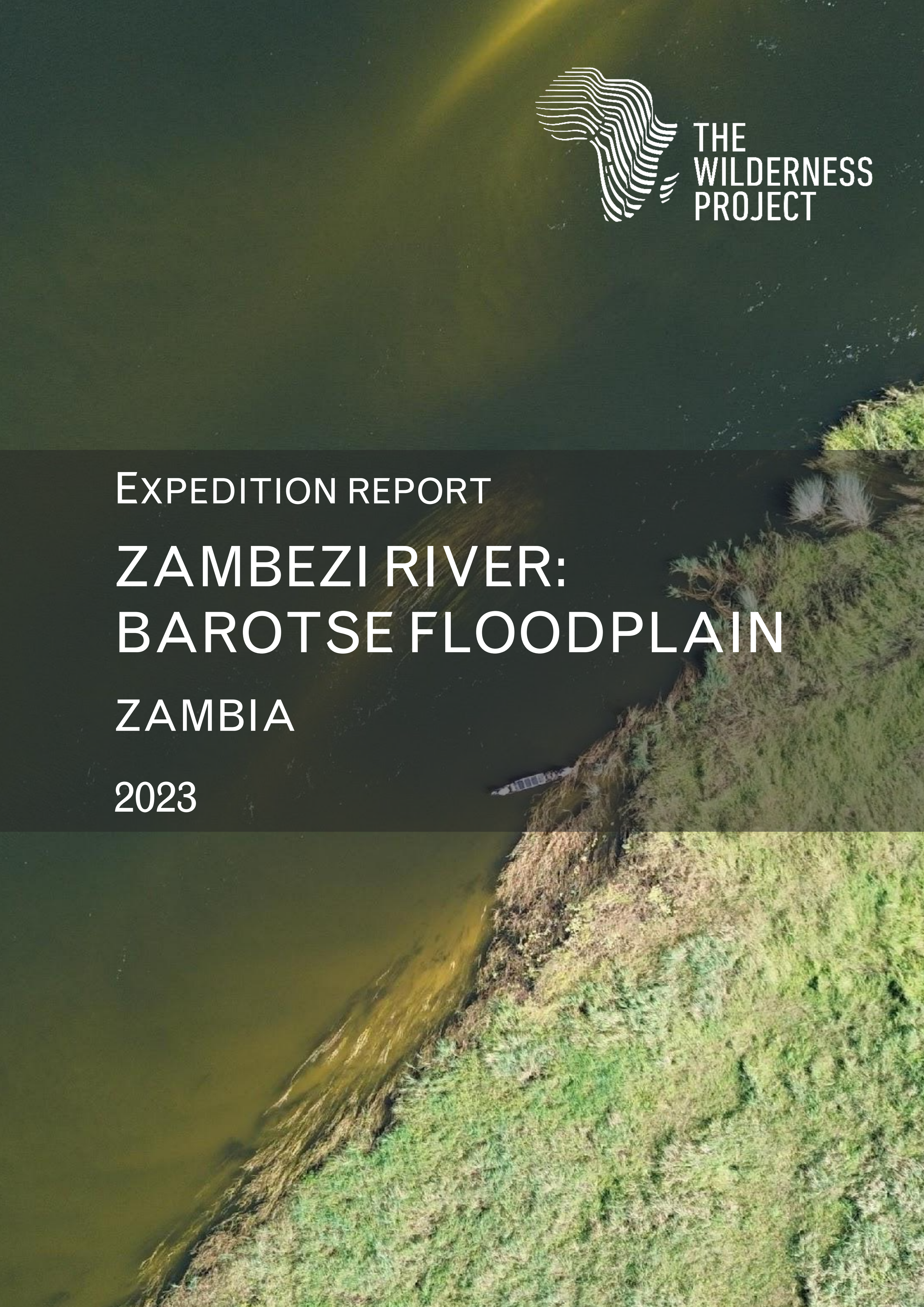

THE WILDERNESS PROJECT

Expedition report

ZAMBEZI RIVER: BAROTSE FLOODPLAIN

ZAMBIA

2023

EXECUTIVE SUMMARY

In 2023, The Wilderness Project launched a series of research expeditions in Southern Africa. One of the goals of these expeditions was to survey the Zambezi River, from its several sources to its outflow into the Mozambican Indian Ocean. As part of this effort, a research transect was conducted on the Zambezi River in Zambia — starting at the town of Chavuma at the Angolan border and ending downstream of the Barotse Floodplain at Sioma. The total distance of the transect was 560 km, all of which was travelled in purpose-built canoes. This report summarises the findings of the expedition and presents an assessment of the health, human development, and ecology of the Zambezi River between Chavuma and Sioma. All data presented herein are available as interactive *ESRI web-maps*, and 360° images of the entire transect are viewable in the *EarthViews web application*.

People and Fisheries
A total of 3,558 people were counted along the transect, a density of 6.35 people/km which is substantially higher than the upstream reaches in Angola (2.3 people/km). More than half of the people were encountered within the Barotse Floodplain in association with ubiquitous seasonal fishing camps (N = 242). Fishing was the most common human activity, with a total of 178 individuals observed along the transect—averaging one fisher every 3 km. Most fishing on the Barotse Floodplain occurs at night, which likely creates an underestimation of activity since the survey was conducted during the day. Overfishing and destructive practices, such as the use of *Sefa-sefa* nets, have greatly reduced fish stocks, forcing fishers to target smaller species and juveniles. Given the strong reliance on fish as a primary livelihood, and the limited availability of alternative income sources, both fish populations and fisher incomes are likely to decline.

Agriculture and Water Quality Risks
Agriculture poses an increasing threat to the Barotse Floodplain as farmers seek more reliable water amid Zambia's worsening drought. This shift is evident in the intensifying agricultural land use along the floodplain margins. The Kabompo River, contaminated by mining, threatens the water quality of the Zambezi River and Barotse Floodplain. While parameters along the transect remained within acceptable levels, water quality declined sharply at the Kabompo confluence. These findings highlight the need for ongoing monitoring to assess the impact of upstream mining on this vital ecosystem.

Biodiversity
The Barotse Floodplain is one of Zambia's most critical wetland ecosystems, hosting the highest recorded density of wetland birds in the country. Observations along the transect documented a density of 115.24 birds/km, far surpassing other wetland ecosystems like the Bangweulu Wetlands (4.91 birds/km) and the Lukanga Swamps (11.27 birds/km). Despite this ecological significance, the Barotse Floodplain faces mounting threats from overfishing, agricultural expansion, and climate change.

Hydrology and Wetland Function
The Lungwebungu and Kabompo rivers contribute an estimated 43% of the Zambezi River's flow after the floodplain, with additional water originating from the surrounding pan-belt. As the dry season progresses, the pan-belt's storage effect becomes more pronounced, gradually releasing water and sustaining downstream flows. Functioning as a natural reservoir, the Barotse Floodplain mitigates hydrological extremes, ensuring stable conditions for biodiversity, fisheries, and agriculture. Contrary to the notion that floodplains merely disperse excess water, the Barotse system plays a crucial role in regulating river flow, highlighting the need for proactive management in the face of upstream modifications and climate variability.

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 Chambeshi River, we thank the Department of National Parks and Wildlife, Copperbelt University, African Parks, the Water Resources Management Authority, the University of Zambia, 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 Zambezi River.

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1. INTRODUCTION

Background of The Wilderness Project

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 rivers 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 governments and NGOs working in the freshwater conservation space; iv) develop local scientific and storytelling capacity; and v) generate targeted interest and funding for the conservation of rivers in Africa.

Expedition Objectives

Between the 17th–31st May 2023, a team from TWP conducted a research transect of the Zambezi River from Chavuma, near the Angolan border, to the town of Sioma — located downstream of the Barotse Floodplain (Figure 1). The total distance surveyed was 560 km, all of which was travelled in purpose-built canoes. Whilst on the transect, researchers collected continuous survey data related to biodiversity, natural resource use and ecological health. Combined, these data offer a snapshot of the state of the Zambezi River between Chavuma and Sioma that can be used to inform ongoing and planned initiatives in the region.

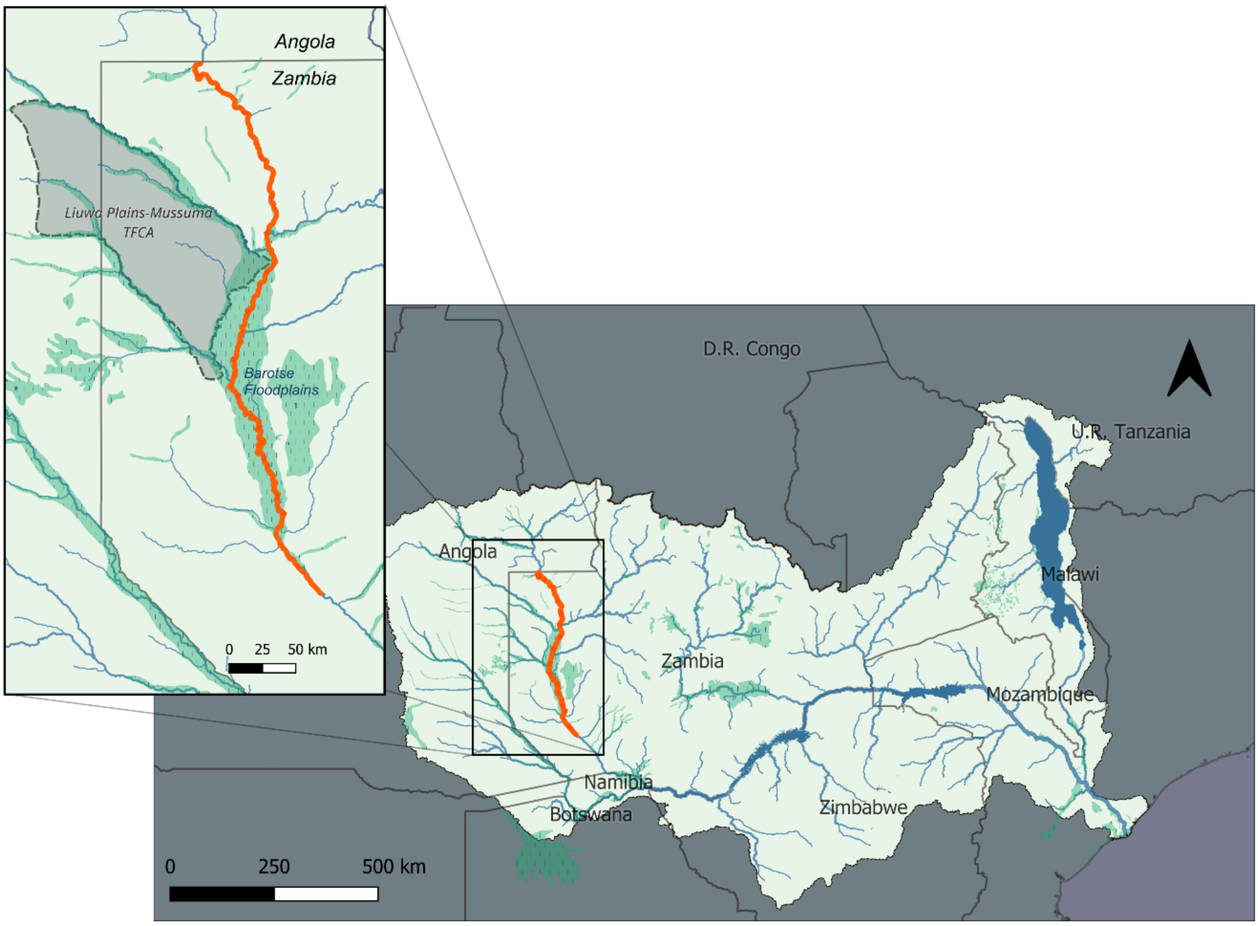

Figure 1. The Zambezi expedition from Chavuma to Sioma (orange) within the greater Zambezi Basin. Note the Barotse Floodplain in the inset, which extends along the Zambezi River for ~230 km.

Study Site Description

The Zambezi Basin is one of the most extensive and ecologically diverse in Africa, encompassing a total area of ~1.3 million km^2 across eight countries[1,2]. Within this basin, water originates as rainfall at several sources in the highlands of Angola and Zambia, ultimately entering the Zambezi River through a network of tributaries and groundwater. The water of the Zambezi River is a vital resource for hydropower generation and household use. In addition, this water is the foundation of significant fisheries, tourism and transportation industries that support the livelihoods of the ~40 million people who live within the Zambezi Basin[3].

The Zambezi Basin is divided into thirteen major sub-basins. These encompass three broadly defined sections — the Upper, Middle and Lower Zambezi River — characterised by their elevation and relative proximity to major biogeographic features. The Upper Zambezi River is generally known as the stretch of river above Victoria Falls and contains six sub-basins: i) Upper Zambezi; ii) Lungwebungu; iii) Kabompo; iv)

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[1] Tweddle, D. 2010. Overview of the Zambezi River system: Its history, fish fauna, fisheries, and conservation. *Aquatic Ecosystem Health and Management*. 13(3):224–240.

[2] Moore, A.E., Cotterill, F.P.D., Main, M.P.L. and Williams, H.B. (2022). The Zambezi: Origins and Legacies of Earth's Oldest River System. In Large Rivers, A. Gupta (Ed.).

