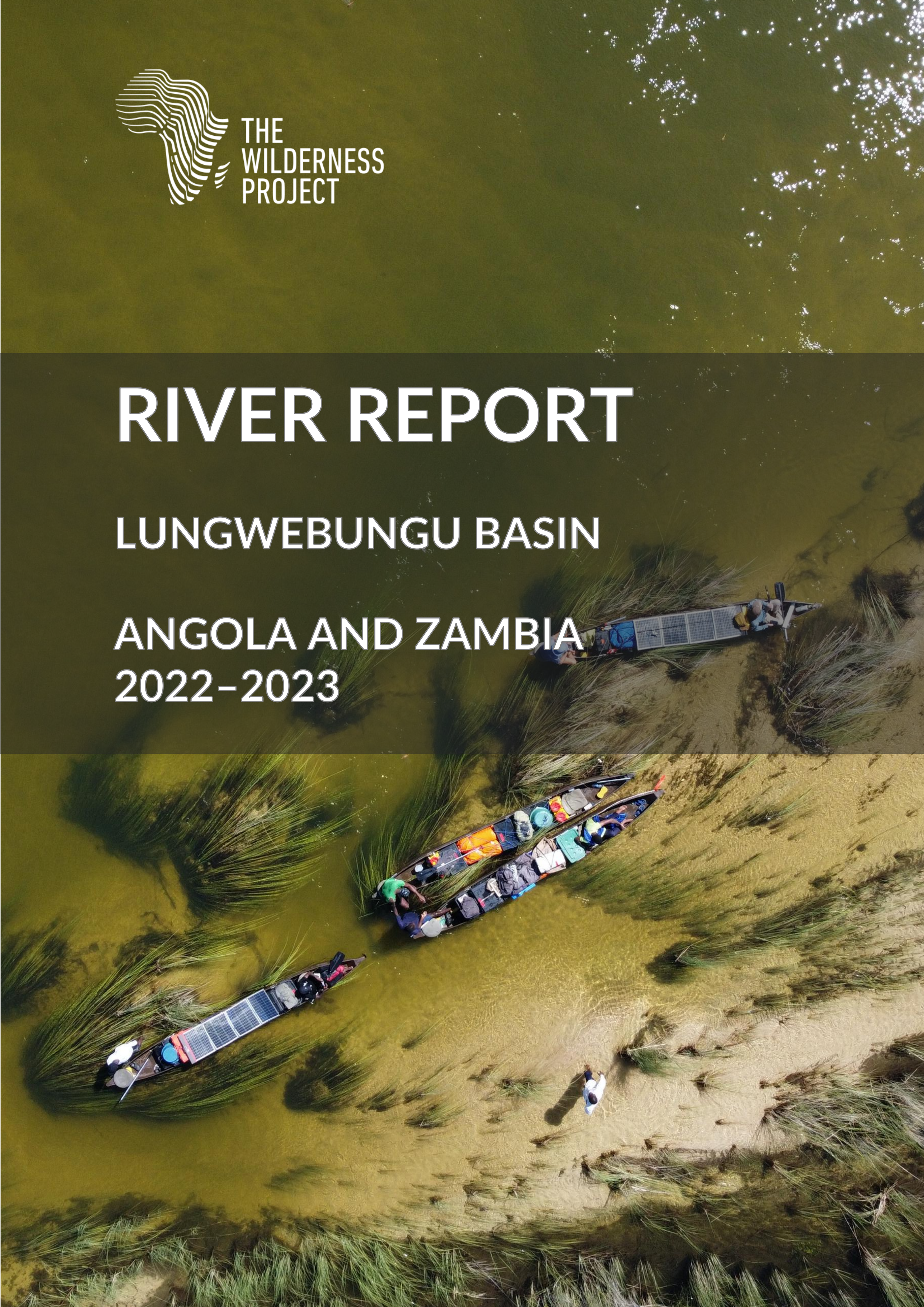

THE WILDERNESS PROJECT

RIVER REPORT

LUNGWEBUNGU BASIN

ANGOLA AND ZAMBIA 2022–2023

ABOUT THE WILDERNESS PROJECT

By 2035, in partnership with local communities, governments, researchers and NGOs, The Wilderness Project aims to explore, study and better protect 1.2 million square kilometres of irreplaceable African wilderness. Central to this effort is to establish detailed hydrological and ecological baselines of the largely undocumented sources and watersheds of Africa's greatest river basins — Zambezi, Congo, Nile, Chad and Niger.

ACKNOWLEDGEMENTS

Our research transects would be impossible without the collaboration of our various partners, who enable information-sharing, provide local advice, and grant permissions wherever we work. For their continued support along the Lungwebungu River, we thank the Department of National Parks and Wildlife, Copperbelt University, African Parks, the Water Resources Management Authority, the University of Zambia, Fundação Lisima, and the Wild Bird Trust. Finally, we extend our gratitude to the traditional custodians who granted us permission to navigate the waters and lands of the Lungwebungu.

EXECUTIVE SUMMARY

The Lungwebungu River is a key source of the Zambezi River. It originates in the Angolan Highlands and flows into Zambia. Spanning a total of 1, 032 km (762 km in Angola and 270 km in Zambia), the river is an essential water source, contributing significantly to the flow of the upper Zambezi River. Despite its ecological importance, the Lungwebungu River remains understudied, with limited information on its biodiversity, water quality, and human impacts.

To address this gap, The Wilderness Project (TWP) initiated two research expeditions. The first expedition, conducted in June–July 2022, covered the river's source in the Angolan Highlands to the Zambian border. A follow-up expedition in March 2023 extended the transect from the Zambian border to the confluence with the Zambezi River. Over the course of 1, 032 km, the expedition collected data on human impacts, biodiversity, water quality, and river discharge. Findings are detailed in this report and presented as interactive web maps with 360-degree imagery (ESRI web application).

Key Findings

People and Human Activity

The Lungwebungu River is characterized by a low population density of **0.03 people/km,** lower than other Zambezi Rivers. The limited infrastructure development along most stretches has allowed the river to remain relatively pristine, with most of the riparian zone intact. However, areas near the EN180 road bridge show higher human activity, including extensive cassava farming, presence of invasive plant species, and frequent fires. Additionally, artisanal mining activities, particularly near the river's source, pose potential risks to water quality. **Ongoing monitoring** of these areas is recommended to prevent negative environmental impacts.

Fire Risks

Fires on the river are seasonal, with most fires occurring during the dry season from June to September. These fires are typically started by local communities for hunting and land-clearing purposes. Satellite fire analysis reveals that large sections of the river have not burned since 2000, but several areas have experienced multiple burns between 2000 and 2023. Fire activity is most frequent in grasslands and shrublands, highlighting the need for **careful management** to mitigate the effects of these fires on the river and its ecosystems.

Biodiversity

The Lungwebungu River supports a high abundance of wetland birds, with **2, 459 birds** from 65 species recorded, representing a density of 2.8 birds/km — lower than the Zambezi River average. Most wetland bird species were evenly distributed along the river in Zambia, likely due to habitat availability, while bird abundance was particularly low near the source and around the EN180 road bridge. The presence of large terrestrial wildlife, such as hippos, was limited, with only two observed along the transect. This scarcity is believed to be linked to **hunting pressures** in Angola and the inundated floodplains in Zambia, which may obscure observations.

Opportunistic fish sampling detected **an estimated 47 species**, with mormyrid genera, such as *Heteromormyrus* and *Pollimyrus*, indicating a strong affinity between the Lungwebungu River and the Okavango, with the presence of *Enteromius chiumbeensis*

Hydrology and River Discharge

The Lungwebungu River is crucial for regulating the flood pulse of the Zambezi River, contributing

16–20% of the upper Zambezi's flow, depending on the season. The river plays a key role in the hydrological cycle, buffering the impacts of seasonal floods. These findings underscore the importance of **transboundary management** of the Lungwebungu River for **maintaining the ecological health** of the Zambezi River system.

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1.1 INTRODUCTION

Background of the Wild Bird Foundation of America

The Wilderness Project (TWP) is a non-profit organisation that supports research and conservation on rivers in Africa. In 2022, TWP launched the Great Spine of Africa series of expeditions (GSOA) in partnership with the ROLEX Perpetual Planet Initiative. The objective of the programme is to explore and protect over 1.2 million km^2 of irreplaceable African watersheds and wetlands by 2035. To date, TWP has enabled important research along thousands of kilometers of rives in Zambia, Angola, Namibia, and Botswana, including the Cassai, Cuando, Chambeshi, Kafue, and Zambezi Rivers.

TWP collects important baseline data on rivers to support their long-term management and conservation. The overarching goals of TWP are to: i) assess the status of Africa's freshwater ecosystems; ii) identify areas of critical concern or conservation significance; iii) support the efforts of managers and NGOs working in the freshwater conservation space; iv) develop local scientific and storytelling capacity; and v) generate interest, enthusiasm, and funding for the conservation of rivers in Africa.

Expedition Objectives

In June—July 2022, researchers from TWP conducted a transect of the Lungwebungu River (known as the Lungué-Bungo River in Angola) from its source in the Angolan highlands to the Zambian border. A subsequent expedition was conducted in March 2023 to continue the transect from the Zambian border to the confluence with the Zambezi River. A total distance of 1,032 km was travelled – 762 km in Angola and 270 km in Zambia (Figure 1). This basin-wide report details the findings of both expeditions. The expeditions aimed to provide a comprehensive overview of the river's health by collecting data on biodiversity, human impact, water quality and discharge. Importantly, the expeditions were conducted by predominantly local teams, thereby building local research capacity by training team-members on river expedition, research and guiding approaches.

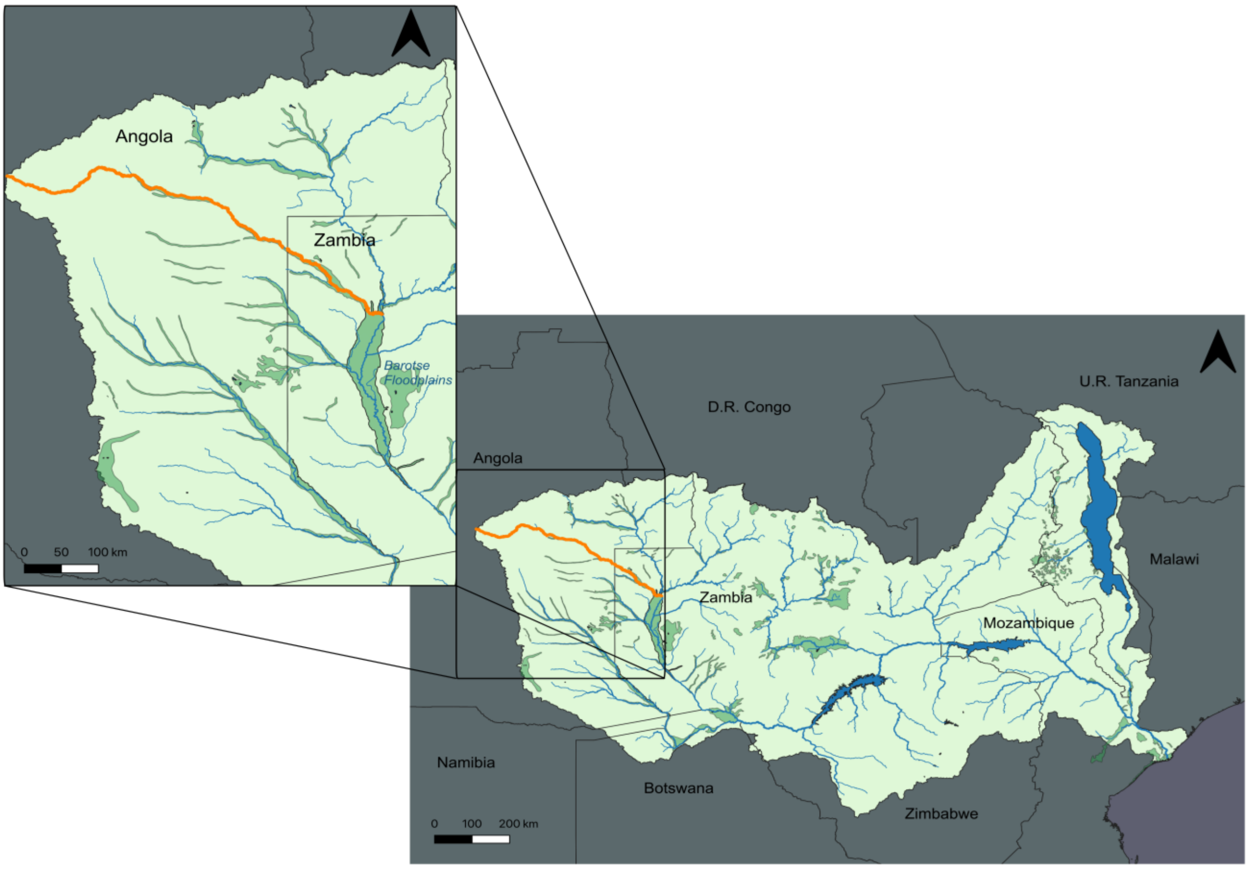


Figure 1. The Lungwebungu River (orange) within the Greater Zambezi basin.

Study Site Description

The Zambezi Basin is the largest basin in southern Africa, comprising a total catchment area of ~1.3 million km^2 across eight countries[1,2]. The Zambezi Basin consists of 13 sub-basins divided into three regions — the Upper, Middle and Lower River. The Upper Zambezi River, which stretches from the Okavango catchment in the west to the headwaters of the Kafue River in the east[3], includes six sub-basins: i) Upper Zambezi; ii) Kabompo; iii) Barotse; iv) Cuando Chobe; v) Luanginga; and vi) Lungwebungu.

The headwaters of the Lungwebungu River are located in the highlands of north-eastern Angola, at an elevation of approximately 1,400 m.a.s.l. (Figure 2). From here, the river flows southeast into Zambia, converging with the Zambezi River near the town of Lukulu in the upper reaches of the Barotse Floodplain ecosystem.. The contribution of clean, regular water to the Barotse Floodplain ecosystem vital not only for supporting the local communities that depend on the system for the livelihoods but also for maintaining the ecological integrity of the floodplain.

As most of the Zambezi Basin comprises moist or dry woodland and grassland, the vegetation surrounding the Lungwebungu River is characterized by moist miombo woodland in the upper and middle reaches, transitioning to grassland in the lower reaches. This miombo-woodland and grassland complex contributes to the immense biodiversity of the second-largest nature and conservation area on the plant: The Kavango-Zambezi (KAZA) Transfrontier Conservation Area (TFCA).

[1] Tweddle, D., 2010. Overview of the Zambezi River System: Its history, fish fauna, fisheries and conservation. *Aquatic Ecosystem Health & Management*, *13*, 224–240.
[2] Beilfuss, R., 2012. A Risky Climate for Southern African Hydro: Assessing Hydrological Risks and Consequences for Zambezi River Basin Dams. *International Rivers.*
[3] WWF and TNC., 2019. Zambezian Headwaters. Freshwater Ecoregions of the World. Written by Scott, L., and Skelton, P. Available at: https://www.feow.org/

Figure 2. The source of the Lungwebungu River in the highlands of Angola.

Figure 3. The lower reaches of the Lungwebungu River in Zambia. Note the aquatic reeds along the channel edge on the right, and multiple oxbow lakes in the background.

Relevant conservation areas and initiatives

The Kavango—Zambezi (KAZA) Transfrontier Conservation Area

The KAZA TFCA lies in the Kavango and Zambezi River basins where Angola, Botswana, Namibia, Zambia and Zimbabwe converge. The vast network of interconnected habitats within the KAZA TFCA ensures the connectivity of populations of migratory species across the landscape. Therefore, various collaborative strategies with partner states have been established for the conservation of targeted wildlife, such as

African wild dogs[4], carnivores[5], elephants[6] and giraffes[7]. Previous projects within the KAZA TFCA also include the Combating Wildlife Project (WWF)[8], which aimed to counter threats to endangered populations of black rhino and African elephant in the KAZA TFCA and Namibia.

Liuwa Plain National Park

The Lungwebungu River borders the Liuwa Plain National Park, which is surrounded by the upper West Zambezi Game Management Area (GMA) (Figure 4). The West Zambezi GMA is the largest in Zambia, covering an area of 38,070 km^2, extending south to Sioma Ngwezi National Park (**Error! Reference source not found.**). The Liuwa Plain National Park has a long history of unsustainable resource use which resulted in significant habitat degradation. However, through effective conservation law enforcement and community land-use plans, the management partnership established in 2003 between African Parks, the Department of National Parks and Wildlife (DNPW), and the Barotse Royal Establishment (BRE) has since restored the park[9].

Figure 4. Areas of conservation importance within the Lungwebungu River Basin.

[4] KAZA TFCA Secretariat, 2014. Conservation Strategy and Action Plan for the African Wild Dog (*Lycaon pictus*) in the Kavango Zambezi Transfrontier Conservation Area, Kasane, Botswana.

[5] KAZA TFCA Secretariat. Carnivore Conservation Strategy 2018-2022.

[6] KAZA TFCA Secretariat. Strategic planning framework for the conservation and management of elephants in the KZA TFCA.

[7] KAZA TFCA Secretariat, 2022. Kavango-Zambezi Transfrontier Conservation Area Giraffe Conservation Strategy 2022–26.

[8] Oglethorpe, J., Russo, V., Neto, J., and Costa, A., 2018. Communities and Biodiversity in Angola: Analysis of the legal and institutional framework for community-based approaches to conservation and natural resource management. WWF US, National Geographic Society, ACADIR and Kissama Foundation.

[9] African Parks. https://www.africanparks.org/the-parks/liuwa-plain

The Liuwa Plain National Park is home to over 12,000 people, leading to the establishment of various programmes aimed at promoting sustainable resource use through community engagement and integration. For instance, the Liuwa Environmental Programme[10] was implemented in several local schools to raise environmental awareness and highlight opportunities for enhanced livelihoods through tourism and conservation. Additionally, the Farmer Field Schools (FFS) programme[11] provides agricultural education, promoting sustainable farming methods among local farmers, used by nearly 5000 farmers. In addition, the Liuwa Plains is one of the focus areas of the WWF Upper Zambezi Landscape Programme[12], which aims to improve ecosystem management at a landscape level through proper planning of water use and safeguarding against unsustainable development.

Liuwa Plain—Mussuma Transfrontier Conservation Area

Within the greater KAZA TFCA is the proposed Liuwa Plains—Mussuma TFCA, which aims to sustainably manage 14,464 km^2 of the catchment area of the upper Zambezi River, including a significant portion of the lower Lungwebungu River Basin (Figure 5**Error! Reference source not found.**)[13]. The Lungwebungu River and its floodplain forms a riparian corridor between Zambia and Angola which supports the transboundary movement of wildlife species, including the second largest migratory population of wildebeest and zebra in Africa. The establishment of the Liuwa Plains—Mussuma TFCA will further strengthen the ecological integrity of the lower Lungwebungu Basin, supporting this annual migration. Moreover, the strengthened connectivity of the ecosystem is likely to ensure the provision of vital ecosystem services to local communities — particularly the Luvale/Lozi, who have an intimate connection to the biodiversity of this region.

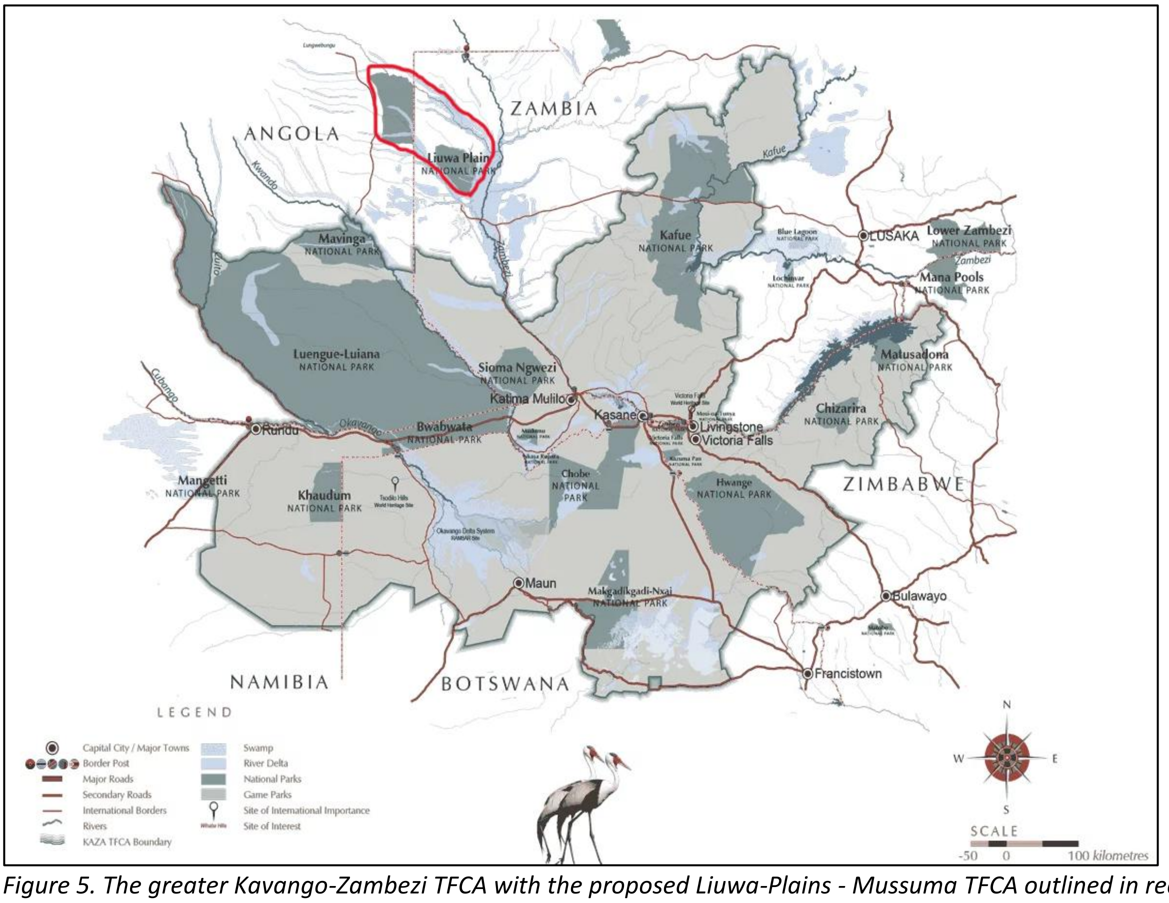


Figure 5. The greater Kavango-Zambezi TFCA with the proposed Liuwa-Plains - Mussuma TFCA outlined in red[14]..

[10] https://www.africanparks.org/the-parks/liuwa-plain/community-development
[11] https://www.africanparks.org/the-parks/liuwa-plain
[12] Upper Zambezi Landscape Fact Sheet. https://www.wwfzm.panda.org/our_news/blog/wwf_zambia_landscapes_fact_sheets/
[13] Kavango Zambezi Transfrontier Conservation Area. 2019. Available: https://www.kavangozambezi.org/about-kaza/.
[14] Kavango Zambezi Transfrontier Conservation Area. 2019. Available: https://www.kavangozambezi.org/about-kaza/.

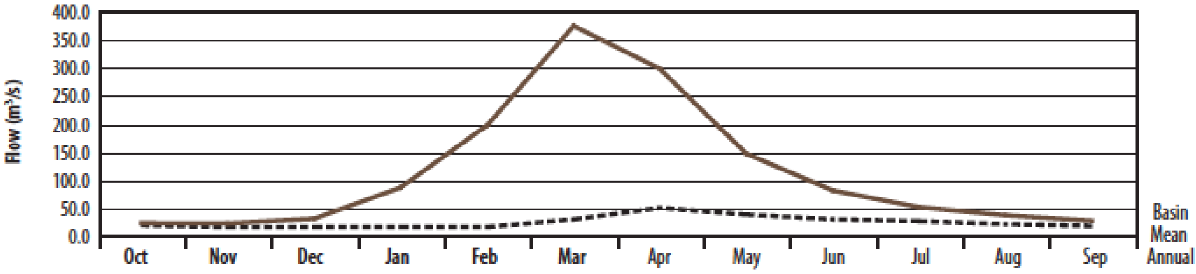
Other initiatives
Various broader-scale programmes have been established in Angola and Zambia. These include The Halo Trust, which aims to remove landmines in the Okavango headwaters to facilitate conservation-led development[15]. Other programmes were established in Angola to improve apiculture and fisheries, and the sustainable use of forest resources[16]. Regional programmes in Zambia include the WWF Upper Zambezi Project which aims to provide key information towards ensuring sustainable resource-use and biodiversity conservation management within the broader landscape[17]. The details of the programmes are summarized in Appendix 2.

Hydrology
The Angolan Highlands Water Tower (AHWT) includes over 42,000 km^2 of the Lungwebungu Basin, ensuring a steady water supply through gradual groundwater flow and highland source lakes[18]. In addition, dambo-dominated headwaters function as a sponge — absorbing water during the wet season (September—April) and releasing it slowly during the dry season (May—August).

Figure 6. The dambo-dominated headwaters of the Lungwebungu River.

In western Zambia, the wet season begins in October, with rainfall peaking in December—January. Following peak rainfall, flooding onset on the Lungwebungu River is generally delayed until February—April by the extensive floodplains. Flows recede steadily during the prolonged dry season reaching an annual minimum in November[19] (Figure 7). Due to its seasonal flooding and accumulation of substantial floodwater buffer, the Lungwebungu River is regarded as a 'reservoir river' since it moderates downstream discharge into the main Zambezi River channel.

[15] https://www.halotrust.org/
[16] Oglethorpe, J., Russo, V., Neto, J., and Costa, A., 2018. Communities and Biodiversity in Angola: Analysis of the legal and institutional framework for community-based approaches to conservation and natural resource management. WWF US, National Geographic Society, ACADIR and Kissama Foundation
[17] https://www.wwfzm.panda.org/our_story/our_impact/upper_zambezi/
[18] Lourenco, M., Woodborne, S., and Fitchett, J.M. 2023. Drought history and vegetation response in the Angolan Highlands. *Theoretical and Applied Climatology*, *151*, 115–131.
[19] Beilfuss, R. 2012. A Risky Climate for Southern African Hydro: assessing hydrological risks and consequences for Zambezi River Basin Dams.
[13] Beilfuss, R. 2012. A Risky Climate for Southern African Hydro: assessing hydrological risks and consequences for Zambezi River Basin Dams.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Basin Mean Annual
Drought	18.7	15.3	15.3	15.3	15.3	28.9	49.3	37.4	28.9	25.5	20.4	17.0	23.9
Average	22.1	21.9	29.9	85.2	196.1	373.4	297.7	145.5	80.3	50.5	35.9	26.6	113.8

Figure 7. Hydrograph for the Lungwebungu sub-basin[20] .

Seasonality of the Lungwebungu River is important to the livelihoods of communities living along the river. When floodwaters recede on the lower Lungwebungu during the dry season, small fishes are flushed into the main river channel. These are easily netted, thereby forming the main animal-based protein source in the dry season. In addition, livestock are grazed on the newly exposed grasslands, which are also cleared to grow seasonal crops, particularly maize. As floodwaters rise again during the wet season, semi-aquatic grasses regrow, concluding an important seasonal cycle that supports both local communities and local biodiversity.

Riparian Habitat

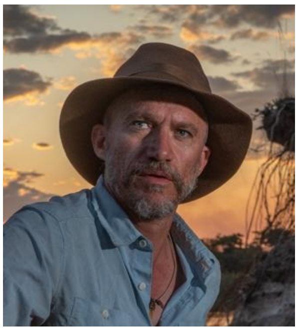
In comparison to the other basins in the upper Zambezi catchment, the Lungwebungu Basin and its surrounding vegetation is particularly understudied, with limited taxonomic exploration. The upper basin is dominated by miombo woodland (*Brachystegia*, *Julbernardia* spp.), interspersed with an extensive network of grassy wetlands and dense gallery forests along major watercourses (Figure 8). Conversely, marginal aquatic grasses, including *Phragmites*, represent the main riparian vegetation along the lower Lungwebungu River, and these grow at varying densities along the riverbanks (Figure 8).

[20] The World Bank, 2010. The Zambezi River Basin: A Multi-Sector Investment Opportunities Analysis, Volume 3, State of the Basin.

Figure 8. The riparian vegetation of the upper Lungwebungu River in Angola (top) and the lower Lungwebungu in Zambia (bottom). Note the marginal vegetation of the river is dominated by Phragmites *reeds, with surrounding vegetation of the upper Lungwebungu primarily consisting of miombo woodland.*

Team Members and Expedition Timing

Table 1. Team members on the Angolan expedition.

 Steve Boyes	 George Butler	 João Cajimbo	 Elias Calueio
 Kerllen Costa	 Claudio Cussomba	 Eduardo Fernando	 Jen Guyton
 Gobonomang Kheto	 Mauro Lourenço	 Gil Luis	 Albertina “Paula” Luneta
 Jesse Manuel	 Glória Mwema	 Götz Neef	 José N’gunga

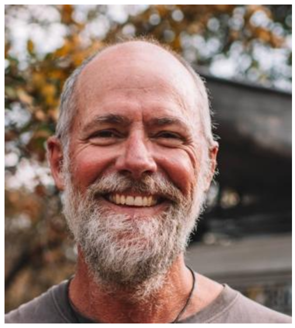
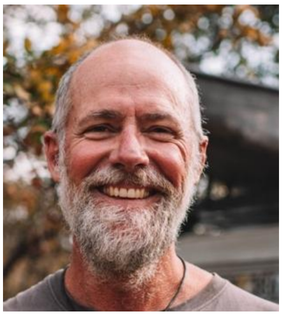
 Josiah Nowake	 Water Stelabosha	 Rob Taylor	 Rainer Von Brandis
 Johan Voster			

Table 2. The team members on the Zambian expedition.

 Joe Cutler	 Nyundu Kuluza	 Stephen Mbewe	 Mutesi Mbundi
 Josiah Nowake	 Nfundisi Nowake	 Rainer Von Brandis	 Oreneile Yeni

Expedition Safety

All possible avenues for medical support and general safety are put into place prior to conducting an expedition. This includes land support vehicles, which follow the river team for resupplies where possible. All team members have full medical cover, and a medical evacuation protocol is established beforehand. Moreover, at least two team members are qualified in advanced medical aid, and TWP provides important access to medical oversight. For on-the-ground emergencies, the expedition team carries full trauma, resuscitation, and medical kits, and emergency communication devices, including satellite phones, spot trackers, and a BGAN satellite internet unit. Finally, at least one team member is always on standby during expeditions to relay messages and liaise directly with the relevant authorities.

Survey Design

The expedition team used fiberglass dugout canoes to survey the Lungwebungu River. These boats were loaded with research and camping equipment that was strategically packed into the middle of the boat, leaving just enough space for a person on either end. Dugout canoes have an extremely shallow draft, allowing the teams to paddle over shallow waters (Figure 9). Expedition teams covered ~30 km per day depending on river flow, obstructions, and weather.

Figure 9. Expedition team members in their dugout canoes.

During the transect, observational survey data and a 360° video were collected continually, with other data at fixed points (Table 3, Figure 10). Survey data included sightings of human activity, agriculture, infrastructure, biodiversity, and fire. In addition, every ~10 km, water quality was analysed, and aerial fixed-point images were recorded. At 50—75 km intervals, eDNA samples were collected and a benthic macroinvertebrate survey was conducted. To further sample for biodiversity along the river, an acoustic bat recorder and several aquatic traps were deployed overnight. Finally, where suitable sites were identified, fish sampling using a dip net and discharge measurements using an acoustic doppler current profiler (ADCP) were conducted.

Table 3. Summary of data collection during the expeditions.

