



Distributional Patterns of Gastropoda Upstream and Downstream of Bujagali Hydropower Project along the Upper Victoria Nile

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Abstract. To better understand the gastropod community dynamics of fresh water snails in the Upper Victoria Nile (UVN), the spatial and temporal abundance changes in gastropod assemblage were assessed biannually from April 2006 to April 2021 at three transects. Biannual abundances of gastropoda were obtained by a ponar grab to examine changes in their community structure in relation to Bujagali Hydropower Project (BHP). The gastropod community consisted of nine species belonging to five families (Thiaridae, Viviparidae, Ampullariidae, Bithyniidae and Planorbidae). Pulmonate species registered five species (*Anisus natalensis*, *Gyraulus sp.*, *Segmentorbis sp.*, *Bulinus sp.* and *Biomphalaria chaenomphala*). Two of the pulmonates (*Bulinus sp.* and *B. chaenomphala*) are schistomiasis vectors. The pulmonates (*A. natalensis*, *Gyraulus sp.*, *Segmentorbis sp.*) were rare and intermittently occurred with abundances up to 47 ind.m⁻². Four prosobranch species (*Gabbia humerosa*, *Pila ovata*, *Melanoides tuberculata* and *Bellamyia unicolor*) were encountered. Of these prosobranchs, *P. ovata* was the rarest while *M. tuberculata* and *B. unicolor* were the commonest. The gastropod community in the UVN was characterised by prosobranchs-dominated abundance which over the 16-year monitoring period often registered peak densities of > 1000 ind.m⁻². The inter-site Percent Similarity Index (PSI) (94-100%) indicated a high degree of similarity of gastropod community across the sites.

Keywords: Water snails, pulmonates, prosobranchs, abundance.

Introduction

The diversity and distribution of fresh water snails in the Upper Victoria Nile remain relatively unstudied. Freshwater snails (Mollusca: Gastropoda Cuvier, 1795) are single-valved and soft-bodied macroinvertebrates. Mollusca is the second largest Phylum on Earth, after Arthropoda with over 50,000 described species. Fresh water snails make up about 5% of global gastropod diversity (4000-8000 species) and contribute 83% of mollusc species found in diverse habitats around the world except in Antarctica (Abbott, 1950; Strong *et al.*, 2008; MolluscaBase 2019 b, c and d). These snails are either pulmonates or prosobranchs (Thompson, 1984; Dudgeon, 1989; Brown, 1997), a dichotomy that makes them useful water quality bio-indicators. Pulmonates are better adapted to low dissolved oxygen-habitats because they are capable of air-

breathing (Lodge *et al.*, 1987, Brown, 1994) while prosobranchs mainly occur in high-oxygenated habitats because they are gill-breathers (Dudgeon, 1989; Brown, 1997). Freshwater prosobranchs are most varied in lakes and larger river systems, whereas freshwater pulmonates are more often occur in small water-bodies and many tolerate seasonal drying. Like many benthic macro-invertebrates, gastropods play a crucial role in the functioning, energy flow and material circulation in their habitats (Stolyarov, 2013; Wan *et al.*, 2018). They as do many freshwater taxa, are experiencing declines due to anthropogenic effects such as habitat degradation and loss, pollution and impoundments. Prior studies focusing on gastropods in the Upper Victoria Nile have been limited and exact number of their taxa is lacking.

The construction of the 250 MW Bujagali Hydropower Project (BHP) on the Upper Victoria Nile (UVN) started in 2008 and commissioned in September 2012. The development and operation of dams create new habitats (Ligon *et al.*, 1995; Rehn, 2009; Mwebaza-Ndawula *et al.*, 2005; Wanda *et al.*, 2017.) that are conducive for survival of freshwater biota including gastropods. To evaluate the impact on gastropod community structure caused by development and management of the 250 MW BHP on the UVN, seasonal and spatial gastropod abundances, composition and Percent Similarity Index (PSI) were examined at three transects, two upstream ones (Kalange-Makwanzi and mid-reservoir) and one downstream (Buyala-Kikubamutwe) from April 2006 to April 2021. Baseline monitoring was carried out in April 2006 and August 2007 as a pre-BHP construction reference for tracking spatial and temporal population fluctuations recorded during and after construction of BHP and to better understand community dynamics useful for conservation planning.

Materials and Methods

Site Description

The study was undertaken within the Bujagali Hydropower Project (BHP) area, stretching from the cross-transects Kalange-Makwanzi to Buyala-Kikubamutwe, at the upstream and downstream, respectively (Figure 1). The hinterland along the banks of this section of the Victoria Nile has been transformed by human activities from wooded savannah landscape to one dominated by small farm holdings of a variety of crops such as coffee, banana and maize. The BHP reservoir is approximately 388 ha in surface area comprising 308 ha original surface of the Victoria Nile, and 80 ha inundated from adjoining land (ESRS, 2018). The reservoir has a maximum depth of 30 m with a mean depth of 9.3 m (ESRS, 2018). This run-of-the river hydropower dam has a residence time of 16 hours and a water head that daily fluctuates between 2 and 2.5 m. (ESRS, 2018) The study area is in the zone characterized by a long wet season (February to May), a short dry season (June to July), a short wet season (August to October) and a long dry season (November to January) (Nicholson, 2017). The April monitoring periods represented the peak of the rainy season while September ones represented a dry-wet period of each year.

