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Rediscovering the critically endangered snails in Lakes Albert and Edward Uganda

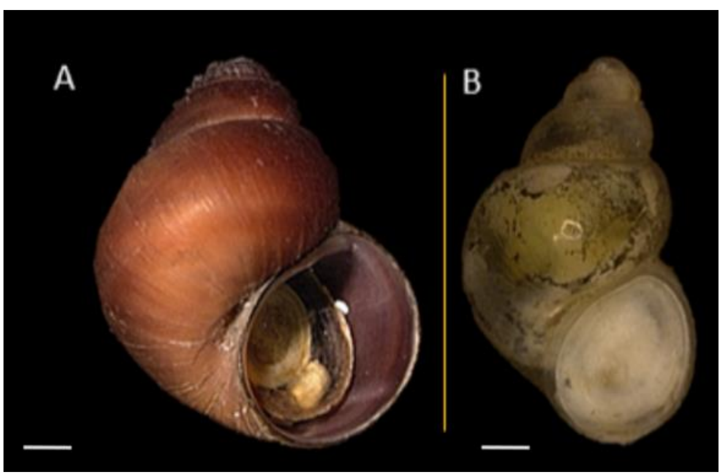
Marie Claire Dusabe[a],

With contributions by Julius Tumusiime[b], *Francis Ssenkuba*[b] *Grace Kagoro*[b] *and Christian Albrecht*[a,b]

[a] *Department of Animal Ecology and Systematics, Justus Liebig University Giessen, Heinrich-Buff-Ring 26 (IFZ), 35392 Giessen, Germany*

[b] *Department of Biology, Mbarara University of Science and Technology, Mbarara, Uganda*

Compiled by the PI Marie Claire Dusabe: dusclaire25@gmail.com



A: *Bellamya rubicunda*, B: *Gabbiella candida*. Scale bar: 1000 µm.

Abstract

Conserving endangered species is crucial for maintaining biodiversity and ecosystem health. Research plays a key role in this by identifying endangered species and suggesting sustainable solutions. In this report, we share findings from a study that aimed to rediscover critically endangered snail species in Lakes Albert and Edward, Uganda. Specifically, the project focuses on identifying the endemic snail species *Gabbiella candida*, *Gabbiella walleri*, *Bellamya rubicunda* from Lake Albert, and *Ceratophallus apertus* from Lake Edward. The methodology involved collecting snails at various depths in the lakes, including locations where these species were last seen, to document their presence or absence. Both morphological features and DNA-based identification were utilized to identify the targeted snail species. To raise awareness about snails and lake conservation, engagement and education activities were conducted with children from Ntoroko Primary School neighboring Lake Albert. Results indicated the presence of *Gabbiella candida* and *Bellamya rubicunda* in Lake Albert, whereas *Gabbiella walleri* was absent. *Ceratophallus apertus* was absent in Lake Edward from all sites sampled. This highlights the need for protection and restoration efforts. The study also emphasizes the importance of community involvement in conservation. This study adds to our understanding of endangered snail species in these lakes and offers insights for future research and conservation projects.

1. Introduction

The lakes in East African Rift Valley are valuable natural resources and serve neighboring countries as important resources for transportation, water supply, fishing, recreation, and tourism (Cohen et al., 2019). However, due to high and densely populated areas nearby, these lakes experience substantial pressure from various human activities. As a result, they undergo continuous environmental degradation, are impacted by climate change, and face significant threats such as unsustainable exploitation of aquatic resources, pollution, and eutrophication. (Nakiyende et al., 2023).

Lake Albert faces multiple challenges, including limited scientific studies due to insufficient research resources, uncontrolled over-exploitation of the resources due to resource users ignoring compliance with established rules, and insufficient enforcement by the services in charge (Soheranda et al., 2015; Nakiyende et al., 2023). The catchment of Lake Albert is experiencing increased human activity, particularly from oil and gas exploration, which could potentially endanger the lake's well-being and biodiversity (Wandera and Balirwa, 2010) as well as affecting the livelihoods of those who depend on its resources. While Lake Edward faces similar threats, human activities do not as heavily impact it as Lake Albert, in part due to the fact that much of its surroundings are protected areas. This makes Lake Edward arguably one of the least studied lakes in Africa (Beadle, 1981). Limited information is available on biodiversity, especially on macroinvertebrates, including the mollusc group (Nakiyende et al., 2023), and genetic characterizations are lacking for most groups. While biodiversity studies have mainly focused on fish (e.g. Wandera and Balirwa, 2010), documentation of threats to snails is inadequate and underestimated (Nakiyende et al., 2023).