[3] Moore, A.E., Cotterill, F.P.D., Main, M.P.L. and Williams, H.B. (2022). The Zambezi: Origins and Legacies of Earth's Oldest River System. In Large Rivers, A. Gupta (Ed.).

Luanginga; v) Cuando Chobe; and vi) Barotse[4]. The Zambezi River from Chavuma to Sioma lies within the Upper Zambezi region and includes the Upper Zambezi and Barotse sub-basins (Figure 2).

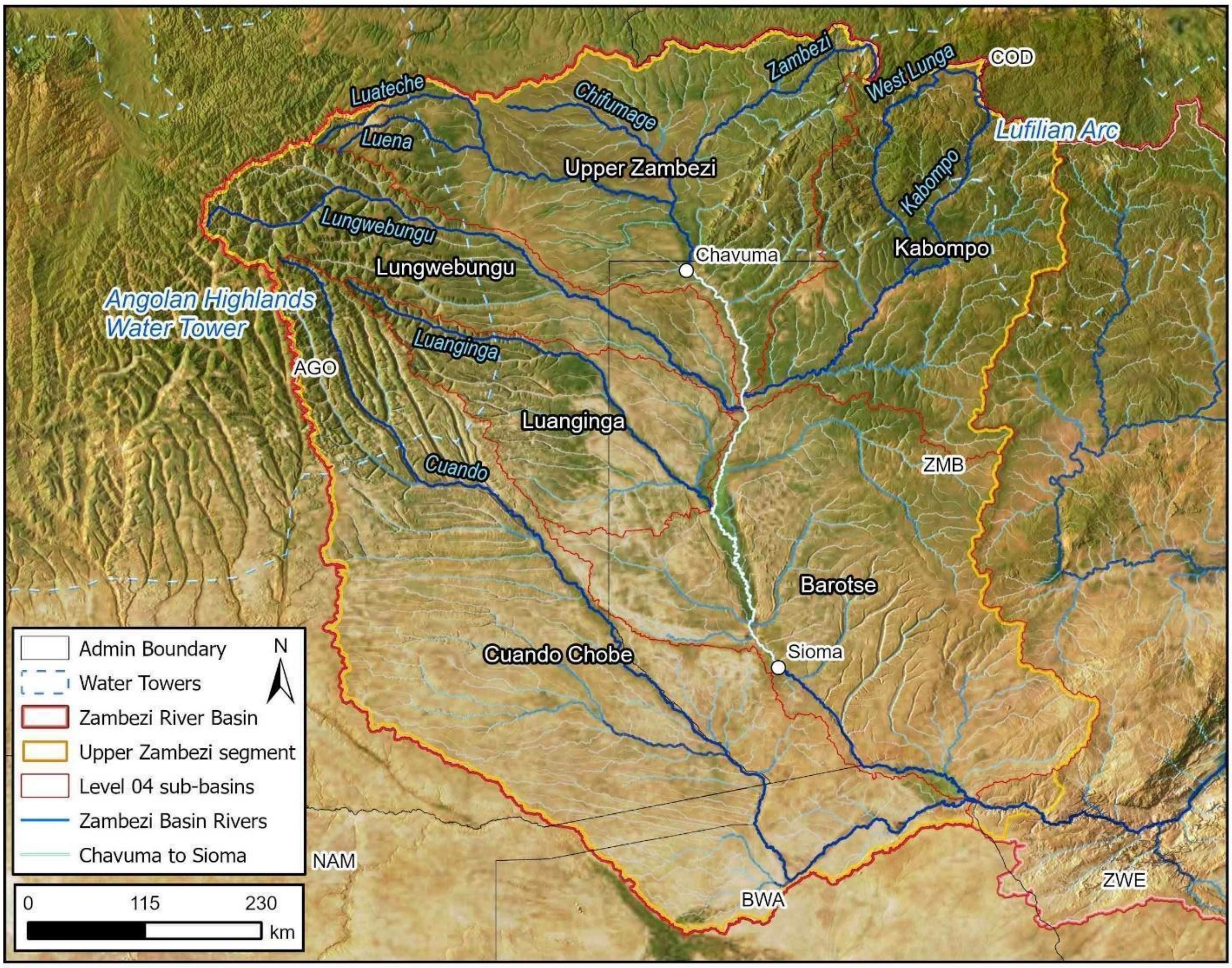

Figure 2. The Upper Zambezi Region within the Zambezi River Basin.

Three major tributaries feed into the Zambezi River between Chavuma and Sioma (Figure 2). These are: i) the Kabompo River, which originates in northern Zambia and joins the Zambezi River north of Lukulu; ii) the Lungwebungu River, which draws its source in the highlands of Angola's Moxico province; and iii) the Luanginga River, which drains the region between the Lungwebungu and Cuando Rivers.

Between Chavuma and Sioma, the Zambezi River traverses three distinct ecoregions[5] (Figure 3). These include i) the area from Chavuma to the Barotse Floodplain, which consists of *Zambezian Cryptosepalum* dry forest and western Zambezi grasslands; ii) the Barotse Floodplain, which is a large, seasonally flooded wetland ecosystem; iii) and the region from the Barotse Floodplains to Sioma, covered by dry deciduous forest dominated by Rhodesian Teak and western Zambezian grasslands.

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[4] Beilfuss, R. (2012). A risky climate for Southern African Hydro: Assessing hydrological risks and consequences for Zambezi River Basin dams (1st ed.). International.

[5] White, F. 1983. The vegetation of Africa. Natural re ed. UNESCO.

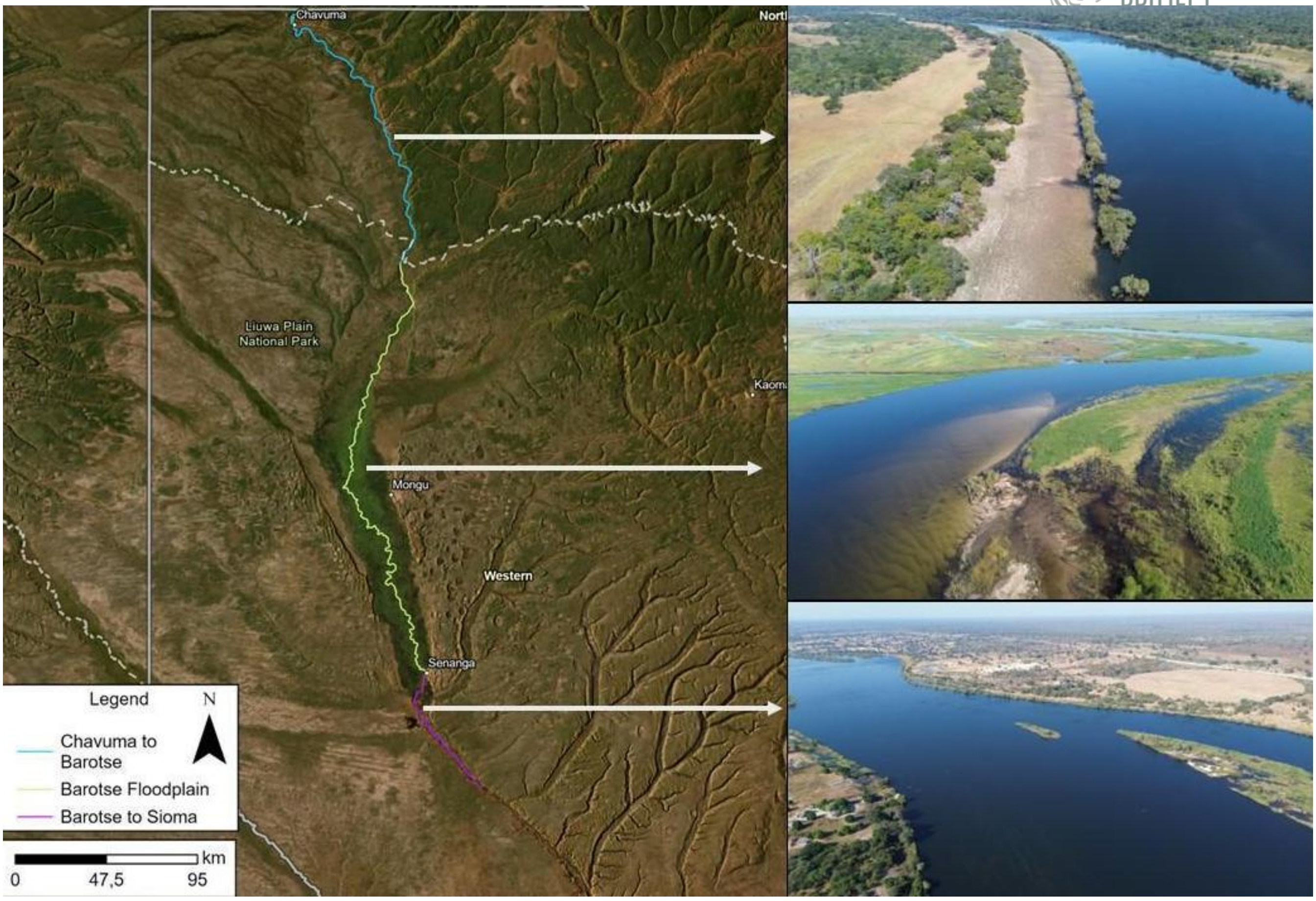


Figure 3. The three biogeographic regions of the Chavuma to Sioma stretch of the Zambezi River.

The Barotse Floodplain

The Barotse Floodplain spans ~5,500 km^2, making it the largest wetland in Zambia (Figure 4)[6]. It begins at the confluence of the Lungwebungu and Kabompo Rivers and continues over 230 km to Ngonye Falls, south of Senanga (Figure 2). The extensive wetlands within this floodplain (up to 50 km wide) regulate the flow of the Zambezi River by collecting water from the upper catchment and slowly releasing it into the lower river[7]. This process involves the mixing and filtering of water from several upstream tributaries, thereby ensuring a consistent flow of clean water from the system.

The Barotse Floodplain supports the livelihoods of ~70,000 people in the wetland surrounds by providing several ecosystem services[8]. These include: i) stabilizing the flow of the Zambezi River between seasons and during extreme weather events; ii) purifying the water that enters the river from several upstream tributaries; iii) housing one of the most commercially important fisheries in Zambia; iv) providing habitat for over 300 species of birds; v) supplying natural resources, such as fish, game, reeds, and edible plants, to local communities; vi) supporting crop cultivation; vii) offering rich pasture for cattle rearing; and viii) offering an important cultural site for traditional ceremonies, including the Kuomboka festival[9].

[6] Zimba, H., Kawawa, B., Chabala, A., Phiri, W., Selsam, P., Meinhardt, M. & Nyambe, I. 2018. Assessment of trends in inundation extent in the Barotse Floodplain, upper Zambezi River Basin: A remote sensing-based approach. Journal of Hydrology: Regional Studies.

[7] WWF. 2020. The Barotse Floodplain.

[8] CGIAR Research Program on Aquatic Agricultural Systems. 2011. Improved Fisheries Management in the Barotse Floodplain of Zambia – An Urgent Call for Action.

[9] Banda, A.M. 2021. Land Use change and its Drivers in the Wetlands of Barotse Floodplain of Zambezi River Sub-Basin, Zambia. (June):1–24.

Figure 4. The Zambezi River within the Barotse Floodplain.

Barotse Floodplain Hydrology

A belt of seasonally inundated pans, some reaching up to 4 km in diameter, borders the Barotse Floodplain. Many of these pans lie within shallow, grassy valleys known as dambos, fringed by densely wooded areas. The dambos act as natural sponges, providing a crucial 'safety valve' for local communities against climate events such as droughts and floods, but also for downstream countries within the Zambezi River Basin[10]. Comparing the hydrographs between areas above (Chavuma) and below the floodplains (Ngonye Falls) reveals this phenomenon—the Zambezi River has a more evenly distributed and consistent flow downstream of the wetland (Figure 5).

The key factors affecting wetland utilisation are the timing and extent of the annual flooding of the Zambezi River and the timing and consistency of the rains. The Barotse Floodplain floods annually, usually towards the end of the rainy season in April and May, when floodwaters from the upper river reach it. By July, the floodplains have generally begun to recede, and the water level in the plains is lowest in September.

The Barotse Floodplain has an average inflow of 845 m^3/s from the Zambezi River at Lukulu and an additional 63 m^3/s from the Luanginga River[11]. Towards the end of the floodplain at Senanga, the Zambezi River flows with an average of 1,029 m^3/s after receiving inputs from groundwater and various tributaries within the floodplain. Once the Zambezi River reaches Ngonye Falls, the hard volcanic rocks form a natural dam, impounding the river above the falls (Figure 6).

[10] WWF. 2020. The Barotse Floodplain.

[11] Deneut, E., Chileya, C. K., & Nativel, C. (2014). Environmental and social impact assessment for the improved use of priority canals in the Barotse Sub-Basin of the Zambezi. BRL ingénierie.