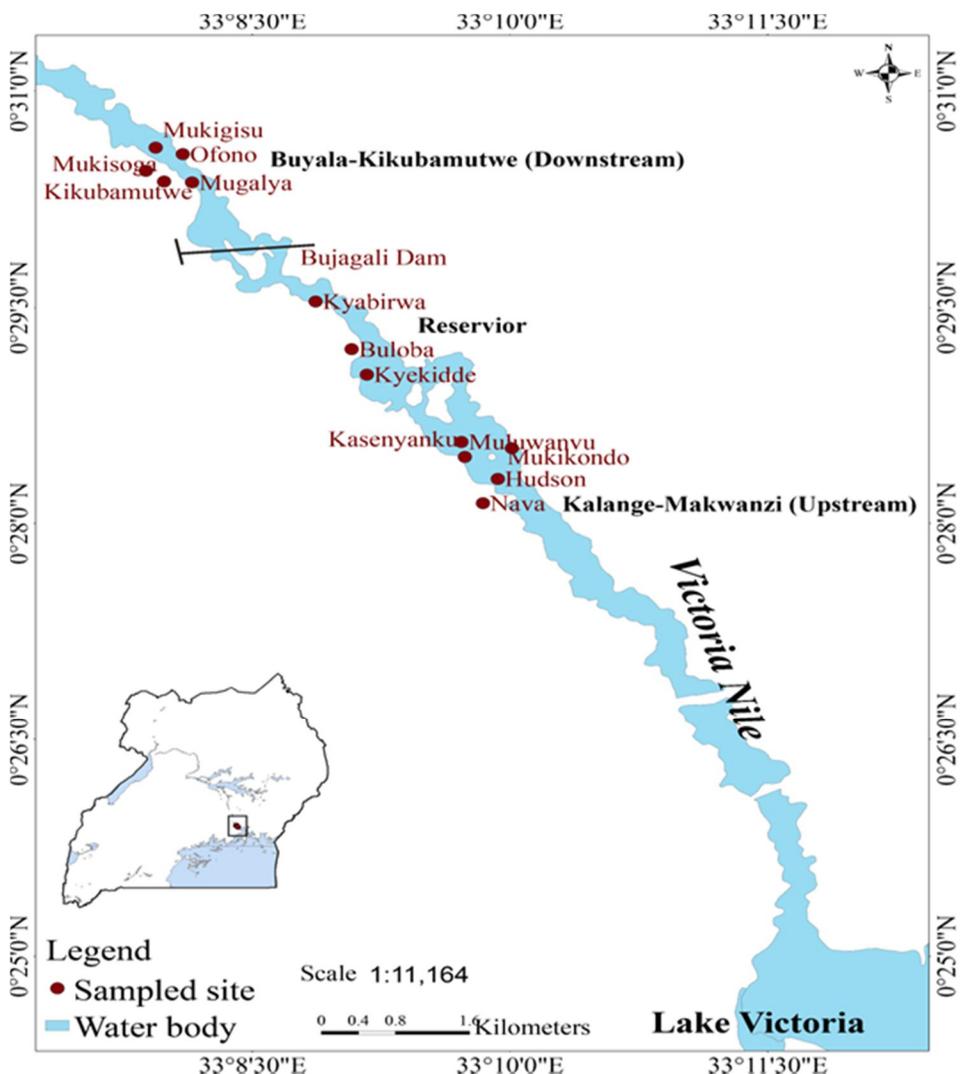


Figure 1. Upper Victoria Nile map showing the location of BHP and transects where gastropods were examined

Sample Collection and Laboratory Analysis

Quantitative sampling of bottom substrates for macroinvertebrates was carried out using a ponar grab with a sampling area of 0.1 m² in triplicates at each site. The collected substrate samples were sieved through a 0.5-mm mesh bag to get the macroinvertebrates that were preserved in 5% formalin. The preserved macroinvertebrates were transferred to National Fisheries Resources Research laboratory where gastropods were sorted and separated from other taxa. The species of gastropods were identified according to Merrit & Cummins 1997, Pennak 1989 and Mandahl-Barth 1954, and quantified as mean numbers per square meter.

Percent Similarity Index (PSI) at p≤0.05 was computed from the species abundance data to determine the degree of similarity of the gastropod community composition among sites, using the formula: $PSI = 100 - 0.5 \sum |P_{ik} - P_{jk}|$.

The index represents the similarity between communities i and j , and varies from 0.0 to 100, with 100 indicating that the two communities have identical composition. P_{ik} and P_{jk} are the proportions of individuals present in communities i and j , respectively, that comprise the k^{th} species. A PSI > 60% is taken to indicate that two communities are similar (Uchikawa *et al.*, 2002; Zhou *et al.*, 2008).

Results

Substrate and River Margin Features at the Monitored Transects

The mean water depth at the eastern bank of the Kalange-Makwanzi transect was 4.38 ± 0.13 m and the bottom was hard with fine sand and a bit of silt; the vegetation at this bank was cleared (Table 1). The mid of this transect was 5.93 ± 0.16 m deep and the bottom was mainly gravel. The western bank is forested with the littoral area of 5.14 ± 0.89 m deep. At the mid-reservoir transect on the eastern bank, water depth was 4.18 ± 0.42 m; the substrate was brown clay silt (Table 1). The mid of this transect was 23.92 ± 3.62 m deep and bottom was mainly gravel. At the western bank, mean water depth was 4.99 ± 0.39 m and littoral area was covered with water hyacinth. At Buyala-Kikubamtwe transect on the eastern bank, water depth was 3.77 ± 0.40 m and littoral bottom was rock and sand (Table 1). The mid of this transect was 5.01 ± 0.42 m deep and the bottom was grey silt. The water depth at the western bank was 2.98 ± 0.31 m and bottom was mainly rocky with fine sand. The littoral areas at both bank had no vegetation (Table 1).