Data Collection Frequency	Data Category
Continuous	• GPS track • 360° video • Observational survey forms relating to human activity, agriculture, infrastructure, biodiversity and fires

Every 10 km	• Water quality • Fixed point aerial drone surveys
Every ~50–75 km	• Zambian Invertebrate Scoring System (ZISS) sampling • Environmental DNA (eDNA) sampling
Every Night	• Acoustic bat recording • Trap and net deployments for fish and invasive crayfish
Opportunistic	• Dip-net fish sampling • Discharge measurement

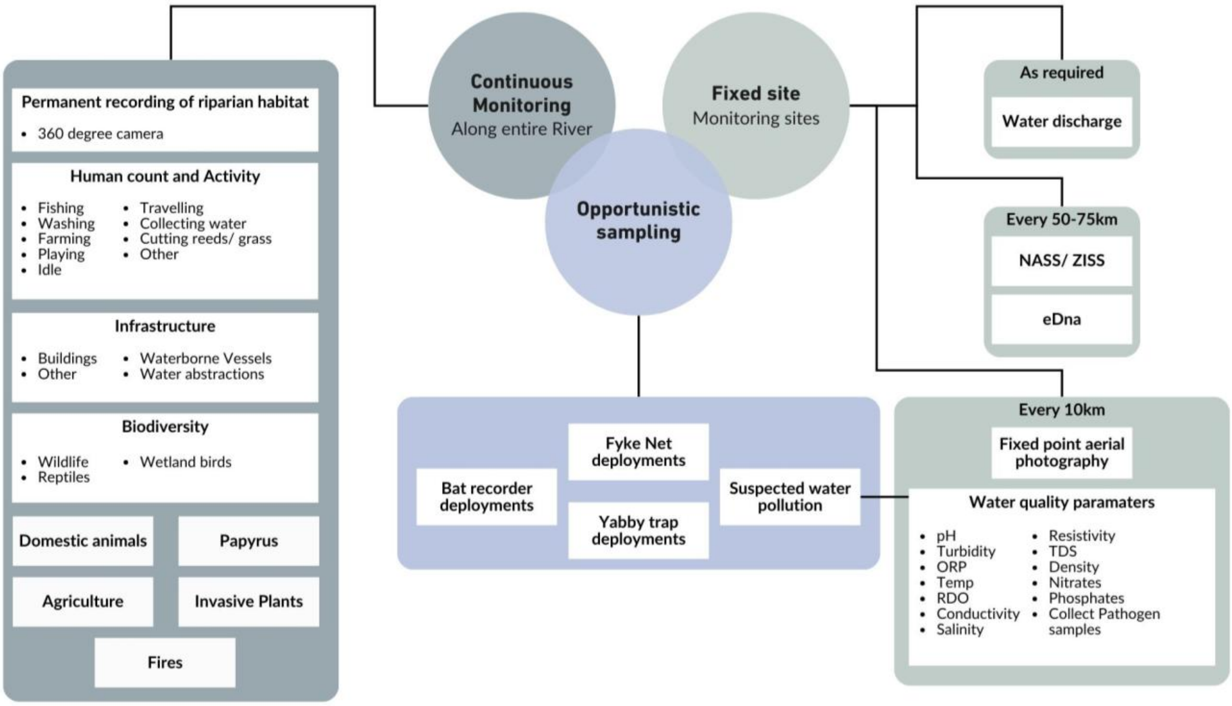


Figure 10. Summary of the data collected on the river.

Survey Limitations and Potential Data Bias

It is important to note that there are several limitations and potential biases involved with data collection on rivers. These may limit the statistical confidence of data analysis and must be considered when interpreting data. The limitations and biases in the data require due consideration when making management decisions and undertaking scientific analyses. Survey limitations and potential biases for the Lungwebungu River transect include:

- Most of the expedition followed the main river channel, and as a result, oxbow lakes and backwaters were excluded from the survey.
- Observers only counted what was visible from their vessels.
- Vegetation density and riverbank height, prevailing weather, team health, rapids, sharp corners in the river, sand banks and other uncontrollable variables may have obscured observations or introduced observer bias.
- Survey time was typically restricted to daylight hours (between 08h30–18h00), however some survey-days were longer or shorter than others.
- Wildlife needed to be large enough to identify by sight from the river. As a result, the wildlife survey does not include smaller species of rodents, amphibians, reptiles and insects.

- The expedition along the Lungwebungu in Zambia was conducted during the wet season when the floodplains are inundated, likely resulting in survey data underestimations, including *inter alia*: fires, wildlife, abundance and diversity, and human activity.
- The presence or absence of people along rivers is influenced by the time of day, as people may spend more time by the river in the mornings and evenings when collecting water, bathing or washing clothes. In addition, there is generally more human activity along rivers on weekends. As a result, human activity densities should be combined with other census information to ensure that they are representative of the current-day population of people along the river.
- The expeditions were conducted over a period of nine days in Zambia, and over 34 days in Angola. As a result, they do not represent the permanent state of the river. Rather, they offer a comprehensive snapshot of the river to which future data can be compared.
- The expedition was conducted in different seasons — specifically, during the dry season in Angola and the wet in season in Zambia. Thus, we expect some seasonal differences in land-use and biodiversity along the river.

1.2 CONTINUOUS MONITORING

The process of collecting survey data on the transect involved two parties: the observer and the recorder (Figure 11). The observers sat at the back of the dugout canoe and visually scanned the river and its banks for relevant observations within 100 m from the water's edge. Sightings of relevance were then relayed to the recorders who used a smartphone to input the data into Survey123 (ESRI). Information obtained for each sighting included the count, the side of the river, and other important notes. From Suvery123, data were uploaded to a cloud database for safekeeping. Survey123 forms were created beforehand and set to
automatically assign geolocation, date, and time for each entry.

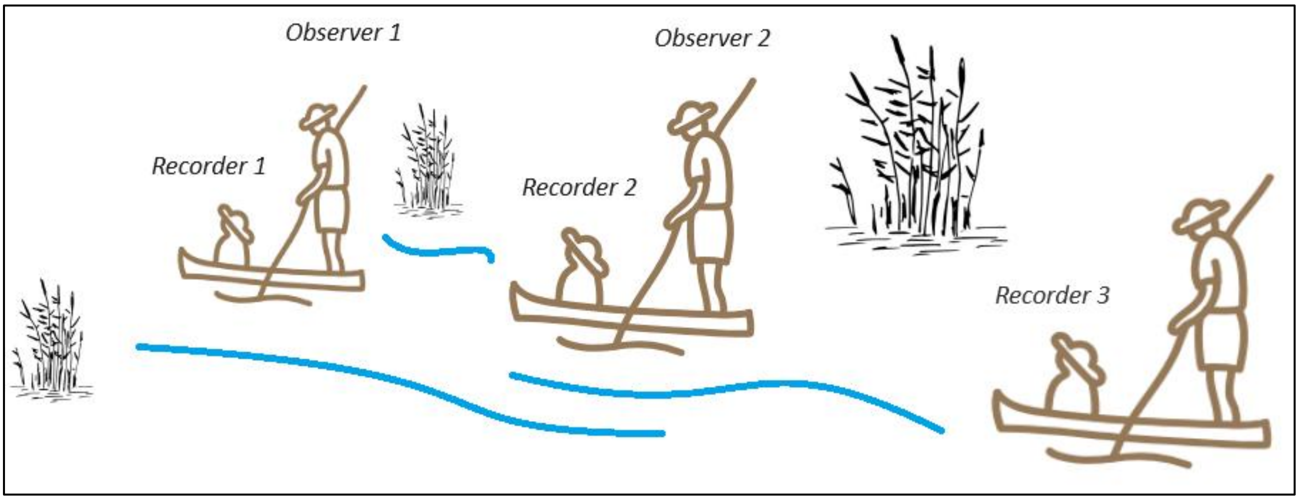


Figure 11. The distribution of observers and recorders within the survey team. Note that observers were seated, not standing, on the Lungwebungu River transect.

Human Activity

Methods: Human Counts and Activity

The presence or absence of people along the Lungwebungu River provides an indication of river-use that can be used to determine levels of anthropogenic disturbance — particularly when combined with satellite analyses of cropland, fire and building extent. In addition, human activities can provide important socio-economic insights about how people engage with the Lungwebungu River. To this end, all people active within the riparian zone of the river were counted, independent of their age, sex or ethnicity. Going forward, long-term monitoring of the number of people interacting with the river is recommended to provide an indication of the trajectory of general river health. Activities documented on the Lungwebungu River were categorized and recorded as follows:

- **Inactive:** People who were present within the river's riparian zone but were not actively engaged in any of the below activities.
- **Travelling**: People travelling on foot, by motorbike or in a waterborne vessel. For this analysis, all parked watercrafts, including dugout canoes, fiberglass canoes, motorised boats, barges, and other vessels, were included in the count.
- **Washing:** People in the process of washing their bodies, clothes or domestic items.
- **Fishing:** People fishing with nets, traps, hooks and lines or other means were counted. In addition, those involved in the cleaning or repairing of fishing nets were included. For the purposes of this analysis, all unmanned but deployed equipment is also discussed.
- **Swimming**: People in the water who were not bathing or washing their clothes.
- **Farming:** People tilling, sowing, harvesting, watering, building enclosures around their farms or other agriculture-related activity.
- **Collecting water:** Only people collecting water by hand were counted. Any use of pumps was counted as an abstraction (see infrastructure section below).
- **Collecting firewood:** People who were collecting dry fuelwood.
- **Construction:** Those involved in building temporary or permanent structures.
- **Other:** Evidence of other human activities was recorded, including evidence of mining, beekeeping and hunting.

Results and Discussion: Human Counts and Activity

A total of 358 people were present within the riparian zone of the Lungwebungu River, equivalent to a density of 0.3 people/km (Table 4). This is low compared to other rivers in the region, including the Zambezi River (5.46 people/km). Moreover, the density of people along the Lungwebungu River was higher in Zambia (0.7 people/km, N=198) than in Angola (0.2 people/km, N=160), likely attributed to the higher number of human settlements on the river in Zambia compared to Angola (see Infrastructure below).

Table 4. Summary of the human activity on the Lungwebungu River.

Activity	Number of People
Inactive	144
Travelling	92
Washing	72
Fishing	19
Swimming	8
Farming	6
Collecting water	3
Collecting firewood	7
Construction	2
Other	5
TOTAL	**358**

Most people were inactive (N=144), travelling (N=92) or washing (N=72) (Table 4). Generally, people were distributed in small groups along the river, often in proximity to seasonal fishing camps or other infrastructure (Figure 12). In addition, the highest density of people was near the border of the proposed Liuwa Plain—Mussuma National Park TFCA and near the confluence of the Zambezi River.

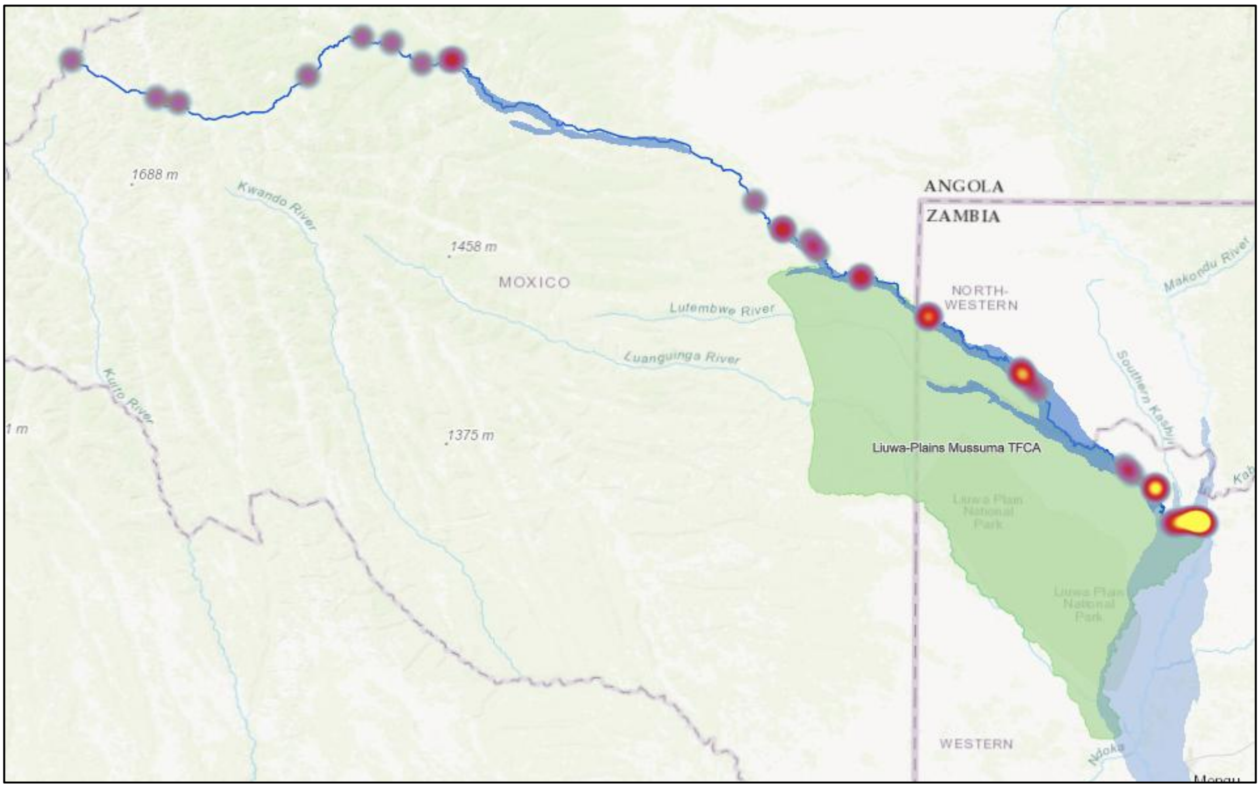


Figure 12. The distribution of people along the river with hotspots near the proposed Liuwa Plains-Mussuma TFCA and at the confluence with the Zambezi River.

Travel

A total of 92 people were travelling along the Lungwebungu River (Figure 13). In Zambia most dugout canoes were concentrated at the confluence with the Zambezi River in the northern reaches of the Barotse Floodplain. People were also seen travelling using other vessels, such as motorbikes and fiberglass boats.

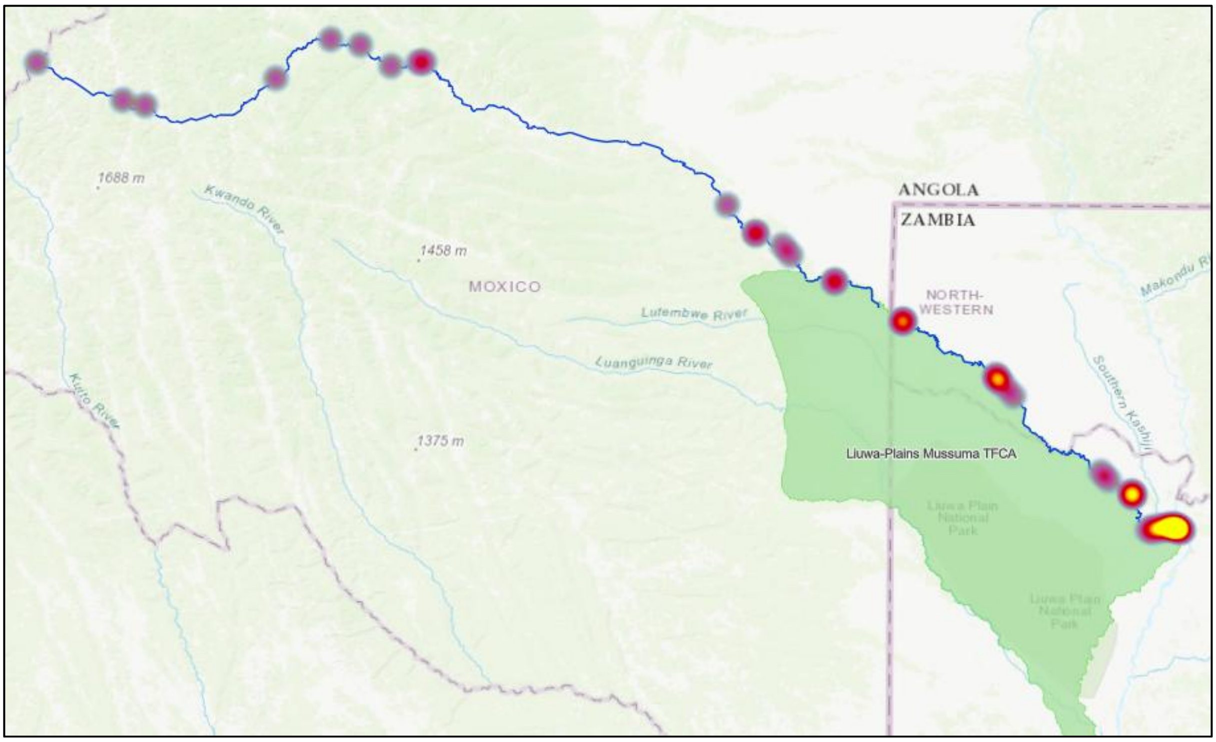


Figure 13. The distribution of people travelling on the river.

The predominant mode of transport was the wooden dugout canoe (N=42), followed by foot (N=24) and motorized boat (N=17) (Table 5). More people were travelling by dugout canoe in Zambia (0.1 people/km, N=33) compared to Angola (0.01 people/km, N=9) (Figure 14).

Table 5. Summary of modes of travel.

Mode of transport	Country	Number of people
Dugout canoe	Angola	9
	Zambia	33
	Sub-total	42
Foot	Angola	18
	Zambia	6
	Sub-total	24
Motorised boat	Angola	6
	Zambia	11
	Sub-total	17
Motorbike	Angola	6
	Sub-total	6
Other paddle vessel	Angola	3
	Sub-total	3
Total		**92**

Figure 14. A person travelling by dugout canoe on the Lungwebungu River in Zambia.

A total of 139 vessels were parked along the riverbanks, 89% of which were dugout canoes (Table 6). The majority of the dugout canoes were constructed with bark (N=86) rather than wood (N=29). This is rare in Africa, as wood is generally considered to be stronger than bark for canoe construction. However, bark canoes are light and mobile, potentially offering an ease of navigation (**Error! Reference source not found.**).

Table 6. Summary of in-use and parked vessels.

Type of Vessel	Usage	Count
Dugout canoe	In use	38
	Parked	123
	Sub-total	161
Motorised vessel	In use	3
	Parked	9
	Sub-total	12
Barge	Parked	1
	Sub-total	1
Other	In use	1
	Parked	6
	Sub-total	7
All	In use	42
	Parked	139
TOTAL		181

Figure 15. A local man travelling on a bark dugout canoe on the Lungwebungu River in Angola.

Vessels were mainly concentrated in the upper reaches of the river, near the proposed Liuwa Plains–Mussuma TFCA and the northern reaches of the Barotse Floodplain at the Lungwebungu–Zambezi River confluence (Figure 16). These areas correspond to infrastructure along the river, such as seasonal fishing camps and human settlements (see Infrastructure below).

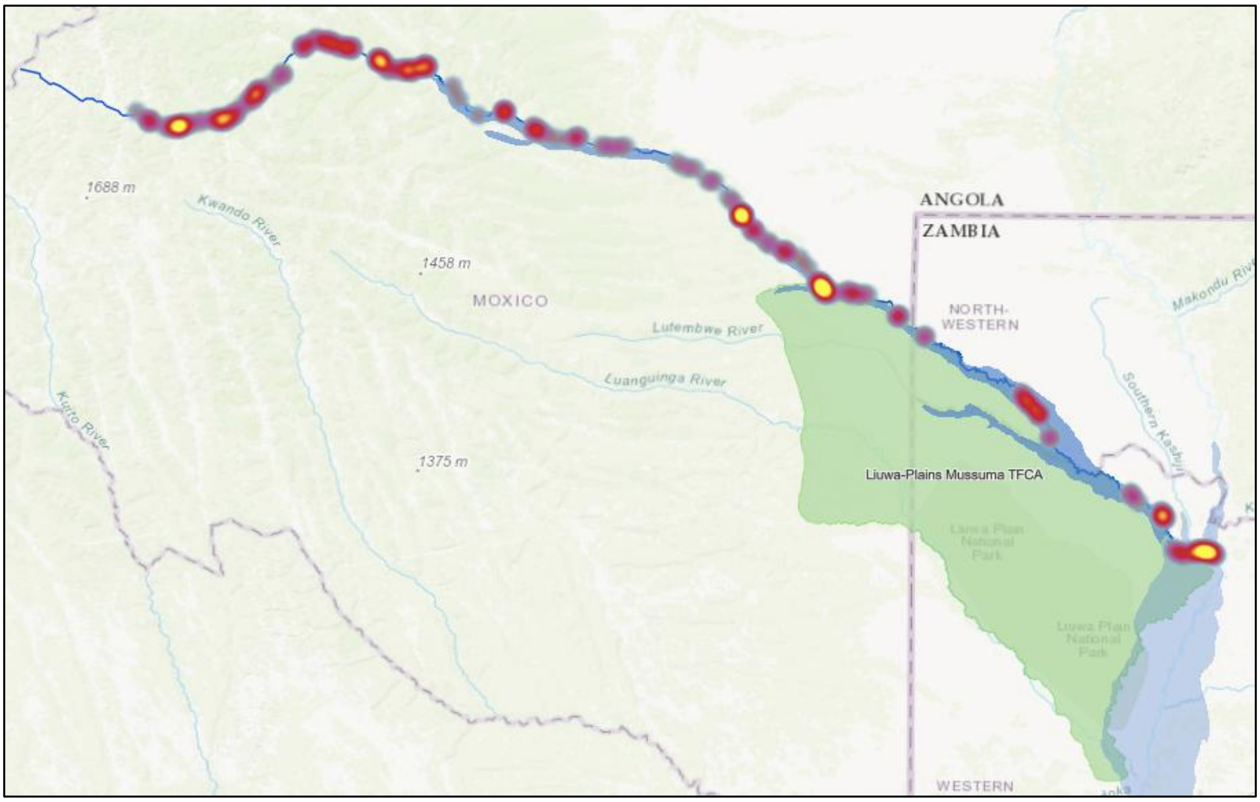


Figure 16. All vessels counted along the Lungwebungu River.

Motorised boats, approximately three to four times the size of a conventional canoe, were present on the river (Figure 17). Designed to travel long distances, these boats are mainly used for transporting people and goods over extended distances.. The Lungwebungu River is used as a major trade route between Angola and Zambia, used to transport agrochemicals and food to Angola and diesel to Zambia.

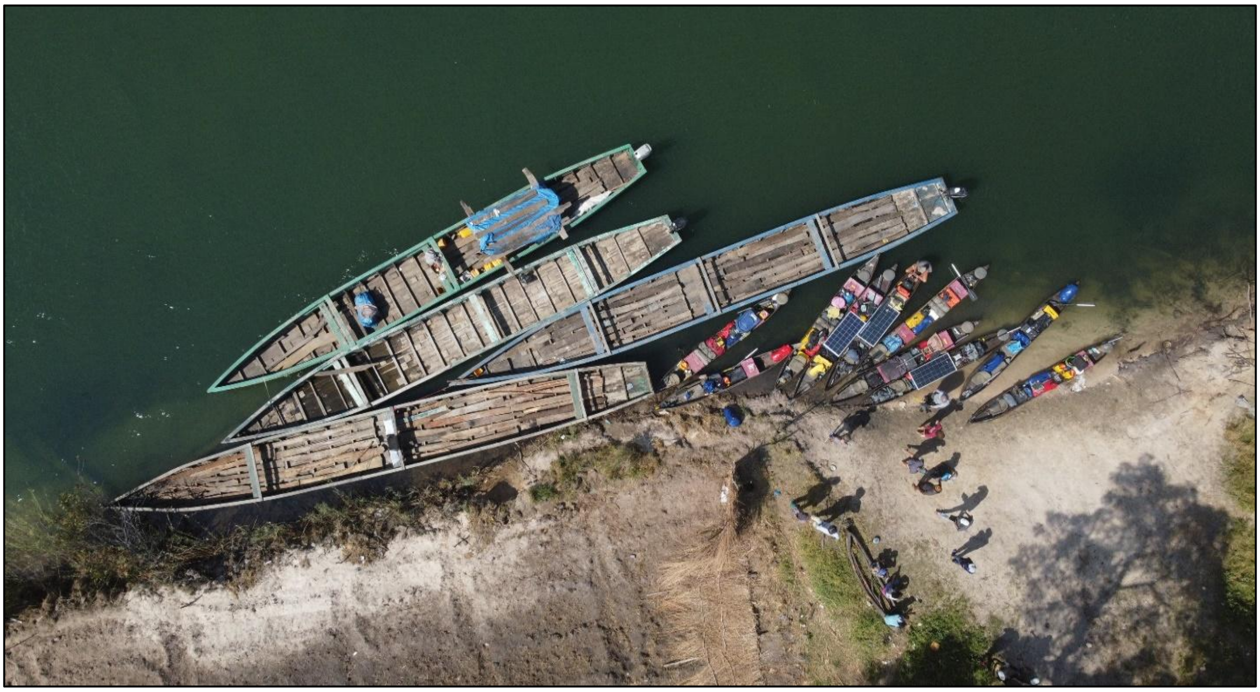


Figure 17. Motorised wooden longboats on the Lungwebungu River. These were typically 3–4x the size of a conventional dugout canoe and were predominantly used for transporting goods.

Washing

A total of 72 people were washing their bodies or clothes along the Lungwebungu River. This is equivalent to a density of 0.07 people/km. Bathing areas can be important sources of potential point pollution and can negatively impact river health by altering the water chemistry of the river by increasing pH and decreasing dissolved oxygen, consequently impacting the aquatic biodiversity of the river. However, current levels of washing activity are unlikely to introduce pollutants at sufficiently high volumes to reduce water quality. Additionally, the water quality results did not indicate any changes near areas where washing occurred. See Appendix 3 for the distribution of people washing along the river.

Fishing

Fishing is an important livelihood activity for local communities along the Lungwebungu River, serving as a primary source of animal protein and income. Fishing activity is highly seasonal in the river's lower reaches, as the annual flooding cycle dictates the availability and abundance of fish. Fish are generally harvested using gillnets, lines and traps. Fish are dried and salted along the riverbank (Figure 18), and once preserved, the fish are transported to local markets, providing a vital source of income for locals.

Figure 18. Fish are dried and salted on wooden rocks along the riverbank.

Only 19 people were fishing along the Lungwebungu River — equivalent to 0.02 fishers/km. This was low compared to the Zambezi River, where fishing activity was 0.28 fishers/km between Chavuma and Sioma. Interestingly, the density of fishers was higher in Zambia (0.05 fishers/ km, N = 14) than in Angola (0.007 fishers/ km , N = 5). Hotspots of fishing activity were located across the river, with fishing particularly common at the Lungwebungu–Zambezi River confluence at the northern reaches of the Barotse Floodplain (Figure 19). These hotspots correspond to human settlements along the river, with settlements mainly located around the EN180 road bridge and the Lungwebungu–Zambezi River confluence.

Figure 19. The distribution of people fishing on the Lungwebungu River. Most fishing activities were concentrated near the Zambezi River.

Fishing gear is generally present within the riparian zone throughout the day — either deployed, in-use or along the banks of the river — even when people are not actively fishing. The count and distribution of fishing gear indicates the intensity of fishing pressure and allows for the identification of overfishing. By monitoring fishing gear, we can better understand the impact on fish populations and other wildlife, as well as the potential for gear loss, which can lead to ghost fishing and environmental degradation.

Gillnets were the most common fishing gear, followed by lines and traps (Table 7). Gillnets were more frequently used in Angola (N=60) compared to Zambia (N=7). In Angola, the survey was conducted during the dry season when water levels were low, making gillnets particularly effective for catching fish concentrated in residual pools or in the main river channel. A dry season survey of the lower reaches of the Lungwebungu River is necessary to determine the full extent of fishing activity along the river.

Table 7. Summary of unmanned and deployed fishing gear.

Type of gear	Count
Nets	67
Lines	9
Fish traps	8
TOTAL	84

Most gillnets were deployed at the northern border of the proposed Mussuma National Park in Angola, and at the confluence of the Zambezi River in Zambia (Figure 20). The higher incidence of gillnets at the northern border of the proposed Mussuma National Park correspond closely with the higher levels of fishing activity and villages in the area.

Figure 20. Gillnets deployed along the Lungwebungu River.

Fish traps were only present in Angola (N=8), predominantly located in the upper reaches of the river (Figure 21). Traditional fish traps and lines were far less common than gillnets, suggesting that these methods are not preferred. Fish funnel traps (Figure 22) need to be strategically placed in shallow areas of the river. As a result, most fish traps were distributed in the upper reaches of the Lungwebungu River.

Figure 21. Fish traps along the Lungwebungu River. Note that fish traps were only located in Angola.

Figure 22. A traditional fish trap.

Diamond Mining

Angola is one of the largest producers of diamonds in Africa and there is considerable investment in the country's commercial diamond mining industry. However, artisanal and small-scale mining (ASM) receives comparatively little attention. Older data from 2016 indicate that ~900,000 people depend on the ASM industry in Angola for their livelihoods[21]. Given the limited regulation of ASM operations in the country, large sections of the ASM industry are unchecked, resulting in negative impacts on surrounding ecosystems. This is particularly concerning when mining occurs in proximity to river sources, where pollution, sedimentation and channel disturbance can have significant downstream impacts (Figure 23).

Four artisanal and small-scale diamond mines were present along the Lungwebungu River in Angola (Figure 24). The largest of these mines was located at the source of the river, where hundreds of holes were excavated along ~ 1 km of the river bank (Figure 22). It is important to note that it is easier to find diamonds during the dry season when water levels are lower[22]. In future, artisanal and small-scale diamond mining on the Lungwebungu River should be monitored to avoid potential negative impacts of the river, especially near its source which can lead to pollution downstream of the river.

[21] Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF). 2017. Global Trends in Artisanal and Small-Scale Mining (ASM): A review of key numbers and issues. Winnipeg: IISD.

[22] Brown, E.K.A., and Kimani, E., 2019. Artisanal and small-scaling mining: the paradox of extraction. *African Center for Economic Transformation.*

Figure 23. *Unregulated diamond mining near the source of the Lungwebungu River.*

Figure 24. Artisanal and small-scale diamond mines. Note that mines were only present in Angola.

Beekeeping

There were 16 apiaries along the Lungwebungu River, all of which were in Angola. Apiaries were mainly located at the source of the river (Figure 25). Honey production is not only used for subsistence but also as a source of income for local communities. It is one of the 'green' products that could help in diversifying exports in Angola, as it has the potential of producing more than 200 tonnes per year, a significant increase from the current ~90 tonnes per year[23]. In addition to its economic potential, honey production is also beneficial for local communities — as food but also as a source of income.

Traditionally, beehives are created using tree bark that is inserted into trees, making it difficult for bee

[23] UNCTAD. 2023. Angola: empowering women through honey. Available at: https://unctad.org/news/angola-empowering-women-through-honey

farmers to climb them to monitor the hives. Additionally, when honey is harvested from these hives they have to be dismantled. Therefore, with the introduction of more modern hives —in programs such as the National Program for Apiculture[24] and Okavango Eternal[25]— the goal is to produce more higher quality honey that will be easier to harvested, including for possible international export, which will provide a valuable source of income for local communities.

Figure 25. Distribution of apiaries along the Lungwebungu River. Note that apiaries were only found in Angola.

Hunting

In Angola, bushmeat is readily available in city markets, road stalls and directly from local hunters. The bushmeat trade has a long history in the country. However, changing socio-economic settings and increasing demographic pressure have made the trade increasingly unsustainable. This has resulted in declining biodiversity and raised several unresolved health concerns, particularly the spread of novel pathogens[26].

Despite concerns surrounding the sustainability of the bushmeat trade, hunting for bushmeat provides an important source of protein and income for communities living along the banks of the Lungwebungu River. Five people were engaged in hunting activities. In one case, a group of four people were transporting four recently killed duiker[27] by motorbike. It is likely that these antelope were being transported to markets in Luena, where they can fetch anywhere from US$ 10—150 depending on their size and species[28]. In addition, there was a crocodile trap along the river in Angola, with a crocodile carcass found on the side of the river (Figure 26). Although not common in the bushmeat trade, crocodiles products, such as their skin or handbags are sold in markets[29].Crocodiles may also be attracted to fish caught in gill nets, resulting in their drowning or killing when the nets are retrieved[30].

[24] Ogelothorpe, J., Russo, V., Neto, J., and Costa, A., 2018. Communities and Biodiversity in Angola: Analysis of the legal and institutional framework for community-based approaches to conservation and natural resource management. WWF US, National Geographic Societym ACADIR and Kissama Foundation.

[25] https://www.nationalgeographic.com/environment/article/paid-content-okavango-eternal-year-one

[26] Teutloff, N. et al. 2021. Hunting techniques and their harvest as indicators of mammal diversity and threat in Northern Angola. *European Journal of Wildlife Research*.

[27] Duikers are several species of small antelopes that are native to sub-Saharan Africa.

[28] Teutloff, N. et al. 2021. Hunting techniques and their harvest as indicators of mammal diversity and threat in Northern Angola. *European Journal of Wildlife Research*.

[29] Bersacola, E., Svensson, M.S., Bearder, S.K., and Mills, M., 2014. Hunted in Angola: surveying the bushmeat trade. www.eawildlife.org

[30] Combrink, X., Lippai, C., and Fergusson, R.A., 2019. Nile Crocodile *Crocodylus niloticus*. In Manolis, S.C., and Stevenson, C. (eds.) *Crocodiles. Status Survey and Conservation Action Plan,4*, pp. 28.