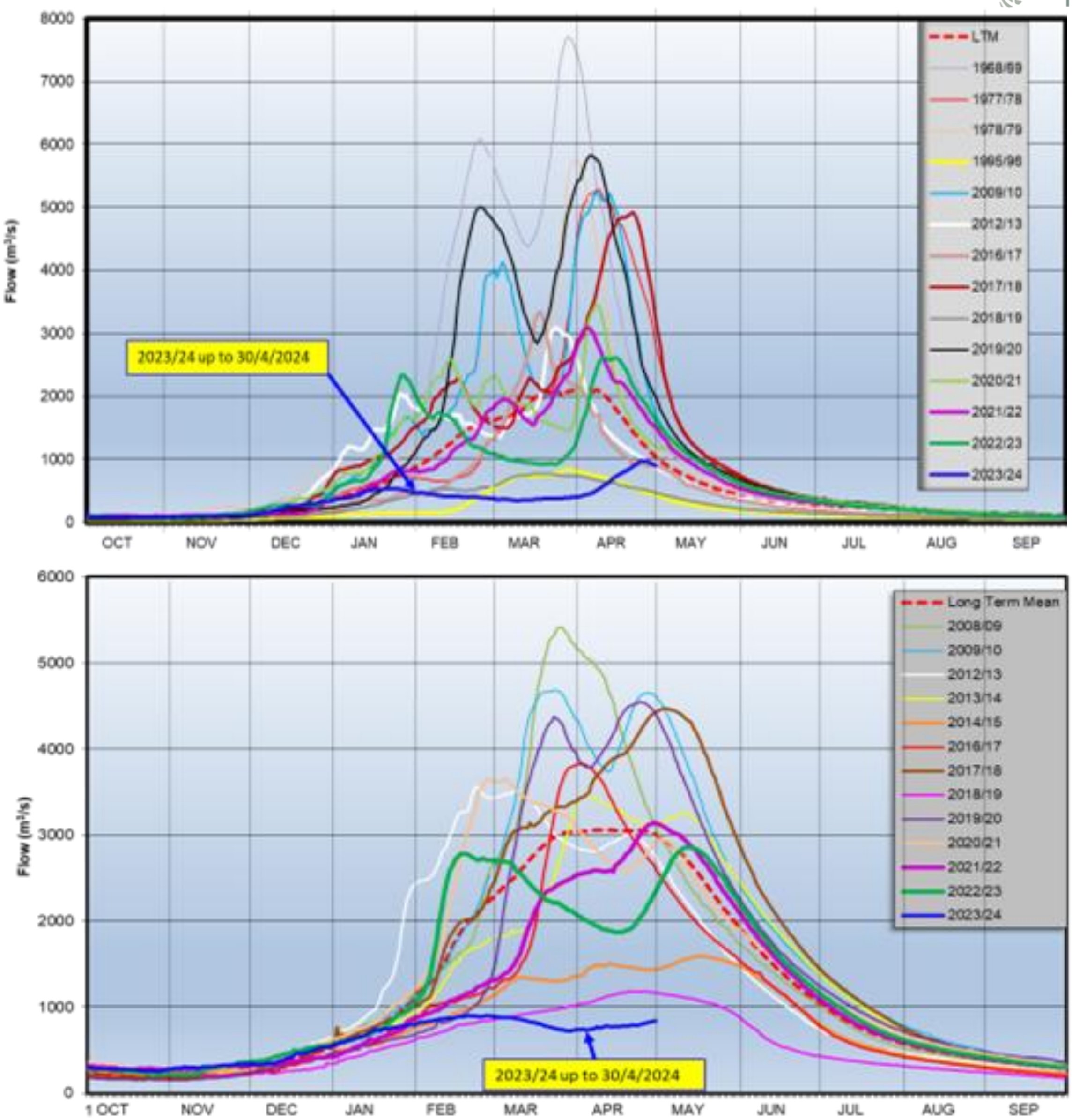


Figure 5. Hydrographs for the Zambezi River at Chavuma (top) and Ngonye Rapids (bottom).


Figure 6. Ngonye falls (image taken by Wim Werrelman).

Socio-economic characteristics of the Barotse Floodplain region

The Barotse is predominantly inhabited by the Lozi and Luvale cultures, who have existed alongside the floodplain for centuries. The traditions and cultures of the Lozi people are directly tied to seasonal flood cycles, which determine the annual movements of people and their livestock. For example, the highly celebrated Kuomboka ceremony — where the Litunga (King of the Lozi people) moves to the uplands and plain fringes[12]. This culturally evolved landscape, characterized by homesteads, royal graves, and canals for transportation, land drainage, flood control, and agricultural activities, demonstrates the harmonious coexistence between the local communities and the natural environment[13]. Due to its unique cultural landscape and the special relationship between the local people and their environment, the Barotse cultural area is a proposed World Heritage Site[14].

Crop farming, livestock grazing, and fishing form the basis of the subsistence-based local economy within the Barotse Floodplain[15]. The floodplain — with its alluvial deposits and high-water availability — is a prime location for agriculture, supporting a wide range of crops, including maize, rice, cassava, sweet potato, sugar cane, fruits, and vegetables[16]. The floodplain provides rich pasture, making it one of the most productive cattle areas in the country. The cattle in the Barotse Floodplain consist of the Barotse breed, also known as Lozi, Rowzi, Rozi, or Baila. Natural pastures form the main feed for the Barotse cattle, and crop residues account for 5% of their intake[17]. The degree and duration of inundation determines the length of time that cattle spend in the floodplain. Cattle generally spend July to January in the floodplain and the remainder of the year in the uplands. The population of cattle in the floodplains are estimated to

[12] Milupi, I. & Sampa Moonga, M. 2020. Transmission mechanisms of Traditional Ecological Knowledge and sustainable management of natural resources among the Lozi-speaking people in Barotse floodplain of Zambia. Multidisciplinary Journal of Language and Social Sciences Education. 3(2):216–228.

[13] WWF. 2020. The Barotse Floodplain.

[14] CGIAR Research Program on Aquatic Agricultural Systems. 2011. Improved Fisheries Management in the Barotse Floodplain of Zambia – An Urgent Call for Action.

[15] Namafe, C.M. 2004. Flooding in the Context of the Barotse People of the Upper Zambezi Wetlands. Southern African Journal of Environmental Education. 21:50–60.

[16] Pasqualino, M., Kennedy, G., Longley, K. & Thilsted, S. n.d. Food and Nutrition Security in the Barotse Floodplain System. Bioversityinternational.Org.

[17] Banda, A.M. & Banda, K. 2022. Assessment of the Wetland Ecosystem Services Status and Their Uses in the Barotse Flood Plains of Zambezi Sub Basin, Zambia. Journal of Food Technology & Nutrition Sciences. 4(1):1–11.

be over 450,000[18] — accounting for more than 12% of Zambia's cattle[19].

The fisheries sector in the floodplain is of immense importance, providing a significant source of protein and income to local communities. Cichlid species constitute most of the catch, and several other groups are targeted, including barbs, mormyrids and catfishes. Fishing activity increases as floodwaters recede and fish are flushed from the floodplains into the main river channel. This activity intensifies from May until December when fishermen stop fishing in anticipation of the rains. When the floodplain becomes fully inundated, fish are mainly caught using traditional maalelo, traps and spears[20].

Conservation Areas and initiatives

The Kavango-Zambezi (KAZA) Trans-frontier Conservation Area (TFCA) is the second-largest nature and landscape conservation area in the world. It lies in the Kavango and Zambezi River basins where Angola, Botswana, Namibia, Zambia and Zimbabwe converge (Figure 7). Part of the greater KAZA TFCA is the proposed Liuwa Plains-Mussuma TFCA, which aims to sustainably manage a portion of the catchment area of the upper Zambezi River. The establishment of the Liuwa Plains-Mussuma TFCA would significantly strengthen the ecological integrity of the Barotse Floodplain and ensure the provision of vital ecosystem services to local communities for generations to come.

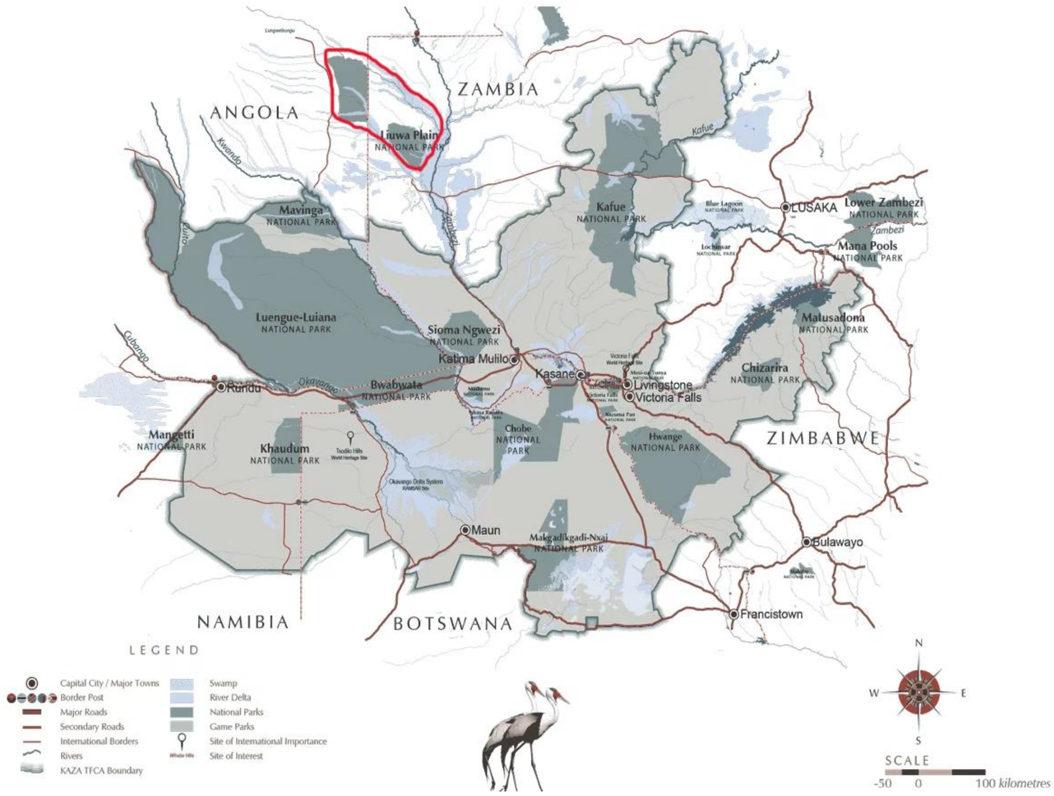


Figure 7. The greater Kavango–Zambezi TFCA with the proposed Liuwa Plains–Mussuma TFCA outlined in red[21]

WWF Zambia plays a significant role in the conservation of the Barotse Floodplains. The organisation is collaborating with various stakeholders, including the Water Resources Management Authority (WARMA), to identify and designate the headwaters of the Zambezi River as a Water Resource Protected Area (WRPA). This initiative aims to safeguard the biodiversity of the Barotse Floodplain and ensure water

[18] Banda, A.M. & Banda, K. 2022. Assessment of the Wetland Ecosystem Services Status and Their Uses in the Barotse Floodplains of Zambezi Sub Basin, Zambia. Journal of Food Technology & Nutrition Sciences. 4(1):1–11.

[19] PRMC Zambia. 2021. Analysis of the 2020 National Livestock Policy. (November).

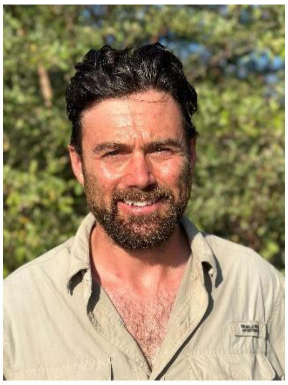
[20] PRMC Zambia. 2021. Analysis of the 2020 National Livestock Policy. (November).

[21] Kavango Zambezi Transfrontier Conservation Area. 2019. Available: https://www.kavangozambezi.org/about-kaza/.

security for local communities[22]. Additionally, WWF implemented the Upper Zambezi Project in 2018, focusing on enhancing ecosystem management through responsible water use planning and protection against unsustainable development. The main focus areas are the Kabompo River, the Barotse Floodplains, and the Liuwa Plains[23]. WWF has also developed an invasive alien plant removal programme in the floodplains with Birdwatch Zambia and the Barotse Royal Establishment[24]. The target is to remove over 35 km^2 of invasive alien plants near the Mongu bridge. Furthermore, WWF supports the National Heritage Conservation Commission in its efforts to have the Barotse Floodplain declared a World Heritage Site. See *Appendix 1* for more information on past and ongoing conservation projects with the Barotse Floodplain.

Team Members and Expedition Timing

Table 1. The expedition team members.

 Joseph Cutler	 Lars Diekman	 Mutesi Mbundi	 David Nkhata
 Josiah Nowake	 Mfundisi Nowake	 Dave Oliver	 Michael von Brandis
			

[22] Comba, M. 2020. Reflecting on the Barotse Floodplain on World Environment Day 2020.

[23] WWF. 2020. *Mimosa Pigra on the Upper Zambezi Landscape*.

[24] WWF. 2020. *Mimosa Pigra on the Upper Zambezi Landscape*.

Rainer von Brandis	Oreneile Yeni	Stanford Zulu	Brian Mukanzu

Expedition Safety

All possible medical support and general safety avenues are put into place before conducting an expedition. This includes land support vehicles, which follow the river team for resupplies where possible. In addition, all team members have full medical cover, and a medevac 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, 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 fibreglass mokoros, or replica dugout canoes, to survey the Zambezi River between Chavuma and Sioma. These boats were loaded with up to 500 kg of equipment strategically packed into the middle of the boat, leaving just enough space for a person on either end (Figure 8). These boats had an extremely shallow draft, allowing the teams to paddle over shallow stretches of the river. Expedition teams covered ~30 km per day depending on river flow, obstructions and wind.