Table 1. Mean depth, substrate characteristics and water margin vegetation characteristics

Monitored cross transects	Kalange-Makwanzi-Upstream transect			Mid-reservoir transect			Buyala-Kikubamtwe-downstream transect		
	Kalange-East	mid-channel	Makwanzi-west	Reservoir-east	Reservoir-mid	Reservoir-west	Buyala-east	mid-channel	Kikubamtwe-West
Mean depth \pm Standard Error (m)	4.38 ± 0.13	5.93 ± 0.16	5.14 ± 0.89	4.18 ± 0.42	23.92 ± 3.62	4.99 ± 0.39	3.77 ± 0.40	5.01 ± 0.42	2.98 ± 0.31
Sediment characteristics	Hard bottom with fine sand and some silt and plant debris	Fine dark Sand/gravel	Soft mud/soil	Brown clay-silt	Gravel	Clay soil bottom	Rocky, clean shells/dark fine sand	Grey silty bottom	Rocky fine sand bottom
Characteristics of the shore	Shoreline cleared of vegetation		Forested shoreline	Water hyacinth-Vossia mixture at bank edge		Luxurious waterhyacinth at the bank.	No shoreline vegetation		No vegetation on the shoreline

Gastropod Species Richness

Nine species of Gastropoda belonging to five families were encountered in the study area (Table 2). Four families of prosobranchs were recorded (Thiaridae, Viviparidae, Ampullariidae and Bithyniidae). Each family was represented by one snail species, *Melanooides tuberculata*, *Bellamyia unicolor*, *Pila ovata* and *Gabbia humerosa*, respectively (Table 2). The pulmonates were represented by two families; Bulinidae with one species *Bulinus sp.* and Planorbidae with four species: *Anisus natalensis*, *Gyraulus sp.*, *Segmentorbis sp.* and *Biomphalaria chaenomphola* (Table 2).

Table 2. Gastropod species encountered at Kalange-Makwanzi, mid-reservoir and Buyala-Kikubamutwe transects

Order	Family	Species name (local name)	Plate
Cerithiida	Thiaridae Gill, 1871	<i>Melanoides tuberculata</i> (Müller, 1774) (Red-rimmed melania)	
Architaenioglossa	Viviparidae Gray, 1847	<i>Bellamyia unicolor</i> (Olivier, 1804)	
	Ampullariidae Gray, 1824	<i>Pila ovata</i> (Olivier, 1804) (apple snail)	
Littorinida	Bithyniidae Gray, 1857	<i>Gabbia humerosa</i>	
Lymnaeida Rafinesque, 1815	Bulinidae	<i>Bulinus sp.</i>	
	Planorbidae Rafinesque, 1815	<i>Gyraulus sp.</i>	
		<i>Anisus natalensis</i> (Krauss, 1848)	
Hygrophila		<i>Biomphalaria choanomphala</i>	
		<i>Segmentorbis sp.</i>	

Species Composition and Temporal Relative Abundance

The prosobranchs, *B. unicolor* and *M. tuberculata* occurred more often than other snails across sites, typically with dominance from 44% to 96% (Figure 2). However, during periods of April and September 2012, the prosobranch, *Gabbia humerosa* dominated abundance by 79 and 82 % respectively (Figure 2). Between April 13 and April 16, *B. unicolor* was the dominant species ranging from 41 to 83% of the snail assemblage. From September 2016 to September 2019, dominance was taken over by *M. tuberculata* by 71 to 96%. In June 2020 and April 2021, again, *B. unicolor* dominated the snail community by 72 and 74% respectively. The snail, *A. natalensis* was stenotopic to Buyala-Kikubamutwe and contributed from 0.3% to 4.3% to total gastropod density (Figure 2). At the mid-reservoir, *Segmentorbis sp.* was recovered once in September 2012, registering 3.3% to total gastropod density.