Albrecht and Clewing, (2022) assessed four endemic snail species from Lake Albert and Lake Edward that are currently threatened as “critically endangered” on the IUCN Red List. These include *Gabbiella candida* (Mandahl-Barth, 1968), *Gabbiella walleri* (Smith, 1888), both endemic to Albert, along with *Bellamya rubicunda* (Martens, 1879), also endemic to Lake Albert. Additionally, *Ceratophallus apertus* (Martens, 1897), endemic to Lake Edward George. All species have not been recorded for over a decade, are vulnerable due to the threats mentioned above. Whether these species still exist or are already extinct remains uncertain.

Funding provided by the Rufford Small Grant Foundation enabled us to assess the status of these snail species and document their habitat threats. Our main aim was to determine if these snail species are still present in Lakes Albert and Edward. We conducted a thorough survey at various depths in both lakes. We used a combination of traditional morphological identification techniques and modern DNA-based methods to accurately identify these snail species.

Additionally, we recognized the importance of community involvement in environmental conservation. We engaged children from Ntoroko Primary School, located near Lake Albert, in educational activities. Our goal was to raise awareness among the younger generation about the significance of snails in the ecosystem and the importance of lake conservation. The findings of this study have implications for the development of effective conservation and restoration strategies to ensure the long-term sustainability of these crucial freshwater ecosystems.

2. Methodology

2.1. Sampling

We conducted sampling along the shores of Lake Edward and Lake Albert on the Uganda side, reaching various depths where surviving organisms could be found (see Fig. 1). Our strategy involved surveying locations where the endangered snails were last observed to increase the chances of rediscovery. The sampled sites cover the southern (Ntoroko), middle (Hoima), and northern (Butiaba) regions of Lake Albert as well as the Ugandan side of Lake Edward (see Fig. 1). We collected snails from both lakes during the wet season (December and March 2023) and the dry season (June and August 2023), as well as in January 2024. We used a scoop net (diameter: 20 cm, mesh size: 1 mm) on the shore or collected specimens by hand from stones and rocky substrates. For sampling in deeper sections of the littoral zone, up to a depth of 35 meters, we used a dredge and an Ekman grab from a boat. We collected detailed information, including geographic coordinates and site characteristics (see Table 1). All collected specimens were preserved in 80% ethanol and labelled, and are now in the UGSB collection (University Giessen Systematics & Biodiversity collection, Germany).

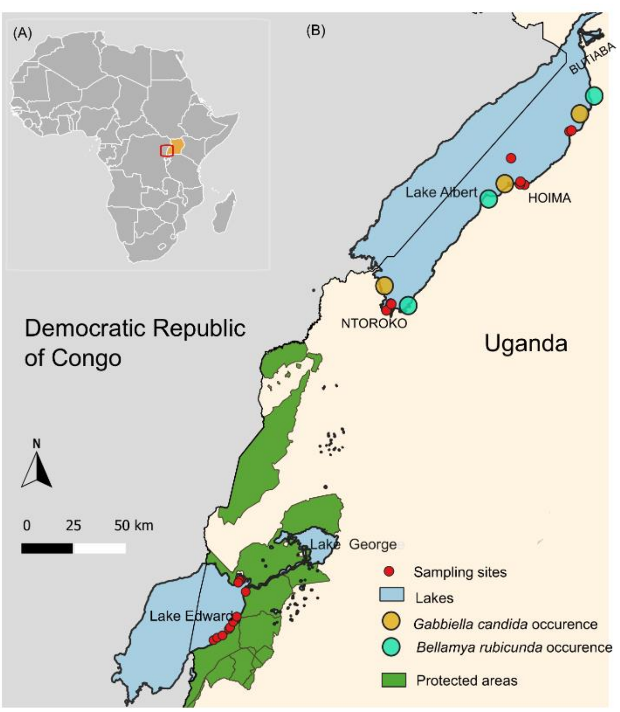


Figure 1. *Map of Lakes Edward and Albert with sampling sites. A: Overview map of Africa indicating the location of Uganda highlighted in yellow, with a red frame around the western Uganda area where Lakes Edward and Albert are located. B: Detailed map showing sites where samples were taken in both lakes (in red), with occurrences of Gabbiella candida (in yellow) and Bellamya rubicunda (in light green).*