Figure 26. A crocodile carcass found along the banks of the Lungwebungu River in Angola.

Infrastructure

Methods: Infrastructure

The type, quantity and distribution of infrastructure along a river provides insights about the level of development in the riparian zone. In addition, infrastructure development can indicate the usage of river resources, particularly water, by surrounding communities. Infrastructure, both within the river and along its banks, was categorized and recorded as follows:

- **Seasonal camps:** These were temporary structures made from thatch, fronds and wood that were often constructed below the high-water mark of the river.
- **Huts:** These were single/pairs of buildings that were built to last throughout the year.
- **Water abstractions:** The pipe circumference and location of each water abstraction was recorded.
- **Bridges:** These were locations where structures were built across the river to aide travel.
- **Other:** Other infrastructure was recorded, including man-made canals, cell-phone towers and gauging stations.

Results and Discussion: Infrastructure

In Angola, infrastructure was concentrated in the upper and middle reaches of the river, particularly near the proposed Mussuma National Park. In Zambia, infrastructure was concentrated at the confluence with the Zambezi River (Figure 27). These hotspots correspond to human activity along the river, such as fishing activity.

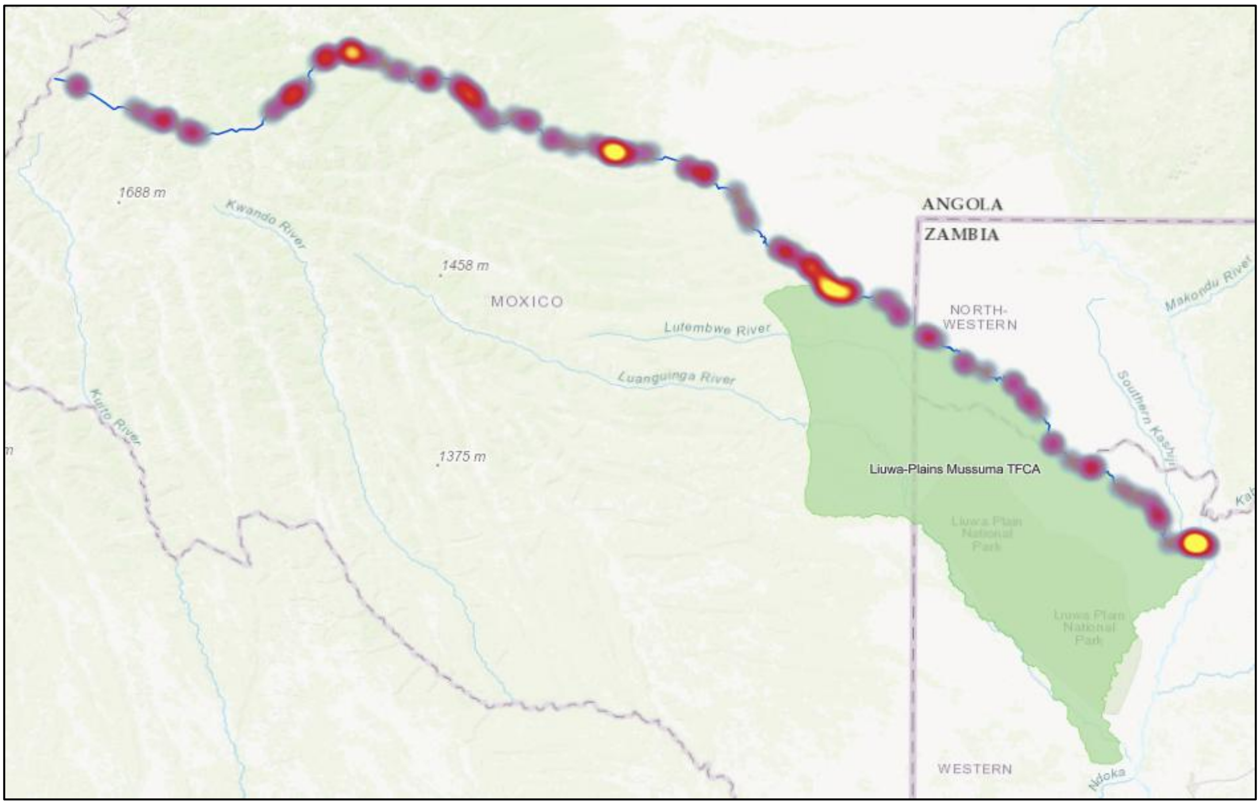


Figure 27. The distribution of infrastructure (excluding villages) along the Lungwebungu River.

The most common type of infrastructure on the Lungwebungu River was seasonal camps (N=71) (Table 8). Other infrastructure included water abstractions, bridges, cell-phone towers, a gauging station and a man-made canal. The canal was more than 1 km long, but it was not visibly connected to agricultural land and its use remained unclear. Moreover, all bridges were in Angola, where there is no extensive floodplain.

Table 8. The type and count of infrastructure on the Lungwebungu River.

Type of Infrastructure	Count
Seasonal camps	71
Huts	25
Water abstractions	5
Bridges	10
Cell-phone tower	4
Man-made canal	1
TOTAL	117

Seasonal camps

Seasonal camps are distributed across the Lungwebungu River (Figure 28), at an average density of 0.06 camps/km. The camp density between Angola (0.07 camps/km) and Zambia (0.04 camps/km) is not considerably different. Seasonal camps are easily distinguished from permanent residences by their construction style (Figure 29Figure 29). In addition, seasonal camps are generally used to access fishing and hunting grounds that are further from established settlements, or to monitor crops and livestock. . Importantly, seasonal camps do not indicate permanent settlement along the river — for more information in this regard, see the Google Open Buildings Analysis below.

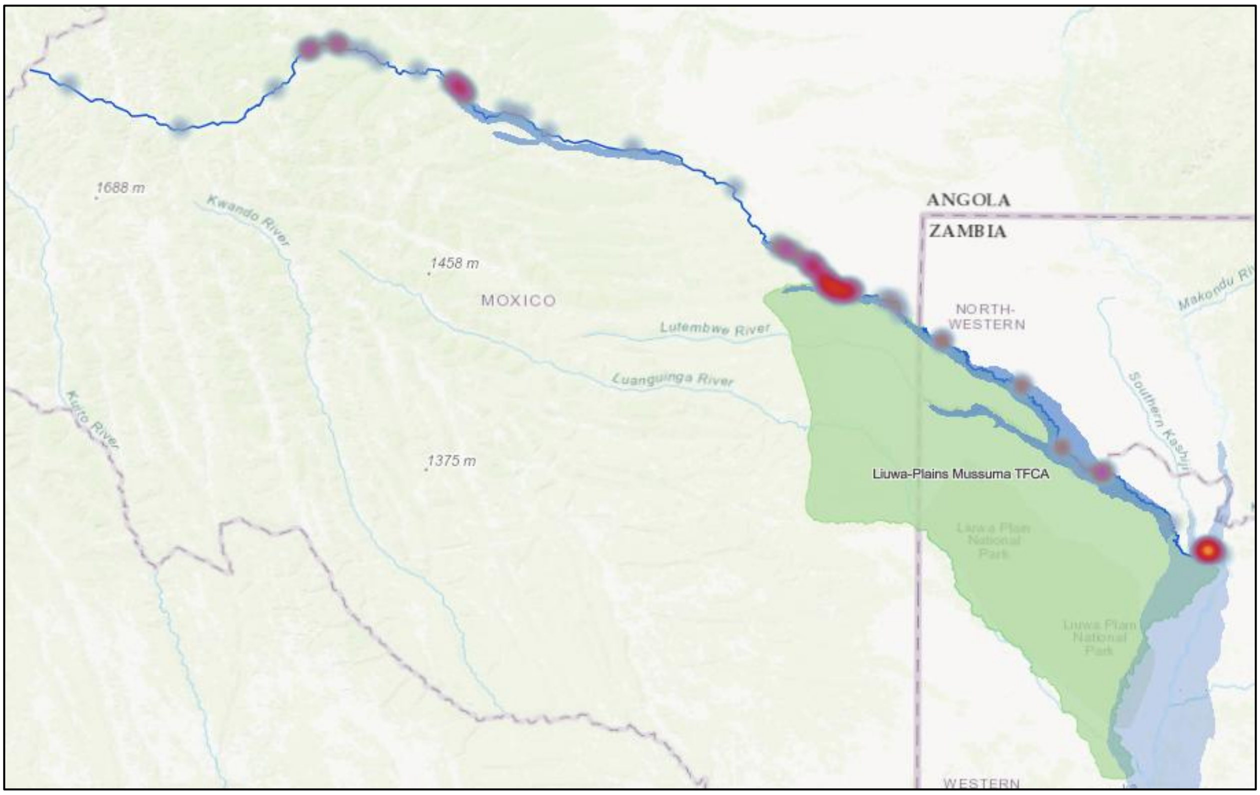


Figure 28. The distribution of seasonal camps along the Lungwebungu River.

Figure 29. Seasonal camp (top) and seasonal fishing camp (bottom) observed in Angola and Zambia, respectively. The building materials used (i.e., reeds) for the seasonal camps indicate they are temporary residences.

Human settlements

Human settlements were located across the Lungwebungu River. These settlements primarily consist of residential clusters and crop farms (Figure 30). Settlements were predominantly located in Zambia (Figure 31), explaining the higher population density in Zambia compared to Angola. However, the overall building footprint in Zambia remains low (see Google Buildings RS Analysis below). There are few settlements in Angola, with the largest settlement situated around the EN180 road bridge (Figure 31), which also has extensive cassava production. Human activity along the river, such as fishing or travelling, correspond to the settlements along the river.

Figure 30. Human settlements on the Lungwebungu River in Zambia (top) and Angola (bottom).

Figure 31. Human settlements on the Lungwebungu River.

Water abstractions

There were only five water abstractions on the river, all of which were in Angola (Figure 32). One of the water abstractions was for commercial use but was not currently pumping. The only abstraction actively pumping was a water truck. The purpose of the other abstractions was unclear. However, given their 28 mm pipe diameters and the prevalence of agriculture in the immediate vicinity, it is likely that they were used for crop irrigation. In contrast, there were no abstractions in Zambia. The absence of water abstractions could be attributed to their use by farmers in the dry season when agricultural activities are concentrated on the floodplains in the river. Therefore, follow-up expeditions should be conducted during different seasons.

Figure 32. Water abstractions on the Lungwebungu River.

Bridges

Ten bridges were present on the Lungwebungu River in Angola — all capable of holding cars and trucks (Figure 33). Six bridges were inactive, most of which were likely to have been destroyed using explosives — a legacy of the damage caused by the Angolan Civil War (Figure 34). The bridges were predominantly made of wood (N = 6) and metal (N = 4). The absence of bridges in Zambia can be attributed to the extensive floodplains that make bridge construction difficult and costly.

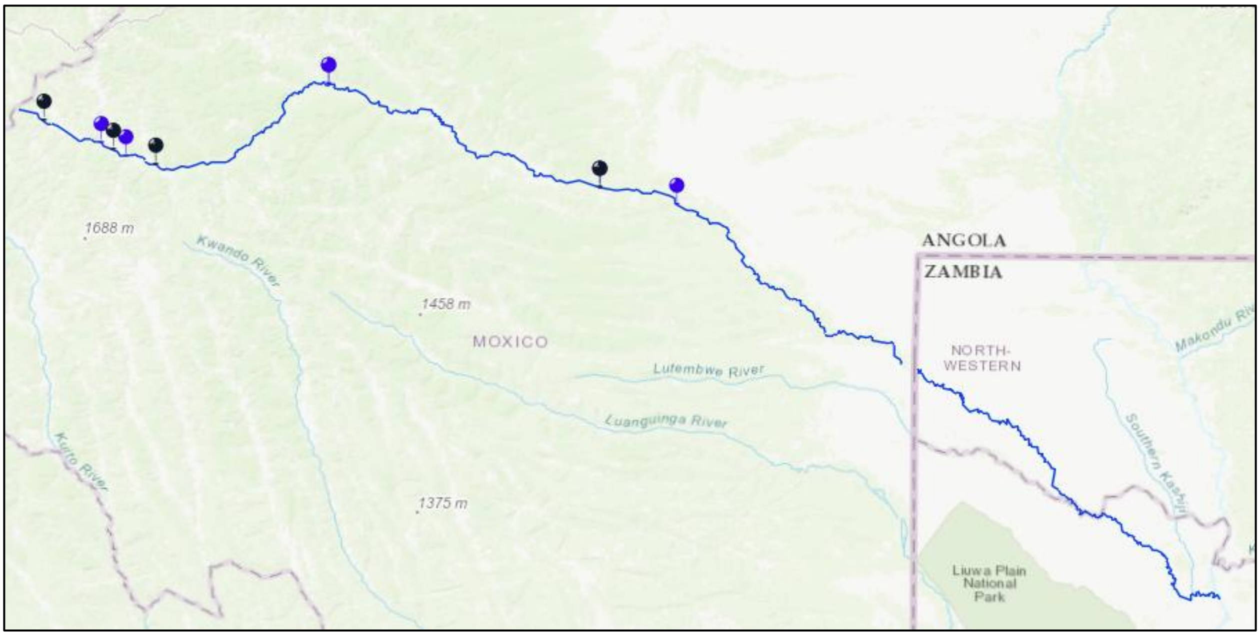


Figure 33. Bridges located along the Lungwebungu River, showing active (black) and inactive bridges (blue) in Angola.

Figure 34. An inactive bridge (left) and the EN180 road bridge shown from different angles.

Agriculture

Methods: Agriculture

All agricultural activity along the river was recorded, including the scale of the activity and the side of the river on which it was taking place. When recording livestock, animal numbers were estimated. For crops, the distance along the riverbank was estimated, and farms were categorised as commercial-scale or subsistence-scale based on the size of the plots (Figure 35). It was assumed that farmers of large agricultural plots were selling their produce, and as a result these were categorised as commercial farms.

Figure 35. A commercial-scale farm in Angola (top) and subsistence-scale farm on the banks of the river in Zambia — note there is no farmer residence present.

Results and Discussion: Agriculture

Crops

Subsistence farming is the predominant type of agriculture on the river. These farms cover a relatively small area of the river — ~2% (Table 9). This is lower than other rivers in the region, such as the Chambeshi, where crop cover is as high as 8%. In Zambia, crop cover is significantly greater than Angola (~20km compared to just ~4 km) — most of which is concentrated at the confluence with the Zambezi River

Table 9. Crop production on the Lungwebungu River.

Crop type	Farm type	Distance Along River Edge (m)
Maize	Subsistence	12,210
	Commercial	1,800
	Sub-total	14,010
Cassava	Subsistence	6,110
	Commercial	3,150
	Sub-total	9,260
Banana	Subsistence	930
	Sub-total	930
Sugar-cane	Subsistence	200
	Sub-total	200
All crops	Subsistence	19,450
	Commercial	4,950
TOTAL		**24, 400**

Given that that Lungwebungu River in Zambia spans 270 km, a significant portion of the river supports crop production (Figure 36). Although agriculture in Zambia is more extensive, it occupies only 2.3% of the landscape area of the Lungwebungu Basin (see LULC analysis below). Additionally, the total cropland area within the buffer zone (within 4 km of the river) is minimal, accounting for just 0.002% (see WorldCereal Cropland Analysis below).

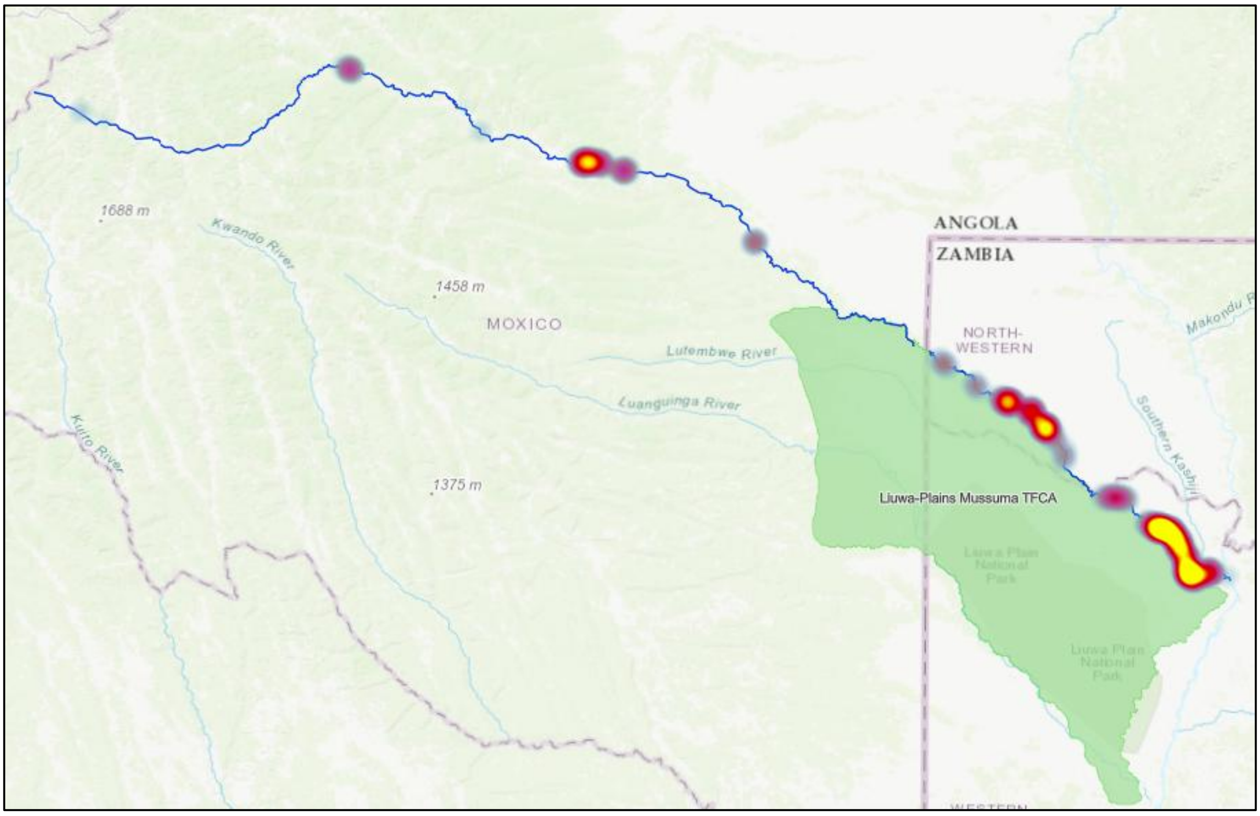


Figure 36. The crop cover along the Lungwebungu River.

Maize is the most abundant crop produced in Zambia, followed by cassava and bananas (Cassava is the main crop produced along the Lungwebungu River in Angola. Cassava comprises 40% of the country's total crop production, with 9.6 million metric tonnes produced in 2019/2020. Cassava is easy to grow and is tolerant to harsh weather conditions, such as high temperatures and drought.

Table 10). Most of Zambia's grain production is from low-yield smallholder farms, with maize as the primary crop produced in the country[31]. The Zambian government supports and subsidises maize production to ensure a steady income for subsistence farmers, who can make a reliable profit from the crop. These subsidies are particularly vital during periods of drought, helping farmers sustain their livelihoods by offsetting losses and supporting minimal crop yields despite adverse weather conditions.

Cassava is the main crop produced along the Lungwebungu River in Angola. Cassava comprises 40% of the country's total crop production, with 9.6 million metric tonnes produced in 2019/2020[32]. Cassava is easy to grow and is tolerant to harsh weather conditions, such as high temperatures and drought[33].

Table 10. Crop production on the Lungwebungu River in Angola and Zambia.

Crop type	Country	Distance along river edge (m)
Maize	Angola	500
	Zambia	13,510
	Sub-total	14,010
Cassava	Angola	3,810
	Zambia	5,450
	Sub-total	9,260
Banana	Angola	80
	Zambia	850
	Sub-total	930
Sugar-cane	Angola	50
	Zambia	150
	Sub-total	200
All crops	Angola	4,440
	Zambia	19,960
TOTAL		**24,400**

In addition to staple crops, fruit trees were counted in the survey. These included mangoes, banana and lemon — all of which are present along the Lungwebungu River. Banana trees are found in both Angola (N = 3) and Zambia (N = 21), whereas lemon and mango trees, are only present in Zambia. Mangoes are the most common fruit tree in Zambia (N = 406).

Crop production and climate change along the Lungwebungu River

Annual rainfall in the areas surrounding the Lungwebungu River is expected to decline by 50—100 mm by 2100 under most climate change scenarios[34]. Furthermore, the number of hot days (over 30 °C) is expected to increase in the region, particularly under the RCP8.5 climate change scenario. Rising temperatures will likely place water-stress on crops, shifting the current limitation on smallholder maize production from nutrient-management to water-management. This will be exacerbated by variable and declining rainfall which will likely increase the reliance of local farmers on the Lungwebungu River as a water source for crop irrigation. As a result, crop cultivation may encroach the shrublands and grasslands surrounding the Lungwebungu River, as well as wetlands in the lower reaches, in response to limited availability of water inland. To account for this, it is important that adaptive management strategies are designed to ensure the sustainable use of fertilizers and pesticides, mitigate human-wildlife conflict, and prevent excessive land-clearing in this area.

In order to combat hunger and poverty in developing countries, the UN Food and Agriculture Organisation and the International Fund for Agricultural Development have advocated for increased cassava

[31] Zambia–Country Commercial Guide, 2024. International Trade Administration.

[32] Statista. 2021. Production volume of main agricultural products in Angola in the crop year 2019/2020. Available at: https://www.statista.com/statistics/1155931/production-volume-of-main-crops-in-angola/

[33] Vlasov, A., 2023. Africa's Major Crop"How Climate-Smart Agriculture is Enabling Farmers to Reap Record-High Cassava Yields Using Nuclear Science and Tencnology. *International Atomic Energy Agency.*

[34] Siatwiinda, S.M., Supit, I., van Hove, B., Yerokun, O., Ros, G.H., and de Vries, W. 2021. Climate change impacts on rainfed maize yields in Zambia under conventional and optimized crop management. *Climate Change, 167*, 39.

production[35]. This is because cassava is drought resilient compared to maize. As a result, cassava farming has the potential to improve food security, particularly under decreased rainfall and higher temperatures predicted by climate change scenarios[36]. This is particularly important given that maize production in Zambia is likely to decline in the near-future (2035—2066) and far-future (2065—2096) because of rising average and extreme temperatures and declining rainfall[37].

Livestock

In addition to field crop production, livestock is a primary source of livelihood and income for rural households in Zambia[38]. Livestock are mainly reared for subsistence use, and unless farmers live close to urban areas, they are reliant on livestock for milk provision[39]. However, livestock production in the country is limited by the low quality of veld grass, particularly during the dry season[40].

Only five groups of cattle were counted along the Lungwebungu River (N = 39) (Figure 37). Cattle were more common in Zambia (N = 37), with only two cows counted in Angola. However, these were near the border and may have wandered from Zambia. While beef is Angola's second-largest agricultural product after cassava, most livestock farming takes place in the southern region of the country[41], which could explain the lack of livestock in Angola. . However in central provinces, such as Huambo and Bié, livestock is mainly used for working on farms[42].

[35] ReliefWeb. 2004. Angola: Food security better in areas farming cassava. Available at: https://reliefweb.int/report/angola/angola-food-security-better-areas-farming-cassava

[36] Jarvis, A., Ramirez-Villegas, J., Campo, B.V.H., Navarro-Racines, C., 2012. Is cassava the answer to African climate change adaptation? *Tropical Plant Biology, 5,* 9 – 29.

[37] Siatwiinda, S.M., Supit, I., van Hove, B., Yerokun, O., Ros, G.H., and de Vries, W. 2021. Climate change impacts on rainfed maize yields in Zambia under conventional and optimized crop management. *Climate Change, 167*, 39.

[38] Tembo, G., Tembo, A., Goma, F., Kapekele, E., and Sambo, J., 2014. Livelihood activities and the role of livestock in smallholder farming communities of southern Zambia. *Open Journal of Social Sciences*, *2*, 299–307.

[39] Hart, N., 2012. Farmers in Zambia Improve Animal Productivity with Bean Once Considered Poisonous. International Atomic Energy Agency.

[40] Daka, D.E., 2002. Livestock sector in Zambia: Opportunities and limitations. IAEA (International Atomic Energy Agency), Eds., Development and Field Evaluation of Animal Feed Supplementation Packages, Proceedings of the Final Review Meeting, Cairo, 25-29 November 2000.

[41] Angola – Country Commercial Guide. 2024. International Trade Administration.

[42] Carranza, F., and Treakle, J., 2014. Land, Territorial Development and Family Farming in Angola. A holistic approach to community-based natural resource governance: The cases of Bie, Huambo, and Huila Provinces. *Food and Agriculture Organisation of the United Nations.*

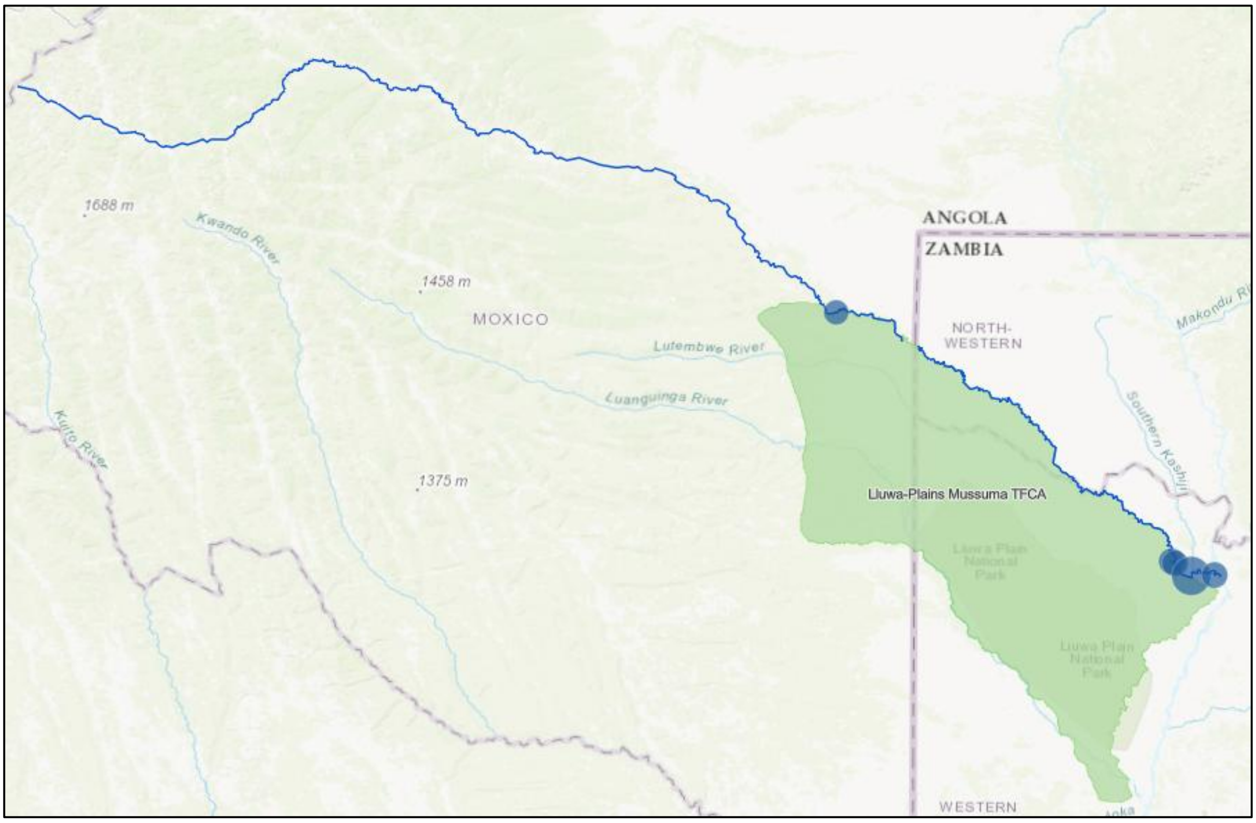


Figure 37. Livestock present on the Lungwebungu River, mainly distributed near the border and near the confluence of the Lungwebungu and Zambezi rivers.

Wetland-Associated Birds

Methods: Wetland-associated birds

Long term monitoring of biodiversity can provide important insights into river health, eco-tourism opportunities and potential for human-wildlife conflict. Birds in particular serve as reliable indicators of disturbance and ecosystem health, often reflecting changes in habitat availability. To this end, continuous monitoring of birds over time allow for detection of threats to riverine ecosystems. In addition, the identification of important nesting sites and foraging grounds informs proactive and effective conservation management.

Results and Discussion: Wetland-associated birds

A total of 2,459 wetland-associated birds and raptors, belonging to 65 species, were counted along the Lungwebungu River transect. This represents a density of 2.8 birds/km — lower than the Zambezi River average (16.3 birds/km). The most common birds were herons, bitterns and egrets (Ardeidae), which represented 640 (26%) of the total wetland bird abundance (Table 11). The most common bird species were reed cormorants (N=456), the pied kingfisher (N=234) and the black-crowned night heron (N=172). A full list of the wetland-associated bird species recorded on the expedition is included in Appendix 9. Bird survey summary.

Table 11. The bird guilds observed along the Lungwebungu River.

Guild	Count	% of Total Count
Ardeidae	640	26.0
Diving birds	458	18.6
Kingfishers	321	13.0
Anatidae	203	8.3
Bee-eaters	174	7.1
Storks	144	5.9
Widowbirds	115	4.7

Raptors	107	4.4
Hamerkop	97	3.9
Lapwings and thick-knees	49	2.0
Coucals	44	1.8
Rallidae and jacanas	23	0.9
African skimmer	18	0.7
Waders	17	0.7
Boubous	14	0.6
Gulls and terns	3	0.1
Other	32	1.3
TOTAL	**2,459**	**100**

There was a higher abundance of birds in Zambia (N=1,399; 5.2 birds/km) compared to Angola (N=1,060; 2.4 birds/km). The high abundance of birds in Zambia can be attributed to the extensive floodplains in the lower reaches of the Lungwebungu River, particularly in the northern Barotse Floodplain, which provides ample habitat and food availability for waterbirds. However, the abundance and composition of wetland birds along the Lungwebungu River differed in response to varying habitat availability (Figure 38).

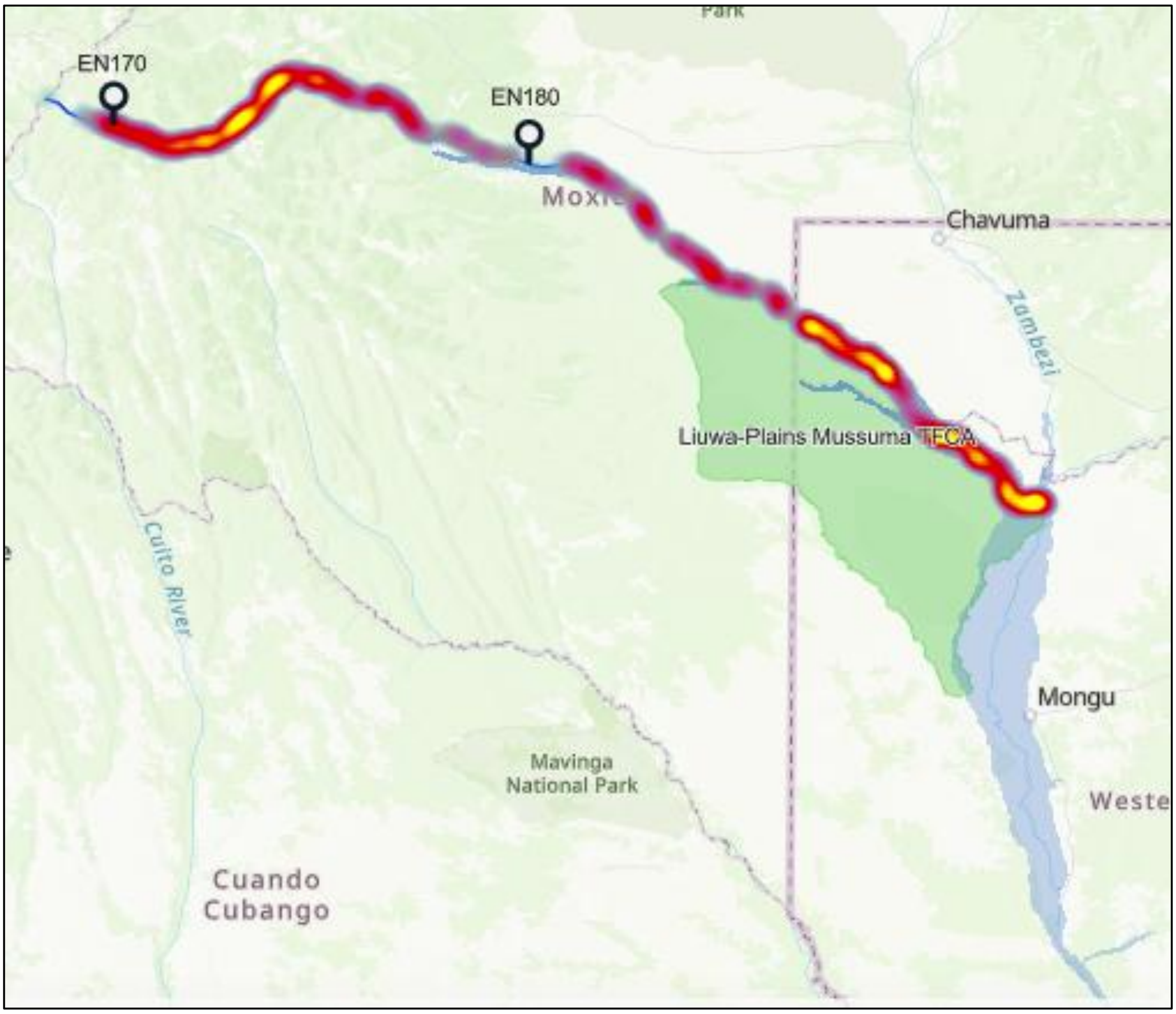


Figure 38. The distribution of wetland-associated birds along the Lungwebungu River.

