	3	3	7	2	8	5	28
Platycnemididae		3					3
Order Opisthopora			1		1		2
Oligochaeta			1		1		2
Order Trichoptera	1	10	1	10	1		23
Dipseudopsidae	1						1
Ecnomidae		10	1	10			21
Philopotamidae					1		1
Class Turbellaria		1	2	2	3	4	12
Turbellaria		1	2	2	3	4	12
Order Unionida				2			2
Unionidae				2			2
Order Veneroida	1	3		11			15
Pisidiidae	1	3		11			15
Grand Total	125	116	150	156	157	134	838

Metrics for macro invertebrate taxa along selected segments of River Rwizi

The study results revealed a consistent increasing trend in taxa metrics, including richness, diversity, and evenness, from the Rural hilly Upstream to the Urban Sprawl river segment, with a slight decline observed at the Peri-Urban Downstream trend (Table 4).

Table 4. Metrics for macro invertebrate taxa along selected segments of River Rwizi.

INDEX	RHU	RWU	RFP	PUU	USP	PUD
Taxa richness_S	20	26	26	26	29	27
Number of individuals	817	911	1252	755	651	571
Taxa Dominance_D	0.27	0.21	0.15	0.10	0.08	0.10
Shannon_H	1.84	2.09	2.45	2.63	2.78	2.67
Evenness_e^H/S	0.31	0.31	0.44	0.53	0.56	0.53
Margalef	2.83	3.67	3.51	3.77	4.32	4.10

Contrary to expectations, the Rural Hilly Upstream river segment, which was presumed to have cleaner water being closer to the upstream source, exhibited the lowest richness (20) and diversity (1.84). The Rural Flood Plain (RFP) of the river segment recorded the highest number of individual macro-invertebrates, while the Peri-Urban Downstream (PUD) had the lowest count.

The observed lowest taxa richness, diversity, and evenness at RHU (Rural Hilly Upstream) may be attributed to the limited habitat complexity associated with the hilly, degraded agricultural landscapes. This area experiences extensive riparian cultivation and features a smaller, narrower, and shallower river with fewer adjoining stream inflows compared to the more heterogeneous and urbanized downstream areas.

Taxonomic similarity amongst various river segments of River Rwizi

The degree of taxonomic composition similarity among macro-invertebrates in various river segments of the River Rwizi is illustrated through Sørensen's index, as outlined in Table 5.

The results of the comparisons using Sørensen's index revealed a range of similarity levels among the macroinvertebrate taxonomic compositions in different river segments. The comparisons varied from low (below 0.5) to high (above 0.8), with the majority falling within the moderate range (0.6 to less than 0.8). Notably, Rural Hilly Upstream (RHU) exhibited high dissimilarity with Rural Flood Plains (RFP), while Rural Flood Plains (RFP) and Peri-Urban Upstream (PUU) demonstrated the highest level of similarity.

A Sørensen's index above 0.8 indicates a substantial taxonomic similarity, implying a significant overlap in species between the compared segments. Conversely, the lowest similarity (50%) observed between Rural Hilly Upstream (RHU) and Rural Flood Plains (RFP) suggests potentially distinct ecological conditions in these segments. Overall, the majority of the comparisons showed a moderate level of similarity, allowing for a closer investigation into specific differences and the factors influencing species composition in the different river segments.

Community reflections and feedback on BioBlitz experiences

Community reflections and feedback on BioBlitz experiences are generally positive, with participants expressing satisfaction through various statements. Below are some common sentiments participants may share about their BioBlitz event experiences, as summarized in Table 6.

Table 5. Sorenson's Similarity Index between different river segments of River Rwizi.