2.2.Physico-chemical parameters and environmental variables

At each sampling site, we assessed the sites utilization and level of disturbance as well as the substrates (see Table 1). Prior to macroinvertebrate sampling, physical parameters (temperature, total dissolved solids (TDS), conductivity, pH, and oxygen) were measured using the HANNA HI 9829 handheld multiparameter tool. The water samples were collected in plastic bottles to measure chemical parameters such as ammonium, nitrite, nitrate, calcium and phosphate using the colorimetric kits. To calculate the percentage human disturbance gradient of the sampled sites, observable human impacts were scored according to the Lake Habitat Assessment Field Sheet developed by the Florida Department of Environmental Protection (FDEPA, 2017). The physicochemical variables and the percentage human disturbance scores for each site were pooled and used to categorize the sites into less, moderately, and highly impacted using hierarchical Cluster analysis in R software.

2.3.Morphological identification

The specimens of the genera *Gabbiella* and *Bellamya* were identified to species level by MCD on the basis of morphological features, with reference to the original literature of Mandahl-Barth (1962) and Brown (1994). Prior to DNA extraction, high-resolution images were taken with a digital microscope (Keyence VHX-600).

Photo credit: Marcellin Rwibutso. Left: Morphological identification. Right: Image capture using Keyence microscope.

2.4. DNA extraction and amplification

DNA extraction was performed specifically on individuals of the genus Gabbiella. A total of 48 individuals from Lake Albert were selected for DNA barcoding, using COI and 16S markers. Genomic DNA was extracted from a small piece of foot muscle using the CTAB protocol of Wilke et al. (2006). Fragments of two mitochondrial markers, COI (cytochrome *c* oxidase subunit I) and 16S rRNA, were amplified using the primers LCO1490 and HCO2198 (Folmer et al., 1994), and 16Sar and 16Sbr (Palumbi et al., 1991), respectively. PCR conditions followed those described by Van Bocxlaer et al. (2018). Sanger sequencing was performed on an ABI 3730xl DNA analyzer using the BigDye Terminator Kit (Life Technologies, LGC Genomics GmbH, Berlin, Germany). All DNA sequence ambiguities at the beginning and end of the sequences were manually edited using BioEdit v7.2 (Hall, 1999). We compared our sequences with those from GenBank. The BLAST hits were sorted by max score (default setting), and we selected the top two hits for each of our specimens.

3. Results and discussion

3.1. Morphological identification of the targeted snail species: Presence/Absence

a) Lake Albert

Through morphological identification, we confirmed the presence of *Gabbiella candida* and *Bellamya rubicunda* in Lake Albert, while *Gabbiella walleri* was absent from Lake Albert and *Ceratophallus apertus* was absent from Lake Edward. Our morphological identification was reliable, particularly for *Gabbiella candida*, which is morphologically distinct from other *Gabbiella* species found in Lake Albert. A small, white, translucent shell with a conical shape and a spire slightly higher than the aperture characterizes it.

Based on morphological identification, we found individuals of the *Gabbiella* specimens at 16 sites. Specifically, we recorded 30 individuals of *Gabbiella candida* at three locations: Ntoroko (south of the lake), Hoima (center of the lake), and Butiaba (north of the lake) (Fig. 1). All individuals were exclusively found on the shores of the lake. *Gabbiella candida*, initially identified by Mandahl-Barth (1968) from Butiaba, Lake Albert, was categorized as Critically Endangered under criteria B2ab (iii) when first assessed in 2004 at a single site in Butiaba (Kyambadde, 2010). Although recorded by Christian Albrecht two years later in the south of the lake, it was not found in Butiaba at that time. Our findings unveil a broader distribution of *Gabbiella candida* than previously expected, possibly due to our comprehensive sampling approach, covering both seasons, various sampling depths, and different microhabitats. It is important to note that data collected over the past 12 years were spatially and temporally limited. Further details on habitat descriptions and threats can be found in Table 1.