The extent of the floodplain, depth and flow of the river, and the extent of marginal vegetation change considerably along the length of the river. Consequently, the distribution of wetland birds differed across different biogeographic zones of the river (Figure 39). In addition to the extensive floodplains in Zambia, the upper reaches and middle-lower reaches of the Lungwebungu River, had a high abundance of wetland-associated birds.

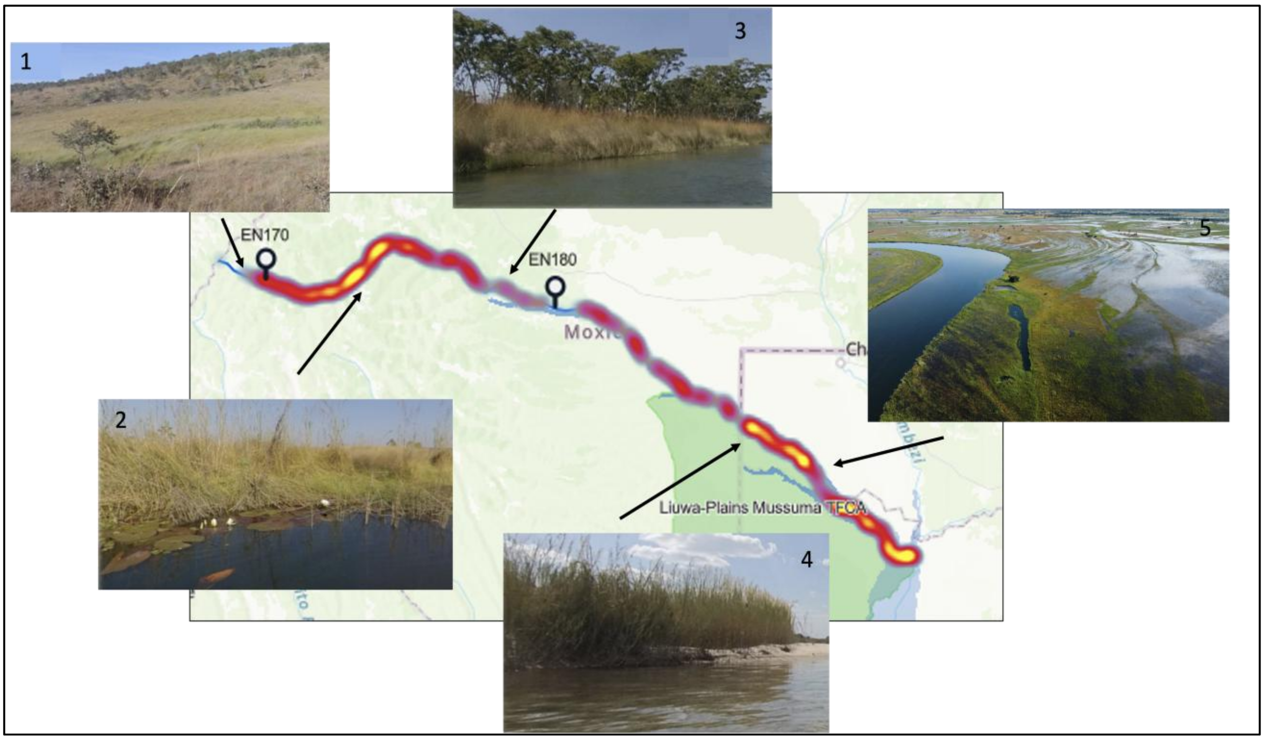


Figure 39. The distribution of wetland birds across different biogeographic zones on the Lungwebungu River. These zones are identified as the: 1. Source-Upper Reaches; 2. Upper Reaches; 3. Middle Reaches; 4. Middle–Lower Reaches; 5. Lower Reaches.

Upper Reaches and Middle–Lower Reaches

The gradual flow and the mix of surrounding grassland and shrubland of the upper reaches of the river (Figure 40) provides ample habitat for wetland birds. Kingfishers (N=321), bee-eaters (N=174), and marsh widowbirds (N=115) were most abundant in Angola and were mainly distributed in this region of the Lungwebungu River

Figure 40. The upper reaches of the Lungwebungu River.

Pied kingfishers (N=234) and malachite kingfishers (N=74) were the most abundant species of this guild, with the striped kingfisher (N=1) and half-collared kingfisher (N=1) only observed in Angola (Figure 41).

Figure 41. The distribution of kingfishers on the Lungwebungu River.

The white-fronted bee-eater (N=87) and little bee-eater (N=77) were the most prominent species of this guild, with the southern carmine bee-eater only observed in Angola (Figure 42). Marsh widowbirds (N=115) were only distributed in the upper reaches of the Lungwebungu River (Figure 42).

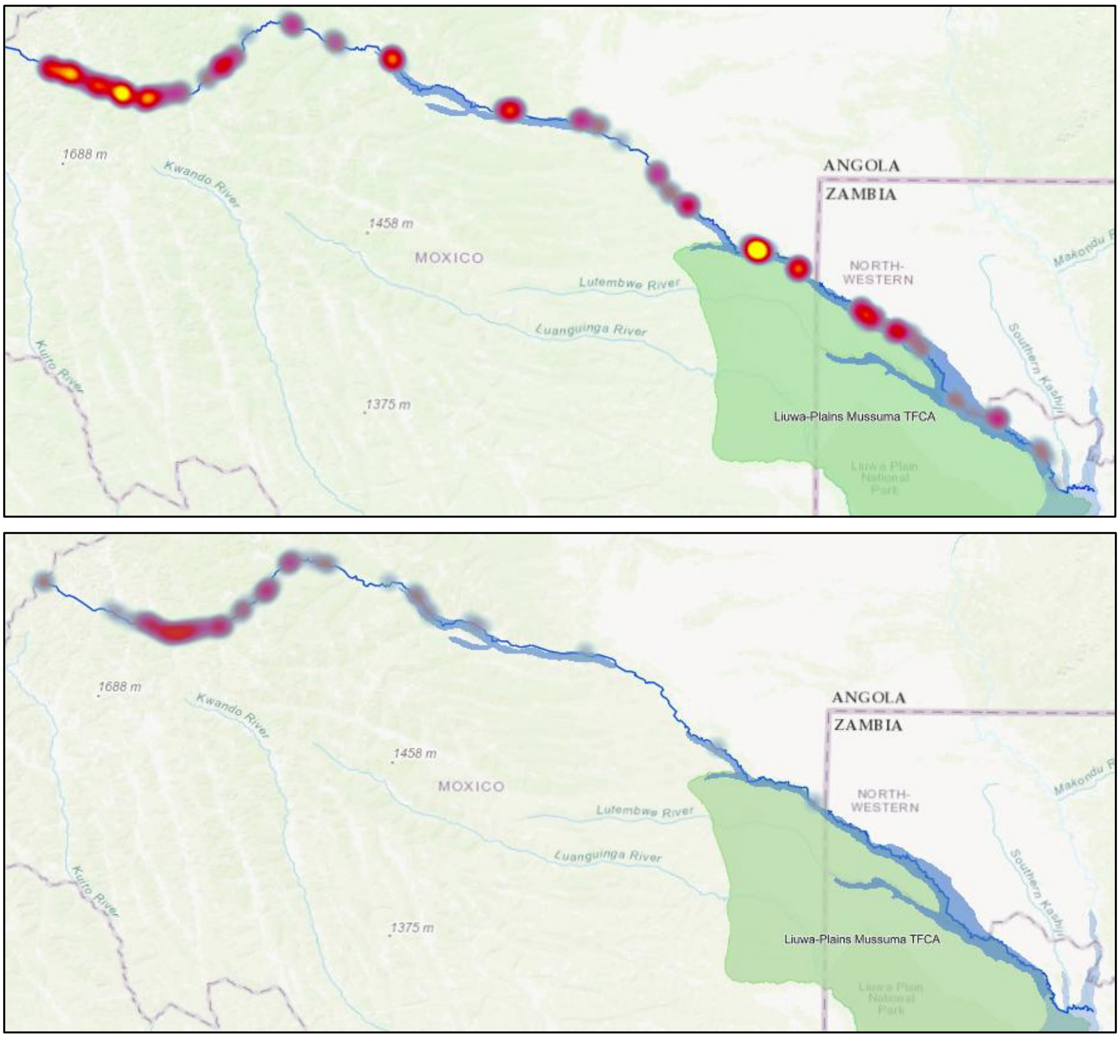


Figure 42. The distribution of bee-eaters (top) and marsh widowbirds (bottom) on the Lungwebungu River.

The middle to lower reaches of the river, north of the proposed Liuwa Plains–Mussuma TFCA, has marginal aquatic vegetation that expands into a widened floodplain (Figure 43), providing ample habitat for wetland birds, such as bee-eaters, and most stork species recorded along the Lungwebungu River (N=144).

Figure 43. The middle–lower reaches of the Lungwebungu River.

Woolly-necked storks (N=12) (Figure 44), saddle-backed storks (N=14) and Marabou storks (N=2) were only recorded in Angola (Figure 45). Contrastingly, African openbills were only in Zambia, mainly located in the Barotse Floodplain at the confluence with the Zambia River (Figure 45). The Barotse Floodplain is one of the most important wetland habitats for openbills, with the high abundance of these bird species attributed to the high productivity of the floodplain[43].

Figure 44. Two woolly-necked storks observed on the Lungwebungu River in Angola.

[43] Gula, J., 2023. The first survey of waterbird nesting colonies on the Barotse Floodplain, Zambia. African Bird Club.

Figure 45. The distribution of storks on the Lungwebungu River.

Wetland-associated birds were notably absent in near the source of the Lungwebungu River in the upper reaches and in the middle reaches of the river — particularly the area around the EN180 road bridge. For the first ~50 km, the river has low flow. In June–July, when the survey of the river in Angola was conducted, the marginal vegetation that consists predominantly of grasses that are mostly dry (Figure 46) and there is limited prey available for wetland birds including Ardeidae, storks and kingfishers. Consequently, this area supports a low bird abundance. In the wet season, inundation of the surrounding grasslands and marshlands increases invertebrates and small amphibians in the ecosystem, potentially supporting more wetland birds. However, this should be validated by conducting a wet season survey.

Figure 46. The source to upper reaches of the Lungwebungu River.

Near the EN180 road bridge in the middle reaches of the river, the river is deep and fast-flowing and has gallery forests that encroach the steep riverbanks (Figure 47). The lack of shallow floodplains and relatively compressed extent of marginal aquatic vegetation reduces suitable wetland habitat, limiting the abundance of wetland-associated birds. In addition, bush clearing for the extensive production of cassava in this region further reduces wetland-associated bird abundance.


Figure 47. The middle reaches of the Lungwebungu River.

The higher abundance of wetland-associated birds in Zambia can be attributed to the greater availability of wetland habitat, particularly because the survey was conducted in the wet season when the floodplains are inundated (Figure 48). Compared to Angola, the wetland birds in Zambia were evenly distributed, indicating the homogeneity of the wetland habitat.


Figure 48. The lower reaches of the Lungwebungu River.

Piscivorous birds, such as Ardeidae (N=558), reed cormorants (N=418), and ducks, geese and terns (Anatidae)(N=133), are especially abundant in the lower reaches of the river, indicating bird abundance can be linked to the seasonal flooding of the river. When the floodplains are inundated, fish are mainly concentrated in shallow waters or lakes that form within the floodplain, making them more accessible to birds and provides suitable nesting sites for colonial species, such as cormorants, egrets and herons, which form large colonies along the river in Zambia (Figure 49 and Figure 50). In addition, many of the wetland birds, such as African openbills (N=56) were only in Zambia, mainly located in the Barotse Floodplain at the confluence with the Zambia River. The Barotse Floodplain is one of the most important wetland habitats for openbills, with the high abundance of these bird species attributed to the high productivity of the floodplain[44].

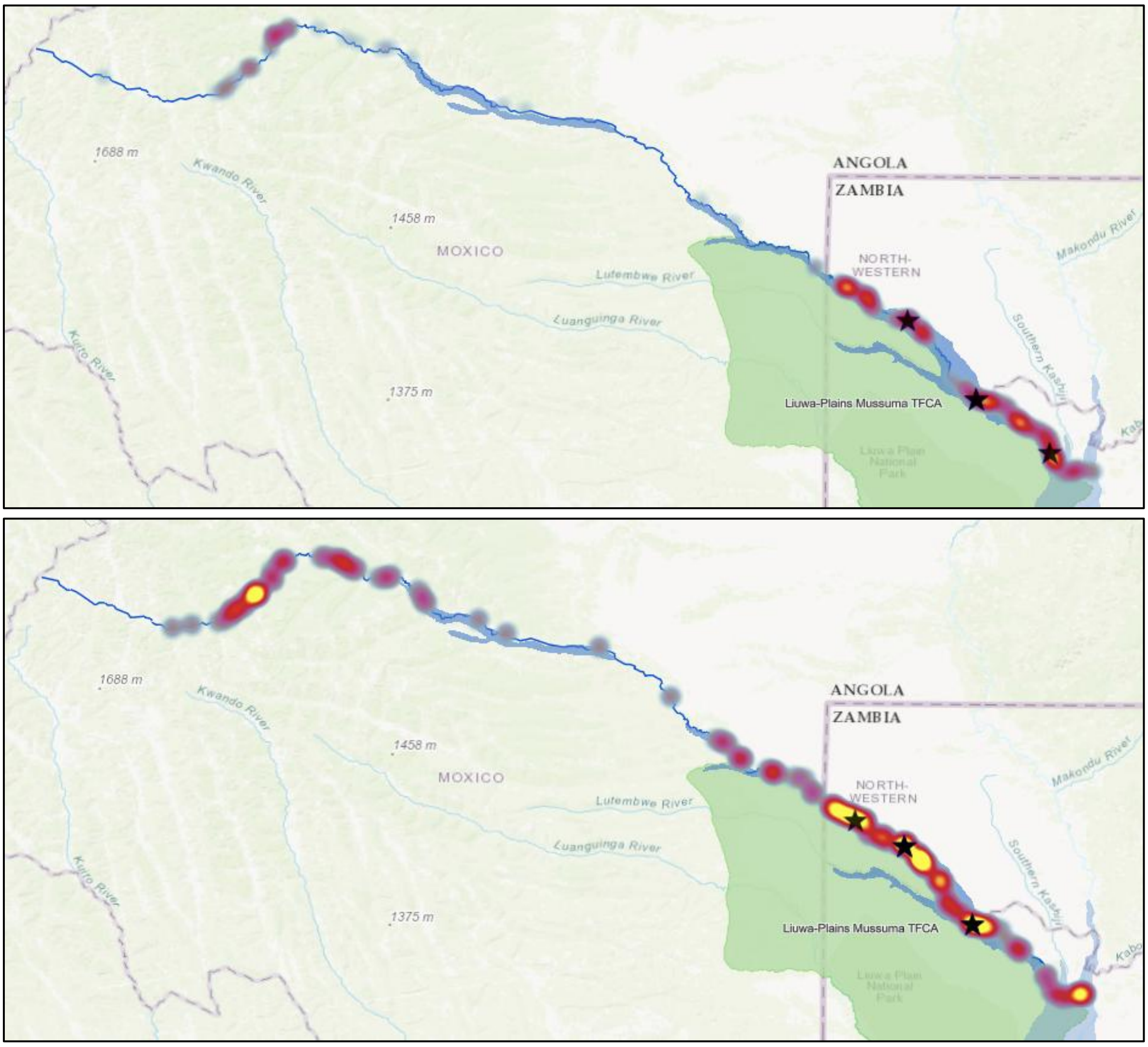


Figure 49. The distribution of diving birds (reed cormorants) (top) and Ardeidae (herons, egrets and bitterns) (bottom). Starts indicate the locations of colonies comprising more than 40 birds in a single location.

[44] Gula, J., 2023. The first survey of waterbird nesting colonies on the Barotse Floodplain, Zambia. African Bird Club.

Figure 50. A little egret (left) and a reed cormorant (right) on the Lungwebungu River.

Wetland Bird Colonies on the Lungwebungu River

Water birds including herons, egrets, ibises and cormorants often nest together in large roosting or breeding colonies, typically in reeds or trees[45]. Three large bird colonies of Ardeidae and reed cormorants were observed on the lower Lungwebungu River (Figure 51). Nesting sites of waterbird colonies are situated close to feeding areas that provide enough food for parents and their offspring during the breeding season[46]. Depending on the bird species, nest sites range from tall trees (e.g. herons, cormorants, storks) to areas with dense undergrowth (e.g. herons, ibises). In addition, reedbeds of *Phragmites* grasses provide important breeding areas for many waterbird species, such as purple herons, ibises and spoonbiils[47]. Thus, marginal aquatic *Phragmites* grasses distributed along the lower Lungwebungu provides habitats that can support large breeding colonies of waterbirds.

Breeding or roosting colonies of cormorants can influence the cycling of nutrients within riverine environments. As piscivores, water bird species, such as cormorants, consume a diet high in nitrogen and phosphorous. The addition of these nutrients in the terrestrial and aquatic environment can promote phytoplankton growth, and fertilize littoral areas, thereby improving fish and invertebrate biomass. Waterbirds are therefore vital to the productivity of wetland ecosystems, particularly in nutrient-poor river systems[48]

[45] Sinclar, I., Hockey, P., Tarboton, W., Perrins, N., Rollinson, D., and Ryan, P., 2020. *Sasol Birds of Southern Africa.* Struik Nature, Penguin Random House, South Africa.

[46] Perennou, C., Sadoul, N., Pineau, O., Johnson, A., and Hafner, H., 1996. Management of nest sites for colonial waterbirds. *Tour du Valat*.

[47] Perennou, C., Sadoul, N., Pineau, O., Johnson, A., and Hafner, H., 1996. Management of nest sites for colonial waterbirds. *Tour du Valat*.

[48] Green, A.J., and Elmberg, J., 2014. Ecosystem services provided by waterbirds. *Biological Reviews*, *89*, 105–122.

Figure 51. A large colony of egrets and herons on the Lungwebungu River in Zambia.

Wildlife

Methods: Wildlife

Long-term monitoring of biodiversity can provide important insights into river health, eco-tourism opportunities and potential for human-wildlife conflict. The continuous monitoring of wildlife over time allows for the detection of threats to riverine ecosystems. For this purpose, all non-avian wildlife within the Lungwebungu River, and its riparian vegetation were counted.

Results and Discussion: Wildlife

In total, 72 individual animals were counted in the observational survey, representing a wildlife density of 0.07 animals/km (Table 12). This is higher compared to other rivers in the region, such as Chambeshi (0.03 animals/km), but lower than the Zambezi River (4.04 animals/km). The most common species were crocodiles (N=33), followed by water monitors (N=17) and vervet monkeys (N=9). Other animals present along the river include situtanga[49], and the spotted-necked otter.

Table 12. The abundance of wildlife species on the Lungwebungu River.

Wildlife species	Count
Crocodile	33
Water monitor	17
Vervet monkey	9
Spotted-necked otter	4
Sitatunga	2
Hippopotamus	2
Oribi	2
African Rock Python	2
Grysbok	1
TOTAL	**72**

Non-avian wildlife species were predominantly located in Angola (~96%,Figure 52), with only three non-avian animals present in Zambia. In Angola, wildlife species such as crocodiles (Figure 53) were mainly

[49] Sitatunga (*Tragelaphus spekii*) or marsh-buck is a swamp-dwelling medium-sized antelope distributed in central Africa.

located in the upper reaches and in wetland areas of the river. The upper reaches of the Lungwebungu River is dominated by peatland vegetation, which absorb water during the wet season — providing a flooded landscape for many aquatic organisms during the dry season. Contrastingly, the lower abundance of wildlife observed in Zambia can be attributed to the inundated floodplains which result in wildlife moving further inland from the mainstream of the river, obscuring observations.

Figure 52. The distribution of non-avian wildlife observed on the Lungwebungu River.

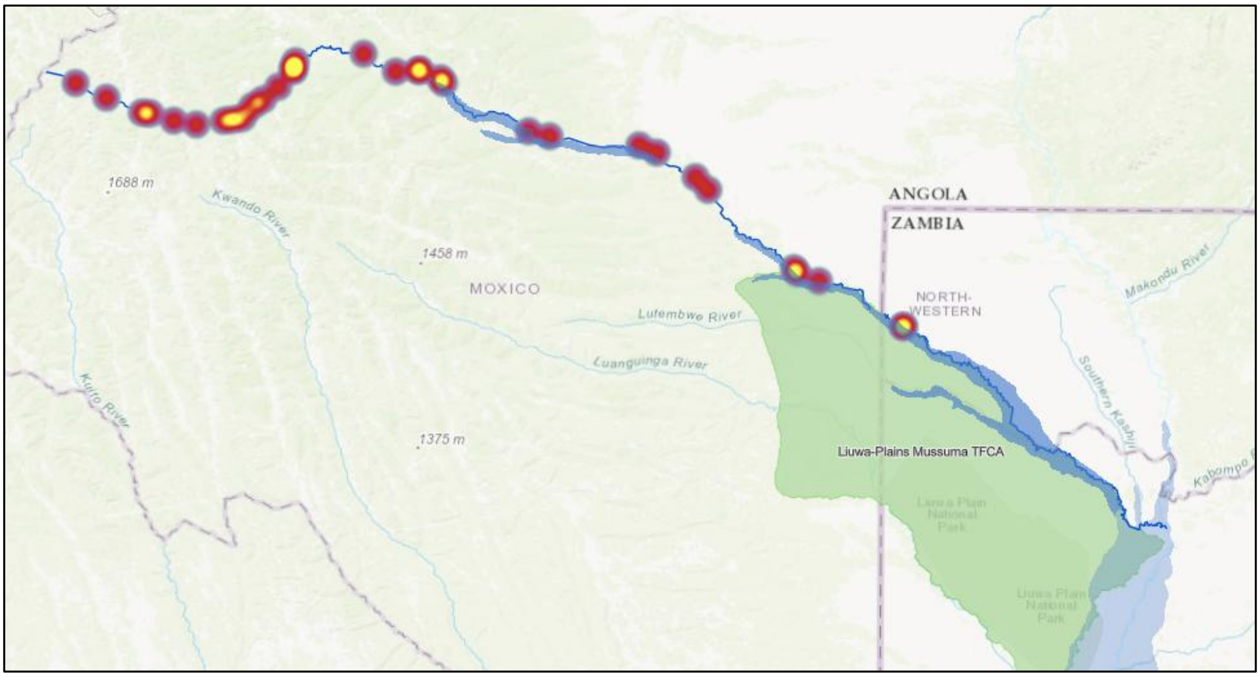


Figure 53. The distribution of crocodiles along the Lungwebungu River.

Large mammals

Hippopotamus were the only large mammals present on the Lungwebungu River — only two hippos were recorded in the Angolan stretch of the river (Figure 54). Hippos were historically widespread in Angola, found in almost all rivers and basins in the country. However, like other large mammals in the country, the hippo population has significantly declined. Presently, hippo populations are restricted to small pockets in large rivers, occurring in isolated pockets along the Cuanza, Queve, and Luando.[50]

Figure 54. Two hippopotamuses observed on the Lungwebungu River.

In Zambia, hippos are predominantly located in the Luangwa River, followed by the Zambezi and Kafue Rivers[51]. While rivers such as the Zambezi have favourable environmental conditions for large hippo populations — river meanders and lagoons with open grasslands — poaching and poor fire management has contributed to the decline of hippos in this area[52]. The Lungwebungu River has intricate meanders with multiple channels and oxbow lakes, with the lower reaches in Zambia comprising extensive grasslands. Therefore, it is likely that observations of hippos could have been obscured by the inundated floodplains. A dry season survey would indicate if hippos are present along this stretch of the Lungwebungu River.

Historical Hunting Activities and Large Wildlife on the Lungwebungu River

The Civil War directly exacerbated hunting in Angola through the proliferation of rifles in the country[53]. For example, shotgun use in hunting increased by 100% in some areas of the country following the Civil War[54]. As a result, several wildlife species in Angola experienced a decline of up to 80% of their pre-war baseline abundances[55].

Large mammals were notably absent from the Lungwebungu River. Given that there is an abundance of suitable habitat downstream of where these hippos were observed, it is likely that the dwindling of large mammals on the river, such as the hippo population, is an indication of hunting pressure rather than a lack of suitable habitat. This is supported by evidence that the hippo population in Angola was reduced

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[50] Beja, P., Vaz Pinto, P., Veríssimo, L., Bersacola, E. et al. 2019. The Mammals of Angola. *Biodiversity of Angola.*

[51] Wilbroad, C., and Milanzi, J., 2010. Population status of the hippopotamus in Zambia. *African Journal of Ecology*, *49*, 130–132.

[52] Wilbroad, C., and Milanzi, J., 2010. Population status of the hippopotamus in Zambia. *African Journal of Ecology*, *49*, 130–132.

[53] Braga-Pereira, F. et al. 2020. From spears to automatic rifles: The shift in hunting techniques as a mammal depletion driver during the Angolan civil war. B*iological Conservation, Volume 249*.

[54] Duda, R. 2017. Hunting Techniques, Wildlife Offtake and Market Integration. A Perspective from Individual Variations among the Baka (Cameroon). The Center for African Area Studies, Kyoto University, Japan.

[55] Braga-Pereira et al. 2020. Warfare-induced mammal population declines in Southwestern Africa are mediated by species life history, habitat type and hunter preferences. *Scientific Reports, Volume 10.*

substantially in both savannah and forest habitats by hunting during the Angolan Civil War[56]. It is however concerning that the hippo population has not recovered, indicating that unregulated hunting of hippos on the Lungwebungu River is likely ongoing.

Alien Invasive Plants

Methods: Alien Invasive Plants

Alien invasive plants (AIPs) are known to have several impacts on river systems in Africa. These include the displacement of native vegetation and changes in nutrient cycling, which have detrimental impacts on native plant communities and local biodiversity. In addition, alien plant invasions alter the fire regimes in invaded areas by changing the size, distribution and plant chemistry of the biomass available for fuel[57]. Moreover, AIPs reduce water quality by increasing evapotranspiration rates and reducing stream flow and dilution capacity[58]. The continuous monitoring of AIPs allows for the detection of threats of riverine ecosystems. For this purpose, all alien invasive plant species within the Lungwebungu Basin, and its riparian vegetation were identified and their extent was recorded.

Results and Discussion: Alien Invasive Plants

Five species of AIPs were counted along the Lungwebungu River — only present in Angola (Figure 55). However, it is likely that AIPs occur in Zambia, particularly around the floodplain margins where human activities are concentrated. AIPs recorded along the river include *Gomprena celosioides*, *Bidens pilosa* and *Ageratum conyzoides* (Table 13). All AIPS occurred in isolated patches, covering a large area — ranging from 10 m^2 to 110 m^2. The most common AIP was *Gomphrena celosioides*, with five individual plants located along the river. *Ageratum* covered 110 m^2, indicating that it is still in the process of establishment.

Table 13. Alien invasive plants recorded along the Lungwebungu River.

Invasive alien plant	Total observed	Occupation size (m^2)
Gomphrena celosioides	5	(individual plants)
Ageratum conyzoides	2	110
Bidens pilosa	2	(individual plants)
Tithonia sp.	1	60
Lantana camara	1	10
TOTAL	**16**	**180**

[56] Braga-Pereira et al. 2020. Warfare-induced mammal population declines in Southwestern Africa are mediated by species life history, habitat type and hunter preferences. *Scientific Reports, Volume 10.*
[57] Vilà, M. et al., 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters.
[58] Schachtschneider, K. et al. 2012. Impacts of invasive alien plants on water quality, with particular emphasis on South Africa. Water S.A.

Figure 55. The distribution of alien invasive plants along the Lungwebungu River.

The prevalence of AIPs along the Angolan transect of the river is associated with infrastructure along the river, such as the EN180 bridge. The patchy distribution and low density of AIPs indicate that they are in their early stages of establishment. To mitigate the spread of established AIPs in the river, immediate implementation of an invasive species eradication programme is required. Furthermore, the monitoring and detection of AIPs should be integrated into ongoing river assessments to monitor the proliferation of these species.

Napier Fodder

Nappier fodder, or elephant grass (*Pennisetum purpureum*) is native to Africa and is commonly used as a livestock crop due to its fast growth and high nutritional value. Napier fodder is present along the upper Lungwebungu River (N=3) near the EN170 and EN180 road bridges, occurring in patches covering as much as 100 m^2 (Figure 56). Napier grass is an ideal fodder for the dry season, as it is a high quality grass and is drought resistant. However, Napier grass can impact local ecosystems due to its rapid growth, which can result in the colonization of new areas, and the formation of dense thickets[59]. In addition, *Pennisetum* grasses can result in more frequent and intense fires[60]

[59] Rojas-Sandoval, J., Acevedo-Rodríguez, P., 2013. *Pennisetum purpureum* (Elephant grass). *CABI Compendium*, *39771*.

[60] D'Antonio, C.M., and Vitousek, P.M., 1992. Biological invasions by exotic grasses, the grass/fire cycle and global change. *Annual Review of Ecology and Systematics*, *23*, 63–87.

Figure 56. The distribution of Napier fodder along the Lungwebungu River.

Papyrus

Papyrus (*Cyperus papyrus*) is a perennial herbaceous sedge native to Africa where it occurs along riverine, floodplain and fringing wetlands. Papyrus wetlands provide a habitat for a variety of organisms, including sitatungas, but they are also one of the most efficient and effective natural pollution filters[61]. Throughout Africa, papyrus biomass is harvested for thatching and making mats, crafts, rafts, household utensils and decorations. However, little is known about its distribution, abundance and conservation status in southern Africa.

A total of 188 patches of papyrus were present, covering a total distance of ~8 km along the river. Papyrus was predominantly located in Zambia (Figure 57), where oxbow lakes, shallow sandbanks and wide seasonal floodplains provide a suitable habitat for papyrus vegetation[28]. As papyrus is sensitive to human disturbance[62], the presence of papyrus along the Lungwebungu River can indicate low levels of human activity.

A single locality of papyrus was found in Angola — the most upstream recorded site of papyrus growth along the river (Figure 57). It was located near the EN180 road bridge and the northern border of the proposed Mussuma National Park. At this site, the river enters its lower reaches, enabling the deposition of sediments and resulting in shallower waters that facilitates papyrus growth. Due to the important role papyrus plays in the environment, the harvesting of papyrus can negatively impact the wetland ecosystem. As a result, the harvesting of papyrus by local communities should be monitored to mitigate the impacts for these ecosystems.

[61] Rongoei, P.J.K., Kipkemboi, J., Okeyo-Owour, J.B., and van Dam, A.A., 2013. Ecosystem services and drivers of change in Nyando floodplain wetland, Kenya. *African Journal of Environmental Science and Technology, 7*, 274 – 291.

[62] Rongoei, P.J.K. and Outa, N.O. 2016. *Cyperus papyrus* L. growth rate and mortality in relation to water quantity, quality and soil characteristics in Nyando Floodplain Wetland, Kenya. *Open Journal of Ecology, 6,*714 – 735.