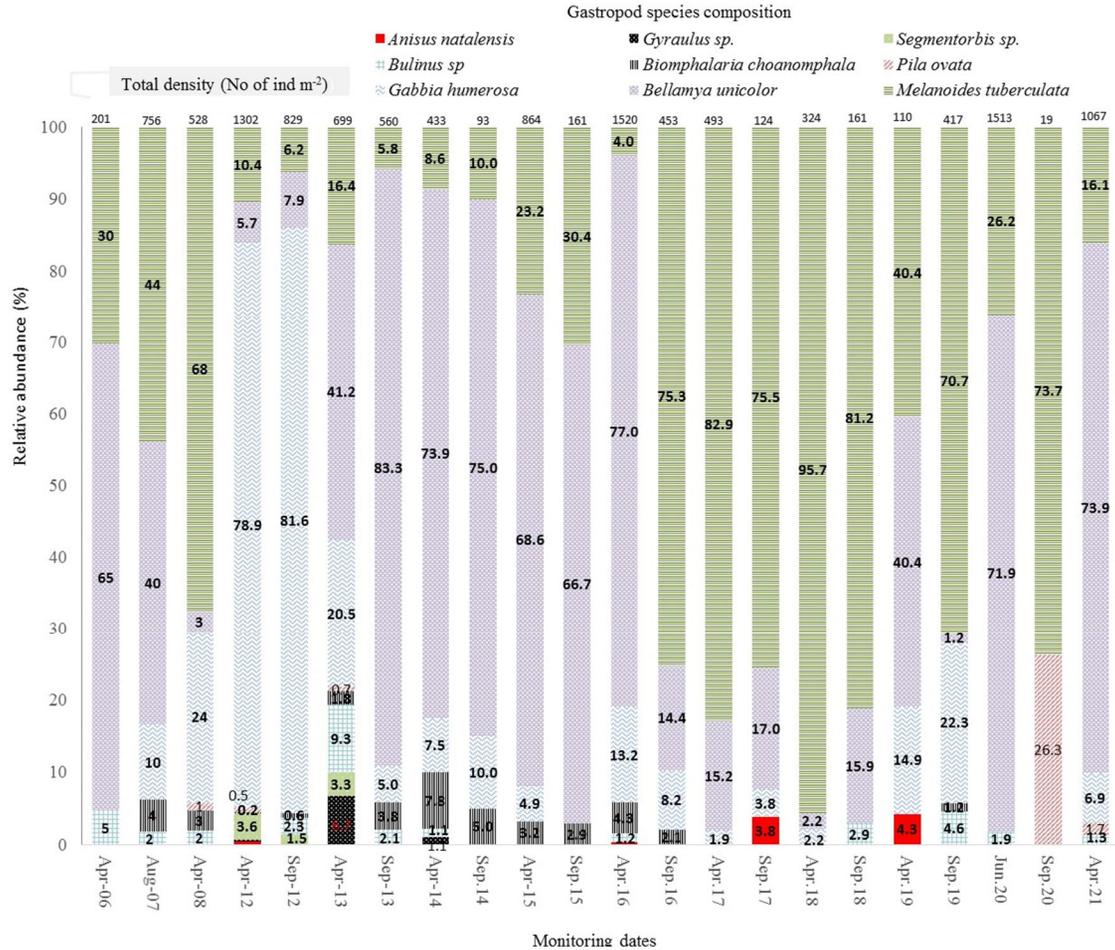


Figure 2. Species composition and temporal relative abundance of Gastropods pre-, during and post-construction of BHPP

Distribution of Pulmonates-Non-Vector Species

The pulmonates (*A. natalensis*, *Gyraulus sp.* and *Segmentorbis sp.*) were uncommon and irregularly occurred (Figure 3). Their abundance ranged from 5 to 47 ind.m⁻². The snail, *A. natalensis* was stenotopic to Buyala-Kikubamutwe and occurred at very low density of 5 ind.m⁻² on each monitoring date, contributing from 0.3% to 4.3% (Figure 3) to total gastropod density. It was absent at Kalange-Mkwanzu and mid-reservoir transects (Figure 3). The snail, *Gyraulus sp.* occurred twice in April 2013 and April 2014 at Buyala-Kikubamutwe at densities of 47 ind.m⁻² and 5 ind.m⁻² respectively (Figure 3). At Kalange-Mkwanzu, it was recovered once in April 2012 at a density of 5 ind.m⁻². It did not occur at the mid-reservoir transect. The pulmonate, *Segmentorbis sp.* was recovered thrice at Buyala-Kikubamutwe at densities of 47, 9 and 23 ind.m⁻² respectively. At the mid-reservoir, it was recovered once in September 2012 at merely a density of 3 ind.m⁻² (Figure 3), registering 3.3% to total gastropod density. It was absent at Kalange-Mkwanzu transect (Figure 3).