Figure 8. Two expedition team members on a mokoro with their equipment packed in the middle.

Along the entire length of the 560km transect, 360° imagery and visual observation data were continually collected. Observation data includes recordings of sightings of human activity, agriculture, infrastructure, wildlife, alien invasive species and fire (Table 2, Figure 9). 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, a benthic macroinvertebrate survey was conducted, and water discharge was measured. A fyke net, crab trap, and acoustic bat recorder were deployed at night.

Table 2. Summary of data collection during the expedition.

Data Collection Frequency	Data Category
Continuous	• GPS track • 360° video • Survey forms relating to human activity, agriculture, infrastructure, biodiversity and fires.
Every 10 km	• Water quality analysis • 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	• Fish sampling • Discharge measurement

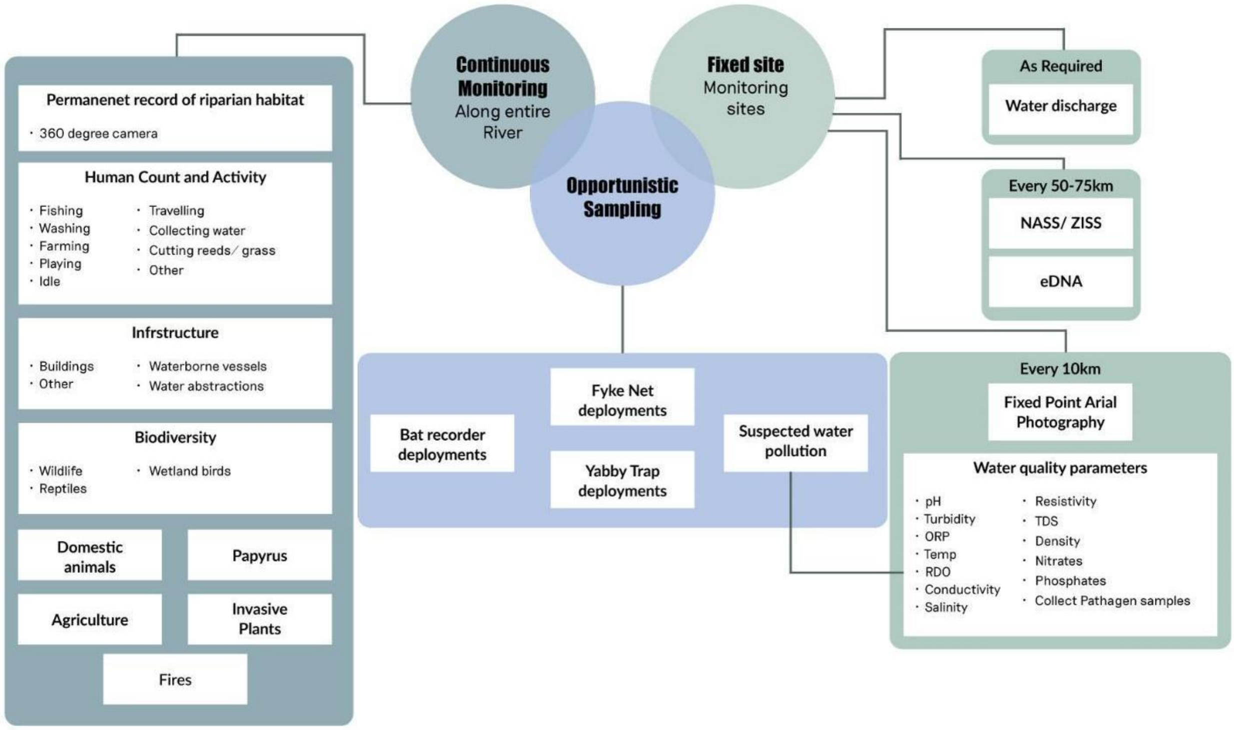


Figure 9. Summary of the data collected on the river.

The process of collecting survey data on the transect involved two parties: the observer and the recorder. The observers sat at the back of the mokoro and visually scanned the river and its banks for relevant observations within 100 m of 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. Data from Survey123 were uploaded to a cloud database for safekeeping. Survey123 forms were created beforehand and set to automatically assign geolocation, date, and time to each entry.

Survey Limitations and Potential Data Bias

It is important to note that several limitations and potential biases are involved with data collection on rivers. These can limit the statistical confidence of data analysis and should be considered when interpreting data. In addition, data limitations and potential biases require due consideration when making management decisions or using data for scientific purposes. Survey limitations and potential data biases include:

- Most of the expedition followed the main river channel, and as a result, oxbow lakes and backwaters were excluded from the survey.
- Uncontrollable variables such as vegetation density and riverbank height, river width, prevailing weather, team health, rapids, sharp corners in the river, and sandbanks may have obscured observations or introduced observer bias.
- Survey time was restricted to daytime hours (between 08:30 and 16:00); however, some survey days were longer or shorter, depending on field conditions and variables.
- The wildlife survey does not include smaller species of rodents, amphibians, reptiles, and insects.
- Initially, we did not count homes in larger towns on the river. This was supplemented by a remote sensing Google Building analysis.
- 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.
- The expedition was conducted over a period of a few weeks and, as a result, does not represent the permanent state of the river. It offers a snapshot of the river to which future data can be compared.

2. CONTINUOUS MONITORING ALONG THE ENTIRE RIVER TRANSECT

Human Activity

Methods: Human counts & activity

The presence or absence of people along a river alludes to the level of anthropogenic disturbance, particularly within highly populated and modified river basins. In addition, human counts can offer important socio-economic insights when combined with details of river-related activities. To this end, all people interacting with the Zambezi River and its riparian zone were counted without considering age, sex or ethnicity. Activities documented on the Zambezi 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.
- Washing: This includes people in the process of washing their bodies, clothes, or domestic items.
- Farming: People tilling, sowing, harvesting, watering, herding livestock, building enclosures around their farms or any other farming-related activity.
- Travelling: People travelling on foot, by motorbike or in a waterborne vessel. For this analysis, all parked watercraft, including mokoros, fibreglass canoes, motorised boats, barges, and other vessels, are discussed below.
- Collecting water: Only people collecting water by hand were counted under this category. Any use of pumps was counted as an abstraction (see *Infrastructure* section below).
- Fishing: People fishing with nets, traps, hooks, and lines or other means were included in this category. In addition, those involved in the cleaning or repairing fishing nets were counted. For the purposes of this analysis, all unmanned but deployed fishing equipment is also discussed in this section.
- Other: Evidence of other human activities was recorded. This includes: i) drying and scaling fish; ii) collecting reeds; iii) swimming for leisure; and iv) sand mining.

Results and Discussion: Human Counts and Activity

A total of 3,558 people were recorded along the Zambezi River from Chavuma to Sioma (6.35 people/km). This density is slightly higher than the downstream Sioma to Livingstone stretch (6.07 people/km) and substantially higher than the upper Zambezi River in Angola (2.3 people/km). People were predominantly inactive (N = 1,437), travelling (N = 1,022), washing (N = 452) or engaged in fishing activities (N = 178) (Table 3). Human activity was concentrated within the Barotse Floodplain (Figure 10).

Table 3. Summary of the human activity on the Zambezi River.

Activity	Number of People
Inactive	1,437
Travelling	1,022
Washing	452
Fishing	178
Collecting water	38
Farming	24
Other	387
Total	3,558

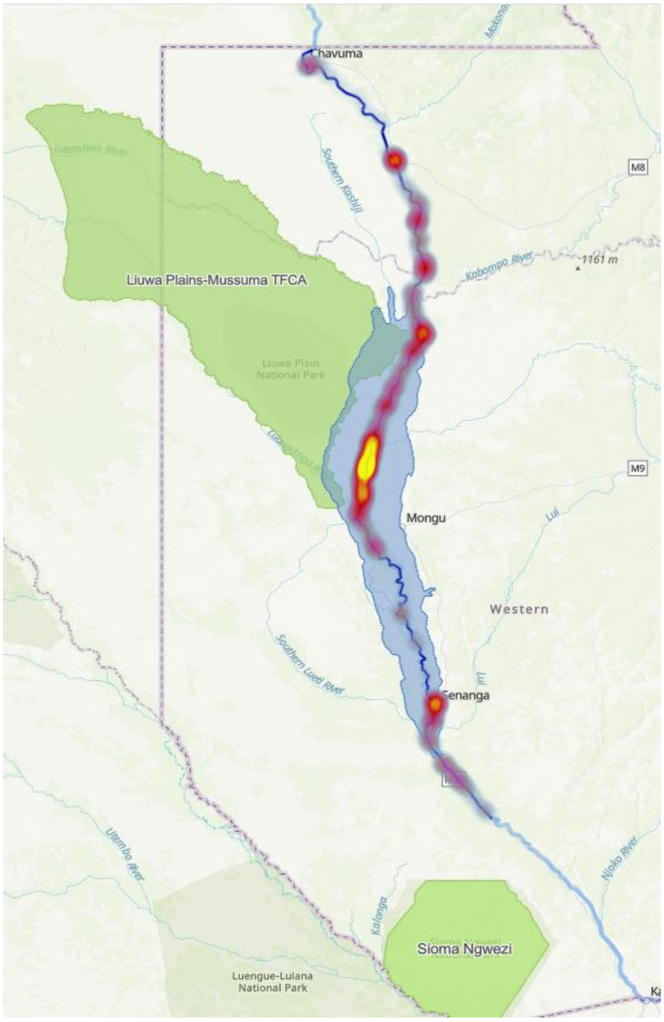


Figure 10. The distribution of people along the river with a hotspot in the Barotse Floodplain.

Travel

A total of 1,022 people were observed travelling along the Zambezi River from Chavuma to Sioma (Table 4). The number of people travelling was much greater on this stretch of the Zambezi River than in other regions, such as Sioma to Livingstone. The predominant mode of transportation, by a considerable margin, was the mokoro (N = 499), followed by motorised boats (N = 211). People were also seen travelling on foot and using other vessels, such as ferries.

Table 4. Summary of modes of travel

Mode of transport	Count
Mokoro	499
Motorised boat	211
On foot	162
Other vessels	144
Total	**1,022**

Most of the people travelling along the river were concentrated in the Barotse Floodplain (Figure 11). Mokoros were preferred in the Barotse Floodplain because their shallow draught makes them efficient for navigating the shallow wetlands (Figure 12). Motorised boats were also common on this stretch as they were used for long-distance travel between Lukulu, Mongu and other towns along the shores of the Zambezi River. Motorized boats transported up to 17 people simultaneously, except for one boat with over 70 people on board (Figure 13).

In addition to the vessels in active use, a total of 895 vessels were parked along the riverbanks, with 91% of these vessels being mokoros (Table 5). A large fleet of 16 motorised boats were parked near Lukulu, which were presumed to be awaiting transport to Angola up the Lungwebungu river or south to Mongu. A major trade route between Zambia and Angola is utilizing the Lungwebungu, transporting agrochemicals and food to Angola and diesel to Zambia.

Table 5. Summary of parked vessels.

Vessel type	Count
Mokoro	816
Motorised Boat	37
Other Paddle Boat	36
Other	1
Barge	5
Total	895

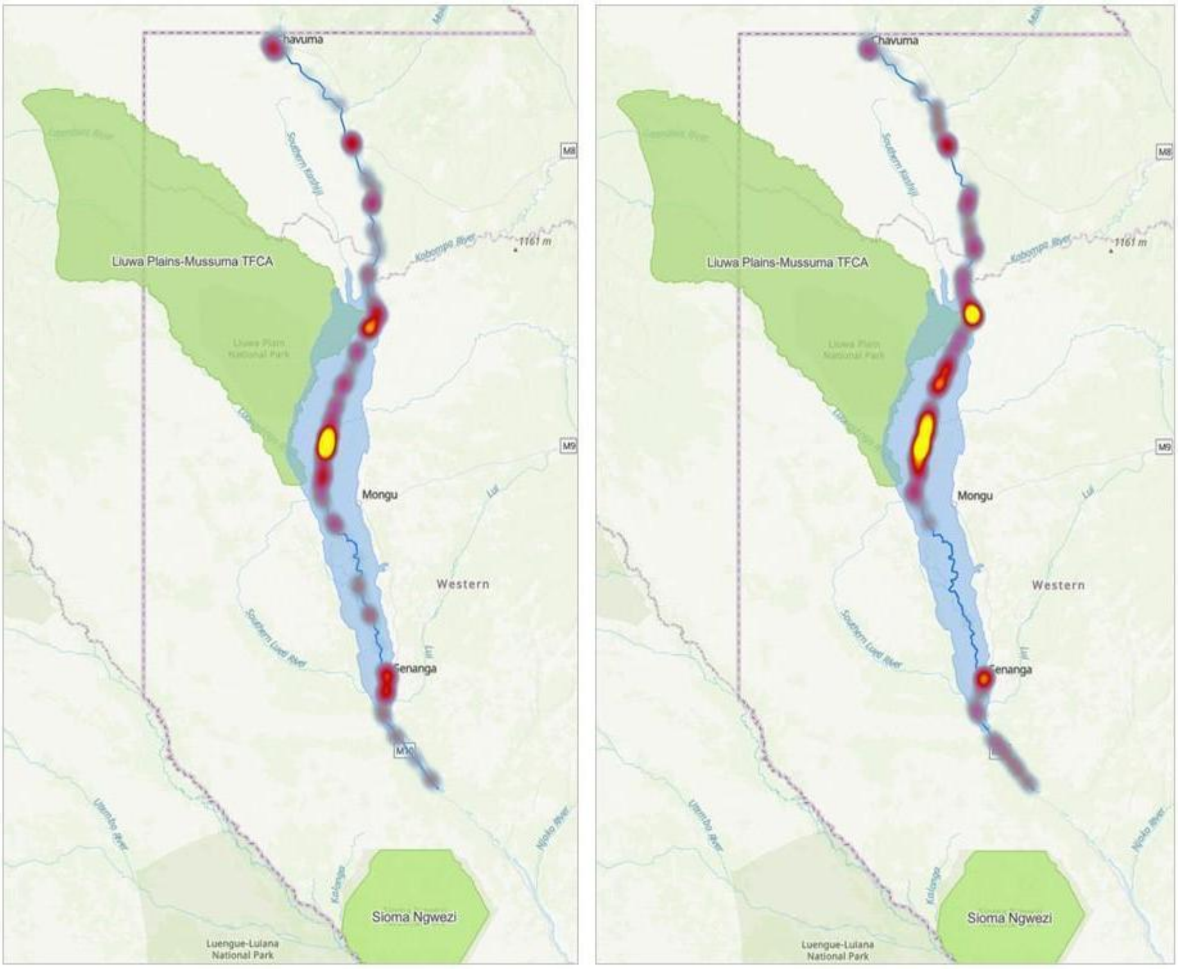


Figure 11. The distribution of people travelling on the river (left) as well as the distribution of parked vessels (right) with a hotspot in the Barotse Floodplain.