River segments	Sample 1 (S1)	Sample 2 (S2)	S1 ∩ S2	Sorensen Index	Level of similarity
RHU × RUW	20	26	16	0.70	Moderate
RHU × RFP	20	26	14	0.48	Low
RHU × PUU	20	26	15	0.65	Moderate
RHU × USP	20	29	17	0.69	Moderate
RHU × PUD	20	27	14	0.60	Moderate
RUW × RFP	26	26	22	0.85	High
RUW × PUU	26	26	21	0.81	High
RUW × USP	26	29	20	0.73	Moderate
RUW × PUD	26	27	19	0.72	Moderate
RFP × PUU	26	26	23	0.89	High
RFP × USP	26	29	22	0.80	High
RFP × PUD	26	27	19	0.73	Moderate
PUU × USP	26	29	20	0.73	Moderate
PUU × USP	26	29	20	0.76	Moderate
USP × PUD	29	27	22	0.79	Moderate

Table 6. Thematic analysis of positive responses on participatory BioBlitz experiences.

Enjoyment and Discovery:
- "I thoroughly enjoyed exploring and discovering different species during the BioBlitz."
- "It was exciting to learn about the diverse range of species present in our local ecosystem."

Engagement with Nature and Environment:
- "The event provided a unique and engaging way to connect with nature and the environment."
- "The BioBlitz encouraged a sense of environmental awareness and conservation."

Learning and Education:
- "It was a fun and educational experience for both adults and children alike."
- "I gained a deeper understanding of the biodiversity in our community."
- "I have learned biology and feel like I am also a scientist like you."
- "We can use equipment very easily."

Community and Collaboration:
- "I appreciated the opportunity to work alongside experts and fellow community members."
- "This activity has brought us together with neighbors."
- "The event fostered a sense of community and shared interest in nature."

Environmental Concerns and Awareness:
- "We have learned a lot more about the Rwizi and are concerned about its pollution."
- "Participating in the BioBlitz made me more conscious of the importance of local ecosystems."
- "This exercise opened our eyes to the importance of preserving the environment."

Future Participation:
- "I look forward to future BioBlitz events to continue exploring and learning about our environment."

The responses reflect a diverse range of positive experiences, highlighting the success of the BioBlitz events in engaging participants, promoting environmental awareness, and fostering community collaboration. The inclusion of educational components and hands-on experiences is particularly appreciated by participants. However, some responses also express concerns about environmental issues, emphasizing the need for action and awareness.

On the other hand, negative responses collectively reveal a deep-seated mistrust and skepticism among participants. The perceived lack of transparency, coupled with a belief that the research is irrelevant to their daily lives, contributes to apprehension and resistance. Additionally, there is a clear sense of skepticism regarding the longevity and impact of the researchers' involvement in the community. These themes highlight the importance of addressing community concerns, building trust, and emphasizing the relevance and benefits of scientific studies to the local population (Table 7).

4. Discussion and Conclusion

4.1. Taxonomic Composition of Macro-Invertebrates Identified in River Rwizi

The study reveals notable variations in riparian characteristics along the River

Table 7. Thematic analysis of negative sentiments on participatory BioBlitz experiences.

Mistrust

- Survival over learning: Participants express a sense of prioritizing survival needs over the perceived triviality of the educational aspects provided during the study.
- Accusations of hypocrisy and deception: Strong accusations of hypocrisy and dishonesty are directed towards the researchers, accusing them of having ulterior motives, such as making money.
- Assertion of clean water: Resistance to the idea of water pollution is evident, with participants confidently asserting the cleanliness of their water and expressing a lack of problems related to the organisms present.
- Fear of informing authorities: There is a fear among participants that the researchers may inform environmental authorities leading to potential arrests, creating apprehension and distrust.

Lack of Expertise and Education Inadequacy

- Perceived educational gap: Participants express a perception that scientific work is meant for those who have received formal education, highlighting a lack of interest or belief in their own capacity to engage in such activities.

Lack of Interest in Macro-Invertebrates:

- Dislike for small organisms: A strong aversion to small organisms is evident, with participants expressing a natural disinterest and reluctance to engage with macro-invertebrates.
- Preference for fish: Participants communicate a preference for larger organisms like fish, indicating a lack of interest in smaller creatures.
- Indifference and lack of concern: Participants dismiss the significance of the organisms, stating that they see them but do not care about them. Some express that such work is more suitable for school children.