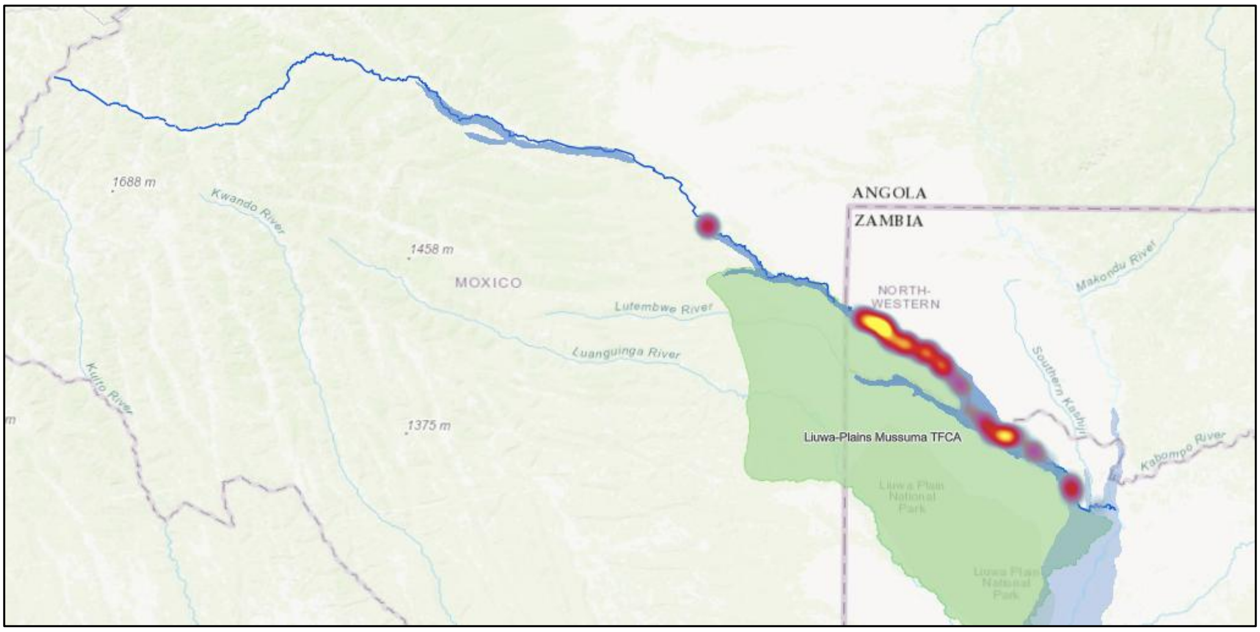

Figure 57. The distribution of papyrus along the Lungwebungu River. Note that papyrus was only observed in one locality in Angola.

Fire

Fire is a key ecosystem process, playing an important role in the structure and composition of ecosystems[63]. For example, fire prevents bush encroachment and clears dead organic material, thereby promoting grass regrowth and even facilitating the germination of seeds for certain plant species. Fires can also influence the water quality of rivers by contributing ash to the river and floodplain, thereby changing physicochemical properties such as nutrient and oxygen concentration, temperature and turbidity[64]. Fires may also influence the distribution of biomes [65,66], as fire suppression of grasslands can promote woodland growth. This can lead to biome switches from savanna to woodland, for example[67,68].

Methods: Fire

To determine the extent of fires along the Lungwebungu River, all recent and ongoing fires within 100 m of the riverbanks were counted. In addition, the following information about the fires was collected:

- The freshness of the burn was estimated based on the level of regrowth in the burned area.
- Burn intensity was estimated based on the vegetation remaining in the burned area. The fire intensity was categorised as follows:
    - *Low*: ground cover burned, but most vegetation remaining
    - *Medium*: groundcover and some low-level vegetation burned, ~50% of vegetation remaining.
    - *High*: all groundcover and vegetation burned.
- The predominant vegetation type where the fire occurred was identified.
- The side of the river on which the fires were noted.

[63] Archibald, S. 2018. Biological and geophysical feedbacks with fire in the Earth system. *Environmental Research Letters, 13, 033003*
[64] Morales, J.J., Paes, N.D.S., Silva, A.C.M., and Teixido, A.L., 2023. Fire and water: fire impacts on physicochemical properties of freshwater ecosystems. *Fundamental and Applied Limnology*, *196,* 137–153.
[65] Bond, W.J., Woodward, F.I., and Midgley, G.F., 2004. The global distribution of ecosystems in a world without fire. *New Phytologist*, *165*, 525 - 538.
[66] Bond, W.J. and Keeley, J.E. 2005. Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. *TRENDS in Ecology and Evolution, 20*, 387 – 394.
[67] Peterson, D.W., and Reich, P.B., 2001. Prescribed fire in oak savanna: fire frequency effects on stand structure and dynamics. *Ecological Applications*, *11*, 914–927.
[68] Van Wilgen, B.W., 2009. The evolution of fire management practices in savanna protected areas in South Africa. *South African Journal of Sciences, 105*, 343-349.

Results and Discussion: Fire

The abundance of fires is influenced by seasonality, with most fires occurring in the dry season. Therefore, fires were only recorded in Angola (Figure 58). However, fires are also common in Zambia as indicated by the satellite analysis (see MODIS Fire RS Satellite Analysis below). A total of 246 fires had recently occurred or were ongoing along the banks of the river, representing a density of 0.03 burns/km (0.2 burns km for the entire river). Most fires were estimated to be medium intensity (55%), followed by high (20%) and low-intensity (20%). Only two burns were ongoing, and most had occurred recently, with most fires showing fresh regrowth (61%) or no regrowth (38%). Fires predominantly occurred in mixed grasslands (90%), with just 7% of burns in wooded areas.

Figure 58. Fires observed along the Lungwebungu River in Angola.

Burns were distributed along the entire length of the Angolan transect, with a hotspot located in the upper reaches of the Lungwebungu River (Figure 59). The fires located here were predominantly high-intensity burns (Figure 60). Although no fires were recorded in Zambia, satellite analysis indicates that fires are common in Zambia in the dry season (see MODIS Fire RS Satellite Analysis below).

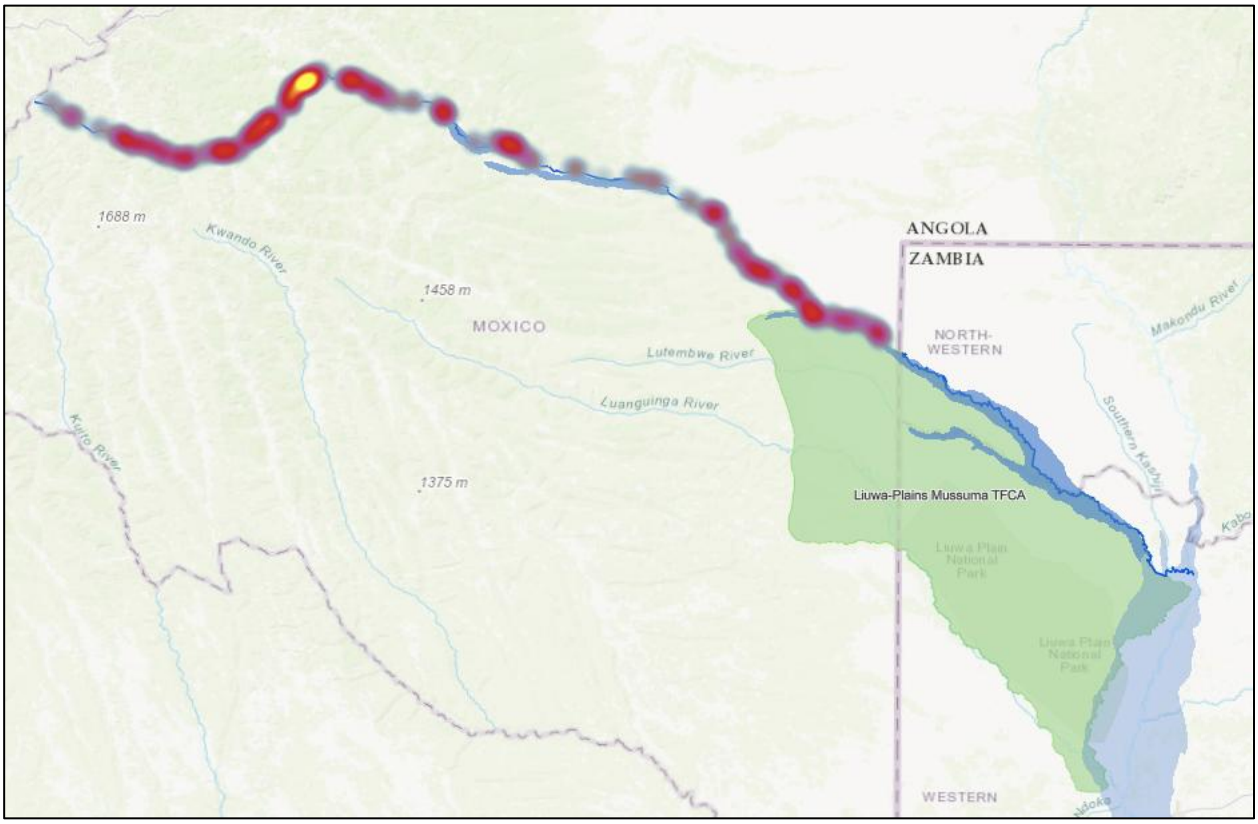

Figure 59. The distribution of fires along the Lungwebungu River. The presence of fire in Angola represents seasonal variation in burn abundance.

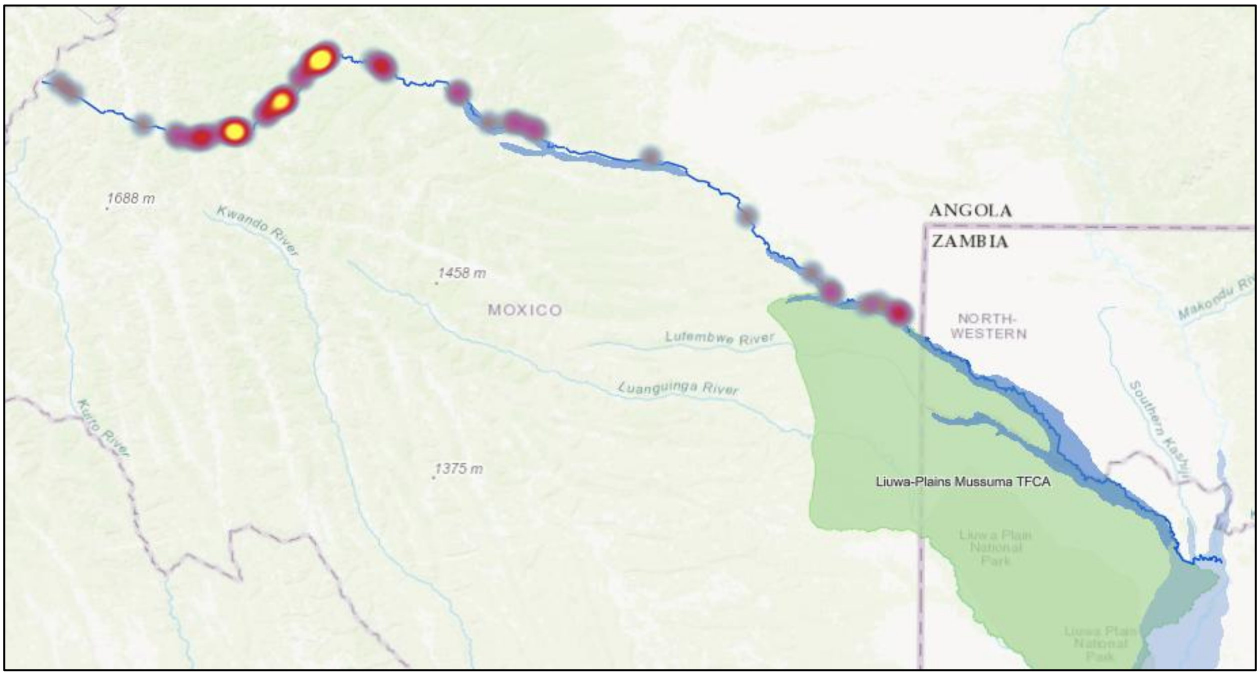

Figure 60. The distribution of high-intensity fires along the Lungwebungu river in Angola.

Fires are common across southern Africa in the dry season. For example, from 2001–2008, more than 50% of the land area of Angola and Zambia was affected by frequent fires, with a large portion of the area burnt more than four times within the 8-year period[69]. Additionally, from 2000–2015, fires became more frequent in Angola, mainly attributed to very dry seasons and consecutive drought periods[70]. The annual burnt area of Angola has shown an increase in provinces such as Moxico, which mainly consists of Miombo woodland[71].

1.3 FIXED SITE MONITORING (EVERY 10 KM)

Every 10 km, a fixed research site was conducted that included water quality analysis and an aerial drone survey. This amounted to a total of 107 research sites along the transect (Figure 61). When combined with continuous observational survey data, water quality and aerial surveys help to identify land-use, development and pollution sources along the river.

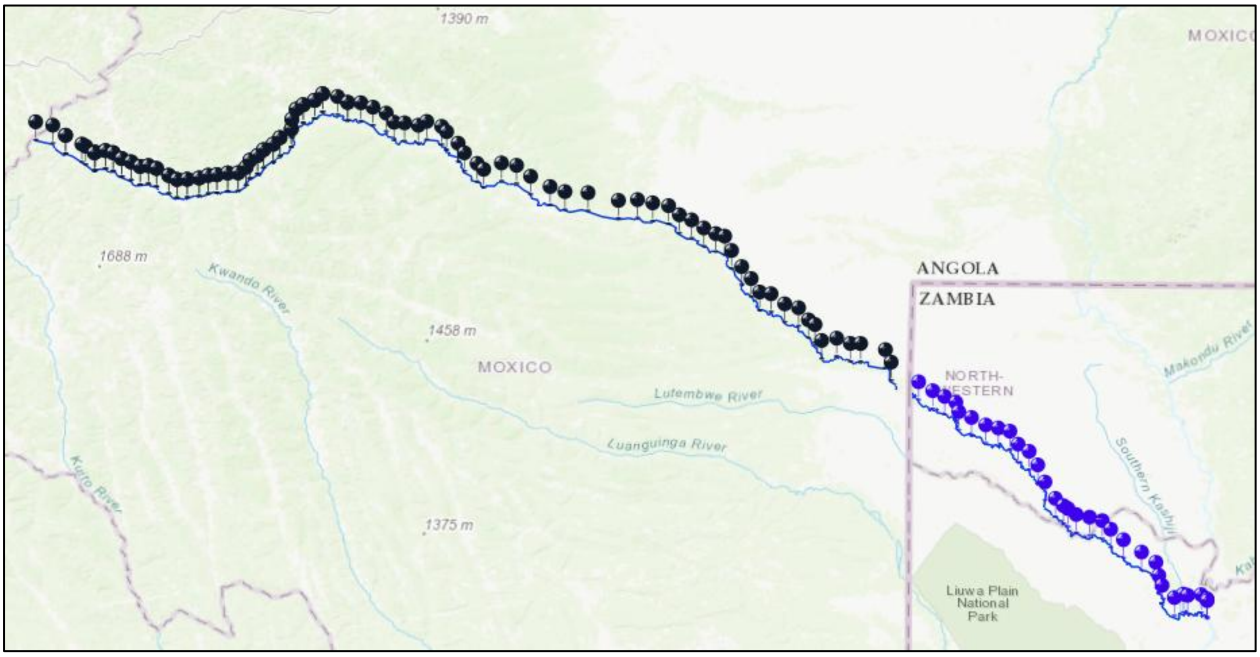

Figure 61. Fixed monitoring sites for water quality and aerial drone surveys conducted every 10 km along the Lungwebungu River in Angola (black) and Zambia (blue).

Fixed Point Aerial Photography

A series of 18 images were collected at each site; nine at 200 m elevation and nine at 100 m elevation. At each elevation, the first image was taken straight down. Then, four images (North, East, South, West) were taken at an angle of -20° to the horizon and four images at -45°. These aerial photographs provide a birds-eye view of the river along its course — evidence against which future changes to the river and the surrounding floodplain vegetation can be compared. In addition, these provide a visual reference of the interplay between grasslands, fire, sediments and floodwaters along this unique river. A collation of photographs taken from 200 m elevation is presented (Figure 62). The full database of aerial photography is available upon request.

[69] Archibald, S., Scholes, R.J., Roy, D.P, Roberts., G., and Boschetti, L., 2010. Southern African fire regimes as revealed by remote sensing. *International Journal of Wildland Fire, 19,* 861–878.
[70] Mendelsohn, J.M., 2019. Landscape changes in Angola. *Biodiversity of Angola*, Huntley, B.J., Russo, V., Lages, F., Ferrand, N. (Eds.), 123-127.
[71] Catarino, S., Romeiras, M.M., Figueira, R., et al. 2020. Spatial and temporal trends of burnt area in Angola: implications for natural vegetation and protected area management. *Diversity, 12*, 307.

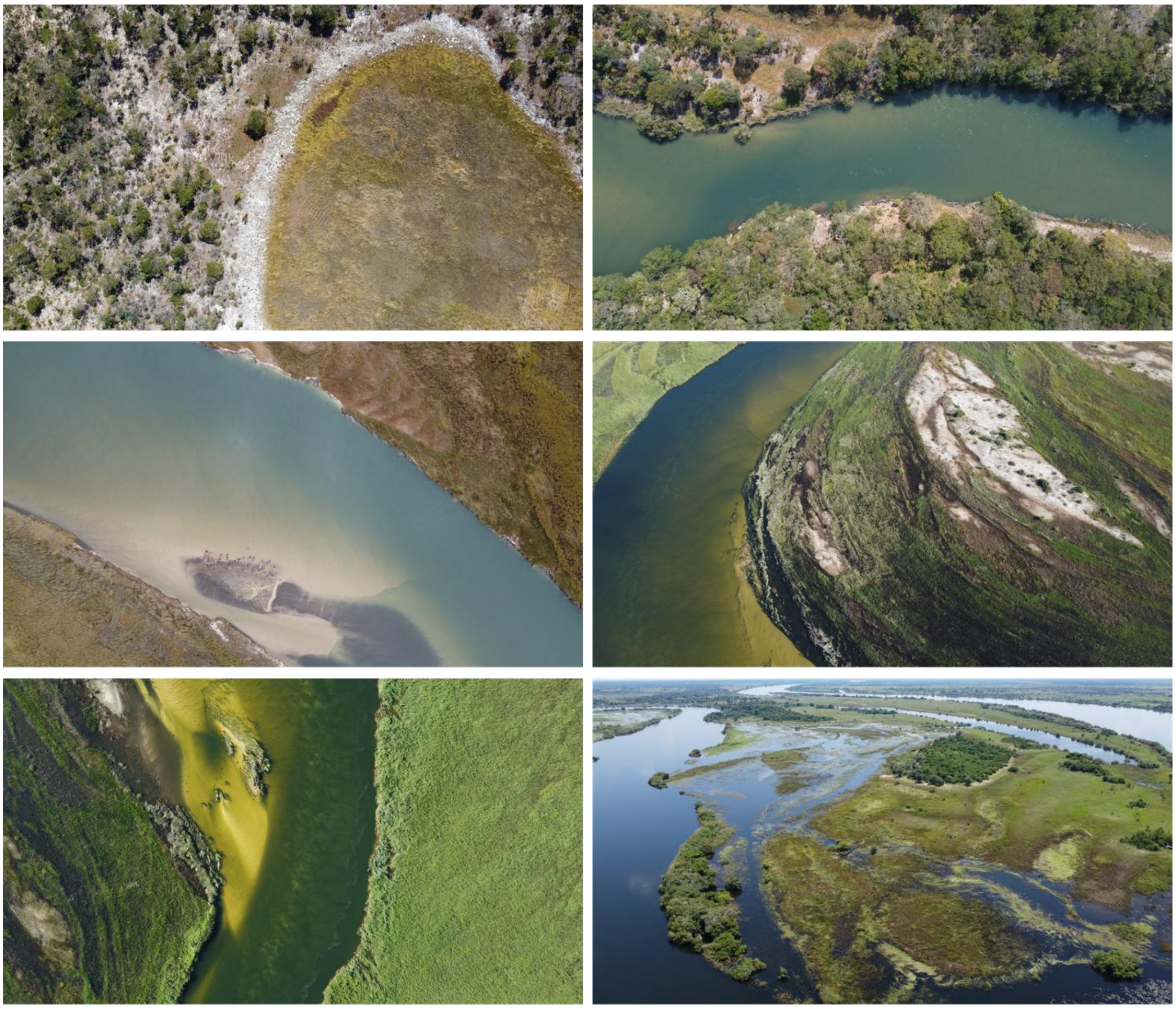

Figure 62. Collation of aerial photographs of the Lungwebungu River, taken from 200 m elevation at several different research sites along the river.

Water Quality

Methods: Water Quality

Water quality analysis was conducted using an InSitu Aquatroll 600 multi-parameter (Figure 63). The sonde was fitted with four sensors, allowing it to measure several parameters including pH, oxidation reduction potential (ORP), total dissolved solids (TDS), turbidity, dissolved oxygen (DO), conductivity, salinity, resistivity, water temperature and water density. Moreover, the instrument was calibrated according to the manufacturer's instructions prior to undertaking the water quality survey along the river transect.

Figure 63. Using the InSitu Aquatroll multi-parameter sonde.

Results and Discussion: Water Quality

All water quality parameters were below the maximum contamination levels (MCL) for drinking-water quality, indicating good river quality status[72]. There were considerable differences in the water quality parameters between Angola and Zambia (Table 14), reflecting seasonal changes and variations in river flow. Seasonal attributes, particularly rainfall, leads to higher river flow and surface runoff, which introduces more organic compounds into the river. This influences water quality parameters, including specific conductivity, TDS and turbidity.

Table 14. Summary of water quality results measured on the Lungwebungu River in Angola and Zambia.

Water quality parameter	Angola	Zambia
Temperature (°C)	18.9 ± 0.7	29.3 ± 1.1
Specific conductivity (µS/cm)	12.0 ± 1.4	22.3 ± 4.3
Total dissolved solids (mg/L)	0.01 ± 0.001	0.01 ± 0.005
Salinity((PSU)	0.004 ± 0.006	0.006 ± 0.004
pH	7.1 ± 0.7	6.7 ± 0.1
Dissolved oxygen (mg/L)	7.9 ± 0.5	5.3 ± 0.8
Turbidity (NTU)	2.8 ± 0.8	14.3 ± 43.1

Temperature

There was a distinct difference in average river temperature between Angola (18.9 ± 0.7 °C) and Zambia (29.3 ± 1.1 °C), primarily because of seasonality (Table 14,Figure 64). At a catchment scale, river temperature variations are caused by variations in climate, geography, biography, and vegetation[73]. At a

[72] WHO. 2008. Guidelines for drinking-water quality. Volume 1. Geneva.

[73] Dallas, H. 2008. Water temperature and riverine ecosystems: an overview of knowledge and approaches for assessing biotic responses, with special reference to South Africa. *Water Sa*.

local scale, factors such as altitude, flow rates, and riparian vegetation play a significant role[74,75]. As such, some variation in the water temperature may be attributed to the high altitude at the source of the river and the forest cover in Angola.

Spatial variation in temperature were observed in Angola (17.2–21.0 °C) and Zambia (26.5–31.1 °C) — attributed to weather conditions and the time-of-day sampling occurred. Fluctuations in water temperature along the river can also be attributed to channel morphology and depth, as variations in the shape of the river and depth can influence the amount of solar radiation absorbed and retained by the water.

Specific Conductivity and TDS

Specific conductivity and TDS are representative of conductive dissolved ions in the river water, some of which are associated with pollutants. It is important to note that eight specific conductivity and TDS recordings had readings of 0 for the Zambian transect — these were considered erroneous and removed from the analysed data. Specific conductivity was higher in Zambia (22.3 ± 4.3 µS/cm) compared to Angola (12.04 ± 1.4 µS/cm), while turbidity was similar in both regions (Table 14,Figure 64). A higher specific conductivity and turbidity, as observed in Zambia, can be attributed to the higher run-off from the increased rainfall during the wet season[76,77], which carries dissolved ions from silt and sand, or from agriculture[78].

Specific conductivity showed a slight increase downstream in both Angola and Zambia (Figure 64), while TDS also increased in Zambia. The downriver enrichment in the dissolved ions can be attributed to: i) progressive contribution of bird colonies along the river; ii) evaporation of river water during transit resulting in evapoconcentration of ions in the water, or iii) the contribution of dissolved ions by tributaries feeding the Lungwebungu River.

pH

pH is a key indicator of water quality and the level of pollution in a river. The river pH in Zambia (6.7 ± 0.1) was slightly more acidic compared to Angola (7.1 ± 0.7). Additionally, site variations in pH were observed along the river. Fluctuations in the pH are likely a result of diurnal variations in biological activity and photosynthesis within the river — changing the CO_2 levels in the water. In addition, spatial variation may be explained by contribution of water from tributaries within the floodplain.

Turbidity

Factors such as suspended silt and clay, organic matter, and plankton influence the turbidity of a river[79]. There were distinct seasonal differences in turbidity between Angola (2.8 ± 0.8) and Zambia (14.3 ± 43.1). Increased runoff during the rainy season carries clay particles, silt, sand, and organic and biological salts from agricultural sites, resulting in a higher turbidity[80,81]. There were sites of elevated turbidity along the lower Lungwebungu in two areas near the Angolan-Zambian border (Figure 64), which may be attributed to the contribution of inorganic and organic matter and dissolved compounds from surrounding bird colonies, since there are no major tributaries feeding the Lungwebungu River near the Angolan border.

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[74] Eady, B.R., Rivers-Moore, N.A., and Hill, T.R., 2013. Relationship between water temperature predictability and macroinvertebrate assemblages in two South African streams. *South African Journal of Aquatic Sciences*, *38*, 163–174.

[75] Rivers-Moore, N.A., Bezuidenhout, C.N., and Jewitt, G.P.W., 2005. Modelling highly variable daily maximum water temperatures in a perennial South African river system. *African Journal of Aquatic Sciences*, *301*, 55–63.

[76] Wright, R., 1982. Seasonal variations in water quality of a West African river (R. Jong in Sierra Leone). *Revue d'hydrobiologue tropicale*, *15*, 19 –199.

[77] Ogbozige, F.J., Adie, D.B., and Igboro, S.B., 2018. Impact of seasonal variability on river quality. *Futo Journal Series, 4*, 85–98.

[78] Ogbozige, F.J., Adie, D.B., and Igboro, S.B., 2018. Impact of seasonal variability on river quality. *Futo Journal Series, 4*, 85–98.

[79] Sibanda, T., Chigor, V.N., Koba, S., Obi, C.L., and Okoh, A.I., 2014. Characterisation of the physicochemical qualities of a typical rural-based river: ecological and public health implications. *International Journal of Environmental Science and Technology, 11,* 1771–1780.

[80] Ogbozige, F.J., Adie, D.B., and Igboro, S.B., 2018. Impact of seasonal variability on river quality. *Futo Journal Series*, *4*, 85–98.

[81] Woldbeab, B., Ambelu, A., Mereta, S.T., and Beyene, A., 2018. Effect of watershed land use on tributaties' water quality in the east African Highland. *Environment Monitoring and Assessment, 191*.

Water Quality Summary

Our findings offer an analysis of water quality of the Lungwebungu River during the wet and dry season. The measured parameters indicate that the water quality of the river is acceptable in both seasons. The difference in water quality parameters between the two transects can be attributed to seasonal differences, as these parameters are influenced by factors such as temperature and rainfall. However, the higher pH and dissolved oxygen in the Angola can also be attributed to natural variation of the river. This highlights the importance of conducting surveys in concurrent seasons to enable a direct comparison of water quality between the two regions.

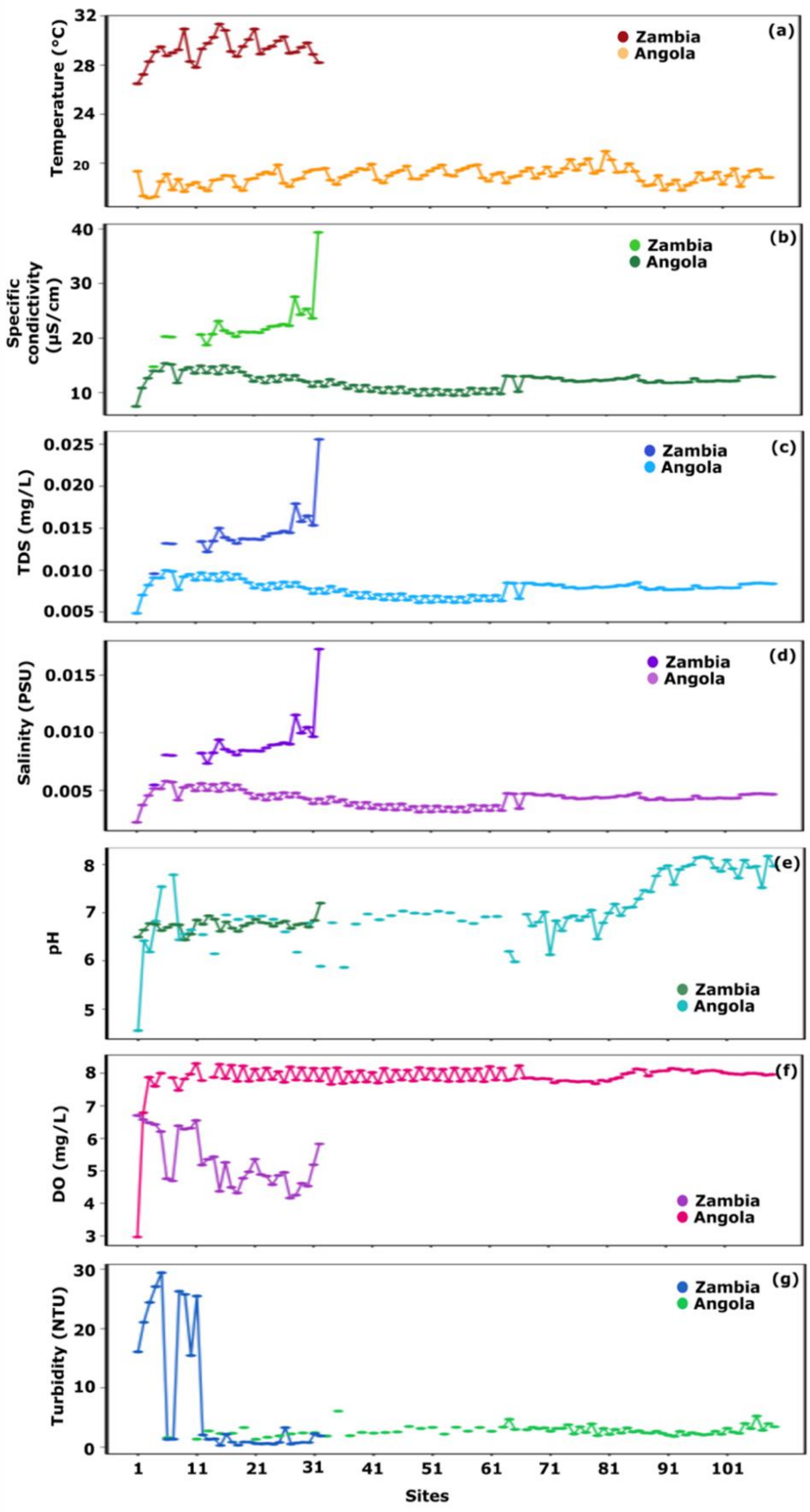

Figure 64. Spatial plots of water temperature (°C), specific conductivity (µS/cm), total dissolved solids (TDS, mg/L), salinity (PSU), dissolved oxygen (DO, mg/L), and turbidity (NTU) measured along the different sampling sites (x-axis) on the Lungwebungu River.

1.4 FIXED SITE MONITORING (EVERY 50–75km)

Site monitoring was conducted every ~50–75 km along the river, where eDNA samples were collected and a benthic macroinvertebrate survey was conducted. A total of 14 intensive monitoring sites were sampled along the Lungwebungu River — nine in Angola and five in Zambia (Figure 65).

Figure 65. eDNA and ZISS sampling was conducted every 50 - 75 km at fixed research sites along the Angolan (black) and Zambian (blue) transect of the Lungwebungu River.

Environmental DNA

Methods: Environmental DNA

Triplicate eDNA samples were collected from the river water at sixteen fixed monitoring sites by filtering up to one litre through a 0.22 µm Sterivex™ filter with a sterile 50 ml piston syringe (Figure 66). Once the filter was full, all excess water was removed by pushing air through. To preserve the DNA and prevent contamination, 2 ml of ATL lysis buffer (Qiagen) was added to the filter and the ends were sealed using Helapet combi-caps and biofilm. Moreover, fresh surgical gloves were worn between each sampling iteration. To detect any contamination of the buffer solution or any other equipment used, field blanks were processed on two occasions by filtering one litre of distilled water. Once field work was concluded, all samples were transported a specialised eDNA extraction laboratory at the Wild Bird Trust facilities in Maun.