Figure 12. People using mokoros for transport along the Zambezi River.

Figure 13. Motorised boats on the Zambezi River,

Washing

A total of 452 people were washing their bodies or clothes along this Zambezi River transect. Designated bathing areas pose significant risks as potential point sources of pollution. The use of robust detergents can precipitate several detrimental impacts: i) an alteration of water chemistry, manifested by elevated pH levels and diminished dissolved oxygen content; ii) an increased likelihood of algal bloom events; and iii) deleterious effects on fish populations and macroinvertebrate communities.

The water quality results did not indicate any changes near areas where washing occurred. Local communities use low levels of washing detergents, rendering them easily diluted in the river's high flow. However, this may not be the case in the dry season as the river's flow rate and volume decline, which is likely to concentrate washing detergents. See *EarthViews web application* for the distribution of people bathing and washing household items.

Fishing

The Barotse Floodplain is considered the heart of the fisheries sector in Zambia's Western Province. The floodplain supports a large fishery, which provides food and income for ~ 70,000 people[25]. Most fish are sold to local markets in the Copperbelt and Lusaka Provinces or internationally to Angola and the Democratic Republic of Congo (DRC). Among the sold fish, cichlids comprises 80%, while the remaining 20% consists of smaller fish such as minnows, tilapia, bottlenose and silver barbels. However, due to high fishing pressure and destructive fishing methods, the fish populations have rapidly declined, forcing local fishermen to target small fish and juveniles to meet the market's demand[26]. Falling fish stocks are directly related to a decline in the per capita fish consumption, which has declined by more than 50% from 2007

[25] CGIAR Research Program on Aquatic Agricultural Systems. 2011. Improved Fisheries Management in the Barotse Floodplain of Zambia – An Urgent Call for Action.

[26] Kabombo, M. 2017. An ethical evaluation of the sustainability of the current fishing methods in the Barotse floodplains of Mongu district on the human and natural environment.

to 2013 in the Barotse Floodplain[27].

A total of 178 people were observed fishing along the Zambezi River during the survey period — equivalent to one fisher every 3 km. While this provides a useful indication of fishing presence, it represents a substantial underestimate of the true extent of fishing activity. This figure reflects only those individuals visible from the main river channel at a specific point in time and does not account for the fishers who operate in off-channel habitats such as lagoons, seasonal floodplain pools, or more remote fishing camps. As such, this snapshot does not capture the full spatial and temporal scale of fishing along the river.

In reality, the Barotse Floodplain supports one of the most significant inland fisheries in the region. Approximately 4,380 people are directly engaged in fishing, and the broader fishery underpins the livelihoods of over 28,000 households, supporting more than 225,000 people[28]. Fishing contributes an estimated 73% of household cash income in many parts of the floodplain, reflecting its central role in local economies and food systems.

Gill nets were the most frequently employed fishing gear, followed by lines and traps (Table 6). The flood regime significantly influences the choice of fishing gear in the floodplains. During this survey, which was conducted as floodwaters were receding, gill nets were predominantly used due to their effectiveness in catching fish concentrated in lagoons. Conversely, traps were less common as they were more efficient in fully inundated floodplain areas or the main stem of rivers. A dry season survey may reveal different fishing methods and increased fishing activity within the floodplain.

Table 6. Fishing gear on the Zambezi River.

Type of gear	Gear in use	Gear unmanned
Net	98	48
Line	77	4
Trap	3	15
Total	178	67

[27] CGIAR Research Program on Aquatic Agricultural Systems. 2011. Improved Fisheries Management in the Barotse Floodplain of Zambia – An Urgent Call for Action.
[28] Njaya, F. (2015). Management of the Upper Zambezi River Fishery.

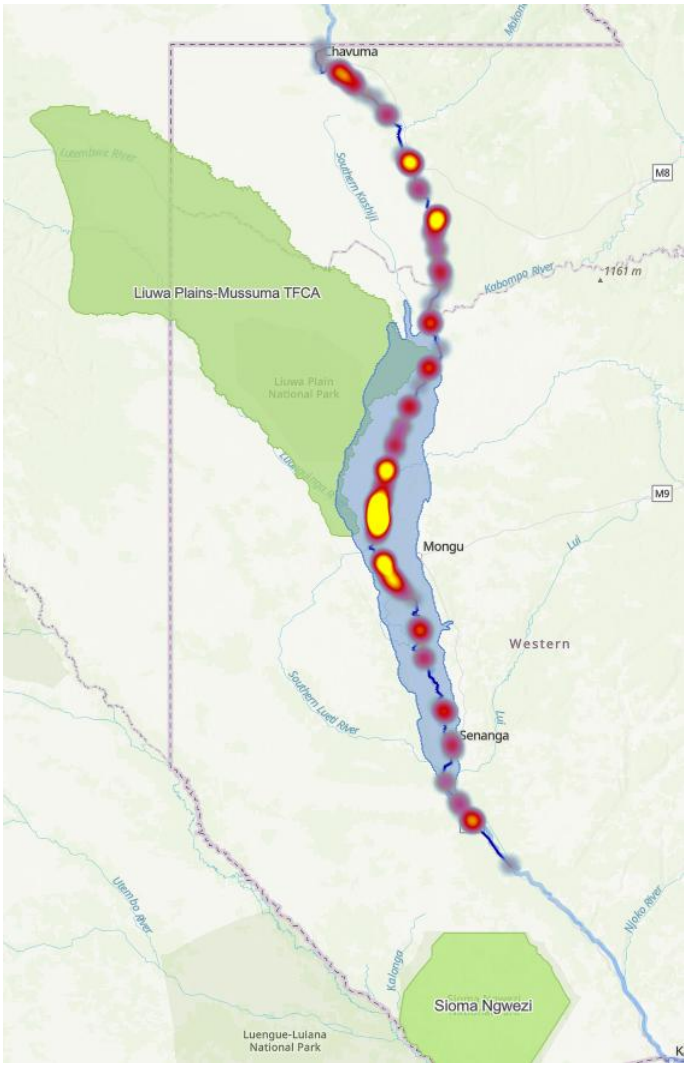


Figure 14. Fishing activity on the Zambezi River.

On the Barotse Floodplain, most people fish at night and are inactive during the day. Fish move to shallower waters to feed at night, making them easier targets for anglers. As a result, the observed results likely understate the true extent of fishing, as our survey is limited to daytime. In addition to the higher fishing pressure, people were observed fishing using illegal *sefa-sefa* nets at night (Figure 15).

Recent studies show *sefa-sefa* nets are replacing traditional fishing methods in the Barotse Floodplain[29]. As fish stocks decline and competition increases, fishers resort to less selective methods to maintain their catch per unit effort (CPUE). They are particularly prevalent in Zambia as they are cheap and easily accessible. Fishing with these nets is problematic because: i) the small mesh traps juvenile fish and fish eggs, potentially disrupting the size-distribution of healthy fish populations; and ii) the nets break easily and are often discarded in the river, killing fish and other animals indiscriminately, beyond their useable lifespan[30].

Large quantities of small, dried fish along the riverbanks provide clear evidence of this shift towards targeting smaller fish (Figure 16). Due to these destructive fishing methods, combined with high fishing pressure and climate variation, fish stocks in the Barotse Floodplain have declined rapidly in recent years. A lack of alternative livelihoods for small-scale fishers means they have no choice but to continue fishing

[29] Kabombo, M. 2017. An ethical evaluation of the sustainability of the current fishing methods in the Barotse floodplains of Mongu district on the human and natural environment.

[30] Larsen, D.A., Welsh, R., Mulenga, A. & Reid, R. 2018. Widespread mosquito net fishing in the Barotse floodplain: Evidence from qualitative interviews. PLoS ONE.

despite dwindling returns [31,32].

Overfishing persists because seasonal fishing bans are often not enforced[33,34]. Moreover, illegal fishing gear remains widespread despite the risk of fines or up to two years in prison. Without immediate action, fish catches will decline further, reducing incomes for fishers, processors, and traders and leading to more expensive fish[35,36]. Stronger policing is necessary to ensure that all fishers and traders comply with the fishing ban and that all illegal fishing gear is confiscated.

Figure 15. Local fishermen preparing a sefa-sefa net for fishing.

[31] Kabombo, M. 2017. An ethical evaluation of the sustainability of the current fishing methods in the Barotse floodplains of Mongu district on the human and natural environment.

[32] Tweddle, D., Cowx, I.G., Peel, R.A. & Weyl, O.L.F. 2015. Challenges in fisheries management in the Zambezi, one of the great rivers of Africa. Fisheries Management and Ecology.

[33] Pasqualino, M., Kennedy, G., Longley, K. & Thilsted, S. n.d. Food and Nutrition Security in the Barotse Floodplain System. Bioversityinternational.Org.

[34] Tweddle, D., Cowx, I.G., Peel, R.A. & Weyl, O.L.F. 2015. Challenges in fisheries management in the Zambezi, one of the great rivers of Africa. Fisheries Management and Ecology.

[35] Tweddle, D., Cowx, I.G., Peel, R.A. & Weyl, O.L.F. 2015. Challenges in fisheries management in the Zambezi, one of the great rivers of Africa. Fisheries Management and Ecology.

[36] Abbott, J.G. & Campbell, L.M. 2009. Environmental histories and emerging fisheries management of the upper Zambezi River floodplains. Conservation and Society.

Figure 16. Piles of dried fish observed in the market (top) and fish trap (bottom).

Inactive

A total of 1,437 people were seen within the river's riparian zone but not actively engaging in any activities. Areas where large groups of inactive people were observed correspond to seasonal fishing camp hotspots (Figure 17). Fishing primarily occurs at night; thus, many inactive people observed along the river may be fishermen who were resting at the time of observation.

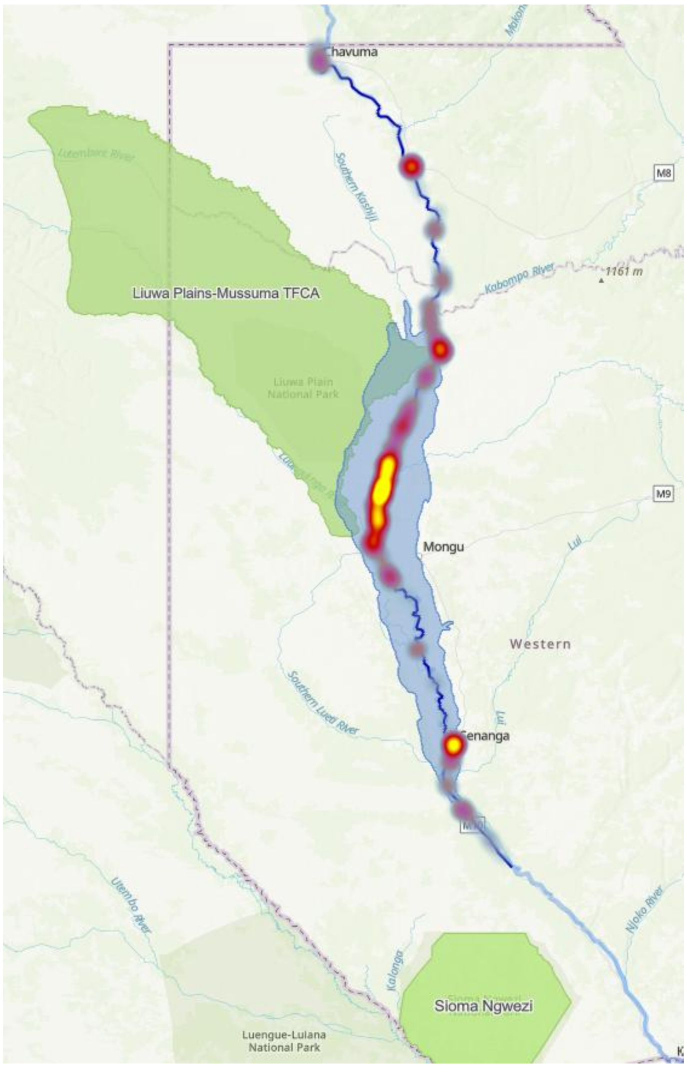


Figure 17. The distribution of people observed inactive along the river survey transect.