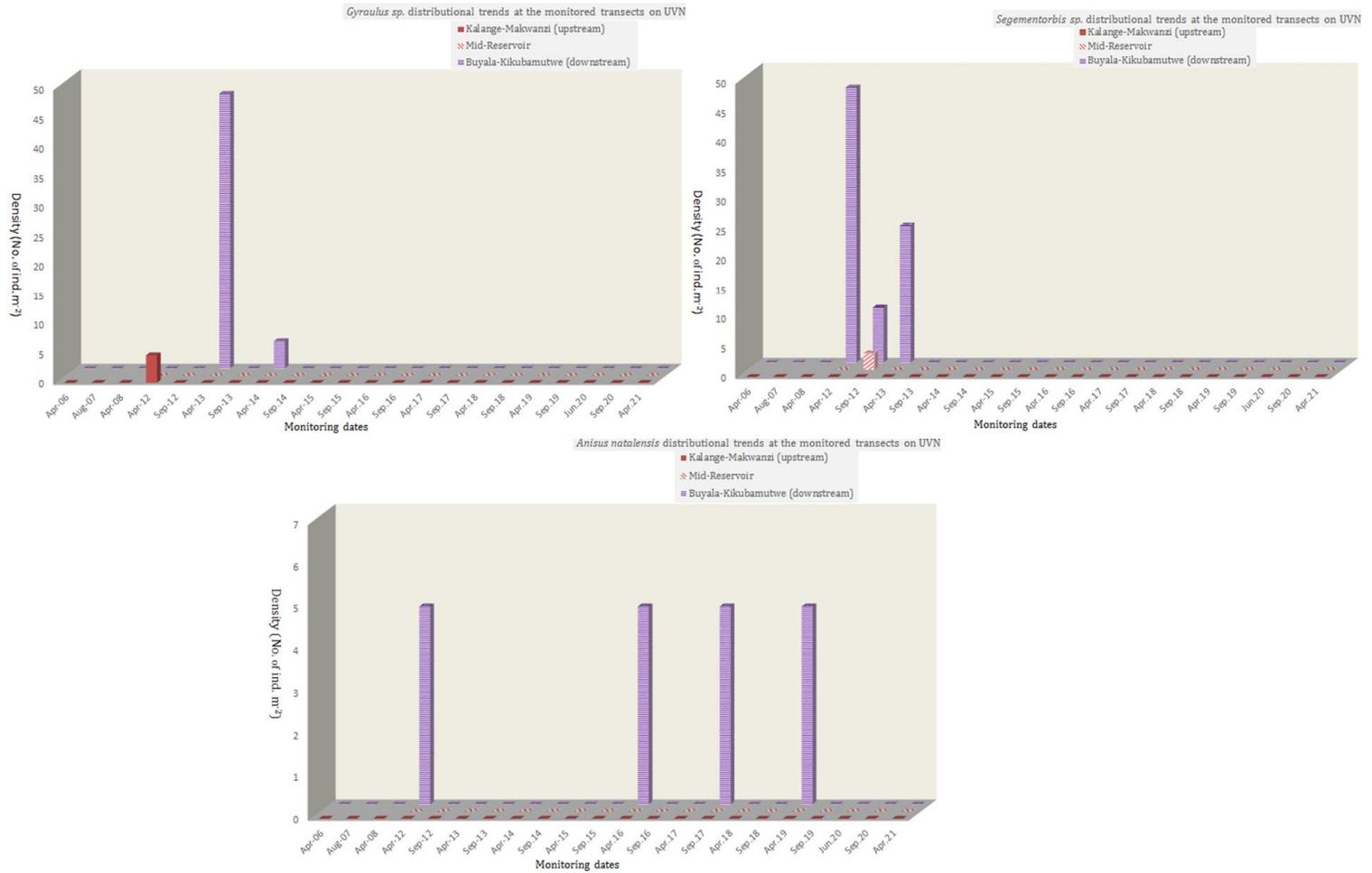


Figure 3. Spatial and temporal abundance and distribution of pulmonate gastropods (non-vector species).

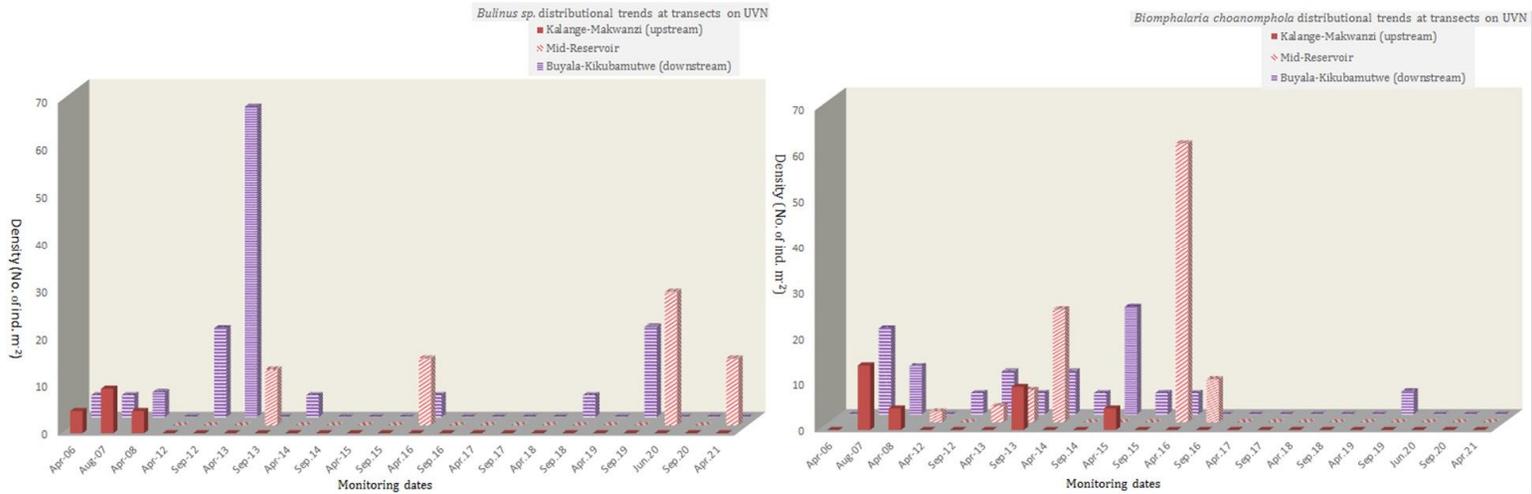


Figure 4. Spatial and temporal abundance and distribution of schistosomiasis vector pulmonate gastropods.