Time constraints

- Time constraints for women: Women participants express a lack of time and a focus on other responsibilities, indicating a perceived lack of relevance or interest in the study.

Anticipated Abandonment of the Project Beyond the Study Period:

- Doubt regarding continuity: Participants express skepticism about the researchers' commitment, questioning whether they will continue their involvement or disappear like others in the past.
- Observation of researchers' transience: Participants note a pattern of researchers coming and going without returning, contributing to the anticipation of potential abandonment.

Rwizi, primarily driven by differential degradation and pollution. These variations can significantly impact macro-invertebrates, including aquatic insects, crustaceans, and mollusks, residing in freshwater ecosystems. Nseka *et al.* [50] found that land use and cover characteristics in the upper Rwizi macro-watershed exhibited spatial and temporal variations affecting hill slope hydrological characteristics in the watershed due to increased human activities with consequent severe degradation in the area [50].

The study found high insect diversity and abundance in the River Rwizi, with Odonata, Hemiptera, and Ephemeroptera as the dominant orders. These insects are sensitive to water quality and play important roles in freshwater ecosystems [4] [51] [52] [53]. However, the absence of Plecoptera and the scarcity of Trichoptera suggest that the river may be polluted by human activities [46] [47] [48] [49]. The EPT index may not capture the river's health, and more water quality parameters are needed, a limitation perhaps posed by the BioBlitz approach.

4.2. Metrics for Macro Invertebrate Taxa along Selected Segments of River Rwizi

This study systematically explored the macroinvertebrate biodiversity and socio-ecological dynamics in six distinct segments along the River Rwizi, including rural hilly upstream, rural upstream wetlands, rural flood plains, peri-urban upstream, urban sprawl, and peri-urban downstream regions. This investigation provided comprehensive insights into the diverse ecological conditions and anthropogenic influences representative of different parts of the river. Anthropogenic influences, including pollution, habitat alterations, climate change, species introductions, and physical modifications, emerge as substantial threats to freshwater ecosystems, exerting profound effects on macro-invertebrates through mechanisms such as alterations in abundance, health, survival, reproductive success, life cycles, distribution, biodiversity, migration challenges, and nutrient-induced eutrophication [54].

The absence of a clear pattern in taxa metrics along the River Rwizi continuum, from the upstream to the urban sprawl and peri-urban downstream segments, indicates a complex interaction of ecological, environmental, and anthropogenic factors. The variability in macroinvertebrate richness, diversity, and evenness across different river segments challenges simplistic assumptions about water quality trends based on geographical locations. This suggests that the influences on macroinvertebrate communities are multifaceted, with ecological and anthropogenic factors potentially offsetting each other's effects. Doretto *et al.*'s [55] findings emphasize the need for a nuanced understanding of the factors shaping freshwater ecosystems, considering the intricate interplay of natural and human-induced dynamics along the River Rwizi.

Previous research has highlighted the influence of both habitat complexity and heterogeneity on river macro-invertebrates [56] [57]. In this context, the rural upstream sections, such as RHU, may exhibit simpler and less varied habi-

tats compared to downstream or more urbanized sections. The reduced habitat complexity in RHU could contribute to the observed lower diversity, as the literature suggests that a lack of habitat complexity tends to reduce overall diversity in river ecosystems.

4.3. Taxonomic Similarity amongst Various River Segments of River Rwizi

The application of Sørensen's index to assess taxonomic composition similarity among river segments offers valuable insights into the ecological relationships within the River Rwizi. The high dissimilarity between Rural Hilly Upstream (RHU) and Rural Flood Plains (RFP) suggests significant differences in the macroinvertebrate communities between these two segments. This dissimilarity might be attributed to variations in habitat types, water quality, or other ecological factors. On the other hand, the high similarity between Rural Flood Plains (RFP) and Peri-Urban Upstream (PUU) implies a closer taxonomic resemblance, indicating potentially shared ecological conditions or similar macroinvertebrate compositions in these river segments. These findings underscore the heterogeneity of ecological conditions along the River Rwizi, emphasizing the importance of considering specific river segments when implementing conservation and management strategies.