Gabbiella walleri, originally documented by Mandahl-Barth (1968) at depths ranging from 8 to 40 meters and later recorded at the shoreline by Christian Albrecht in 2010 (Albrecht & Clewing 2022), was not found in this study. Further exploration is necessary on both sides of the lake to determine conclusively the presence or absence of *Gabbiella walleri* in the lake. Additionally, considering the threats facing the lake and the destruction of shoreline habitats, we urgently emphasize the necessity of enforcing lake conservation measures to ensure the sustainable protection of vulnerable species.


Ntoroko site


Butiaba site

Bellamya rubicunda were found at three major localities: Ntoroko, Hoima, and Butiaba. It is noteworthy that *B. rubicunda* was classified as Near Threatened in the 2004 IUCN Red List of Threatened Species (Kyambadde, 2010). During our fieldwork, we observed a significant number of empty shells of *B. rubicunda* on the shoreline of Lake Albert, often collected for use as chicken feed. However, it remains unclear whether people collect only empty shells, leaving live ones behind. Further survey is recommended to clarify this aspect. The distribution of *B. rubicunda* across the sites where it was found is consistent with the findings of Sengupta et al. (2009), who identified *B. rubicunda* in three locations: Butiaba, Rwangala in Ntoroko, and Bugoigo in Bulisa.

During the Pleistocene, populations of *Bellamya* periodically entered the Lake Albert basin and eventually became extinct (Van Damme et al., 1998). The former species became extinct due to the increasing salinity/alkalinity of the lake waters. Given the threats present at these sites, increased effort is necessary for the sustainable conservation of both the sites and the threatened species.

Photo credit: Marie Claire Dusabe. Local communities collecting snails for chicken feed in the Butiaba area along the shoreline of Lake Albert.

B) Lake Edward

During our survey of 11 sites in Lake Edward, neither live nor empty shells of *Ceratophallus apertus* were found. Brown (1994) on the northwestern shore of Lake Edward near Kirima documented the last known locality of C. apertus. Adam (1957) described a shell from Lake Edward near the Kigera River, identified as *Gyraulus apertus*. *C. apertus* is classified as Endangered (Albrecht and Clewing 2022) and is endemic to the Lake Edward-George system in Uganda, previously known from four localities (Holmberg et al., 2011). The complete absence of *C. apertus* reported by Schultheiß et al. (2011) and in our study raises doubts about its existence. A comprehensive study is required to confirm its absence on both sides of the lake, particularly given the ongoing eutrophication, pollution, and boat traffic (Kyambadde, 2004), as well as oil exploration activities in the lake and its basin. Brown (1994) noted that the anatomy of *C. apertus* is unknown and that its generic position requires confirmation.

Table 1. Overview of Sampling Sites in Lake Albert: Species distribution across sampling sites, sampling depths, latitude, and longitude coordinates; habitat characterization details such as substrates, site utilization, and the degree of anthropogenic disturbance.

Species	**Site location**	**Site code**	**Depth/m**	**Latitude**	**Longitude**	**Substrates**	**Sites utilization and level of disturbance**
Gabbiella candida	Ntoroko		>1	1.03089	30.51656	Submerged aquatic vegetation, detritus, sand, silt and gravel	Very high human impact, domestic pollution, fishing.
	Butiba		>1	1.814749	31.31993	Sand, detritus and macrophyte	Moderate human impact, animal rearing, settlements, and direct effluent discharge.
	Hoima-Tonya		>1	1.583764	31.10286	Sand, mud, aquatic vegetation	Low human impact, mostly native vegetation and few hyacinth.
Bellamya rubicunda	Hoima-Rwentale		>1	1.58376	31.10286	Sand, mud, aquatic vegetation	Low human impact, mostly native vegetation and few hyacinth.
	Ntoroko		>1	1.03059	30.51652	Sand, detritus, clay, artificial substrates	Very high human impact, cattle rearing, laundry work, waste disposal.
	Butiba		>1	1.81475	31.31993	Sand, detritus and macrophyte	Moderate human impact, animal rearing, settlements, fishing, people collecting snails for chicken feed.