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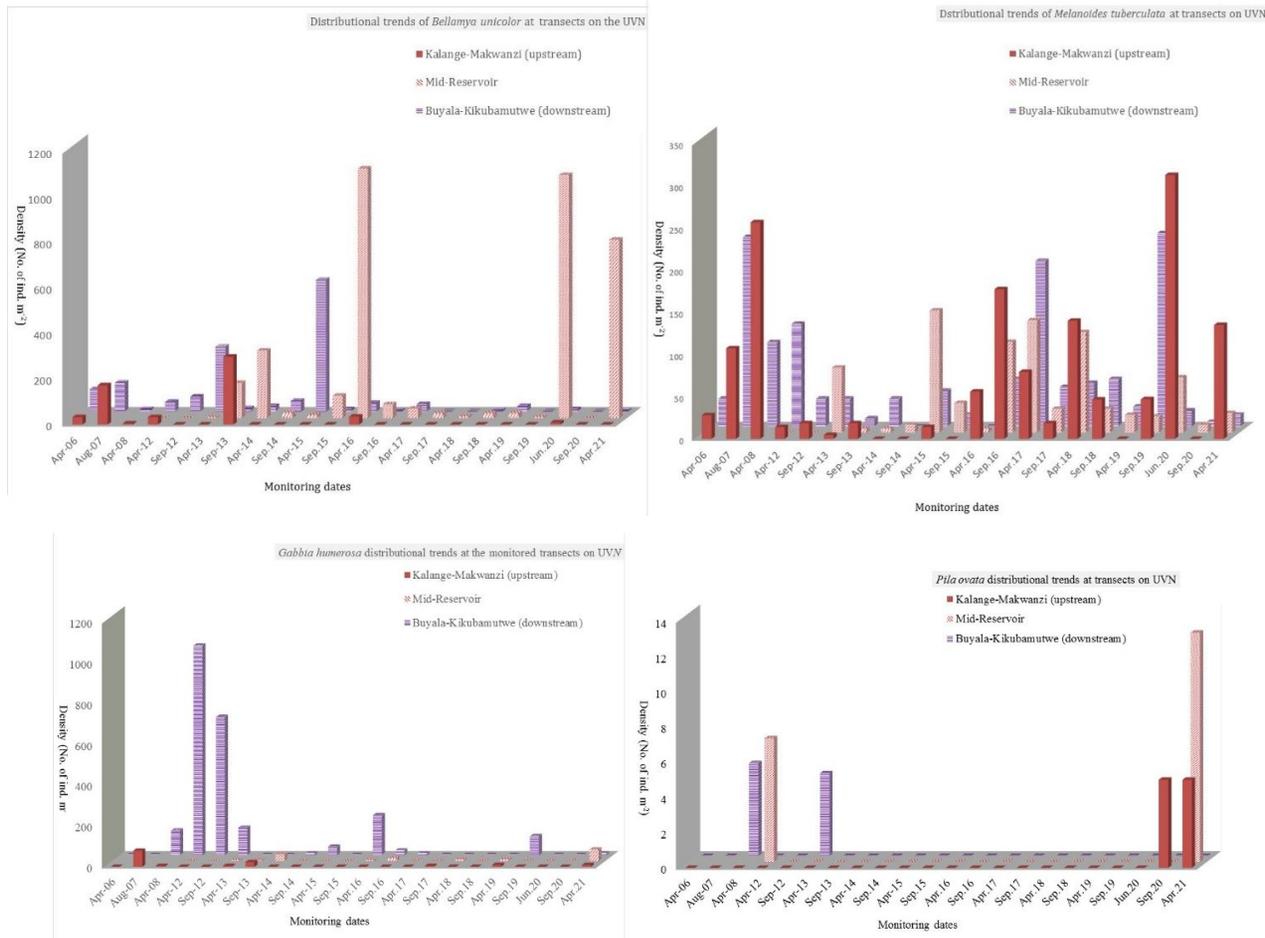


Figure 5. Spatial and temporal abundance and distribution of prosobranchs of at the monitored transects along the Upper Victoria Nile (UVN).

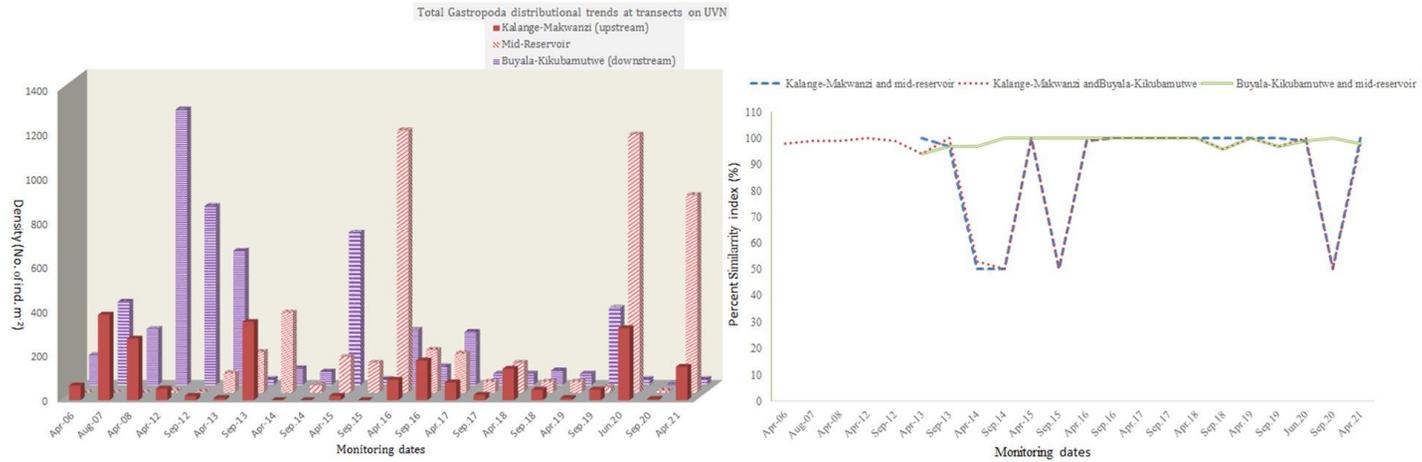


Figure 6. Spatial and temporal aggregated abundance, distribution and Percent Similarity Index (PSI) of Gastropoda

Distribution of Pulmonates (the Schistosomiasis-Vector Species)

The schistosomiasis snail vector, *Biomphalaria chaenomphala* was present at Kalange-Makwanzi 4 times (in August 2007, April 2008, September 2013 and April 2015) at low densities, from 5 to 9 ind.m⁻² (Figure 4). It occurred at the mid-reservoir 6 times (at 2 ind.m⁻² in April 2012, 4 ind.m⁻² in April 2013, 25 ind.m⁻² in April 2014, 61 ind.m⁻² in April 2016, 7 ind.m⁻² in September 2013 and 9 ind.m⁻² in September 2016). At Buyala-Kikubamutwe, it featured 9 times with density varying from 4 to 23 ind.m⁻². The schistosomiasis vector snail, *Bulinus sp.*, occurred thrice at Kalange-Makwanzi (in April 2006, August 2007 and April 2012), registering density between 5 and 9 ind.m⁻² (Fig 4). It was recorded at the mid-reservoir transect 4 times (in September 2013, April 2016, June 2020 and April 2021) at abundances between 12 and 28 ind.m⁻². It featured 9 times at Buyala-Kikubamutwe with a peak density of 65 ind.m⁻² in April 2013. In April 2008, August 2007, April 2012, April 2014, April 2016 and September 2018, 5 ind.m⁻² were respectively recorded while in September 2012 and September 2019, 19 ind.m⁻² were registered on both occasions.