Infrastructure

Methods: Infrastructure

The type, amount and distribution of infrastructure along a river offers insights about: i) the level of development in the riparian zone; and ii) how river resources are utilised. Infrastructure, both in 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 river's high-water mark.
- **Huts:** These were single/pairs of buildings built to last throughout the year.
- **Water abstractions:** Each water abstraction's pipe circumference and location were recorded.
- **Bridges:** These are locations where structures were built across the river to aid travel.
- **Other:** Other infrastructure was recorded, including brick factories, cell towers, lodges, gauging stations, sewage treatment facilities

Results and Discussion: Infrastructure

The most common type of infrastructure on the Zambezi River from Chavuma to Sioma was seasonal camps (N = 242) (Table 7). This stretch of the Zambezi is heavily populated, with the towns of Zambezi, Lukulu, Mongu, Senanga and Sioma on its banks. Infrastructure was present throughout the transect

(Figure 18), and many seasonal fishing camps were observed in the Barotse Floodplain. The concentration of infrastructure suddenly subsides in the middle of the floodplain due to the flood state (Figure 18). During this expedition, the top half of the floodplain was starting to drain, thus exposing dry land suitable for camps, whereas the southern half had not yet started to drain. See [EarthViews web application] for the distribution of lodges and gauge stations.

Table 7. The type and count of infrastructure on the Zambezi River.

Type of infrastructure	Count
Seasonal Camp	242
Huts	12
Water Abstraction	12
Bridge	2
Other	43

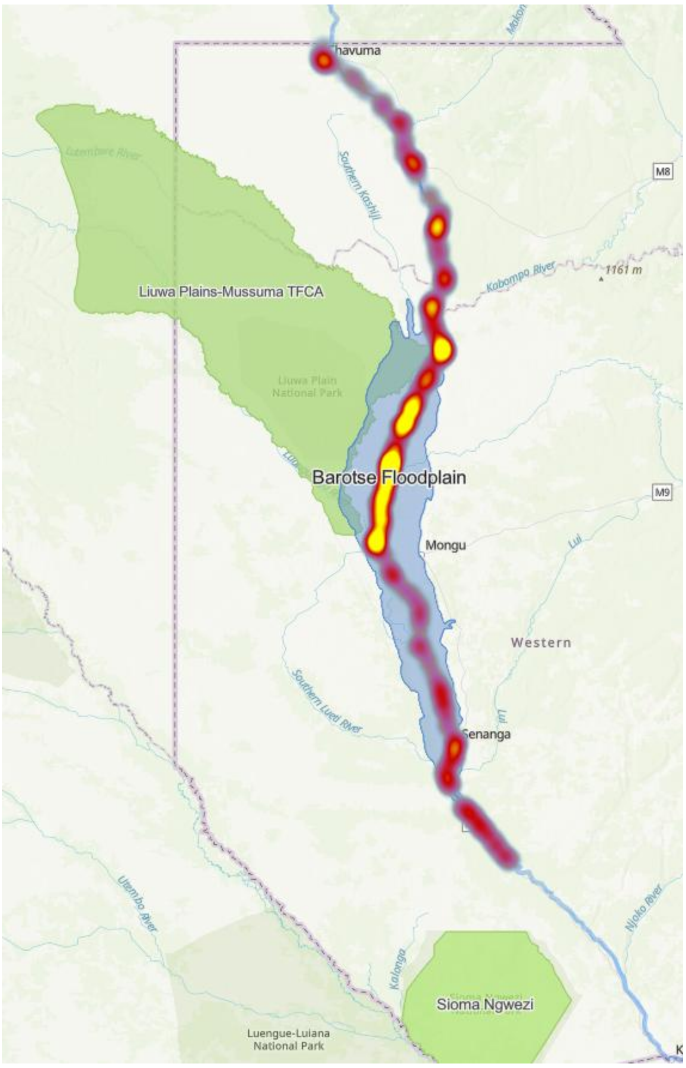


Figure 18. The distribution of infrastructure (excluding villages) along the Zambezi River from Chavuma to Sioma.

Seasonal Camps

There were 242 seasonal camps along this stretch of the Zambezi River. Two were seasonal agricultural camps, whereas the rest were seasonal fishing camps. The agricultural camps were at the beginning of the transect before the floodplain (Figure 20). The seasonal fishing camps were all in the Barotse Floodplain — corresponding with the high fishing pressure observed in this region (Figure 19).


Figure 19. Seasonal fishing camps observed in the Barotse Floodplain.

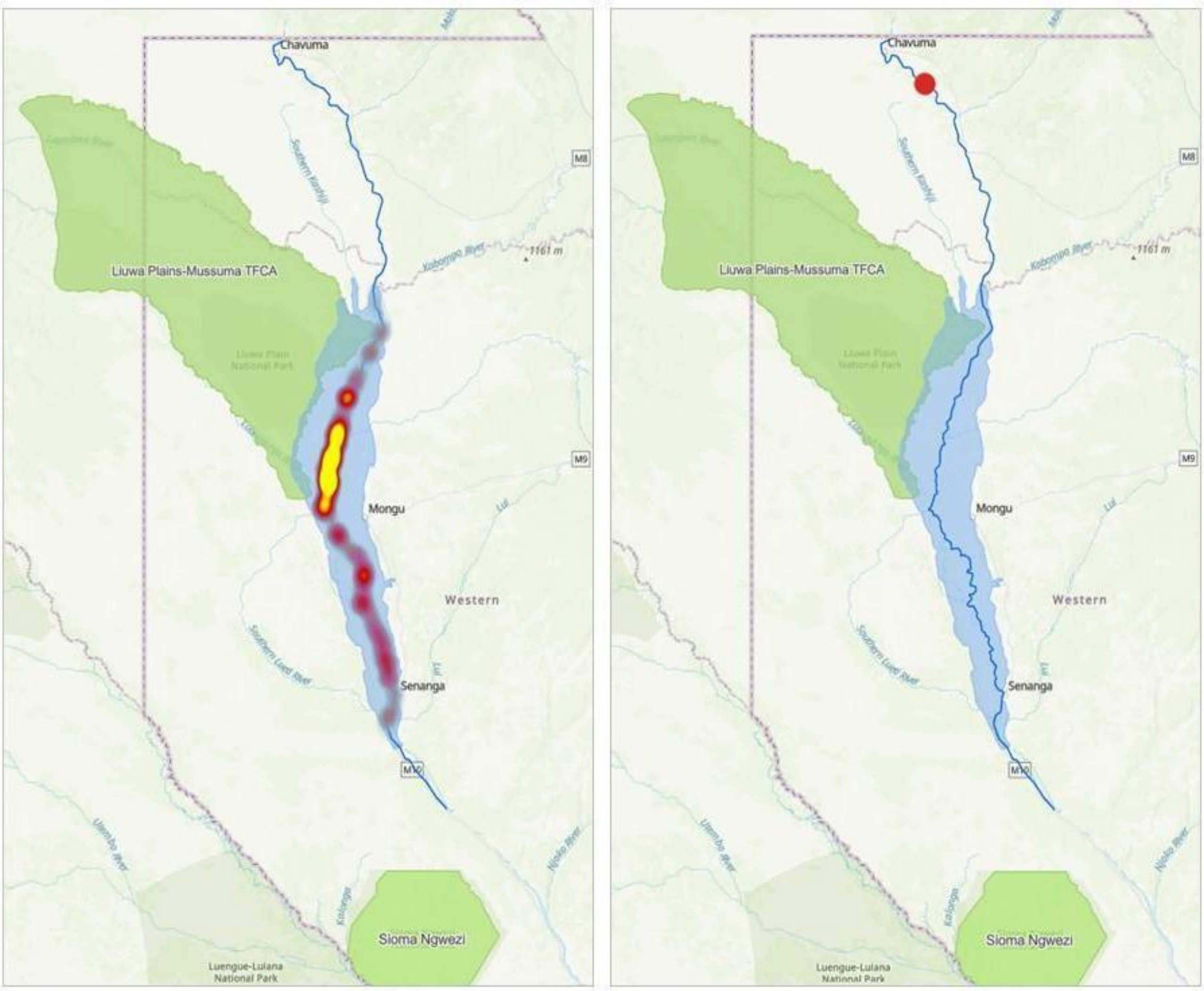


Figure 20. The distribution of seasonal fishing camps (left) and seasonal agriculture camps (right) on the Zambezi River from Chavuma to Sioma.

Water abstraction

A total of 11 water abstractions were observed along the river (Figure 21). These were predominantly for agricultural use with 3–15 mm diameter pipes or larger 30–50 mm pipes for municipal use. Municipal abstractions were observed in the towns of Zambezi, Senanga and Sioma. Very few abstractions were observed in the Barotse Floodplain, most likely due to the seasonal use of the floodplains and the lack of permanent infrastructure and farms in this region.

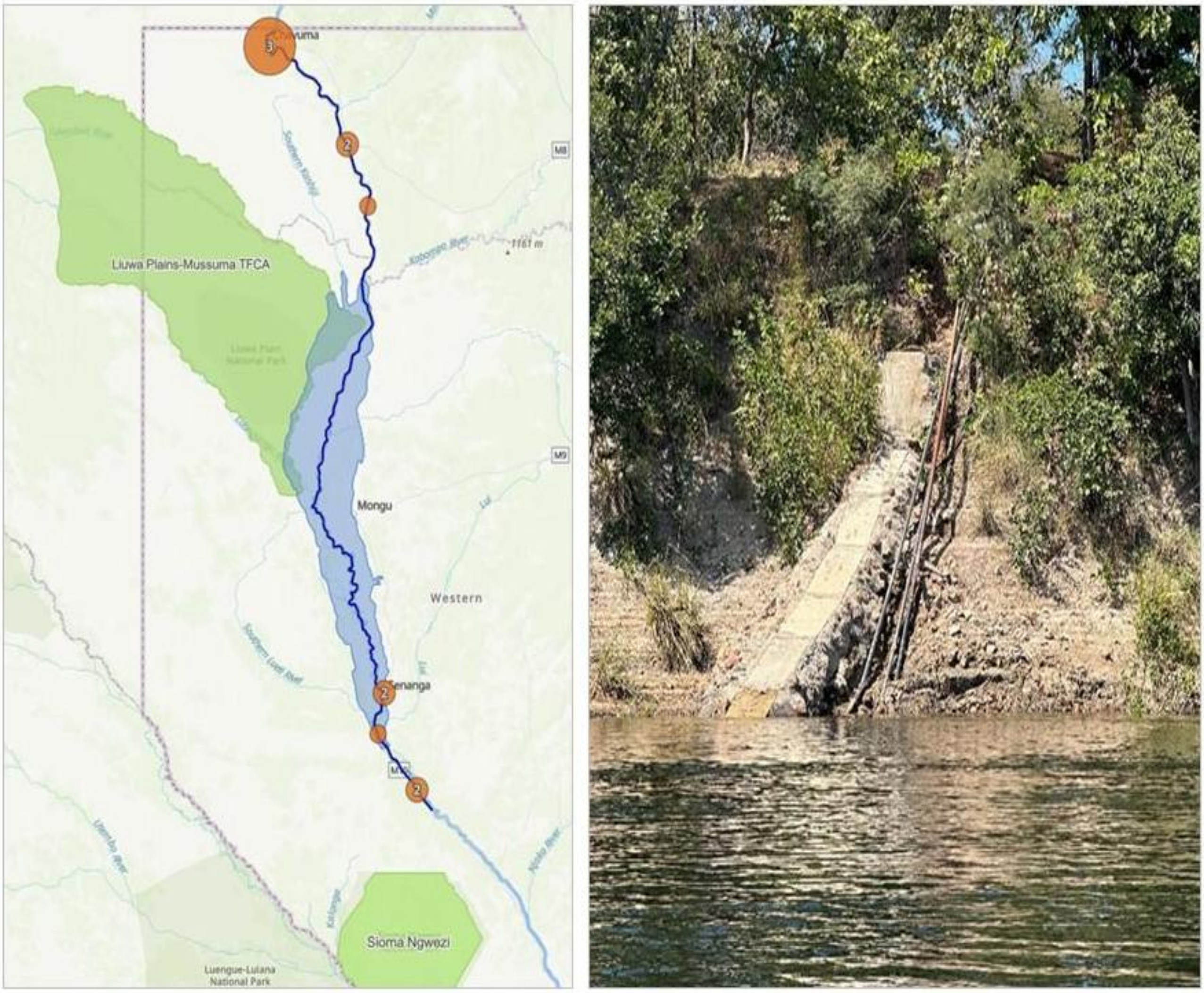


Figure 21. Water abstractions observed along the Zambezi River. Note that abstractions are clustered, and numbers represent the count.