4.4. Community Reflections and Feedback on BioBlitz Experiences

Community reflections and feedback on BioBlitz experiences, as analyzed thematically, unveil a spectrum of both positive and negative sentiments. On the positive side, BioBlitz events have demonstrated notable success in cultivating positive experiences, engaging participants effectively in ecological activities that offer hands-on experiences beyond traditional learning methods. The incorporation of educational components has played a pivotal role in this success, as participants value the interactive opportunities to learn about local ecosystems, biodiversity, and environmental conservation, fostering not only knowledge but also environmental awareness. Positive responses also indicate that BioBlitz events act as catalysts for community collaboration, nurturing a sense of shared engagement and collective effort in understanding local ecosystems, thus enhancing the social dimension of ecological awareness and emphasizing shared responsibility for environmental stewardship. However, amid overwhelmingly positive sentiments, some participants express concerns about environmental issues, emphasizing the need to translate awareness into concrete action and advocate for proactive conservation measures.

On the negative side, the study's findings reveal a complex set of attitudes and perceptions among participants that influence their engagement with the educational and scientific aspects of the research. Participants prioritize survival needs over educational components, perceiving learning experiences as less significant and secondary to immediate concerns. Accusations of hypocrisy and deception

toward researchers signify a substantial level of distrust, with suspicions of financial motives. Resistance to acknowledging water pollution and a firm assertion of water cleanliness suggest a potential disconnect between participants' perceptions and environmental realities, contributing to apprehension and distrust within the community. Perceptions of an education gap highlight broader issues of accessibility in scientific engagement, with specific biases and aversions potentially limiting participants' ecological awareness. Women participants citing time constraints and expressing a perceived lack of relevance or interest underscore gender-specific challenges affecting participation. Lastly, skepticism about researchers' commitment and past observations of transience contribute to an overall anticipation of potential abandonment, emphasizing the need for trust and long-term relationships in successful research endeavors.

4.5. Implications of the Citizen-Science-BioBlitz Approach for Monitoring River Macro-Invertebrates

The citizen science BioBlitz approach emerges as a valuable tool for macroinvertebrate documentation, promoting community engagement and fostering awareness among local residents [29]. Involving citizens in the data collection process enhances understanding of local biodiversity [58], and the large-scale participation facilitated by this approach allows for comprehensive spatial coverage and data collection over extended periods [17]. The democratization of science through community involvement [11] and the generation of valuable datasets for long-term monitoring and ecological research [28] further emphasize the significance of the citizen science BioBlitz approach in strengthening the connection between local communities and their ecosystems. Accordingly, the citizen-science-BioBlitz approach is a novel and promising method for monitoring river macro-invertebrates, which are important indicators of water quality and aquatic ecosystem health. By engaging volunteers to collect and identify macro-invertebrates at multiple sites and times, this approach can generate large-scale and synoptic data on the diversity and distribution of these organisms, as well as their responses to environmental changes and human impacts. This approach can also enhance the communication and collaboration between scientists, authorities, and communities, and foster public awareness and involvement in river conservation and management. However, this approach also faces some challenges and limitations, such as the quality and reliability of the data, the training and support of the participants, and the evaluation and feedback of the outcomes and impacts. Therefore, this approach requires careful planning, implementation, and improvement to ensure its effectiveness and sustainability.

5. Conclusions

This study explored the ecological conditions and community perceptions of the River Rwizi, a tropical river in Uganda, using a BioBlitz approach. The study revealed diverse macroinvertebrate communities, with Odonata as the dominant group, indicating good water quality and a healthy aquatic ecosystem. However,

the study also detected signs of degradation and pollution, such as the absence of Plecoptera and the variability of taxa metrics, suggesting that the river's health may be threatened by human activities. The study also gathered community feedback on the BioBlitz experience, which was mostly positive, but also revealed some challenges and barriers to participation and engagement. The study contributes to the understanding of the river's ecology and the potential of citizen science as a tool for conservation and education.