Distribution of Prosobranch Species

The most frequent prosobranch species across all sites was *Bellamya unicolor* (Figure5). Over the monitoring period, it occurred 6 times in April 2006, August 2007, April 2012, September 2013, April 2016 and June 2020 at Kalange-Makwanzi transect at respective densities of 33 ind.m⁻², 173 ind.m⁻², 33 ind.m⁻², 289 ind.m⁻², 35 ind.m⁻² and 9 ind.m⁻² (Figure5). This water snail recorded densities of over 1000 ind.m⁻² at the mid-reservoir transect, registering 1097 ind.m⁻² in April 2016 and 1069 ind.m⁻² in June 2020. At this transect, it was also recovered in September 2013, April 2014, September 2015, September 2016, April 2017 and April 2021 at respective densities of 154, 296, 98, 61, 42 and 784 ind.m⁻². At Buyala-Kikubamutwe transect, abundance peaked in April 2015 at 519 ind.m⁻² and in April 2013 at 285 ind.m⁻². In August 2008, a density of 126 ind.m⁻² was recorded while that of < 100 ind.m⁻² was registered on other monitoring occasions. Like *Bellamya unicolor*, *M. tuberculata* too was a common prosobranch (Figure5). It was recovered at Kalange-Makwanzi on all monitoring dates except in April 14, April 2015, September 2014, April 2019 and September 2020 (Figure 5). Its peak densities were recorded in April 2008 and June 2020 at respective abundance of 257 ind.m⁻² and 313 ind.m⁻². Densities of 107 ind.m⁻², 177 ind.m⁻² and 135 ind.m⁻² were recorded in August 2007, September 2018 and April 2021, respectively. From April 2012 to September 2013 and April 2016, abundance was very low, ranging from 5 to 19 ind.m⁻². In 2006, a density of 28 ind.m⁻² was recorded. At the mid-reservoir, density peaks occurred in April 2015 and April 2021 at respective abundances of 145 and 133 ind.m⁻² (Figure5). In September 2013, April 2014, September 2014 and September 2015, paltry densities of 5 ind.m⁻² to 9 ind.m⁻² were recorded. In April 2013, 71 ind.m⁻² were recovered. At Buyala-Kikubamutwe, peak abundance of *M. tuberculata* were recorded in August 2007, April 2017 and September 2019 at respective densities of 224 ind.m⁻², 196 and 299 ind.m⁻². Recovery of this snail did not occur in September 2014 and April 2016. Densities of 100, 121 and 56 ind.m⁻² were recorded in April 2008, September 2012 and September 2018, respectively. At Kalange-Makwanzi, *Gabbia humerosa* was recorded four times in August 2007, September 2013, April 2019 and April 2021 at very low densities ranging from 9 ind.m⁻² to 79 ind.m⁻² (Figure5). At the mid-reservoir, it occurred eight times at low abundances, ranging from 4 to 14 ind.m⁻² except in April 2014 and April 2021 when densities of 33 ind.m⁻² and 56 ind.m⁻² respectively were recorded. The rarest prosobranch was *Pila ovata* (Figure5). At all the three

transects, *P. ovata* was recovered twice (Figure 5). At Kalange-Makwanzi, this rare snail was recovered in September 2020 and April 2021 at 5 ind.m⁻² on each monitoring date. At the mid-reservoir, the snail was present in April 2012 and April 2021 at abundance of 7 ind.m⁻² and 13 ind.m⁻² respectively. It was recorded at Buyala-Kikubamutwe in April 2008 and April 2013 at 5 ind.m⁻² on each monitoring date.

Total Gastropod Abundance and Distribution

At Kalange-Makwanzi transect, gastropods were not recovered in April 2014, September 2014 and September 2015 (Figure 6). A density of > 50 ind.m⁻² recorded at the transect occurred in September 2012, April 2013, April 2015, September 2017, September 2018, April 2019, September 2019 and September 2020. Respective abundances of 65, 91, 177, 79, 140 and 149 ind.m⁻² within a density range of 51-200 ind.m⁻² were registered in April 2006, April 2016, September 2016, April 2017, April 2018 and April 2021. In the density range 201-300 ind.m⁻², an abundance of 275 ind.m⁻² was recorded in April 2008. Respective densities of 385, 350 and 322 ind.m⁻² in the density range of 301-500, were recorded in August 2007, September 2013 and June 2020. Densities > 500 ind.m⁻² were not recorded at this transect.

At the mid-reservoir, total Gastropod abundance of > 50 ind.m⁻² was recorded in April 2012, September 2012, September 2014, September 2017, September 2018, April 2019, September 2019 and September 2020 at respective densities of 9, 3, 33, 49, 49, 49, 24 and 9 ind.m⁻² (Figure 6). Abundance range of 51-200 ind.m⁻² was registered in April 2013, September 2013, April 2015, September 2015, September 2016, April 2017 and April 2018 at respective abundances of 88, 182, 159, 133, 191, 175 and 133 ind.m⁻². In the density range 201-300 ind.m⁻², abundance was not encountered over the monitoring period. In the density range 301-500, abundance of 358 ind.m⁻² was recorded in April 2014. Densities > 500 ind.m⁻² were recorded in April 2016, June 2020 and April 2021 at abundances of 1183, 1162 and 890 ind.m⁻² respectively.