Bridges

There were only two bridges along the entire stretch of the river — a small pedestrian bridge near Chinyingi and the two-lane paved highway of the Mongu-Kalabo road. The Mongu-Kalabo road is the only vehicle bridge that crosses the Barotse Floodplain — it was only completed in 2016 after delays caused by the difficulty of construction in the floodplain[37].

Other infrastructure

Other noteworthy infrastructure observed along the Zambezi River included brick factories (N = 11) and two effluent discharge pipes (Figure 22). No correlations were found between the effluent discharge and water quality, whereas the areas around the brick factories showed decreased water quality. Brick factories are clustered around the confluence of the Kabompo River (Figure 22). Three of these factories were south of the confluence of the Lungwebungu River inside the Barotse Floodplain.

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[37] Banda, A.M. & Banda, K. 2022. Assessment of the Wetland Ecosystem Services Status and Their Uses in the Barotse Flood Plains of Zambezi Sub Basin, Zambia. Journal of Food Technology & Nutrition Sciences.

The production of bricks involves the extraction of clay soil through mining operations. The clay material deemed unsuitable for the manufacturing process is often deposited into the area surrounding the mining site. This practice leads to the contamination and degradation of the topsoil, groundwater reserves, and surface water bodies in the surrounding environment. In areas with many brick factories, water quality assessments showed an increase in turbidity (see *Water Quality* section).

The deposition of discarded clay residues constitutes a potential source of pollution that can increase the number of suspended particles in the river and adversely impact the river ecosystem[38]. Large amounts of suspended materials may clog fish gills and kill them directly. High turbidity can also make it difficult for fish to see and catch prey and may bury and kill eggs on the bottom of rivers. Consequently, it is recommended that monitoring protocols be implemented to assess the water quality and evaluate the environmental ramifications associated with brick manufacturing facilities on an ongoing basis.

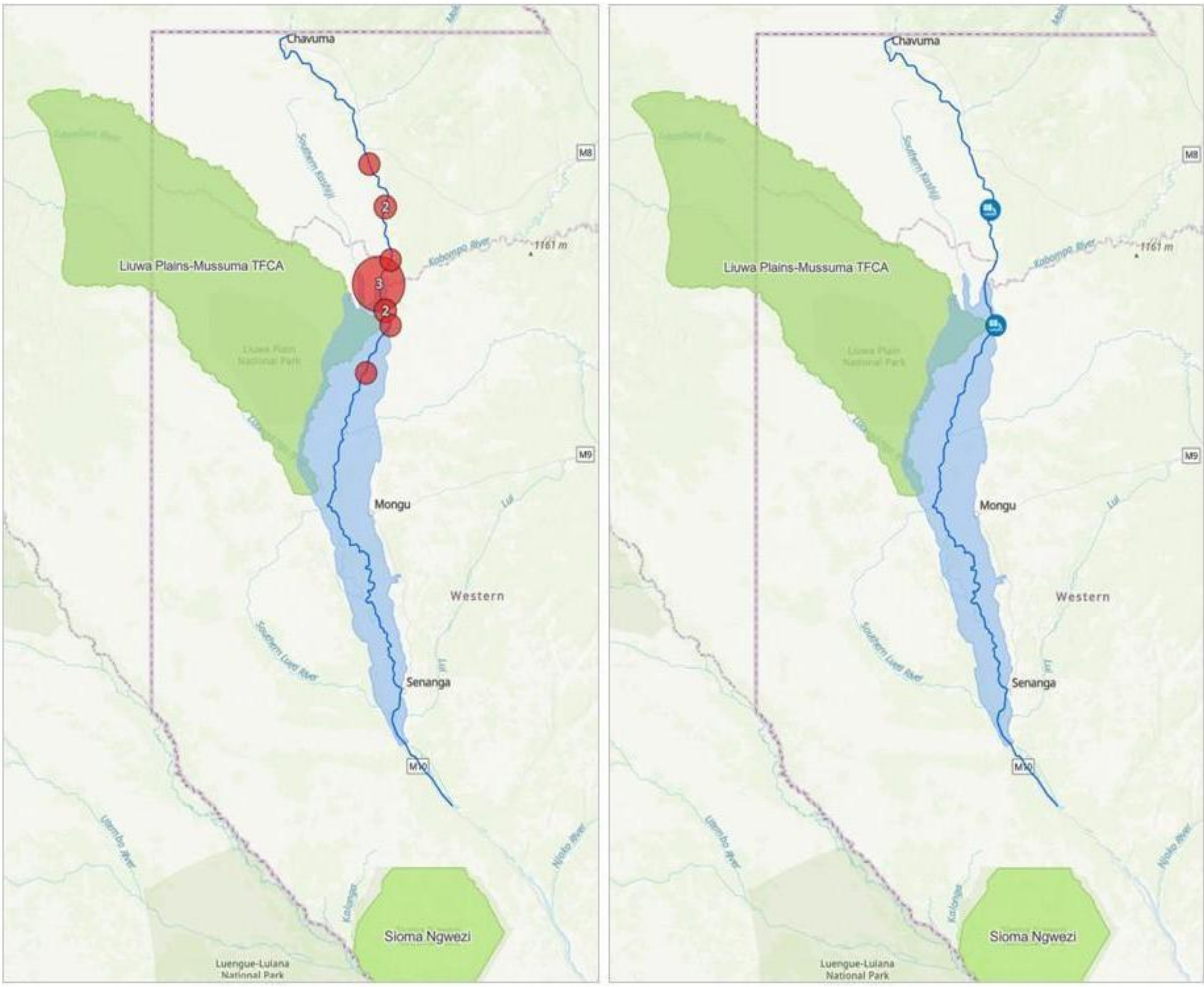

Figure 22. The distribution of other infrastructure, including brick factories (left) and effluent discharge (right).

Agriculture

Methods: Agriculture

All agricultural activity along the river was recorded, including the scale of the activity and the side of the

[38] Padmalosan, P., Vanitha, S., Sampath Kumar, V., Anish, M., Tiwari, R., Kishor Dhapekar, N. & Singh Yadav, A. 2023. An investigation on the use of waste materials from industrial processes in clay brick production.

river on which it was taking place. Where livestock were observed, the number of individual animals was 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. It was assumed that farmers of large agricultural plots were selling their produce, and as a result, these operations were categorised as commercial farms.

Results and Discussion: Agriculture

Crops

As with most of Zambia, subsistence farming is the predominant type of agriculture on this stretch of the Zambezi River. These farms covered a relatively small area of the riverbank — just 1% of the transect (Table 8). On rivers such as the Chambeshi, crop cover is as high as 8%. Moreover, crop cover on the upstream section of the Zambezi River in Angola and the source of the Zambezi is 2% and 6%, respectively. Maize was the most common crop, followed by cassava and bananas. 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.

Table 8. Crop agriculture on the Zambezi River from Chavuma to Sioma.

Crop type	The distance along the river edge (m)
Maize	3,420
Cassava	1,572
Banana	1,222
Sugarcane	532
Mango	324
Vegetables	160
Paw paw	49
Total	7,279

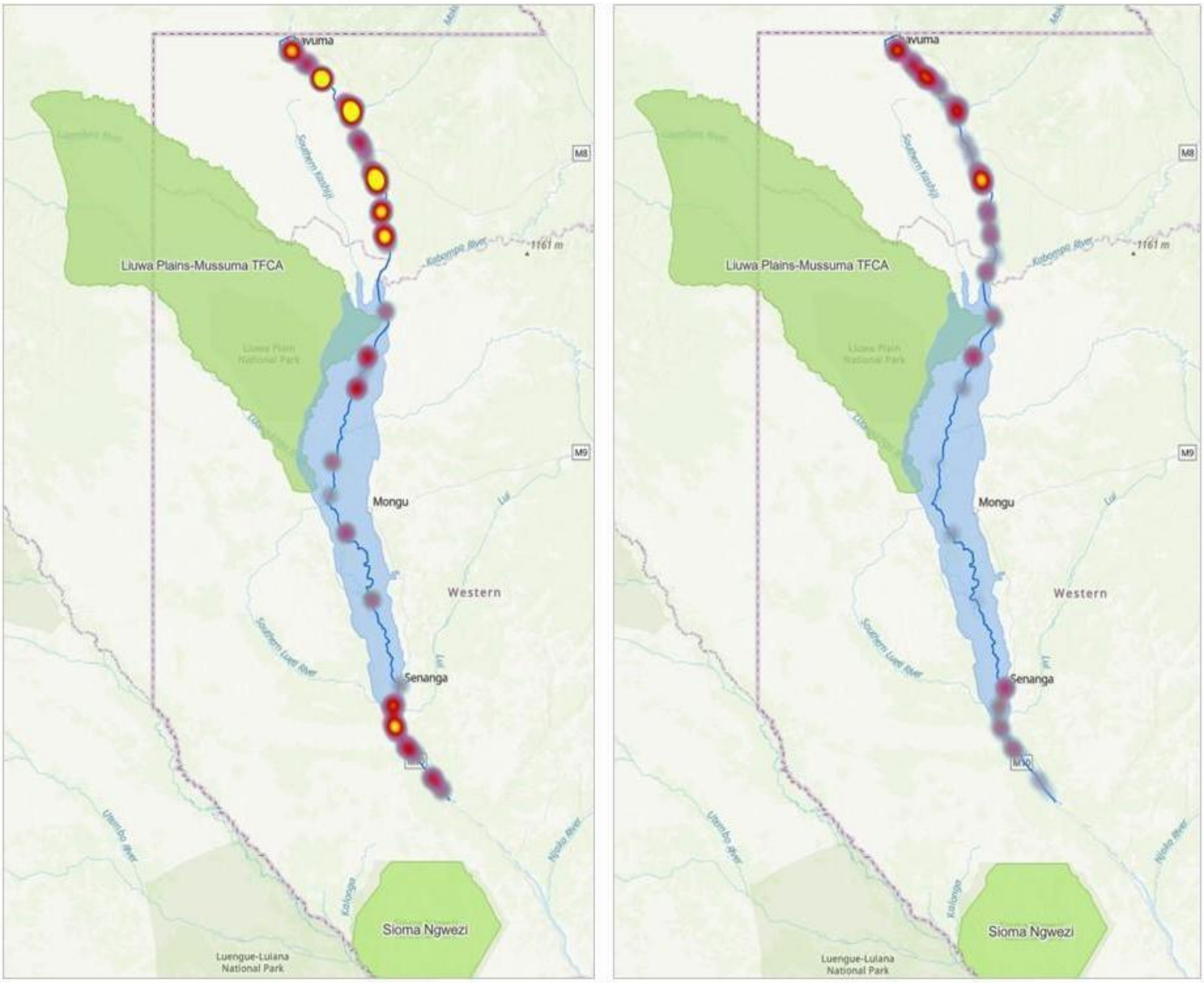

Figure 23. The distribution of maize (left) and all crop agriculture (right) along the Zambezi River from Chavuma to Sioma.

Crop agriculture was prevalent outside of the Barotse Floodplain (Figure 23). For subsistence farmers in Zambia, the ability to cultivate crops is heavily influenced by the region's seasonal rainfall patterns. With only one rainy season per year, these farmers predominantly rely on rainfed agriculture, utilizing minimal agricultural inputs. In the Barotse Floodplain, farmers start preparing the land for crops in October, the crops start growing from November onwards, and the harvesting season takes place from March to the end of May (Table 9). See *EarthViews web application* for the distribution of other crops along the Zambezi River from Chavuma to Sioma.

Table 9. The agricultural schedule of Barotse Floodplain farmers[39].

<table>
<tr><th colspan="12">General cropping calendar in the Barotse</th></tr>
<tr><td>Oct</td><td>Nov</td><td>Dec</td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>June</td><td>July</td><td>Aug</td><td>Sept</td></tr>
<tr><td colspan="4">land preparation</td><td colspan="8"></td></tr>
<tr><td></td><td colspan="6">growing season</td><td colspan="5"></td></tr>
<tr><td colspan="5"></td><td colspan="3">harvesting</td><td colspan="4"></td></tr>
</table>

Maize stands out as the central food crop, serving as a major staple for smallholder farmers who make up

[39] Pasqualino, M., Kennedy, G., Longley, K. & Thilsted, S. n.d. Food and Nutrition Security in the Barotse Floodplain System. Bioversityinternational.Org.

the bulk of food producers in the country. The timing and duration of the single rainy season plays a crucial role in determining food availability and trade dynamics for these predominantly rainfed crops. Consequently, the seasonality of maize cultivation is critical, as it directly impacts the subsistence farmers' ability to secure sustenance for their families and communities throughout the year[40].

Zambia is currently facing a severe drought. The reduction in rain has negatively affected the yields of subsistence farms that rely on rain for crop irrigation. These dry spells, compounded by the El Niño effect, are driving the overall increasing severity of food insecurity[41]. This is expected to worsen as Zambia's climate is projected to change mainly by a decrease in precipitation and an increase in temperature[42]. Without countermeasures, maize yields will decline by 20 - 40%, particularly in the southern and western regions. As a result, subsistence maize farming may become more prevalent in the Barotse Floodplain, where floodplains can provide a reliable water source, mitigating the impacts of the region's seasonal rainfall variability[43]. This pattern is intensifying agricultural land-use along the Barotse floodplain margins, thereby threatening the sustainability of the wetland (see the *Land-Use and Land-Cover Change Analysis 2019-2021* and *WorldCereal Cropland Analysis*).