The cluster analysis revealed that Ntoroko sites clustered together with a percentage disturbance score (PDS) of 36%, indicating high pollution levels. Hoima sites formed another cluster with a PDS of 69%, suggesting comparatively lower pollution levels in Hoima. Butiaba sites clustered together as moderately disturbed sites with a PDS of 41% (Fig. 2).

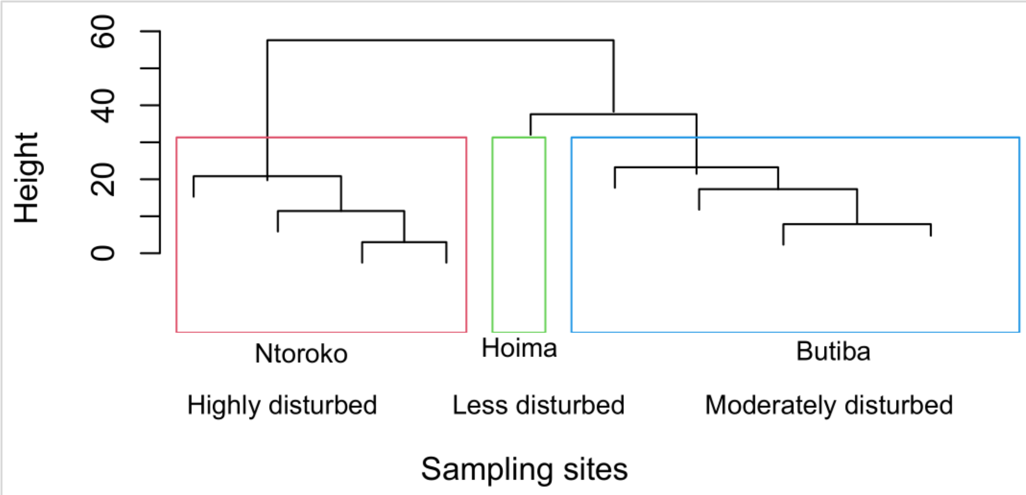


Figure 2. Cluster analysis of physico-chemical parameters and environmental variables a cross samples sites in Lake Albert. Ntoroko sites show a high level of disturbed, while Hoima is comparatively less disturbed, and Butiaba falls in the moderate disturbance range.

3.2. Identification outcomes using morphological and DNA barcoding

Our molecular identification analysis focused on 48 specimens of the *Gabbiella* genus, including 17 individuals of *Gabbiella candida*. The BLAST searches confirmed that *Gabbiella humerosa alberti* from Lake Albert showed the two highest matches, with a 99.70% similarity to *Gabbiella* sp. and *Gabbiella humerosa* from Lake Victoria. However, they did not confirm at least the genus identified based on the shell morphology of *Gabbiella candida*. This was unexpected, considering that the genus *Gabbiella* is published in GenBank (Wilke et al., 2023; Dusabe et al., 2024). Using COI, the first two top blast results for *G. candida* indicated *Bithynia siamensis* at 87.23% (KY118607) from Thailand, and *Gabbiella candida* 16S matched with *Bithynia siamensis* at 94.58% (MW305340). The discrepancy could be due to possible misclassifications resulting from the exclusive reliance on morphological features based identification methods used in the past. DNA barcoding databases like GenBank and BOLD (Barcode of Life Data Systems) are continually expanding, yet they may not include all species, particularly those that are rare, newly discovered, or poorly studied. Incomplete reference databases limit the efficacy of DNA barcoding for species identification. Furthermore, among the *Gabbiella* species from Lake Albert, there might be cryptic species. Understanding cryptic diversity is critical to characterize the degree of endemism in local faunas such as those of the Great Lakes of East Africa and to accurately assess the patterns and processes of speciation. Addressing these challenges requires DNA barcoding using mitochondrial and nuclear markers as well as phylogenetic and evolutionary analyses to clarify their differences and taxonomic status within the genus. While our morphological identification successfully distinguished *G. candida* as morphotypically distinct among other *Gabbiella* species in Lake Albert, the BLAST results indicating *Bithynia siamensis* necessitate further phylogenetic analysis to ascertain whether it actually belongs to the genus *Gabbiella* or not.