At Buyala-Kikubamutwe transect, total Gastropod abundance of > 50 ind.m⁻² was recorded in September 2013, September 2015, June 2020 and April 2021 at respective density of 28 ind.m⁻² and in September 2020 at a density of 5 ind.m⁻² (Figure 6). Abundance range of 51-200 was registered in April 2006, September 2014, September 2017, April 2018, September 2017 and April 2021 at respective abundances of 135, 61, 51, 51, 65 and 61 ind.m⁻². In the density range 201-300 ind.m⁻², abundances were encountered in April 2008, April 2016 and April 2017 at respective densities of 252, 247 and 238 ind.m⁻². In the density range 301-500 ind.m⁻², abundances were recorded in August 2007 and September 2019 at densities of 373 and 346 ind.m⁻² respectively. Densities > 500 ind.m⁻² were recorded in April 2012, September 2012, April 2013 and April 2015 at abundances of 1242, 808, 602 and 686 ind.m⁻² respectively.

Percent Similarity Index (PSI) indicated a very high degree of similarity (94-100 %) in Gastropoda community at Kalange-Makwanzi, mid-reservoir and Buyala-Kikubamutwe transects over the monitoring period (Figure 6). However, PSI > 60% happened in April 2014, September 2014 and September 2020 when gastropod community between Buyala-Kikubamutwe and Kalange-Makwanzi sites indicated dissimilarity.

Discussion

The inter site faunal Percent Similarity Index (PSI) indicated abundance, species composition and distribution patterns at the upstream-downstream sites before, during and after

construction of BHP were comparable. The water quality parameters too across the sites were found to be within standard allowable NEMA and WHO values, typical of unpolluted waters, and did not vary so much over the monitoring period (Wanda *et al.*, 2017). The distribution of freshwater snails depend on substrate type and water quality, e.g. pH, DO, calcium and temperature (Bronmark, 1987; Zhou *et al.*, 2008; Zeybek *et al.*, 2012).. Gastropods, especially the prosobranchs were eurytopic to upstream and downstream habitats indicating that both water and substrate quality did not impede their survival in the study area. Factors such as temperature, turbidity, DO, pH, CO₂ and water hardness influence toxicity of pollutants that affect snail populations (Christian *et al.*, 2021; Abbot, 1950). In this study, DO, temperature, pH, water clarity and conductivity occurred within acceptable limits of WHO and NEMA (Wanda *et al.*, 2017). Thus, water quality across the sites was not of environmental concern either due to excessive loading of nutrients into the river or dam operations. The prosobranchs, *B. unicolor* and *M. tuberculata* occurred more often than other snails across sites, typically in high densities. However, during BHP construction periods of April and September 2012, the prosobranch, *Gabbia humerosa* dominated abundance by 79 and 82 % respectively. Between April 13 and April 16, *Bellamyia unicolor* became the dominant species ranging from 41 to 83% of the snail assemblage. From September 2016 to September 2019, dominance was taken over by *Melanooides tuberculata* by 71 to 96%. In June 2020 and April 2021, dominant species was *Bellamyia unicolor* by 72 and 74% respectively.

Disturbed fresh water habitats are predicted to have higher abundances of pulmonates than of prosobranchs (Mandal-Barth, 1957 a; Brown *et al.*, 1998; Strzelec and Królczyk, 2004). In this assessment, pulmonate abundance was extremely low with restricted and discontinuous distribution, implying disturbance from construction and operation of BHP did not show significant impact on the gastropod community. Gastropod assemblage before construction of BHP was comparable to the one encountered during and post construction periods.

The nine Gastropoda species encountered in the Upper Victoria Nile at the three sites (Table 1) are all considered for purposes of conservation, species of least concern for the IUCN Red List of Threatened species (Jørgensen 2008; Ghamizi *et al.*, 2009). Eight species occurred at the three sites except *Anisus natalensis* that was recorded only at Buyala-Kikubamutwe. Though the species is considered as one of least concern on the IUCN Red list Threatened species (Jørgensen 2008; Ghamizi *et al.*, 2009), Christian *et al.* (2021) postulated that species which occur exclusively in one locality could be considered as vulnerable. The home range of *P. ovata* in Africa spans from Egypt down to East Africa to northern Mozambique (Brown, 1994), however, in the current evaluation, this prosobranch was irregularly distributed across sites in the UVN. On the other hand, *B. unicolor* occurred with continuous distribution at the three sites. Brown (1994) described its range to be from the northern part of sub-Saharan Africa and along the Nile. Like *B. unicolor*, *M. tuberculata* occurred with regular distribution at the three sites.

All in all, the gastropod community in the UVN was characterised by prosobranchs-dominated abundance which often peaked at densities > 1000 ind.m² over the 16-year monitoring period and inter-site PSI (94-100%) suggested a high degree of similarity of gastropod community across the sites. This is indicative that the construction and operation of BHP did not significantly impact on the dynamics of gastropod assemblage in the upstream and downstream sites of the UVN. Wanda *et al.* (2017) and Mwebaza *et al.* (2005) did not find significant negative effect on the major water physico-chemical parameters and zooplankton community respectively at the same sites probably because BHP is a run-of-the river impoundment with a short residence time of 16 hours.

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