Extraction of DNA from samples was conducted in an ultra-clean, DNA free room using the DNeasy Blood and Tissue kit (Qiagen) for water samples, following a modified protocol[82,83,84]. Surfaces were sterilized with a combination of high intensity UV for 30 minutes prior to the extraction process, as well as frequent wiping with a 10% bleach solution. To account for contamination, DNA extractions were carried out on negative controls in the lab using Ultra Clean DNA free water.

The 12S rNA gene was used for metabarcoding, as it is considered an effective marker for assessing fish communities[85,86]. Samples were amplified using the polymerase chain reaction (PCR), using MiFish primers. Following sequencing, the DNA sequencing data was processed by filtering low-quality reads to

[82] Czachur M.V., et al. 2022. Novel insights into marine fish biodiversity across a pronounced environmental gradient using replicated environmental DNA analyses. Environmental DNA 4, 181–190.
[83] Rossouw et al., in review. Where and when to sample: Investigating spatio-temporal variation of community assemblages in kelp forest systems with eDNA metabarcoding. npj biodiversity.
[84] Von der Heyden S et al. 2023. Environmental DNA biomonitoring in biodiversity hotspots: A case study of fishes of the Okavango Delta. Environmental DNA 5, 1720–1731. 4.
[85] Miya, M., 2022. Environmental DNA metabarcoding: a novel method for biodiversity monitoring of marine fish communities.
[86] Miya, M., Gotoh, R.O., and Sado, T., 2022. MiFish metabarcoding: a high-throughput approach for simultaneous detection of multiple fish species from environmental DNA and other samples. Fisheries Science, 86, 939–970.

generate Amplicon Sequence Variants (ASVs)[87]— unique DNA sequences that were identified through amplification. Amplicon Sequence Variants were assigned taxonomic identities, which form Molecular Operational Taxonomic Units (MOTUs) — clusters of DNA sequences based on similarity thresholds[88]. The similarity thresholds used for taxonomic-level identifications were as follows: species (98 %), genus (95 %), family (80 %), order (85 %), class (80 %) and phylum (70%).

To refine taxon assignments, particularly unidentified MOTUs, sequences were used to create a family-level phylogeny. Sequences were aligned, and a neighbour-joining tree was constructed using Kimura two-parameter distances in Mega[89]. Taxa were reassigned as follows: for MOTUs that formed a monophyletic group comprising a single genus, the unidentified MOTUs were assigned the genus name and 'sp.' and numbered consecutively (e.g., *Petrocephalus* sp. 1, sp. 2). MOTUs only identified to family-level were assigned the family name and 'sp' and numbered consecutively (e.g., Poecillidae sp. 1, sp. 2)[90].

Figure 66. eDNA collection.

Results and Discussion: Environmental DNA

The Lungwebungu River is characterized by a rich fish diversity, with 15 families and 21 genera identified by the eDNA metabarcoding of the 12S gene. This is comparable to the 14 families and 29 genera identified by traditional sampling methods. The most represented families — comprising the most detected taxa by eDNA metabarcoding — include Mormyridae, Cyprinidae and Cichlidae (Figure 67). The most common genera detected across all sites include *Hydrocynus*, *Coptodon*, *Marcusenius* and *Heteromormyrus* (Figure 68). Conversely, *Pollimyrus* and *Schilbe* comprise the least detected genera.

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[87] Von der Heyden S et al. 2023. Environmental DNA biomonitoring in biodiversity hotspots: A case study of fishes of the Okavango Delta. Environmental DNA 5, 1720–1731. 4.
[88] Von der Heyden S et al. 2023. Environmental DNA biomonitoring in biodiversity hotspots: A case study of fishes of the Okavango Delta. Environmental DNA 5, 1720–1731. 4.
[89] Tamura, K., Stecher, G., and Kumar, S., 2021. MEGA11 :Molecular Evolutionary Genetics Version 11. Molecular Biology and Evolution, 38, 3022–3027.
[90] Von der Heyden S et al. 2023. Environmental DNA biomonitoring in biodiversity hotspots: A case study of fishes of the Okavango Delta. Environmental DNA 5, 1720–1731. 4.

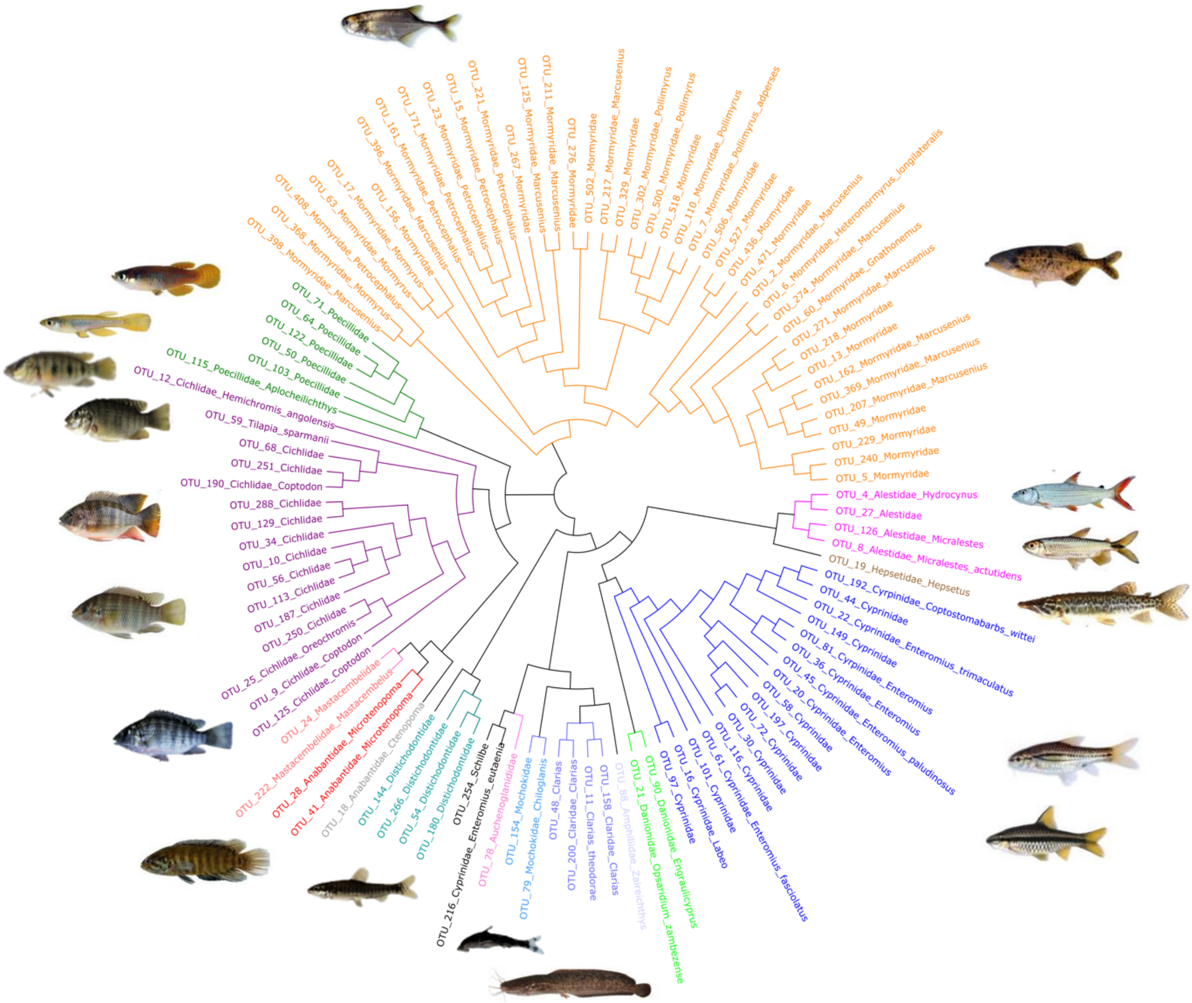

Figure 67. Family-level phylogeny showing the most common families detected by eDNA metabarcoding.

There was spatial variation in detections of certain genera. For example, *Clarias, Ctenopoma* and *Microctenopoma* were commonly detected in Zambia but did not feature significantly in Angolan samples. Conversely, *Mastacembelus*, *Osparidium*, and *Chiloglanis* were generally detected in Angola (Figure 68). This may be attributed to seasonality and habitat preferences. For example, both *Mastacembelus* and *Opsaridium zambazense* inhabit areas with abundant vegetation cover, and may have been deep within the wetland vegetation in Zambia at the time of sampling.

Comparison with traditional sampling methods

Environmental DNA metabarcoding may be more effective than traditional techniques for sampling fish biodiversity in river systems, as it is cost-effective, can cover a broader habitat range, explore inaccessible aquatic environments, and detect new or rare species[91]. For example, eDNA metabarcoding successfully detected species that were not collected during the fish sampling survey. However, several of the taxa detected by the eDNA metabarcoding were also recorded during the fish sampling survey, including *Hemichromis angolensis*, *Tilapia sparmanii*, *Enteromius eutania* and *Enteromius paludinosus.* These will be used as voucher specimens to construct an eDNA database for the region, further enhancing the power of this unique sampling tool and highlighting the importance of sampling using both traditional and novel genetic methods.

[91] Jerde, C.L., 2019. Can we manage fisheries with the inherent uncertainty from eDNA. *Journal of Fish Biology*, *98*, 341– 53.

Limitations of eDNA metabarcoding

Several of the taxa detected through eDNA metabarcoding were only identified to family-level, such as cichlids, Cyprinidae, Mormyridae and Poecillidae. In addition, there were many genus-level identifications, including *Coptodon*, *Eutania*, *Marcusenius* and *Petrocephalus*. Several fish species sampled during the survey belong to these genera, suggesting that these species may correspond to these taxa (Table 15). In addition, some families were only detected by the fish sampling survey, such as *Claroteidae*. Moreover, eDNA metabarcoding detected species that are unlikely to be present in the river, such as *Macrusenius senegalensis*, and marine fishes. This misidentification is likely due to genetic similarities between closely related species[92].

Additional resolution can be obtained using species-specific primers[93] or using multiple genetic markers, which could increase the likelihood of species detection or address shortcomings associated with specific gene regions[94]. As a result, a local reference sequence database containing species known to- or likely to-occur at the study site is under development in partnership with the American Museum of Natural History (AMNH).

[92] Shaw, J.L.A., Clarke, L.J., Wedderburn, S.C., Barnes, T.C., Weyrich, L.S., and Cooper, A., 2019. Comparison of environmental DNA metabarcoding and conventional fish survey methods in a river system. *Biological Conservation*, *197*, 131–138.
[93] Von der Heyden S et al. 2023. Environmental DNA biomonitoring in biodiversity hotspots: A case study of fishes of the Okavango Delta. Environmental DNA 5, 1720–1731. 4.
[94] Shaw, J.L.A., Clarke, L.J., Wedderburn, S.C., Barnes, T.C., Weyrich, L.S., and Cooper, A., 2019. Comparison of environmental DNA metabarcoding and conventional fish survey methods in a river system. *Biological Conservation*, *197*, 131–138.

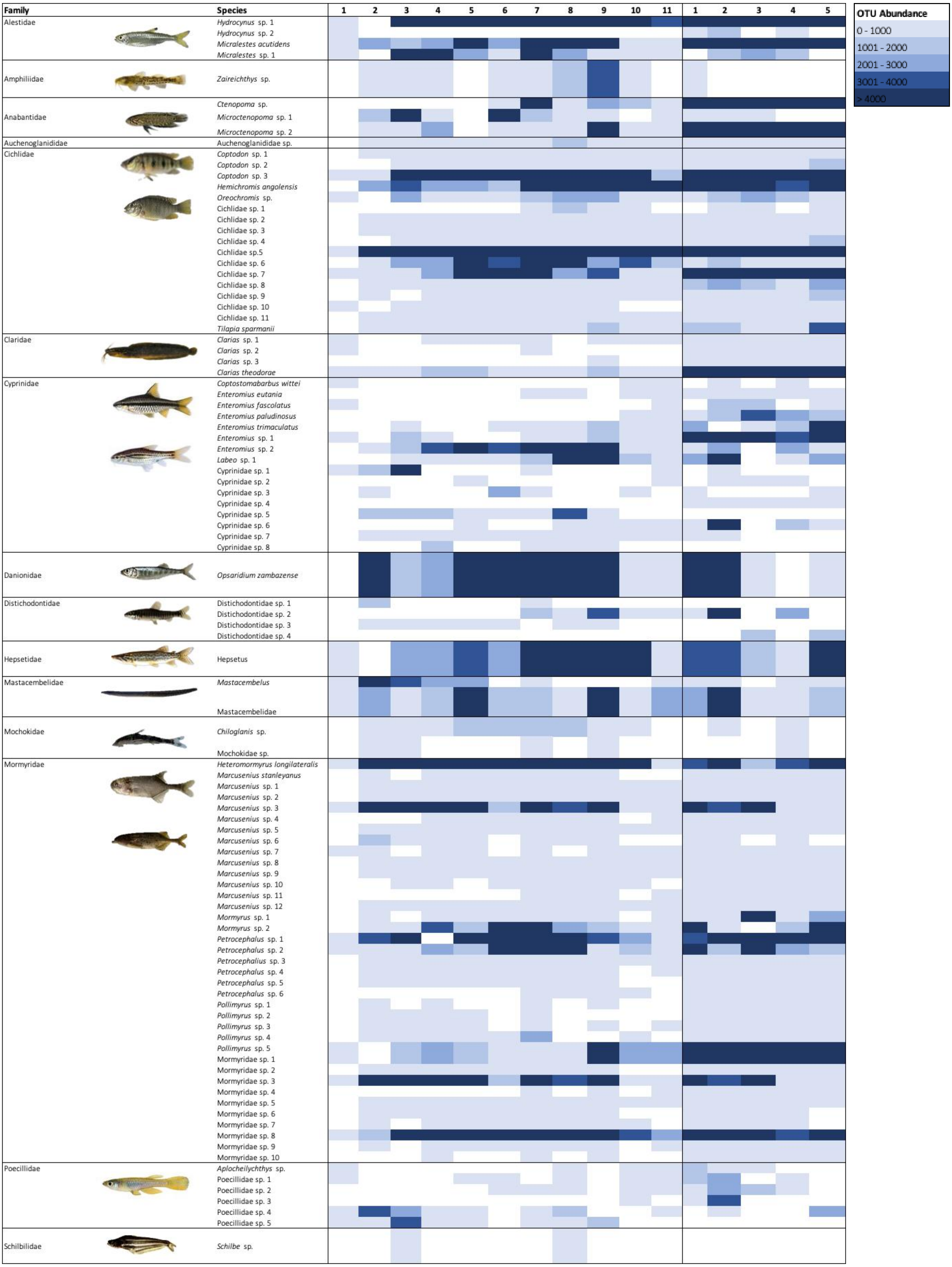

Figure 68. The abundance of OTUs across sites on the Lungwebungu Basin in Angola and Zambia.

Table 15. Fish taxa identified using eDNA metabarcoding and the fish sampling survey that are classified in the same genera.

Family	**Identified fish taxa**	
	eDNA	**Fish sampling survey**
Alestidae	*Hydrocynus* sp.	*Brycinus lateralis*
	Micralestes acutidens	
	Micralestes sp.	
Amphillidae	*Zaireichthys* sp.	*Zaireichthys kavangoensis*
		Amphillus cubangoensis
Anabantidae	*Ctenopoma* sp.	
	Microctenopoma sp. *1*	*Microctenopoma steveboyesi*
	Microctenopoma sp. 2	
Cichlidae	*Coptodon* sp. 1	*Coptodon rendalii*
	Coptodon sp. 2	
	Coptodon sp. 3	
	Hemichromis angolensis	*Hemichromis angolensis*
		Hemichromis elongatus
	Oreochromis sp.	*Oreochromis marcochir*
		Pharyngochromis acuticeps
		Pharyngochromis sp.
		Pseudocrenilabrus philander
		Sargochromis carlottae
		Serranochromis sp.
	Tilapia sparmanii	*Tilapia sparmanii*
Cyprinidae	*Enteromius fasciolatus*	*Enteromius* sp.
	Enteromius sp. 1	*Enteromius afrovernayi*
	Enteromius sp. 2	*Enteromius barnadi*
	Enteromius eutania	*Enteromius eutania*
	Enteromius sp. 3	*Enteromius multilineatus*
	Enteromius paludinosus	*Enteromius paludinosus*
	Enteromius trimaculatus	*Enteromius radiatus*
		Enteromius thamakanensis
	Labeo sp.	*Labeo cylindricus*
Danionidae	*Osparidium zambazense*	*Osparidium zambezense*
Distichodontidae	Distichodontidae sp. 1	*Nannocharax dageti*
	Distichodontidae sp. 2	*Nannocharax lineostriatus*
	Distichodontidae sp. 3	*Nannocharax multifasciatus*
	Distichodontidae sp. 4	
Mastabemlidae	*Mastacembelus* sp.	*Mastacembelus frenatus*
Mochokidae	*Chiloglanis* sp.	*Chiloglanis fasciatus*
	Mochokidae sp.	*Synodontis macrostigma*
		Synodontis macrostoma

Table 15 (cont.). Fish taxa identified using eDNA metabarcoding and the fish sampling survey that are classified in the same genera.

Family	**Identified fish taxa**	
	eDNA	**Fish sampling survey**
Mormyridae		*Cyphomyrus cubangoensis*
	Heteromormyrus longilateralis	*Heteromormyrus szaboi*
	Marcusenius stanleyanus	*Marcusenius moorii*
	Marcusenius sp. 1	*Marcusenius altisambesi*
	Marcusenius sp. 2	
	Marcusenius sp. 3	
	Marcusenius sp. 4	
	Marcusenius sp. 5	
	Marcusenius sp. 6	
		Micralestes acutidens
	Petrocephalus sp.1	*Petrocephalus longicapitis*
	Petrocephalus sp. 2	*Petrocephalus okavangensis*
	Petrocephalus sp.3	
	Petrocephalus sp.4	
	Petrocephalus sp.5	
	Petrocephalus sp.6	
	Pollimyrus sp. 1	*Pollimyrus marianne*
	Pollimyrus sp. 2	
	Pollimyrus sp. 3	
	Pollimyrus sp. 4	
	Pollimyrus sp. 5	
Schilibidae	*Schilbe* sp.	*Schilbe intermedius*
		Schilble yangambianus

Aquatic Macroinvertebrates

The Zambian Invertebrate Scoring System (ZISS) is a standardized, rapid, field-based bioassessment tool assessing aquatic macroinvertebrate fauna at family-level to determine the health of perennial rivers in Zambia. The ZISS is based on the South African Scoring System (SASS) and, if repeated over time, can be used to assess the ecological state of a river.

The ZISS protocol scores the health of a site based on the sensitivity scores of each macroinvertebrate species recorded at the site. Generally, higher ZISS scores indicate healthier and more diverse aquatic habitats. Additional metrics for comparison include the total number of taxa recorded and the average score per taxon (ASPT). Given that most of the Lungwebungu is non-wadable, the ZISS protocol focuses exclusively on aquatic and marginal vegetation that can be safely sampled from the banks or from a boat.

Methods: ZISS

Benthic macroinvertebrate sampling was conducted at 14 sites along the river. These corresponded with the intensive research sites above. To conduct the ZISS assessments, an invertebrate d-net was used to sweep marginal and aquatic vegetation for a total of 2 minutes and 15 minutes were spent sorting and identifying each collection. These sites were spaced roughly 50–75 km apart. The total number of taxa, the average score per taxon (ASPT) and the final ZISS score were then calculated and recorded. Representative samples of each family were retained in 95% ethanol and transported to the Botswana

Wild Bird Trust office in Maun for identification verification.

Figure 69. The ZISS sampling sites along the Lungwebungu River.

Results and Discussion: ZISS

The overall mean ZISS score of the Lungwebungu River was 75.1 ± 23.1, with a high range (28–121). Angola had a higher average ZISS score (86 ± 23.1) than Zambia (75 ± 23, Table 16). This is typical of high order streams in the Zambezi headwaters ecoregion and suggests a low level of river disturbance and pollution[95]. This is particularly relevant given the good water quality that was detected on the river.

The number of taxa ranged from 5–19. More taxa were detected at each site in Angola (N = 14) than in Zambia (N = 10). Since the number of macroinvertebrate taxa are influenced by habitat heterogeneity, such as patchiness, patch shape and the number of substrates[96], the lower ZISS score in Zambia could be a result low substrate diversity due to the steep riverbanks whereby sand, gravel and mud were only present at some of the sites, resulting in low habitat diversity and subsequent lower macroinvertebrate diversity.

The average score per taxon (ASPT) ranged from 4.5–6.9, with a higher ASPT on the Angolan transect (mean = 6.0) compared to the Zambian transect (mean = 5.3). In addition to seasonal influences on water quality, habitat availability and flow rate, the lower ZISS and ASPT score observed on the Zambian Lungwebungu is likely attributed to the relatively homogenous wetland vegetation along the river. In addition, the dense and inundated wetland vegetation restricted sampling efforts to the marginal vegetation.

[95] Dallas et a. 2018. Zambian Invertebrate Scoring System (ZISS): A macroinvertebrate-based biotic index for rapid bioassessment of southern tropical African river systems. African Journal of Aquatic Science.
[96] Biesel, J., Usseglio-Polatera, P., and Moreteau, J., 2000. The spatial heterogeneity of a river bottom: a key factor determining macroinvertebrate communities. *Hydrobiologia*, *422*, 163 – 171.

Figure 70. The results of a ZISS sampling effort on the Lungwebungu River. The sample includes species of the Coenagrionidae (bottom-right — long, forked tails), Libellulidae (top left) and Corixidae (top right — beetle).

Table 16. Summary of aquatic invertebrate sampling results. ZISS = Zambian Invertebrate Scoring System. ASPT = Average Score per Taxon.

ZISS Site	Latitude	Longitude	No. of Taxa	ASPT	ZISS Score
Angola					
1	-12.5841	18.6677	12	6.3	75
2	-12.6222	18.8141	15	5.9	88
3	-12.6728	19.1289	15	5.8	87
4	-12.4860	19.4648	19	5.3	100
5	-12.3959	19.7962	11	6.3	69
6	-12.6396	20.2491	15	6.2	93
7	-12.7585	20.7984	16	6.9	111
8	-13.3068	21.6302	10	6.2	62
9	-13.3907	21.9139	16	5.5	88
		AVERAGE	**14**	**6.0**	**86**
Zambia					
1	-13.4657	22.0261	11	4.5	49
2	-13.6419	22.3656	5	5.6	28
3	-14.0003	22.6498	10	4.6	46
4	-14.1042	22.8935	12	5.5	66
5	-14.3168	23.2060	14	6.4	89
		AVERAGE	**10**	**5.3**	**55**
		OVERALL AVERAGE	**12**	**5.8**	**75**

1.5 OPPORTUNISTIC SAMPLING

River Discharge

River discharge — the volume of water flowing per unit of time — is vital for understanding river dynamics. In addition, key metrics such as river width, mean flow velocity, and maximum depth not only contribute to scientific understanding of river processes but also inform effective water resource management strategies in diverse environmental contexts.

Methods: Discharge

A SonTek RS5 Acoustic Doppler Current Profiler (ADCP) was used to measure river discharge at nine sampling sites in Angola, and seven sampling sites in Zambia (Figure 71). This included measurements of flow rates, depth and river profile. The ADCP was towed behind a dugout canoe when conducting measurements (Figure 72Figure 72). At each ADCP site, a minimum of two transects per site was run, or until the coefficient of variation between transects was < 0.05.

The ADCP was deployed on average every ~100 km and at places of interest, including the start and end of an expedition, and at major confluences (Figure 71). Sites that were considered suitable for ADCP sampling included those with: i) smooth laminar flow without bends or turns in the river; and ii) no obstructions or hazards including downed trees or current eddies.

Figure 71. River discharge sampling sites along the Lungwebungu River.

Figure 72. The ADCP is pulled across the upper Lungwebungu River (top) and towed across the river by dugout canoe (bottom).

Results and Discussion: Discharge

River discharge was recorded during the dry season in Angola, and during peak flow in the wet season in Zambia. This provides a useful comparison of the volume of water entering Zambia from Angola in both the wet and dry seasons. For example, the river discharge entering from the Angolan border (104.9 m^3/s) during the dry season was considerably lower than the river discharge recorded at the Zambian border during the wet season (201.4 m^3/s).

Table 17. Acoustic Doppler Current Profiler (ADCP) measurements along the Lungwebungu River

ADCP Site	Latitude	Longitude	Q (m^3/s)	Area (m^2)	Mean speed (m/s)	Max depth (m)
Angola						
1	-12.5838	18.6655	8.2	12.7	0.64	2.1
2	-12.6217	18.8139	13.1	20.1	0.65	2.5
3	-12.6594	18.9252	21.6	29.2	0.74	2.8
4	-12.4858	19.4648	36.8	49.7	0.74	3.1
5	-12.3558	19.6518	55.6	81.9	0.68	2.4
7	-12.7491	20.7319	86.8	109.0	0.80	6.1
8	-13.0804	21.3462	90.4	149.3	0.61	2.0
9	-13.3168	21.8183	104.9	145.5	0.72	3.0
Zambia						
1	-13.46570	22.02616	201.4	288.6	0.69	3.2
2	-13.69722	22.41845	213.1	261.0	0.82	2.9
3	-14.00031	22.64982	257.8	362.9	0.71	3.6
4	-14.10429	22.89353	288.3	335.4	0.86	4.2
5	-14.31682	23.20603	335.7	426.7	0.79	6.2
Kashiji River	-14.29708	23.11118	75.6	413.2	0.18	5.3
Zambezi River	-14.31597	23.20708	1471.1	1593.5	0.92	6.4

The Upper Zambezi River is fed through a series of tributaries from the Angolan and Zambian highlands including the Luena, Kabompo and Lungwebungu Rivers — each of these contributing a significant amount of water to the Zambezi River, but at different periods in the year. In particular, the buffering effect of the extensive Lungwebungu River floodplain in Zambia plays a major role in regulating the Zambezi River's discharge and flood pulse.

To measure the relative contribution of the Lungwebungu River to the flow of the Zambezi, discharge was measured in the Zambezi River just upstream from the Lungwebungu – Zambezi confluence. Here, the Zambezi River was flowing at 1,471.1 m^3/s and the Lungwebungu River at 335.7 m3/s (Table 17). Based on this measurement, in March 2023, the Lungwebungu River contributed ~20% of the flow of the Zambezi River before it enters the Barotse Floodplains. In a repeat measurement during a subsequent dry-season expedition in May 2023, the Lungwebungu River was flowing at 193.9 m^3/s and the Zambezi was flowing at 1,194.2 m^3/s, indicating a slightly reduced contribution of ~16%.

By contributing a further 16–20% to the flow of the Zambezi River directly upstream of the Barotse Floodplains, the Lungwebungu River has a direct and tangible impact on the seasonal flood pulse and year-round inundation of this system. Dam development on the Lungwebungu River — or any of the Upper Zambezi tributaries — will drastically alter the flow dynamics of the Upper Zambezi system. This will in turn affect downstream communities that depend on seasonal flow to regulate fisheries productivity. Moreover, biodiversity in the system is intricately linked to the ebb and flow of water on the floodplains. As a result, damming of the Lungwebungu River should be avoided at all costs.

Bat recorder deployments

Bat call recordings were obtained at five camp sites during the river expedition in Zambia using a Wildlife Acoustics Song Meter SM4BAT-FS detector. To ensure peak activity was captured the recorders were set to begin recording 30 minutes before sunset and stop recording 30 minutes after sunrise. A total of at least 285 recordings were made over the course of the transect. The data has been sent to Dr. Siena Weier and Professor Peter Taylor as part of a larger bat diversity study of the KAZA landscape, which includes the entire Okavango Basin and parts of the Zambezi.

Fish Sampling

The freshwater fishes of the upper Zambezi are relatively well studied[97,98,99], with a total of 165 species of recorded from the basin, most of which are located in the Zambian portion of the Upper Zambezi system[100]. Although Angola has ~358 species of freshwater fishes (22% endemism), historical fish sampling efforts in Angola have been limited. As a result, there remains a dearth of information regarding the freshwater fish biodiversity of the Lungwebungu River, particularly in Angola.

In April 2018, the Wild Bird Trust conducted a short, vehicle-based, expedition to the Lungwebungu headwaters, focused on biodiversity sampling and peat core collections. The fish team, led by Prof. Skelton of the South African Institute of Aquatic Biodiversity (SAIAB), surveyed nine sites in the upper Lungwebungu River. This was the first in-depth assessment of fish biodiversity in the Angolan Lungwebungu River and provided a wealth of information. The expedition recorded 37 fish species, four of which were potentially new to science, including Clariallabes, serranochromine cichlids, and a dwarf climbing perch[101]. Moreover, seven of the fish species sampled represent new records for the country.

Methods: Fish sampling

The TWP transect of the Lungwebungu River between 2022 and 2023 sampled fish diversity at 18 sites — 13 in Angola and 5 in Zambia, including the confluence with the Zambezi River. Primary sampling techniques included: fyke net, dip net, and a freshwater crayfish trap (Figure 73). Once captured, fish were anaesthetized with clove oil, photographed and preserved in 10% formalin. Tissue samples were collected from two representatives per species and preserved in 99%. These samples are intended for future DNA analysis and the creation of a reference library to facilitate eDNA analyses.

Figure 73. The dip-net used for fish sampling.

Results and Discussion: Fish sampling

[97] Jackson, P.B.N. 1961. Ichthyology. The fish of the Middle Zambezi. Kariba Studies 1: 1–36.
[98] Bell-Cross G. and Minshull J.L. 1988. The fishes of Zimbabwe. Harare: National Museums and Monuments of Zimbabwe.
[99] Tweddle D. 2010. Overview of the Zambezi River System: Its history, fish fauna, fisheries, and conservation. Aquatic Ecosystem Health & Management, 13:3, 224-240.
[100] Timberlake, J., 2000. Biodiversity of the Zambezi Basin.
[101] Skelton P.H. 2019. The Freshwater Fishes of Angola. In: Huntley, B., Russo, V., Lages, F., Ferrand, N. (eds) Biodiversity of Angola. Springer, Cham.

A total of 245 specimens representing 47 species were collected on the Lungwebungu River. Most of the fish collected were barbs (~39%), catfish (~16%), cichlids (~12%) and mormyrids (~11%,Figure 74). Of the species recorded, 12 were present along both transects of the Lungwebungu River, with 28 and 7 species unique to the Angolan and Zambian sections of the river, respectively. The higher abundance and diversity of fish present along the Angolan stretch of the Lungwebungu River could be a result of seasonality or habitat diversity. However, the Angolan expedition was considerably longer than the Zambian expedition, resulting in greater sampling effort that likely accounts for this difference.

Given that there are very few biogeographic barriers between the upper Zambezi and the Lungwebungu River, it is somewhat unsurprising that most of the species collected are associated with the Zambezian Headwaters Freshwater Ecoregion, including speciose endemic Synodontis catfishes and the Serranochromine cichlids. Moreover our results indicate a strong faunal affinity between the Lungwebungu and the Okavango (e.g. mormyrids of the genera *Hippopotamyrus, Marcusenius*, *Petrocephalus*, and *Pollimyrus*, and the sand catlets*, Zaireichthys* species). The presence of *Enteromius chiumbeensis* in the Lungwebungu watershed (first documented by the land-based team in 2018), suggests a historical connection with the Congo and coastal basins.