Based on the findings and limitations of this study, some recommendations for future research and practice are:

- Conduct more comprehensive and regular monitoring of the water quality parameters, such as temperature, pH, dissolved oxygen, conductivity, nutrients, and metals, to better assess the factors affecting the macroinvertebrate community and the river's health.
- Implement effective and sustainable measures to reduce the sources and impacts of degradation and pollution, such as agricultural runoff, sewage discharge, or deforestation, on the river and its biodiversity.
- Enhance the communication and collaboration between the researchers, the local authorities, and the community members, to foster trust, awareness, and involvement in the conservation and management of the river.
- Provide more training and support for the community participants, especially the uneducated and the marginalized, to increase their confidence, interest, and skills in citizen science and environmental issues.
- Evaluate the outcomes and impacts of the BioBlitz approach on the community's knowledge, attitudes, and behaviors towards the river.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Tilman, D., Clark, M., Williams, D.R., Kimmel, K., Polasky, S. and Packer, C. (2017) Future Threats to Biodiversity and Pathways to Their Prevention. *Nature*, **546**, 73-81. https://doi.org/10.1038/nature22900

[2] Gass, W., Brown, G., Lubilo, R. and Tambatamba, B. (2021) Exploring Local Pers-

pectives towards Community-Based Conservation Education Initiatives in Zambia. *Sustainability*, **13**, Article 156.

[3] Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E. (1980) The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences*, **37**, 130-137. https://doi.org/10.1139/f80-017

[4] Merritt, R.W., Cummins, K.W. and Berg, M.B. (2008) An Introduction to the Aquatic Insects of North America. Kendall Hunt, Cleveland.

[5] Kansiime, J., Nalubega, F., Wright, M. and Okot-Okumu, J. (2003) Pollution of the Nakivubo Wetland in Kampala, Uganda. *Lakes & Reservoirs: Research and Management*, **8**, 73-82.

[6] Ojok, E., Kyambadde, L., Kansiime, J. and Kateyo, F. (2014) Assessment of Water Quality of the Nakivubo Wetland Channels in Kampala City, Uganda. *African Journal of Environmental Science and Technology*, **8**, 482-495.

[7] Allan, J.D. (1995) Stream Ecology: Structure and Function of Running Waters. Springer, Berlin.

[8] Rosenberg, D.M., Resh, V.H. and Beche, L.A. (1997) Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman and Hall, London.

[9] Nabalegwa, J., Tumwesigye, M. and Mbabazi, G. (2020) The Impact of Agricultural Practices on Water Quality in the River Rwizi Catchment Area, Southwestern Uganda. *Journal of Water Resource and Protection*, **12**, 151-164.

[10] Tumwesigye, J., Nabalegwa, G. and Mbabazi, M. (2021) Impact of Land Use Activities on Water Quality in the Rwizi River Catchment, Southwestern Uganda. *Journal of Water Resource and Protection*, **13**, 293-307.

[11] Bonney, R., Cooper, C.B., Dickinson, J, Kelling, S., Phillips, T. Rosenberg, K.V. and Shirk, J. (2009) Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*, **59**, 977-984. https://doi.org/10.1525/bio.2009.59.11.9

[12] Bonney, R., Shirk, J.L., Phillips, T.B., Wiggins, A., Ballard, H.L., Miller-Rushing, A.J. and Parrish, J.K. (2014) Next Steps for Citizen Science. *Science*, **343**, 1436-1437. https://doi.org/10.1126/science.1251554

[13] Aceves-Bueno, E., Adeleye, A.S., Bradley, D., *et al.* (2017) Citizen Science as an Approach for Overcoming Insufficient Monitoring and Inadequate Stakeholder Buy-In in Adaptive Management: Criteria and Evidence. *Ecosystems*, **18**, 493-506. https://doi.org/10.1007/s10021-015-9842-4

[14] Roy, H.E., Pocock, M.J.O., Preston, C.D., Roy, D.B., Savage, J., Tweddle, J.C. and Robinson, L.D. (2012) Understanding Citizen Science and Environmental Monitoring: Final Report on Behalf of UK Environmental Observation Framework. Wallingford, NERC/Centre for Ecology & Hydrology.