Awareness campaign

We visited the Ntoroko Primary School, which is located near Lake Albert in the Ntoroko region. Approximately 600 children were engaged. On the way there, our team composed a song titled "Mwitanzige inyanja yayitu," which translate as "Our Lake Albert," which is the former and local name of the lake, Mwitanzige. The purpose of our visit was to conduct eeducational campaigns to raise awareness about Lake Albert, its biodiversity, the importance of conserving freshwater snails, protecting their habitat, and to slowly change some of the traditional beliefs and practices that impact the snails population. The campaign was strategically designed to take place outdoors. Equipped with microphones, we started by singing to engage children's attention. We then delivered key conservation messages, interspersed with quizzes, competitions, and prizes to keep the children's attention and interest. Purposefully, we asked children questions that create further discussions, reinforcing the messages and inspired the children or encouraged them to know more.

Photo credit: Miklos Balint

Pupils, teachers, and the project team members gather after an engaging campaign filled with fun activities

Photo credit: Miklos Balint

Members of the project team, alongside teachers and the principal of Ntoroko Primary School, come together for a group photo following the successful completion of the campaign.

Evaluation

Evaluation consisted of a questionnaire that was administered in person as we were setting up before starting the campaign. We distributed the questionnaire to 103 pupils ranging from P4 to P7, gave them 30 minutes to respond before collecting their feedback and then we collected the questionnaire prior starting the campaign. Following the completion of the campaign, we re-administered the questionnaire to the same group of pupils to assess the knowledge gained. Throughout the campaign, the children not only acquired valuable insights but also enjoyed participating in activities such as singing our song, which emphasized the importance of protecting our lakes and safeguarding against waterborne diseases.

Knowledge of snails

We asked pupils if they knew snails and if yes, where they had saw them. All 103 pupils responded affirmatively, indicating that they had previously saw snails in the lake.

Thoughts on seeing a snail

We asked pupil what they think if they see a snail.

Before campaign	After campaign
• 11.4% wanted to study them • 12.9% thought they caused diseases • 20% liked playing with them • 20% wanted to kill them • 12.9% saw them as a source of money • 10% felt happy • 12.9% felt bad	• 24.2% wanted to study them • 12.1% thought they spread diseases • 9.1% liked playing with them • No one wanted to kill them • 12.1% considered selling them for money • 30.3% felt happy • 12.1% felt bad

The pupils' perception towards snails significantly varied before and after the Rufford snail campaign ($X^2(6, N=103) = 16.22$; p=0.01).

Snails' important role

Before campaign	After campaign
• 15.7% as medicine • 28.6% as food • 25.7% in animal feed • 10% seen as bad, causing diseases • 18.6% for selling and money • 1.4% seen as useless	• 30.3% as medicine • 6.1% as food • 44.4% in animal feed • 19.2% for selling and money • None seen as bad or useless

Are snails beneficial to you/your community?

Before the campaign 41% of the responds said 'Yes' while 55.7% said 'No', and 2.8% did not respond. After the campaign 93.9% of the responds said 'Yes' and 6.1% said 'No'. Marking an increase of 52.9%.

Thoughts on Snail Conservation

We asked pupils what they think of snail conservation. In addition, who should be responsible for snail conservation?

Before campaign	**After campaign**
• 15.7% said conserve for medicine • 45.7% for income • 17.1% as tourist attractions • 10% for animal feeds • 1.4% not to kill them • 10% none Who should be responsible: • 27.1% government • 25.7% Ministry of Water and Environment • 12.1% local community • 34.3% everyone	• 3.0% for medicine • 30.3% for income • 30.0% as tourist attractions • 18.2% for animal feeds • 9.1% not to kill them • 6.1% none • 3.0% as fish food Who should be responsible: • 3.0% government • 18.2% Ministry of Water and Environment • 6.1% local community • 72.2% everyone

Pupil views on snail conservation and responsibility significantly changed after the campaign as follow ($X^2(3, N=103) = 15.34$; p=0.00) and ($X^2(3, N=103) = 15.34$; p=0.00), respectively.