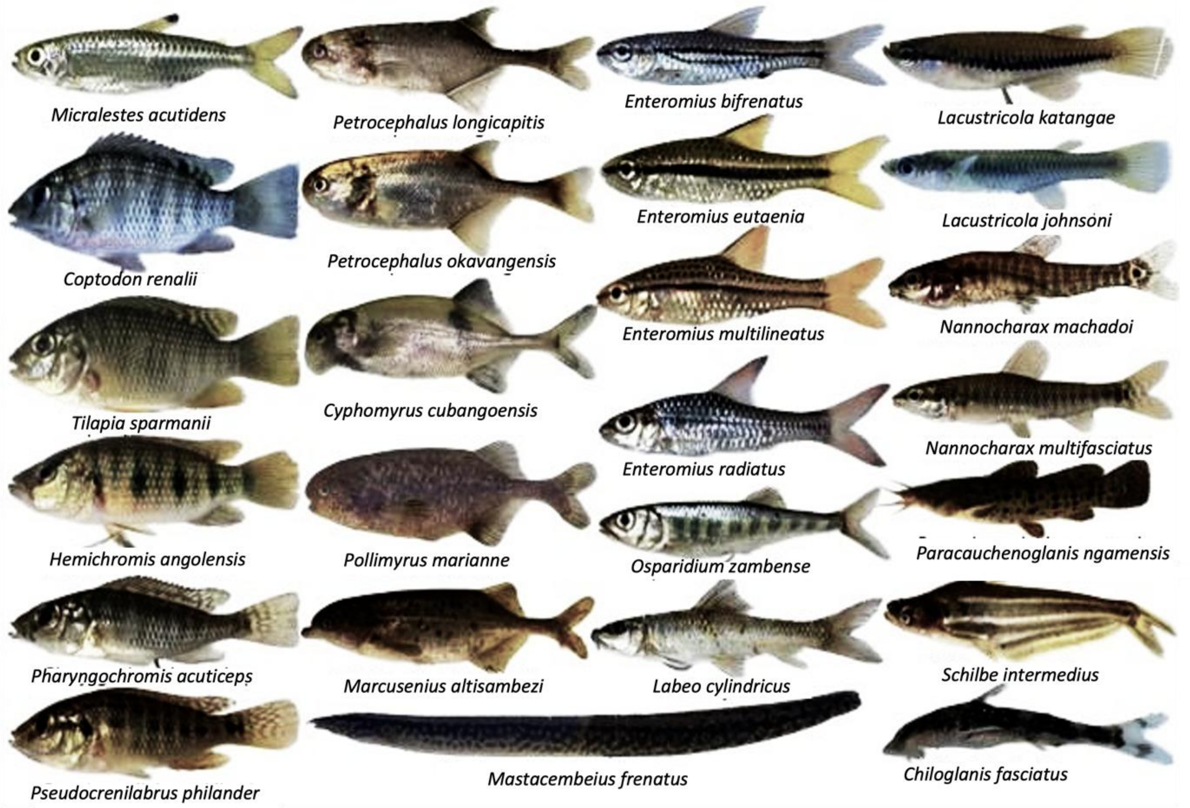

Figure 74. Some of the fishes collected on the Lungwebungu River.

Fish specimens were transported to the American Museum of Natural History (AMNH) for identification verification and to be accessioned into their ichthyology collection. For a full description of fish species collected refer to **Error! Reference source not found.**.

Invasive Crayfish Survey

To assess the presence of invasive crayfish (*Cherax quadricarinatus*), a yabby trap was baited with dry dog food and set overnight at four campsites along the river transect (same sites as the fish sampling except the confluence with the Zambezi). No invasive *Cherax* crayfish were collected along the transect of the Lungwebungu River. However, this does not mean that *Cherax* sp. do not exist within the system. *Cherax* crayfish were collected on the Zambezi mainstream in the nearby Barotse Floodplains, and given there are no major biogeographical barriers between the Barotse and the Lungwebungu floodplains, it is highly likely that the *Cherax* crayfish have already, or will eventually, colonize the Lungwebungu River. As a result, it is critical to continue detection monitoring for *Cherax* crayfish within the river.

1.6 SATELLITE ANALYSES

MODIS Fire RS Satellite Analysis

Methods: MODIS Fire RS Satellite Analysis

The burned area frequency between 2000 and 2023 of the Lungwebungu catchment was extracted from the MCD64A1.061 MODIS Burned Area Monthly Global 500m product[102]. A total of six burned area frequency categories were included in the analysis. Considering that the Lungwebungu River expedition was conducted over two separate years in different seasons, the burned area for 2022 and 2023 were also extracted for the Lungwebungu catchment and its surrounds. These were grouped into monthly categories for each year. It must be noted that, although this product does estimate burn area with accuracy, the size of burn areas must be greater than 500 m to be recorded. As a result, some smaller fires may not be identified by this product.

Results: MODIS Fire RS Satellite Analysis

Fire frequencies in this region are closely related to landcover[103,104]. According to this satellite product, the burned area frequency reveals that large sections (34%, 16,237 km^2) of the Lungwebungu catchment have not burned since 2000 (Figure 75). These areas are predominantly in Angola, within the miombo woodlands adjacent to the main drainage lines. The largest burn area, representing 32% (15,272 km^2) of the catchment area, had 1–5 burns between 2000 and 2023 (Figure 75). The highest burn frequencies (21–23 burns) occurred near the Angola and Zambia border and within Zambia, which are predominantly covered by grassland and shrubland.

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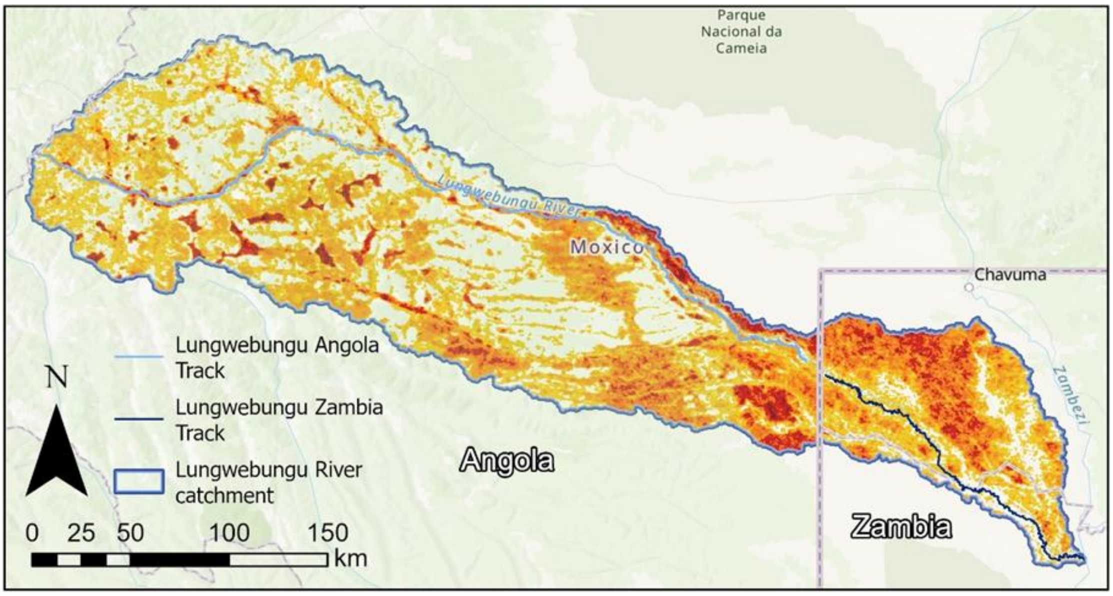
[102] Giglio, L., Justice, C., Boschetti, D., and Roy, D., 2021. MODIS/Terra+Aqua Burned Area Monthly L3 Global 500m SIN Grid V061. Distributed by NASA EOSDIS Land Process Distributed Active Archive Center. Accessed 2024-03-14.

[103] Lourenco, M., Woodborne, S., and Fitchett, J.M., 2023. Fire regime of peatlands in the Angolan Highlands. *Environmental Monitoring and Assessment*, *195*, 78.

[104] Van Wilgen, B.W., De Klerk, H.M., Stellmes, M., and Archibald, S., 2022. An analysis of the recent fire regimes in the Angolan catchment of the Okavango Delta. Central Africa. *Fire Ecology*, *18*, 1–12.



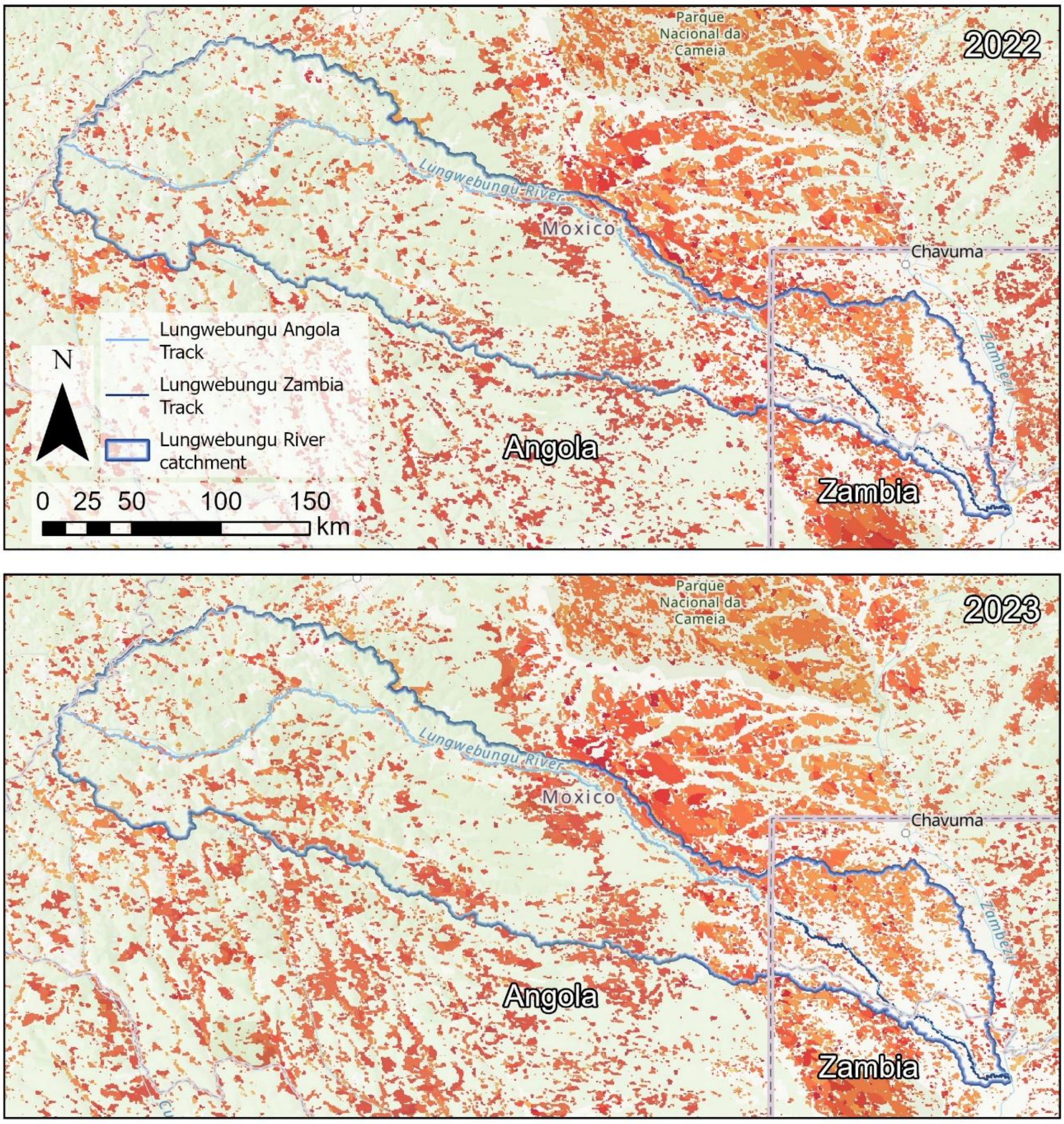
Legend	Burn Frequency (2000-2023)	Area (km^2)	Proportion (%)
	No Burn	16,237	34%
	1-5 Burns	15,272	32%
	6-10 Burns	8,444	17%
	11-15 Burns	5,226	11%
	16-20 Burns	2,940	6%
	21-23 Burns	315	1%
	Total Area	48,433	-

Figure 75. Fire frequency from 2000–2023 within the Lungwebungu River basin. The lower Lungwebungu has the highest frequency of fires.

The burned area per month in 2022 and 2023 indicate that the majority of burning occurs from June to September each year, consistent with literature for this region[105,106] (Figure 76). During 2023, a total of 12,132 km^2 of area was burnt — 2,076.25 km^2 more than during 2022. Most of the burning occurred during August, whereby 110.75 km^2 (33.88%) was burned.

The Angolan portion of the expedition took place during June and July 2022. During these two months, 14.94 % and 22% of the burned area burned, respectively. However, most of burned area occurred after the expedition period in August (22.24%) and September (28.23%). The Zambian portion of the expedition took place in early 2023. However, notable burning only started in June 2023 after the expedition had been completed.

[105] Lourenco, M., Woodborne, S., and Fitchett, J.M., 2023. Fire regime of peatlands in the Angolan Highlands. *Environmental Monitoring and Assessment*, *195*, 78.
[106] Van Wilgen, B.W., De Klerk, H.M., Stellmes, M., and Archibald, S., 2022. An analysis of the recent fire regimes in the Angolan catchment of the Okavango Delta. Central Africa. *Fire Ecology*, *18*, 1–12.



		2022		2023	
Legend	Month	Burn Area (km^2)	Burn (%)	Burn Area (km^2)	Burn (%)
	No Burn	38,455.50	-	36,379.25	-
	January	-	-	-	-
	February	-	-	0.25	0.002%
	March	-	-	-	-
	April	14.75	0.15%	62.75	0.52%
	May	241.50	2.40%	166.00	1.37%
	June	1,502.25	14.94%	2,675.00	22.05%
	July	2,212.25	22.00%	2,710.50	22.34%
	August	2,738.75	27.24%	4,110.75	33.88%
	September	2,899.25	28.83%	2,235.00	18.42%
	October	446.75	4.44%	168.25	1.39%
	November	0.25	0.002%	-	-
	December	-	-	3.50	0.03%
	Total Burn Area	**10,055.75**	**-**	**12,132.00**	**-**

Figure 76. The burned area per month in 2022 and 2023 within the Lungwebungu River basin.

Discussion: MODIS Fire RS Satellite Analysis

Fire plays an integral role in the structure and distribution of ecosystems and biodiversity, and influences biochemical cycles[107]. Fire is the second most important driver of vegetation in savannas after rainfall, shaping the distribution, ecology, and maintenance of African savannas and grasslands [108,109]. The regular burning maintains savanna vegetation that could otherwise transition into closed woodlands[110]. However, wildfires and unregulated burns occur throughout much of southern Africa's biome[111]. In the Angolan Highlands Tower source water region, human activity has resulted in an increasing fire trend[112,113]. The annual fire frequencies are far greater than what would be expected in the absence of anthropogenic ignition[114]. Therefore, the role of human activity and increasing fire frequency remains a concern for this region.

The MODIS fire product provides an indication to the seasonality and burned area during 2022 and 2023. Fires commonly occur during the dry season and is closely related to land cover — moist woodlands experience the least frequent burns and most frequent burns occur in grasslands and shrublands[115,116]. In addition, the peatlands, occurring extensively within the dambos and river floodplains, burn more frequently within the Angolan Water Tower region compared to other land cover types[117]. The type of vegetation burned, along with the timing and frequency of fires, depends on land management practices[118].

Grasslands burn in the early dry season (June to July) to aid in hunting practices and clear village surroundings, and woodlands are burnt late in the dry season (August to September) to prepare fields for the growing season[119,120]. It is hypothesised that humans do not change the fire frequency, but that they can change the amount of landscape that is flammable[121]. Therefore, adaptive fire management strategies are needed in the upper catchments of the Okavango Delta[122,123].

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107 Wie, F., Wang, S., Fu, B., Brandt, M., Pan, N., Wang, C., and Fensholt, R., 2020. Nonlinear dynamics of fires in Africa over recent decades controlled by precipitation. *Global Change Biology*, *26*, 4995–4505.

108 Catarino, S., Romeiras, M.M., Figueira, R., Aubard, V., Silva, J., and Pereira, J., 2020. Spatial and temporal trends of burnt area in Angola: implications for natural vegetation and protected area management. *Diversity*, *12*, 307.

109 Wie, F., Wang, S., Fu, B., Brandt, M., Pan, N., Wang, C., and Fensholt, R., 2020. Nonlinear dynamics of fires in Africa over recent decades controlled by precipitation. *Global Change Biology*, *26*, 4995–4505.

110 Bond, W.J., Woodward, F.I., and Midgley, G.F., 2005. The global distribution of ecosystems in a world without fire. *New Phytologist*, *165*, 525–538.

111 Cassidy, L., Perkins, J.S., and Bradley, J., 2022. Too much, too late: fires and reactive wildfire management in northern Botswana's forests and woodland savannas. *African Journal of Range & Forage Science*, *39*, 160–174.

112 Van Wilgen, B.W., De Klerk, H.M., Stellmes, M., and Archibald, S., 2022. An analysis of the recent fire regimes in the Angolan catchment of the Okavango Delta. Central Africa. *Fire Ecology*, *18*, 1–12.

113 Lourenco, M., Woodborne, S., and Fitchett, J.M., 2023. Fire regime of peatlands in the Angolan Highlands. *Environmental Monitoring and Assessment*, *195*, 78.

114 Cassidy, L., Perkins, J.S., and Bradley, J., 2022. Too much, too late: fires and reactive wildfire management in northern Botswana's forests and woodland savannas. *African Journal of Range & Forage Science*, *39*, 160–174.

115 Van Wilgen, B.W., De Klerk, H.M., Stellmes, M., and Archibald, S., 2022. An analysis of the recent fire regimes in the Angolan catchment of the Okavango Delta. Central Africa. *Fire Ecology*, *18*, 1–12.

116 Lourenco, M., Woodborne, S., and Fitchett, J.M., 2023. Fire regime of peatlands in the Angolan Highlands. *Environmental Monitoring and Assessment*, *195*, 78.

117 Lourenco, M., Woodborne, S., and Fitchett, J.M., 2023. Fire regime of peatlands in the Angolan Highlands. *Environmental Monitoring and Assessment*, *195*, 78.

118 Meller, P., Frazão, R., Lages, F., Jürgens, N., and Finckh, M., 2022. Tipping the scales: how fire controls the balance among functional groups in Angolan grasslands. *African Journal of Range & Forage Science*, *39*, 56–69.

119 Meller, P., Frazão, R., Lages, F., Jürgens, N., and Finckh, M., 2022. Tipping the scales: how fire controls the balance among functional groups in Angolan grasslands. *African Journal of Range & Forage Science*, *39*, 56–69.

120 Teutloff, N., Meller, P., Finckh, M., Cabalo, A.S., Ramiro, G.J., Neinhuis, C., and Lautenschläger, T., 2021. Hunting techniques and their harvest as indicators of mammal diversity and threat in Northern Angola. *European Journal of Wildlife Research*, *67*, 1–16.

121 Van Wilgen, B.W., De Klerk, H.M., Stellmes, M., and Archibald, S., 2022. An analysis of the recent fire regimes in the Angolan catchment of the Okavango Delta. Central Africa. *Fire Ecology*, *18*, 1–12.

122 Van Wilgen, B.W., De Klerk, H.M., Stellmes, M., and Archibald, S., 2022. An analysis of the recent fire regimes in the Angolan catchment of the Okavango Delta. Central Africa. *Fire Ecology*, *18*, 1–12.

123 Lourenco, M., Woodborne, S., and Fitchett, J.M., 2023. Fire regime of peatlands in the Angolan Highlands. *Environmental Monitoring and Assessment*, *195*, 78.

Land-Use and Land-Cover Change Analysis 2019–2021

Methods: LULC Change Analysis

To generate the land-use and land-cover change (LULC) analysis, 300 m resolution land cover classification maps for 1992 and 2020[124] were extracted from the European Space Agency Climate Change Initiative. These maps provide an estimate of the land cover change for the Lungwebungu River Basin. Classes from this global land cover product were combined into general change detection classes according to this product's user guidelines. For more information, see Appendix 1

Results and Discussion: LULC Change Analysis

Vegetation cover

The upper Lungwebungu basin is dominated by forest (34,721 km, 72%), with riparian grassland (3,793 km, 8%) surrounding the narrow river floodplain (Figure 77). These riparian grasslands form because of ferralsols[125] in the vegetated interfluves that sustain seeps and underlie peatbeds along floodplains. This is a well-known feature of the 'amphitheatre valleys' or 'pediments' surrounding the Angolan Highlands Water Tower, and these are dominant landform at the regional scale. The dense forest cover along the Lungwebungu River in Angola is in stark contrast to the limited forest cover along the river in Zambia.

The lower Lungwebungu River is surrounded by shrublands and grasslands, which cover 7,651 km^2 (~16%) and 3,793 km^2 (~8%) of the total basin, respectively (Figure 77). This is attributed to a biogeographical pattern rather than a pattern of human-driven deforestation. The gradient of the river basin steadily drops towards the Lungwebungu–Zambezi confluence, resulting in sediment deposition and the formation of complex shallow wetlands known as dambos. These dambos contain Zambezian grasslands and shrublands that are interspersed by woody vegetation. The flat land associated with dambos provides communities with excellent opportunities for agriculture. Almost all the shrublands in the Lungwebungu Basin are in Zambia, where the gradient is lower. These vegetation types are maintained by regular burning and flooding cycles, which suppress tree growth and favour shrubs and grasses.

There was negligible change in the proportion of shrubland and grassland cover within the Lungwebungu Basin in 1992–2020. Moreover, the distribution of these land-cover types within the basin appears to be consistent over this period. Interestingly, the small, isolated patches of tree cover within the lower basin in Zambia appear to be in decline, likely corresponding with the ~5% increase in agriculture across the basin — most of which takes place in Zambia. Furthermore, ongoing trends of deforestation across Zambia support this observation[126].

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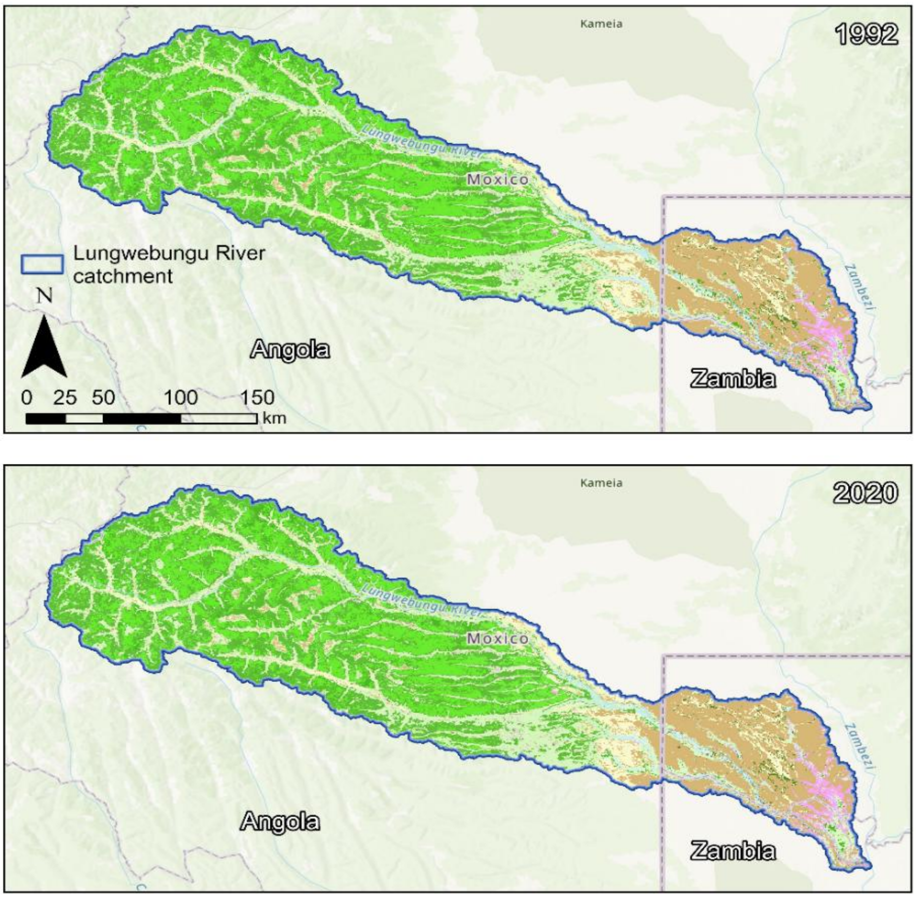
[124] Copernicus Climate Change Service, Climate data store 2019.

[125] Ferralsols are the classically deeply weathered red or yellow soils of the humid tropics.

[126] The World Bank. 2018. Zambia Takes the Keys Away from 'Drivers' of Deforestation. Available at: https://www.worldbank.org/en/news



Legend	ESA CCI LULC Classes	1992 (km^2)	2020 (km^2)	Change (%)
	Agriculture	1057	1108	4.76%
	Evergreen, closed to open forest	3	3	0.00%
	Deciduous, closed to open forest	13899	13722	-1.27%
	Deciduous, closed forest	11232	11232	0%
	Deciduous, open forest	9738	9764	0.27%
	Mosaic tree and shrub	319	350	9.72%
	Grassland	3883	3793	-2.34%
	Wetland	760	776	2.05%
	Settlement	3	4	40.63%
	Shrubland	7507	7651	1.92%
	Water	31	31	0%
	Total Area	**48433**	**48433**	**-**

Figure 77. ESA CCI LULCA 300 m resolution 1992 and 2020 maps for the Lungwebungu Basin, including change percentage between 1992 and 2020.

Human land-use cover

Human land uses are known to negatively influence river discharge and water quality, even at low levels. For example, unsustainable agricultural practices can result in pesticide runoff, eutrophication of water bodies and erosion. When combined with infrastructure development, hunting, livestock grazing and fishing, the cumulative impact on rivers can be significant.

While the Zambian portion of the basin shows a higher prevalence of agricultural land use compared to the Angolan side, there is limited evidence of significant large-scale land conversions within the mapped area. Since 1992, there has been an increase (40.63%) in settlements within the Lungwebungu River catchment, with the area of land increasing from just 3 km^2 in 1992 to 4 km^2 in 2020. Despite this increase, the overall extent of built infrastructure within the basin remains low (see Google Buildings RS below), with human land-use only representing a fraction (2.29%) of the land-cover within the basin.

There has been a small net percentage increase in observable agriculture (4.78%) within the Lungwebungu River catchment. Despite this, agriculture is only present within the Lungwebungu Basin at very low levels. This is confirmed by the LULC change analysis and survey observations on the river (Figure 77).

Land use cover and climate change

In southern Africa, the extent and condition of woodlands have been impacted by various factors, including clearing land for agriculture and the occurrence of fires [127]. In Angola, the loss of woodland and forest is largely attributed to agricultural expansion, bushfires (which convert woodland to shrubland), and the use of trees for fuel and timber[128]. From 1972–2016 , agriculture had the most significant impact on land cover change in Zambia[129]. Climate variability, particularly in the Barotse Floodplain, is the primary driver of land use change, with the greatest reductions observed in forest and woody vegetation[130]. Annual rainfall in the Lungwebungu Basin is expected to decline by 50–100 mm by 2100 under most climate change scenarios[131]. Additionally, as many of woodland species are water-dependent, climate change may result in reduction of suitable habitats[132]. In addition, climate change will likely result in changes in the frequency, severity, seasonality and area of fires, which will result in structural and compositional changes of woodlands[133].

Google Buildings RS Analysis

Methods: Google Buildings Analysis

Google Buildings data[134] was used to calculate building areas within a 4 km buffer zone around the river. Building footprints isolated and extracted from this dataset, and a 4 km buffer zone around the river was defined using GIS software. This buffer area was chosen because it is the furthest distance that people are likely to travel to collect water or other resources from the river on a regular basis[135,136].

Results and Discussion: Google Buildings Analysis

The Lungwebungu River is characterized by low human development, as indicated by the small building footprint of 0.15 km^2 — representing 0.003% of the building area within the buffer zone of the river (Figure 78). Angola has a smaller building footprint of 0.03 km^2 (0.001% of its buffer area) while Zambia has a building footprint of 0.12 km^2 (0.008% of its buffer area,Figure 78). The higher building footprint in Zambia can be attributed to the greater density of people in the region (0.7 people/km) compared to Angola (0.2 people/km). In addition, most of the infrastructure observed along the river comprises seasonal camps, which are temporary structures. Other permanent infrastructures, such as bridges, are also not abundant on the river. The analysis suggests that while there is some level of human presence and development

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[127] Chidamayo, E., 2011. Climate change and the woodlands of Africa. *African Forest and Wildlife Resources.* In Chidamoyo, E., Okali, D., Kowero, G., and Larwanou, M. (Eds.), *The African Forest Forum.*

[128] Mendelsohn, J., 2019. Landscape changes in Angola. In *Biodiversity of Angola,* Huntley, B.J., Russo, V., Lages, F., and Ferrand, N. (Eds.)

[129] Phiri, D., Morgenroth, J., and Xu, C., 2019. Long-term land cover change in Zambia: an assessment of driving factors. *Science of the Total Environment*, *697*, 134206.

[130] Banda, A.M., Banda, K., Sakala, E., Chomba, M., and Nyambe, I.A., 2023. Assessment of land use change in the wetland of Barotse Floodplain, Zambezi River Sub-Basin, Zambia.

[131] Siatwiinda, S.M., Supit, I., van Hove, et al., 2021. Climate change impacts on rainfed maize yields in Zambia under conventional and optimized crop management. *Climate Change*, *167*, 39.

[132] hidamayo, E., 2011. Climate change and the woodlands of Africa. *African Forest and Wildlife Resources.* In Chidamoyo, E., Okali, D., Kowero, G., and Larwanou, M. (Eds.), *The African Forest Forum.*

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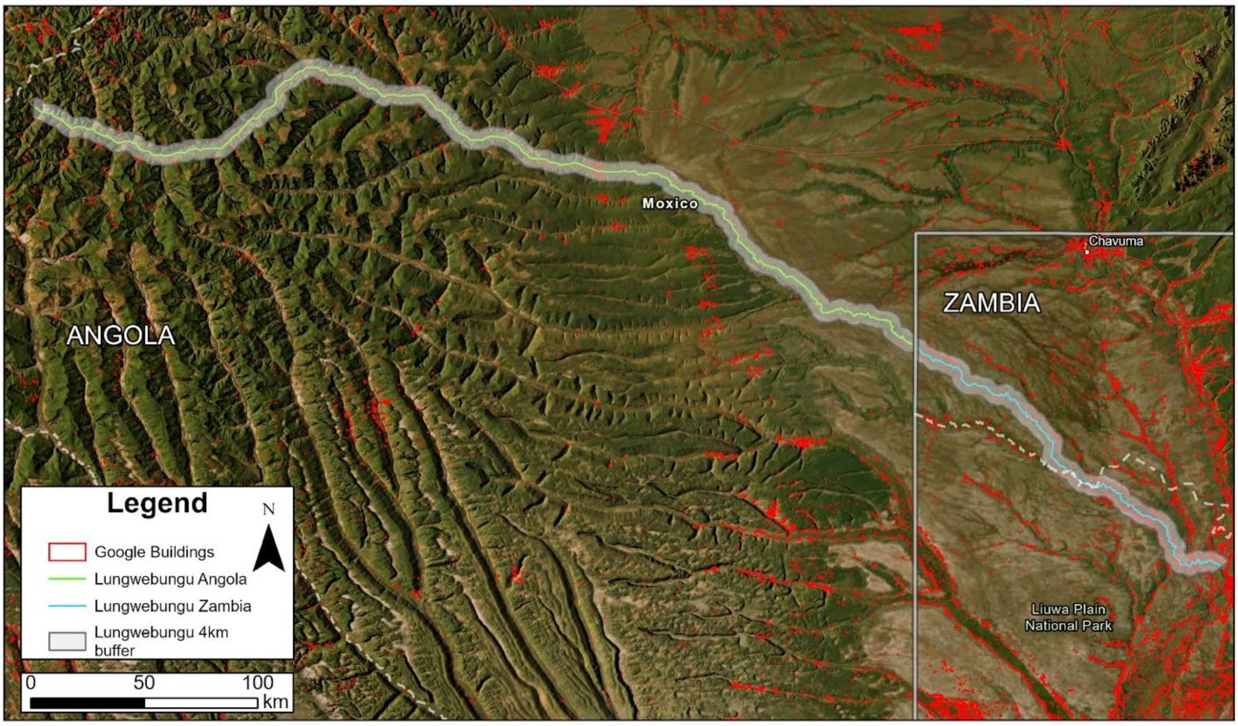
[134] Sirko, W. et al. 2021. Continental-scale building detection from high resolution satellite imagery. *arXiv preprint.*

[135] UNICEF, 2016. Collecting water is often a colossal waste of time for women and girls.

[136] Gross, E., Günther, I., and Schipper, Y., 2017. Women are walking and waiting for water: the time of public water supply. The University of Chicago.

within the Lungwebungu Basin, the overall extent of built infrastructure remains low, particularly in Angola (Figure 78). Combined with the findings of the LULCA (Figure 77), these results indicate that the Lungwebungu Basin remains largely pristine with a low human footprint — especially in Angola.