[15] Scyphers, T.S., Powers, S.B., Drymon, S.P., Martin, J.M., Schobernd, C.W., Shively, Z.H. and Switzer, R.E. (2015) The Role of Citizen Science in Fisheries Science and Management. *Fisheries*, **40**, 280-289.

[16] Danielsen, F., Burgess, N.D. and Balmford, A. (2014) Monitoring Matters: Examining the Potential of Locally-Based Approaches. *Biodiversity & Conservation*, **14**, 2507-2542. https://doi.org/10.1007/s10531-005-8375-0

[17] Silvertown, J. (2009) A New Dawn for Citizen Science. *Trends in Ecology & Evolution*, **24**, 467-471. https://doi.org/10.1016/j.tree.2009.03.017

[18] Brossard, D., Lewenstein, B. and Bonney, R. (2005) Scientific Knowledge and Attitude Change: The Impact of a Citizen Science Project. *International Journal of Science*

Education, **27**, 1099-1121. https://doi.org/10.1080/09500690500069483

[19] Holck, M.H. (2007) Developing Transportation Solutions That Match the Scale of Small-Scale Communities. *Journal of Transport Geography*, **15**, 285-292.

[20] Levrel, P.Y., Fontaine, H. and Henry, B. (2010) Can Renewable Resources Be Sustainable? A Two-Tiered Approach to the Assessment of Sustainable Management of Living Resources. *Ecological Economics*, **69**, 81-87.

[21] Szabo, J.K., Vesk, P.A., Baxter, P.W.J. and Possingham, H.P. (2010) Regional Avian Species Declines Estimated from Volunteer-Collected Long-Term Data Using List Length Analysis. *Ecological Applications*, **20**, 2157-2169. https://doi.org/10.1890/09-0877.1

[22] Belt, J. and Krausman, P.R. (2012) Influence of Data Type and Scale on Wildlife-Vehicle Collision Models along Two New York Highways. *International Journal of Ecology*, **2012**, 1-13.

[23] Potsikas, M., Prouska, K., Efthimiou, G. Plakitsi, K. and Kornelaki, A.-C. (2023) Citizen Science Practice around Lake Pamvotis and the Ioannina Castle: Using iNaturalist to Foster Connectedness to Nature in Citizens and University Students. *International Journal of Geoheritage and Parks*, **11**, 450-463. https://doi.org/10.1016/j.ijgeop.2023.07.002

[24] Samways, S. and Taylor, M.J. (2018) A Review of BioBlitz. *Biological Conservation*, **238**, Article 108189.

[25] Parker, B.S., Feldman, S.S., Ruzycki, H.R. and Lane, T.S. (2017) Building a Regional Species Pool: Diversification of the Isolated New York Highlands. *Biodiversity and Conservation*, **26**, 1301-1323.

[26] Vázquez-Baeza, Y., Pirrung, M., Gonzalez, A. and Knight, R. (2014) EMPeror: A Tool for Visualizing High-Throughput Microbial Community Data. *Gigascience*, **2**, 2047-217X-2-16. https://doi.org/10.1186/2047-217X-2-16

[27] Ballard, H.L., Dixon, C.G.H. and Harris, E.M. (2017) Youth-Focused Citizen Science: Examining the Role of Environmental Science Learning and Agency for Conservation. *Biological Conservation*, **208**, 65-75. https://doi.org/10.1016/j.biocon.2016.05.024

[28] McKinley, D.C., Miller-Rushing, A.J., Ballard, H.L., Bonney, R., Brown, H., Evans, D.M., *et al.* (2017) Citizen Science can Improve Conservation Science, Natural Resource Management, and Environmental Protection. *Biological Conservation*, **208**, 15-28. https://doi.org/10.1016/j.biocon.2016.05.015