Can you help conserve snails in your community?

Before the campaign, only 37.1% reported they could join, while 62.9% said they could not. After the campaign, 97.0% said they could join, with only 3.0% saying they could not. This marks a significant change after the campaign ($X^2(1, N=103) = 32.63$; p=0.00). We asked student how they could help in conserving snail around their community. Below are their answers which significantly change after the campaign ($X^2(9, N=103) = 44.50$; p=0.00).

Before campaign	**After campaign**
• 8.6% reporting misuse of the lake • 7.1% protecting the lake • 14.3% stopping bathing in the lake • 8.6% stopping lake misuse • 58.6% stopping rubbish dumping • 2.9% controlling water weeds.	• 18.2% reporting misuse • 12.1% protecting the lake • 36.4% stopping lake misuse • 3.0% stopping rubbish dumping • 6.1% controlling water weeds • 6.1% stopping rubbish throwing • 6.1% stopping snail killing • 12.1% stopping urinating in the lake."

Impacts

Funding for a project in Lakes Albert and Edward, Uganda, aimed to find endangered snails could have big impacts. It allowed us to study these snails in their natural habitat, providing important data for conservation. The project also involved local communities, especially schoolchildren; teaching them about the environment and helping them feel connected to the lakes. Moreover, the project's findings could influence policies about managing freshwater ecosystems, leading to better conservation efforts. Overall, the funding supports long-term sustainability by protecting biodiversity and ecosystem services for future generations.

Future

Future steps: The team plans to advance this project by verifying the genus classification of *Gabbiella candida* and determining the presence or absence of *Gabbiella walleri* and *Ceratophallus apartus*. Extensive fieldwork is necessary to thoroughly sample the Congo area of the lakes. Additionally, further phylogenetic and evolutionary analyses, along with the utilization of both DNA and nucleus markers, are essential to accurately and conclusively confirm the presence/absence and taxonomic classification of these species. Upon confirmation, we plan to share information with policymakers and the IUCN Species Program and publish the results in a peer-reviewed journal.

Expanding the project to the Congolese side of both lakes to enhance the possibility of species rediscovery depend on the availability of funds. The team also aspire to maintain engagement with the local community around Lake Albert by involving local leaders and educating communities about the significance of snails and the lakes in general.

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Appendix

Knowledge and perception of water snail Conservation among elementary school children in the Lake Albert area

This questionnaire is meant to collect information from elementary school students around Lake Albert about the knowledge and conservation of aquatic snails and will be used for scientific purposes only.

Date: ______________ Nearest Lake: _________________Nearest Town/Village:____________

Respondent Name: _________________________________ Age:______ Name of the school:…………………………………… Class: P4……..P5……….P6……….

KNOWLEDGE OF SNAILS

1. Have you ever seen a snail……………………………….

If yes

a. Where ……………………………………………….......
b. How many. 1-5…5-10………..10-50………more than 50……….

2. How many types of Snails do you know? List them.

………………………….……………………………………………………..

3. What comes into your mind when you see a snail

………………………………………………………………………………………

4.What important role do snails play?

……………………………………………………………………………………..

……………………………………………………………………………………..

BENEFITS AND CONFLICTS FROM SNAILS

4. Are Snail beneficial to you/your community in any way……………………………

If yes, How…………………………………………………………………….

5. Do snail affect you/your community negatively……………………………………

If yes, How…………………………………………………………………….

6. What do you think of snail conservation
   ………………………...

…………………………………………………………………………………………

7. Who do you think should be in charge of snail conservation?

   - The Government of Uganda
   - Ministry of water and Environment
   - Community around lake Albert
   - Everyone
   - None

8. Can you join in conserving snail around your community?……………………………
9. If the answer is yes above, how can you help in conserving snail around your community
   ………………………………………………………………………………………