Lungwebungu 4 km buffer	Buffer area (km^2)	Total no. of buildings	No. of buildings/km^2	Total building area (km^2)	Building Area (%) within Buffer Zone
Angola	3755	1313	0.35	0.03	0.001%
Zambia	1533	4611	3.01	0.12	0.008%
Total	5288	5924	3.36	0.15	0.003%

Figure 78. The Google Buildings around the Lungwebungu River.

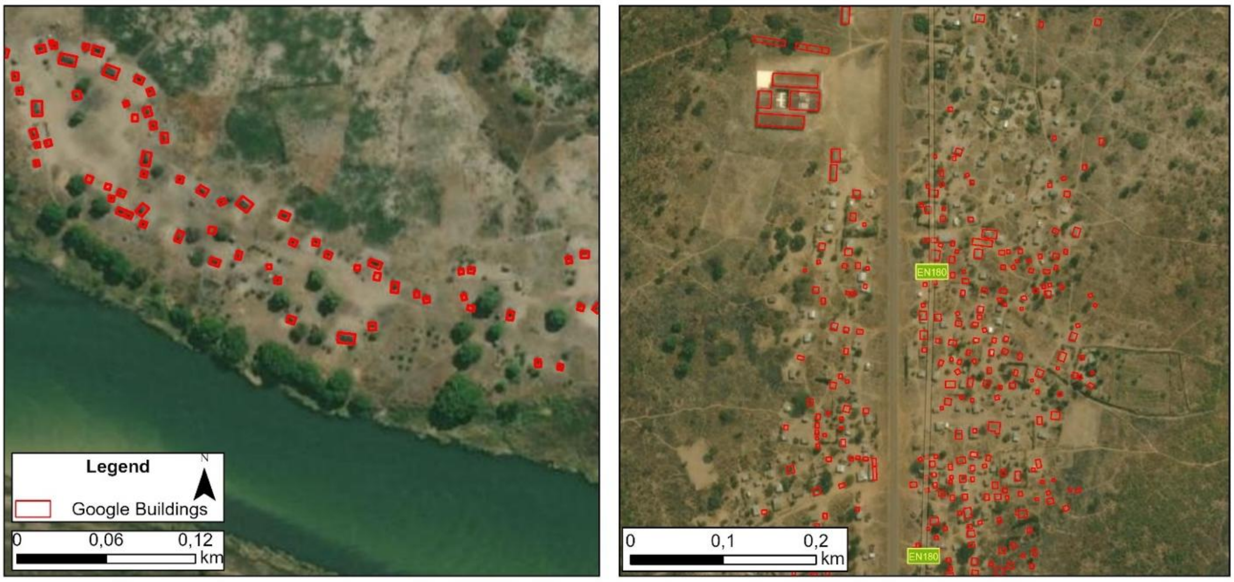


Figure 79. Zoomed in locations of the Google Buildings with an area on the Lungwebungu River near the confluence of the Zambezi (left) and an area south of the EN180 road bridge in Angola (right).

WorldCereal Cropland RS Analysis

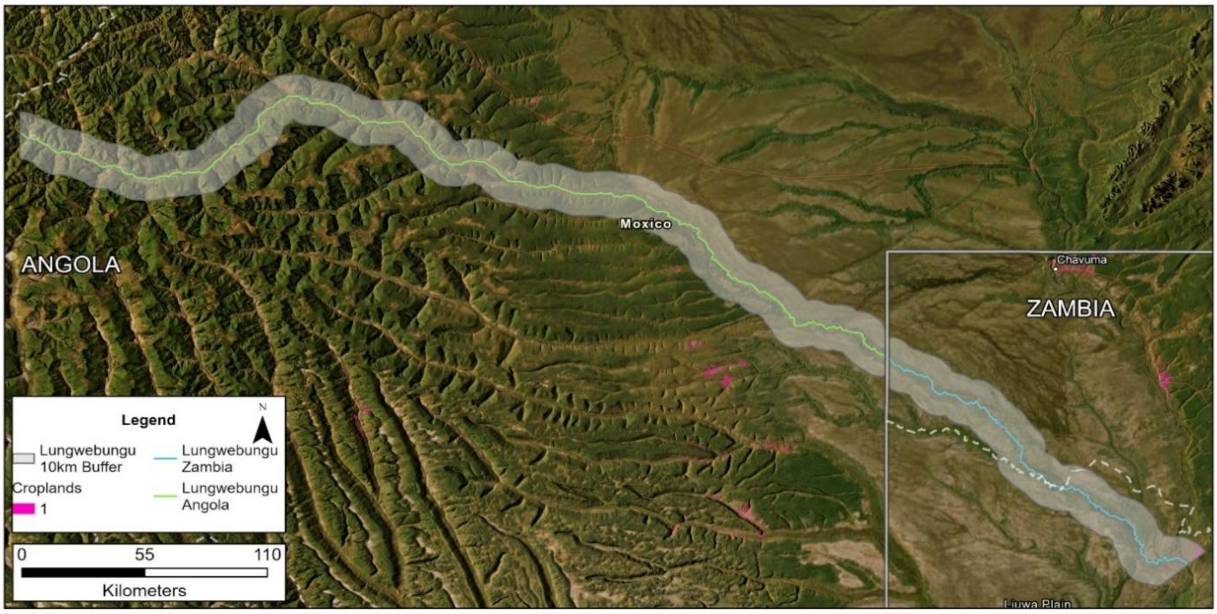
Methods: WorldCereal Cropland RS Analysis

WorldCereal is an open-source system which provides comprehensive seasonal and reproducible mapping of crop extents and irrigation practices worldwide[137]. Developed under the European Space Agency's Initiative, WorldCereal generates a suite of global products, including temporary crop extent, seasonal maps for major cereals such as maize and wheat, and detailed irrigation and cropland maps.

WorldCereal data was used to calculate the extent of cropland within a 10 km buffer zone around the river. Croplands were extracted from this dataset, and a 10 km buffer zone around the river was defined using GIS software. The total cropland area within this buffer zone was calculated by totalling the area of the croplands.

Results and Discussion: WorldCereal Cropland RS Analysis

The Lungwebungu Basin has a small cropland area of 0.31 km^2 — representing only 0.002% of the total buffer area (12 828 km^2,Figure 80). Therefore, although 2.3% of the distance along the river consists of farms, most of the buffer area along the river remains intact. Crop cover is more extensive in Zambia (crop distance of ~20 km) compared to Angola (crop distance of ~4 km). However, Angola has a greater cropland area in the buffer zone (0.26 km^2) compared to Zambia (0.05 km^2). Therefore, even though agricultural farms covers a considerable portion of the river in Zambia, this analysis further supports the notion that the Lungwebungu Basin is relatively undisturbed by agriculture within the 10 km buffer area. Therefore, the Lungwebungu Basin remains largely pristine, with low human impacts.



Lungwebungu 10 km buffer	Buffer area (km^2)	Total cropland area (km^2)	Cropland area (%) within Buffer Zone
Angola	9171	0.26	0.003%
Zambia	3657	0.05	0.001%
Total	12828	0.31	0.002%

Figure 80. A map showing the croplands around the Lungwebungu River.

[137] Van Tricht, K. et al. 2023. WorldCereal: a dynamic open-source system for global-scale, seasonal, and reproducible crop and irrigation mapping. *Earth System Science Data.*

1.7 CONCLUSION AND RECOMMENDATIONS

The Lungwebungu River is a major source of the Zambezi River and serves as a key transboundary river between Angola and Zambia. There is a low density of people and permanent infrastructure along the river and within the greater Lungwebungu Basin. This has contributed to good water quality in the river and sufficient riparian habitat to support a diverse and abundant population of wetland-associated birds, particularly in the upper reaches of Angola, and throughout the Zambian river section. Moreover, sampling suggests that there are healthy communities of both benthic macroinvertebrates and fishes in the river.

Overall, the river has a low density of people. Fishing activity is highly seasonal, as evidenced by the presence of fish camps along the river. Nevertheless, fishing activity is low compared to other rivers in the region, particularly those in Zambia. However, fishing activity should be monitored, particularly at the confluence with the Zambezi River, where fishing activity is concentrated.

The relatively unmodified riparian zone is indicative of the low levels of human impact on the river. While agriculture covered a large area in Zambia, it only comprised a small proportion of the 10 km buffer zone around the river. Subsistence farming was the predominant type of agriculture, with the main crops differing between Angola and Zambia. While cassava is drought-tolerant and may provide food security during extreme climatic events, maize is a rain-fed crop and local communities are susceptible to crop-failure. Reduced rainfall due to climate change may result in the encroachment of crop agriculture in the shrubland and grassland surrounding the Lungwebungu River, particularly in the lower reaches of the river. Therefore, Adaptive management strategies should be implemented to prevent excessive land-clearing in this region.

Few non-avian wildlife species were present along the river, with only two hippopotamuses observed. Most wildlife was recorded in the upper reaches of the river, indicating the inundated floodplains may have obscured observations of wildlife further inland. A dry season survey is necessary to ascertain the wildlife along the entire stretch of the river. However, the overall decline of large mammals in the region can be attributed to hunting for the bushmeat trade, particularly in Angola, and efforts to conserve and improve wildlife populations in the region should prioritise addressing the demand for bushmeat.

The Lungwebungu River has a high abundance and diversity of wetland-associated birds. These birds are primarily concentrated in the inundated floodplains of Zambia. This region hosts three large breeding colonies of herons, egrets, and cormorant. The breeding colonies introduce important nutrients, such as nitrogen and phosphorous, to the ecosystem. This nutrient influx enhances the wetland ecosystem by promoting productivity, subsequently supporting various aquatic organisms. As a result, these birds play a vital role in the functioning of the wetland ecosystem. Therefore, monitoring these breeding colonies is important to determine the seasonal use of these sites, and whether the same sites are used annually. If so, these sites and their surrounding habitats should be protected.

There are sites of human disturbance, particularly in Angola. An area of notable concern is the EN180 road bridge and surrounds, which has been transformed by agriculture and human settlements. This disturbance is also shown by the presence of alien invasive plants (AIPs). Therefore, areas surrounding the EN180 road bridge should be monitored to assess the impacts of agriculture and AIPs on the river. In addition, AIPs should be controlled to mitigate their downstream establishment, particularly near the source of the river.

Unregulated artisanal and small-scale mining (ASM) are primarily located in the upper reaches of the Lungwebungu River. ASMs can introduce contaminants and facilitate downstream pollution of the river. This poses a significant threat to the source of the river, and these sites should be closely monitored.

The Lungwebungu River contributes 16–20% to the flow of the Zambezi River at their confluence, depending on the season. As a result, the Lungwebungu River moderates the flow of the Zambezi River upstream of the Barotse Floodplains. In the late wet season, most of this water (~60%) originates in Angola, with the remaining 40% supplied by Zambian tributaries to the Lungwebungu River. These findings emphasise the transboundary nature of water resources in southern Africa and highlight the importance of sustainable river management in upstream countries to ensure the provision of ecosystem services to downstream communities.

The long-term health of the Lungwebungu Basin should be maintained by the regular monitoring of human impacts and fire. Future studies should assess: i) seasonal human activity and biodiversity; ii) assess crop production trends within the context of climate change; iii) continued assessment of river flows by monthly measurements at the Angolan border and the Lungwebungu–Zambezi confluence; iv) monitoring bird colonies; v) regular monitoring of fires and invasive species; and vi) socioeconomic drivers of the bushmeat trade within the basin. Finally, the Wilderness Project supports the designation of the Liuwa Plains – Mussuma TFCA to strengthen the ecological integrity of the basin and ensure the provision of vital ecosystem services to local communities for future generations.

1.8 APPENDICES

Appendix 1. LULC Analysis Supplement.

IPCC Classes considered for the change detection (with color)	LCCS legend used in the CCI-LC maps	
1. Agriculture	Code	Description
	10, 11, 12	Rainfed cropland
	20	Irrigated cropland
	30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)
	40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (< 50%)
2. Forest	50	Tree cover, broadleaved, evergreen, closed to open (>15%)
	60, 61, 62	Tree cover, broadleaved, deciduous, closed to open (> 15%)
	70, 71, 72	Tree cover, needle leaved, evergreen, closed to open (> 15%)
	80, 81, 82	Tree cover, needle leaved, deciduous, closed to open (> 15%)
	90	Tree cover, mixed leaf type (broadleaved and needle leaved)
	100	Mosaic tree and shrub (>50%) / herbaceous cover (< 50%)
	160	Tree cover, flooded, fresh or brackish water
	170	Tree cover, flooded, saline water
3. Grassland	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)
	130	Grassland
4. Wetland	180	Shrub or herbaceous cover, flooded, fresh-saline or brackish water
5. Settlement	190	Urban
6. Shrubland	120, 121, 122	Shrubland
7. Bare / sparse vegetation	140	Lichens and mosses
	150, 151, 152, 153	Sparse vegetation (tree, shrub, herbaceous cover)
	200, 201, 202	Bare Areas
8. Water	210	Water

Appendix 2. *Summary of historical and current programmes.*

Programme	Organization	Priority area	Programme details
Giraffe Conservation Foundation Regional Programme (2022–2026)	Giraffe Conservation Foundation	KAZA TFCA	Together with the KAZA Secretariat and KAZA partner states, using a collaborative integrated landscape-level approach, to create an environment that optimizes ecological and economic opportunities for giraffe conservation.
Carnivore Area Conservation Strategy (2018–2022)	KAZA TFCA Carnivore Conservation Coalition	KAZA TFCA	Conserve carnivores in the region. Funding provided by WWF Namibia, Panthera, Range Wide Program for Cheetah and African Wild Dogs
Conservation Strategy Action Plan for the African Wild Dog (*Lycaon pictus*) in the KAZA TFCA (2014–2019)	KAZA TFCA in partnership with numerous organizations such as WWF Namibia, Rang Wide Conservation Programme, Wildlife Conservation Society	KAZA TFCA	The goal is to create a resilient and ecologically functional population of wild dogs by linking habitats within the KAZA. This effort aims to improve the long-term sustainability of the largest contiguous wild dog population by ensuring suitable habitats, facilitating transboundary movement, and highlighting the species' importance in the region.
Strategic Planning Framework for Conservation and Management of Elephants in KAZA		KAZA TFCA	The initiative aims to establish Africa's largest viable and interconnected elephant population, benefiting both people and nature within a diverse landscape.
Zambian Carnivore Programme (2010–present	Zambian Carnivore Programme and Cheetah Conservation Initative	Liuwa Plains–Mussuma TFCA	The initiative aims to conserve Zambia's large carnivores and their ecosystems by fostering restored and thriving habitats, collaboratively managed by local communities, scientists, and policymakers using evidence-based methods. Operating in the Greater Liuwa Plains Ecosystem, the program partners with African Parks and Zambia's Department of National Parks and Wildlife to enhance adaptive conservation management strategies and practices.
Cheetah Conservation Initiative (2018–present)	Cheetah Conservation Initiative (2018–present)	Liuwa Plains–Mussuma TFCA	In collaboration with the Angolan Institute for Biodiversity and Conservation and the Moxico Province environment department, the CCI is working to identify potential areas for wildlife population recovery in Angola. This effort aims to inform political

			decisions for the formal establishment of the Liuwa-Mussuma Transfrontier Conservation Area (TFCA).
The Halo Trust (2020 – present)	The Halo Trust	Zambezi Basin	In partnership with the Angolan government, the trust aims to clear mines in the Okavango headwaters to set the foundation for conservation-led development.
Upper Zambezi Project (2022–2032)	WWF Zambia	Upper Zambezi	Provide key information towards ensuring sustainable resource-use and biodiversity conservation management within the broader landscape.
Combating Wildlife Crime Project (2017–2022)	WWF	Namibia, Angola, Botswana, Zambia, Zimbabwe	The initiative addresses threats to endangered black rhino and African elephant populations in Namibia and the KAZA TFCA. It aims to enhance community involvement in fighting wildlife crime by providing increased benefits, fostering stewardship, and instilling pride in local wildlife. Additionally, the program seeks to bolster anti-poaching and surveillance efforts through collaboration among communities, the private sector, and law enforcement, while supporting effective investigations and prosecutions
National Forest Inventory (Ongoing)	Ministry of Agriculture and Forestry (Angola)	Angola	Provide a better understanding of the status of Angola's forest, enabling sustainable planning and use of forest resources in the country, including community forestry.
National Program for Apiculture (2019–present)	Ministry of Agriculture and Forestry (Angola)	Moxico, Cuando Cubangand other provinces in Angola	Incentivize and modernize the Angolan apiculture industry.
Fisheries Program (2018–2022)	Government of Angola	Moxico and other provinces	Promote socioeconomic and territorial development nationwide. Aim to increase fisheries production by 13% annually.

Appendix 3. The distribution of people washing along the river.

Appendix 4. The distribution of maize farms.

Appendix 5. The distribution of cassava farms.

Appendix 6. The distribution of mango trees.

Appendix 7. The distribution of banana farms.

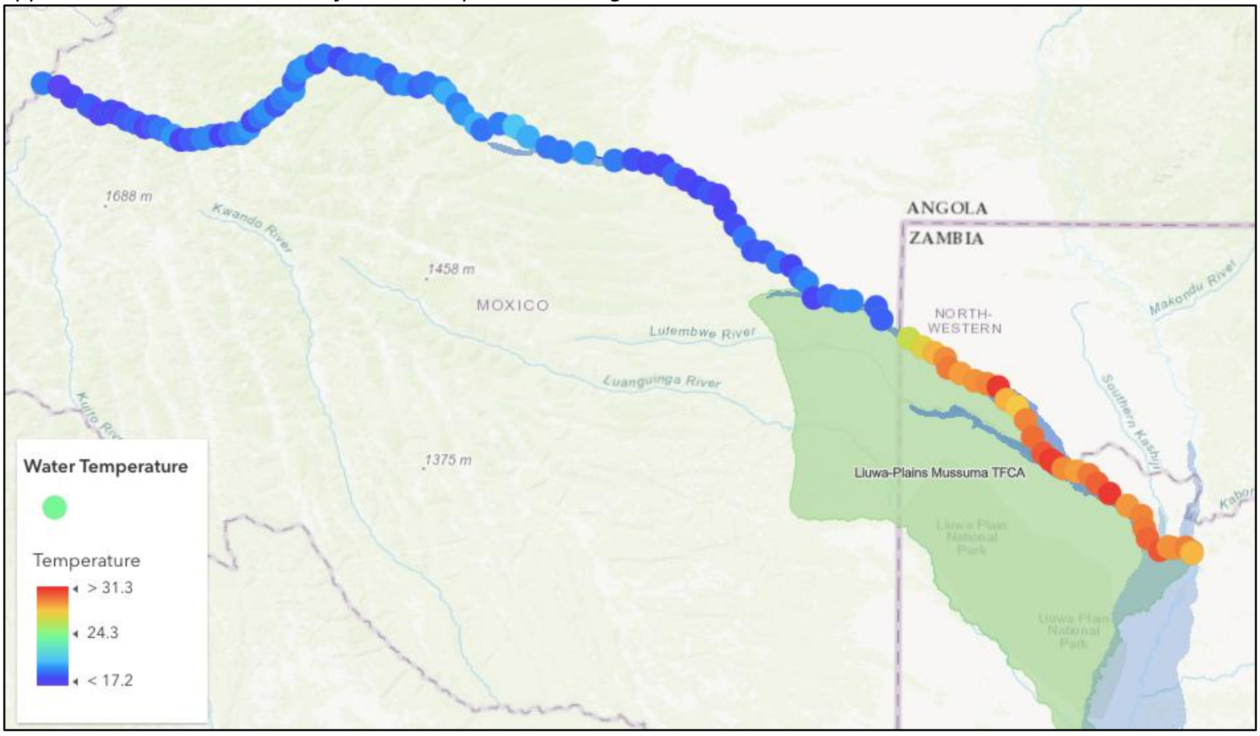
Appendix 8. The distribution of sugar-cane farms.

Appendix 9. Bird survey summary.

Species Name	Observations	Count
Reed cormorant	176	456
Pied kingfisher	173	234
Black-crowned night heron	15	172
Western cattle egret	13	136
Marsh widowbird	56	115
Great egret	11	112
White faced whistling duck	25	112
Hamerkop	52	97
White fronted bee-eater	36	87
Little bee-eater	56	77
Malachite kingfisher	61	74
Rufous bellied heron	19	72
Woolly necked stork	26	72
African openbill	19	56
Purple heron	41	48
Coppery-tailed coucal	43	44
Yellow-billed duck	15	43
Squacco heron	21	41
African wattled lapwing	20	40
Bateleur	34	37
Spur winged goose	9	37
Striated heron	24	36
African fish eagle	28	33
Black crake	15	21
African skimmer	3	18
Little egret	4	16
African marsh harrier	15	15
Saddle billed stork	9	14
Swamp boubou	8	14
White-fronted plover	5	13
Southern carmine bee-eater	2	10
Long-toed lapwing	2	8
Giant kingfisher	7	7
Meyer's parrot	3	7
White-backed vulture	3	7
Black-winged kite	6	6
Little bittern	5	6
African black duck	3	5
Black-chested snake eagle	4	5
Southern ground hornbill	1	5
African pygmy goose	3	4
Brown-hooded kingfisher	4	4
African harrier hawk	3	3
African hawk eagle	3	3
Collared pratincole	1	3
Palm nut vulture	3	3
Western banded snake eagle	2	3
White-winged tern	1	3
African jacana	2	2

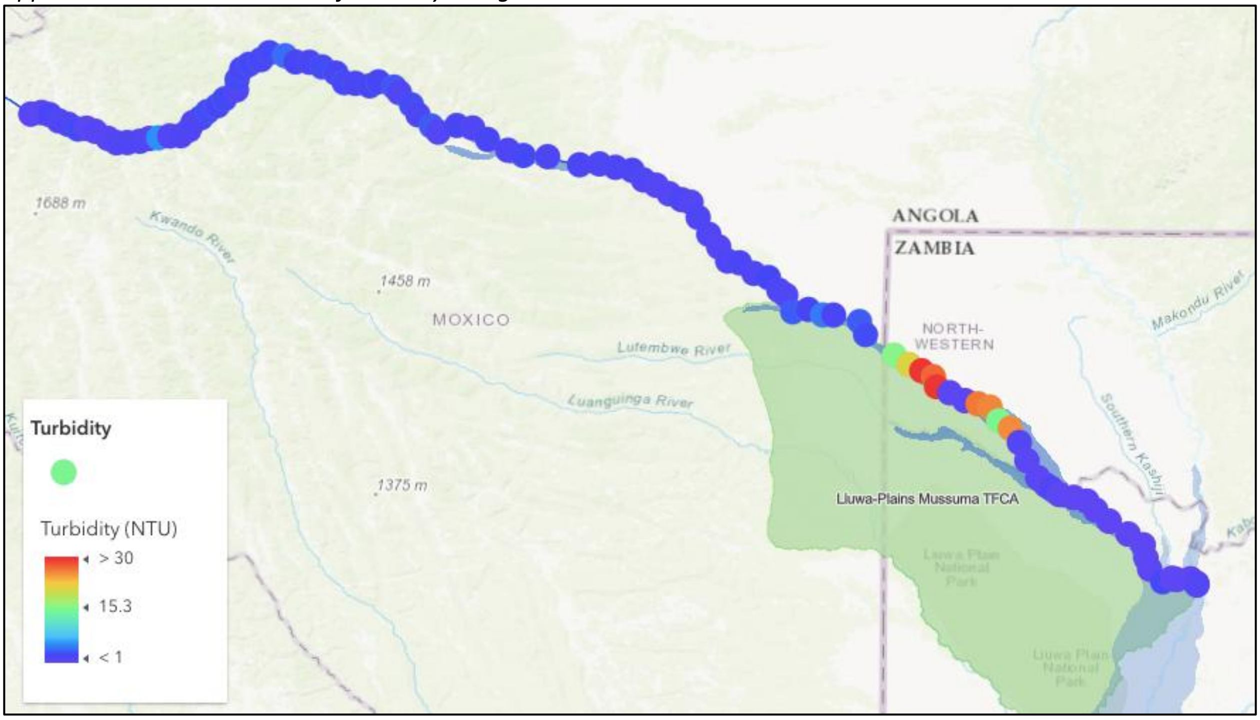
Fork-tailed drongo	1	2
Kittlet plover	1	2
Lilac-breasted roller	1	2
Lizard buzzard	1	2
Marabou stork	2	2
Rock pratincole	1	2
Yellow-billed kite	2	2
African pied wagtail	1	1
Cape wagtail	1	1
Common sandpiper	1	1
Half-collared kingfisher	1	1
Pin-tailed whydah	1	1
Slaty egret	1	1
Striped kingfisher	1	1
Three-banded plover	1	1
Water thick knee	1	1
Total		**2459**

Appendix 10. The distribution of water temperature along the river.



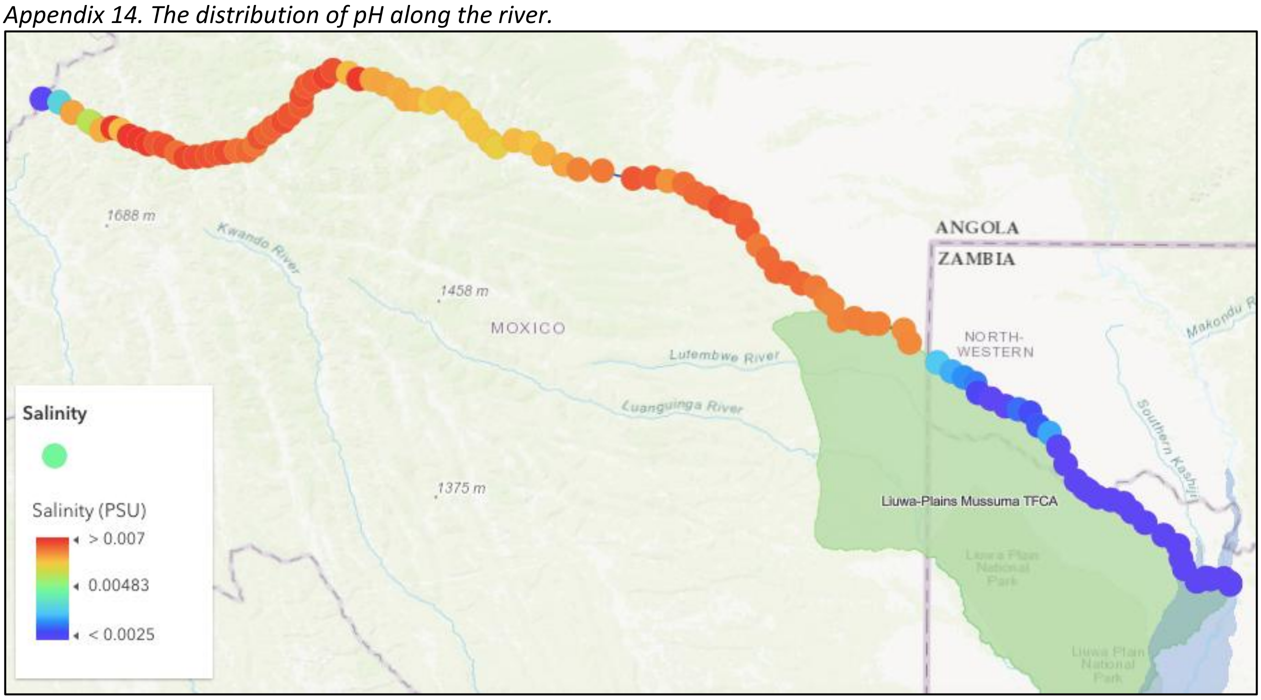
Appendix 11. The distribution of specific conductivity along the river.

Appendix 12. The distribution of turbidity along the river.

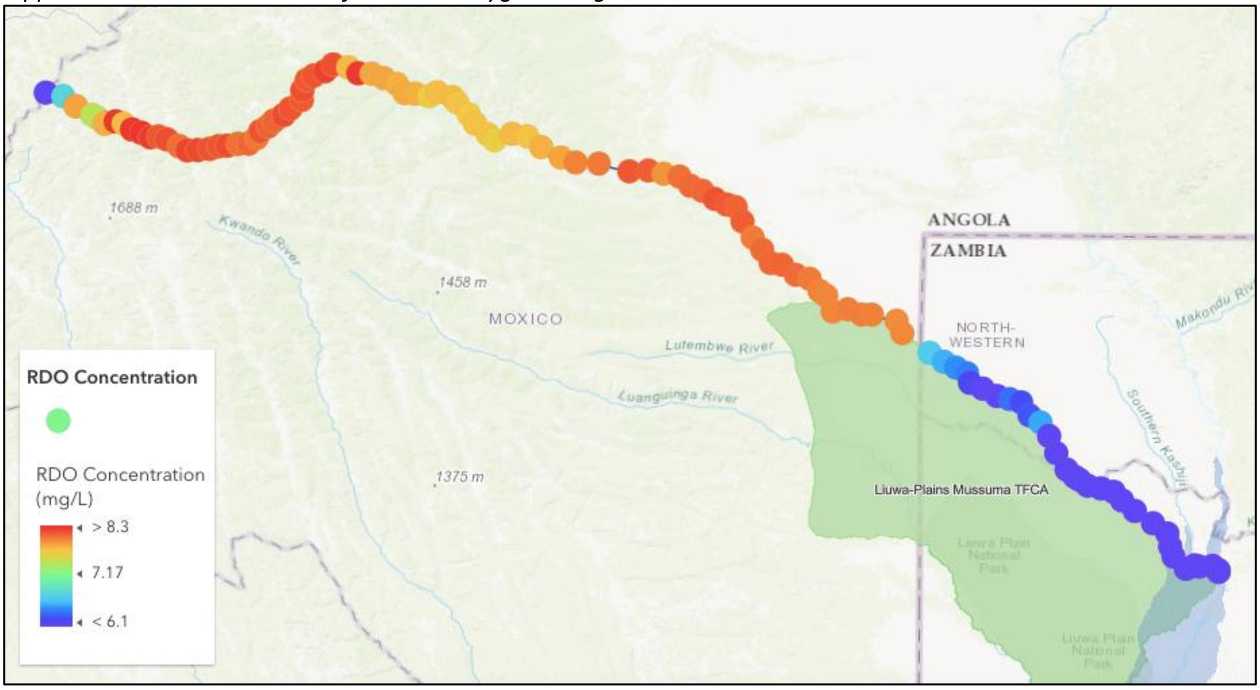


Appendix 13. The distribution of salinity along the river.

Appendix 14. The distribution of pH along the river.



Appendix 15. The distribution of dissolved oxygen along the river



Appendix 16. Fish sampling survey.

Species	Number of specimens
Angola	
Enteromius eutaenia	25
Enteromius thamalakanensis	17
Enteromius radiatus	13
Petrocephalus okavangensis	13
Synodontis macrostigma	11
Tilapia sparrmanii	10
Heteromormyrus szaboi	7
Schilbe intermedius	7
Cyphomyrus cubangoensis	4
Enteromius sp.	4
Enteromius multilineatus	4
Hemichromis angolensis	4
Mastacembelus frenatus	4
Nannocharax multifasciatus	4
Parauchenoglanis ngamensis	4
Pharyngochromis 'blotch'	4
Lacustricola katangae	3
Amphilius cubangoensis	2
Enteromius bifrenatus	2
Micralestes acutidens	2
Petrocephalus longicapitis	2
Pollimyrus marianne	2
Pseudocrenilabrus philander	2
Schilbe yangambianus	2
Zaireichthys kavangoensis	2
Brycinus lateralis	1
Chiloglanis fasciatus	1
Coptodon rendalli	1
Enteromius afrovernayi	1
Enteromius barnardi	1
Enteromius paludinosus	1
Marcusenius moorii	1
Marcusenius altisambesi	1
Microctenopoma steveboyesi	1
Nannocharax dageti	1
Nannocharax machadoi	1
Opsaridium zambezense	1
Pharyngochromis acuticeps	1
Sargochromis carlottae	1
Serranochromis	1
Zambia	

Enteromius eutaenia	26
Schilbe intermedius	8
Pharyngochromis acuticeps	7
Lacustricola mediolateralis	6
Lacustrcola johnsoni	5
Lacustricola mediolateralis	4
Micralestes acutidens	4
Oreochromis macrochir	2
Synodontis macrostoma	2
Nannocharax dageti	2
Chiloglanis fasciatus	1
Cyohomyrus cubangoensis	1
Enteromius bifrenatus	1
Hemichromis elongatus	1
Labeo cylindricus	1
Nannocharax lineostriatus	1
Nannocharax multifasciatus	1
Opsaridium zambezense	1
Petrocephalus longicapitis	1
Petrocephalus okavangensis	1
TOTAL	245