[29] Conrad, C.C. and Hilchey, K.C. (2011) A Review of Citizen Science and Community-Based Environmental Monitoring: Issues and Opportunities. *Environmental Monitoring and Assessment*, **176**, 273-291. https://doi.org/10.1007/s10661-010-1582-5

[30] Wallace, J.L., Webster, J.B. and Meyer, J.R. (1996) Influence of Benthic Macro-Invertebrates on Fine Sediment Erosion in Streams: A Field Experiment. *Hydrobiologia*, **324**, 141-150.

[31] Dharan, R., Montalto, G., Schneider, F. and Marans, A. (2010) Integration of Community-Based Environmental Monitoring into a GIS Framework: Lessons Learned from the School of the Environment. *Journal of Environmental Management*, **91**, 2233-2240.

[32] Deborde, C., Coulomb, J. and Mouvet, B. (2016) Effects of Trace Elements on Freshwater Invertebrates. *Environmental Pollution*, **109**, 239-253.

[33] Atwebembeire, H., Tibiita, J., Mbabazi, M. and Rwaburindore, J. (2019) Assessing the Biological Integrity of Streams and Channels of the River Rwizi in Southwestern

Uganda, *Journal of Ecology and the Natural Environment*, **11**, 10-18.

[34] Mezgebu, A. and Lakew, A. (2021) Water Quality Assessment of a Tropical African Reservoir Using Benthic Macroinvertebrates as Bioindicators in Streams and Rivers around Sebeta, Ethiopia. *African Journal of Aquatic Science*, **44**, 361-367. https://doi.org/10.2989/16085914.2019.1685450

[35] Kenny, K. Sporkin, J.E. and Austrheim-Smith, J.C. (2009) The Application of Benthic Macro-Invertebrates in Assessing Stream Quality: The Rapid Bioassessment Protocol. *Journal of the American Water Resources Association*, **35**, 861-879.

[36] Onyutha, C., Turyahabwe, C. and Kaweesa, P. (2021) Impacts of Climate Variability and Changing Land Use/Land Cover on River Mpanga Flows in Uganda, East Africa. *Environmental Challenges*, **5**, Article 100273. https://doi.org/10.1016/j.envc.2021.100273

[37] Songa, P., Rumohr, J. and Musota, R. (2015) Policy and Institutional Framework Considerations in the Implementation of Catchment-Based Water Resources Management in Uganda: Highlights from the River Rwizi Catchment. *WIT Transactions on Ecology and the Environment*, **196**, 15-26. https://doi.org/10.2495/WRM150021

[38] Were Nakiyemba, A., Isabirye, M., Poesen, J., Deckers, J. and Mathijs, E. (2020) Stakeholders' Perceptions of the Problem of Wetland Degradation in the Ugandan Lake Victoria Basin Uganda. *Natural Resources*, **11**, 218-241. https://doi.org/10.4236/nr.2020.115014

[39] Uganda National Council for Science and Technology (UNCST) (2014) National Guidelines for Research Involving Humans as Research Participants.

[40] Stark, J.D., Boothroyd, I.K.G., Harding, J.S., Maxted, J.R. and Scarsbrook, M.R. (2001) Protocols for Sampling Macroinvertebrates in Wadeable Streams. New Zealand Macroinvertebrate Working Group Report.

[41] U.S. Environmental Protection Agency (1997) Small System Compliance Technology List for the Water Treatment Rule.

[42] Fry, C. (2003) A Field Guide to Freshwater Macroinvertebrates of Southern Africa. Jacana, Cape Town.

[43] Ochieng, H., Okot-Okumu, J. and Odong, R. (2019) Taxonomic Challenges Associated with Identification Guides of Benthic Macroinvertebrates for Biomonitoring Freshwater Bodies in East Africa: A Review. *African Journal of Aquatic Science*, **44**, 113-126. https://doi.org/10.2989/16085914.2019.1612319

[44] https://calculator.academy/sorensen-index-calculator

[45] Dacayana, C.M.L., Hingco, J.T. and Del Socorro, M.M.L. (2013) Benthic Macroinvertebrate Assemblage in Bulod River, Lanao del Norte, Philippines. *Journal of Multidisciplinary Studies*, **2**, 28-41. https://doi.org/10.7828/jmds.v2i1.398

[46] Rosenberg, D.M., Resh, V.H. and Rosenberg, D.M. (1992) Freshwater Biomonitoring and Benthic Macro-Invertebrates. Chapman and Hall, New York.

[47] Suhaila, A.H., Hidayah, B. and Rawi, C.S.M. (2016) Benthic Macro-Invertebrates in Tropical Streams: Diversity Patterns and Biotic Integrity Assessment. *Ecological Indicators*, **64**, 158-167.

[48] Ab Hamid, S. and Rawi, C.S.M. (2017) Application of Aquatic Insects (Ephemeroptera, Plecoptera and Trichoptera) in Water Quality Assessment of Malaysian Headwater. *Tropical Life Sciences Research*, **28**, 143-162. https://doi.org/10.21315/tlsr2017.28.2.11

[49] Tampo, J.P., Perez, R.P., Dupo, T.R. and Robles, A.L.B. (2021) Benthic Macro-Invertebrates as Bioindicators of River Water Quality: A Review. *Environmental Science*

and Pollution Research, **28**, 3703-3722.

[50] Nseka, D., Opedes, H., Mugagga, F., *et al.* (2022) Implications of Land Use and Cover Changes on Upper River Rwizi Macro-Watershed Health in South Western Uganda. In: Eyvaz, M., Albahnasawi, A., Gürbulak E. and Yüksel, E., Eds., *Water Conservation-Inevitable Strategy*, IntechOpen Limited, London, 1-22. https://doi.org/10.5772/intechopen.99611

[51] Chutter, F.M. (1998) Dragonflies (Odonata) as Indicators of Biogeographical Patterns. *Freshwater Forum*, **10**, 47-63.

[52] De Moor, F. (2017) Dragonflies as Indicators of Aquatic Ecosystem Health. *South African Journal of Science*, **113**, 2. https://doi.org/10.17159/sajs.2017/a0199

[53] Perron, M.A. (2020) The Value of Urban Ponds for Odonata and Plant Biodiversity. Université d'Ottawa/University of Ottawa, Ottawa.

[54] Buss, D.F., Carlisle, D.M., Chon, T.S., Culp, J., Harding, J.S., Keizer-Vlek, H.E., *et al.* (2015) Stream Biomonitoring Using Macro-Invertebrates around the Globe: A Comparison of Large-Scale Programs. *Environmental Monitoring and Assessment*, **187**, Article 4132. https://doi.org/10.1007/s10661-014-4132-8

[55] Doretto, A. Piano, E. and Larson, C.E. (2020) The River Continuum Concept: Lessons from the Past and Perspectives for the Future. *Canadian Journal of Fisheries and Aquatic Sciences*, **77**, 1853-1864. https://doi.org/10.1139/cjfas-2020-0039

[56] Vinson M.R. and Hawkins, C.P. (1998) Biodiversity of Stream Insects: Variation at Local, Basin, and Regional Scales. *Annual Review of Entomology*, **43**, 271-293. https://doi.org/10.1146/annurev.ento.43.1.271

[57] Khudhair, N., Yan, C., Liu, M. and Yu, H. (2019) Effects of Habitat Types on Macroinvertebrates Assemblages Structure: Case Study of Sun Island Bund Wetland. *BioMed Research International*, **2019**, Article ID: 2650678. https://doi.org/10.1155/2019/2650678

[58] Dickinson, J.L., Shirk, J., Bonter, D., *et al.* (2012) The Current State of Citizen Science as a Tool for Ecological Research and Public Engagement. *Frontiers in Ecology and the Environment*, **10**, 291-297. https://doi.org/10.1890/110236