To address the potential increase in subsistence maize farming in the Barotse Floodplain, it is crucial to implement climate change adaptation strategies that benefit local communities while reducing environmental degradation. Adopting drought-resistant crop varieties can enhance food security for subsistence farmers while minimizing pressures on the floodplain ecosystem, ensuring sustainable agricultural livelihoods and environmental conservation.

Livestock

A total of 694 livestock were counted on the Zambezi River between Chavuma and Sioma (Table 10). Cattle accounted for 95% of this livestock observed. Livestock were most common before and after the Barotse Floodplain, probably because the floodplain margins offer the best grazing at high water levels (Figure 24).

Table 10. Count of livestock.

Livestock type	Count
Cattle	658
Goats	18
Pigs	18
Total	694

Although 95% of the livestock observed were cattle, this only represents a small fraction of the cattle in the region, as the Barotse Floodplain is known to be one of the most productive cattle areas in the country[44]. Most cattle are kept beyond the floodwaters and are not visible from the river's main stem. This was particularly evident as more cattle were recorded in the Barotse Floodplain's upper regions than in the mid to lower floodplain region, where there was more flooding (Figure 24). See *EarthViews web application* for the distribution of other livestock.

[40] Govereh, J., Jayne, T.S., Mason, N. & Chapoto., A. 2007. Trends in agricultural and poverty indicators in Zambia. (February)

[41] Kimirei, I.A., Mubaya, C.P. & Bere, T. 2022. Ecological changes in the Zambezi River Basin.

[42] ACF, IFPRI, C. 2023. From climate risk to resilience: Unpacking the economic impacts of climate change in Kenya. International Food Policy Research Institute (IFPRI). (November).

[43] Siatwiinda, S.M., Supit, I., van Hove, B., Yerokun, O., Ros, G.H. & de Vries, W. 2021. Climate change impacts on rainfed maize yields in Zambia under conventional and optimized crop management. *Climatic Change*. 167(3–4).

[44] IUCN. 2003. Barotse floodplain, Zambia: local economic dependence on wetland resources. Integrating Wetland Economic Values into River Basin Management.

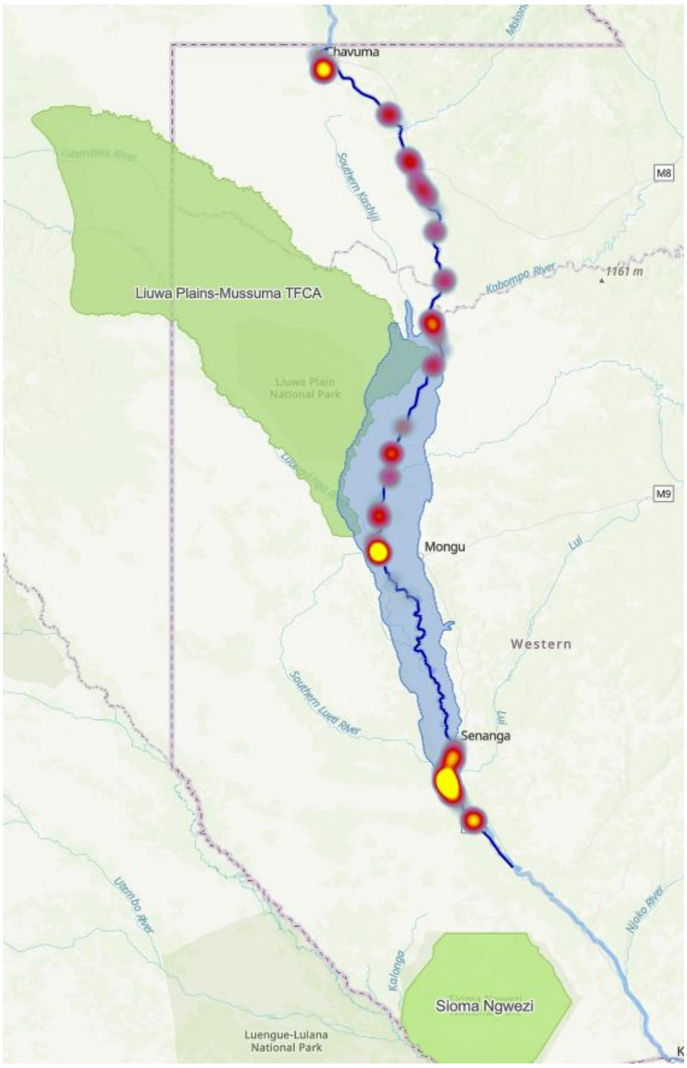

Figure 24. The distribution of livestock along the Zambezi River from Chavuma to Sioma.

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 allows for detection of threats to riverine ecosystems. In addition, the identification of important nesting sites and foraging grounds informs proactive and effective conservation management. Consequently, all wetland-associated bird species interacting with the Zambezi River, and its riparian vegetation were counted.

Results and Discussion: Wetland-associated birds

A total of 35,215 individual birds belonging to 67 species were present within the riparian zone of the river (Figure 25). This represents a density of 62.88 birds/km — a significantly higher density than any other section of Zambezi River surveyed to date (average of 7.37 birds/km). This is attributed to a higher abundance of wetland habitat the Barotse Floodplain provides. The most common bird species observed was the African openbill (N = 28,049), followed by the reed cormorant (N = 2,354) and the grey-headed gull (N = 892). A list of all the bird species recorded on this expedition can be viewed in *Appendix 2*.

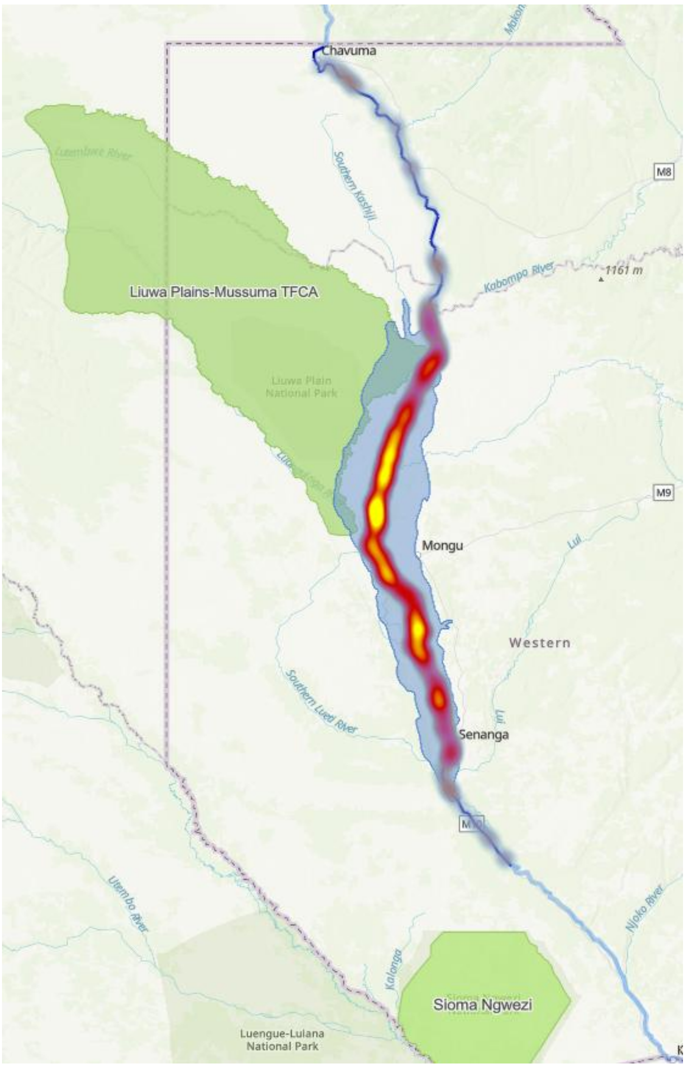

Figure 25. The distribution of all bird species along the Zambezi River.

Wetland birds and habitat availability

The depth and flow of the river and the type and extent of marginal vegetation change considerably along this stretch of the Zambezi River (see *Study Site Description*). To this end, the river can be divided into three distinct biogeographic zones: i) north of the Barotse Floodplain; ii) the Barotse Floodplain; and iii) south of the Barotse Floodplain. These areas support different abundances and compositions of wetland bird diversity. The three biogeographic areas and their associated bird abundances are discussed below.

Chavuma Town to Barotse Floodplain

The river flows through a mosaic of Zambezian Cryptosepalum dry forest and western Zambezi grasslands in this region. The marginal vegetation consists predominantly of trees, and there is limited habitat and resources available to wetland birds, including diving birds, egrets, and storks. Consequently, this area accounted for less than 0.7% of wetland bird abundance. Despite this low abundance, Ross's turacos — common residents of riverine forests — were exclusively observed in this area (Figure 26).

Figure 26. The distribution of Ross's turacos.

Barotse Floodplain

Edaphic grasses and semi-aquatic vegetation characterise the Barotse Floodplain[45]. The ample wetland habitat and high productivity support the abundance and diversity of birds. During this expedition, 99% of the wetland-associated birds observed (N = 34,801) were found in the Barotse Floodplain, establishing it as a significant hotspot for wetland birds.

Large colonies of African openbills, up to 15,000 individuals, thrive in the Barotse Floodplain (Figure 27 and Figure 30). Previous studies confirm that this floodplain hosts the largest openbill breeding colonies ever recorded and ranks among the world's largest waterbird nesting sites[46]. The floodplain's ability to support such large colonies likely stems from its high productivity for molluscs — the primary food source for openbills. Floods promote the reproduction and movement of mollusc populations, sustaining their abundance. Indeed, a previous study observed high mollusc abundances at the Luanginga River confluence[47] , which coincided with the hotspot of openbills in the middle of the Barotse Floodplain (Figure 27).

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[45] White, F. 1983. The vegetation of Africa. Natural re ed. UNESCO.

[46] Gula, J. 2023. The first survey of waterbird nesting colonies on the Barotse Floodplain, Zambia.

[47] Banda, K., Ngwenya, V., Mulema, M., Chomba, I., Chomba, M. & Nyambe, I. 2023. Influence of water quality on benthic macroinvertebrates in a groundwater-dependent wetland. Frontiers in Water.

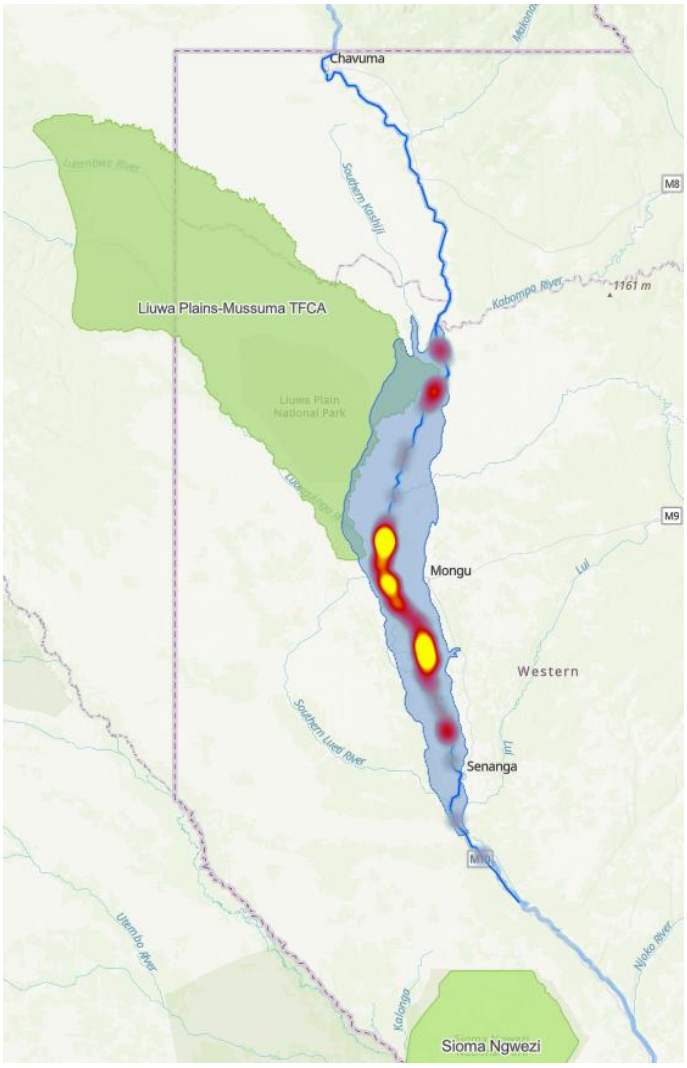

Figure 27. The distribution of African openbills.

Diving birds, including reed cormorants (N = 2,354), were also common in the floodplains (Figure 28). As the floodplain recedes, aquatic animals like fish concentrate in the ephemeral pans and lagoons, creating an ideal hunting ground[48]. Similarly, African skimmers were observed in flocks of over 200 individuals (Figure 28). The skimmers were confined to the upper portion of the floodplain because the water was still draining from the floodplain, exposing sandbanks only in this region. The skimmers prefer these sandbanks for breeding, as the damp sand beneath their nests helps keep the eggs cool[49].

[48] "Reed Cormorant". 1981. In *The Atlas of Southern African Birds*. 36–37.

[49] SABAP. 1992. African Skimmer. In Kenya Bird Map. V. 1991. 490–491.

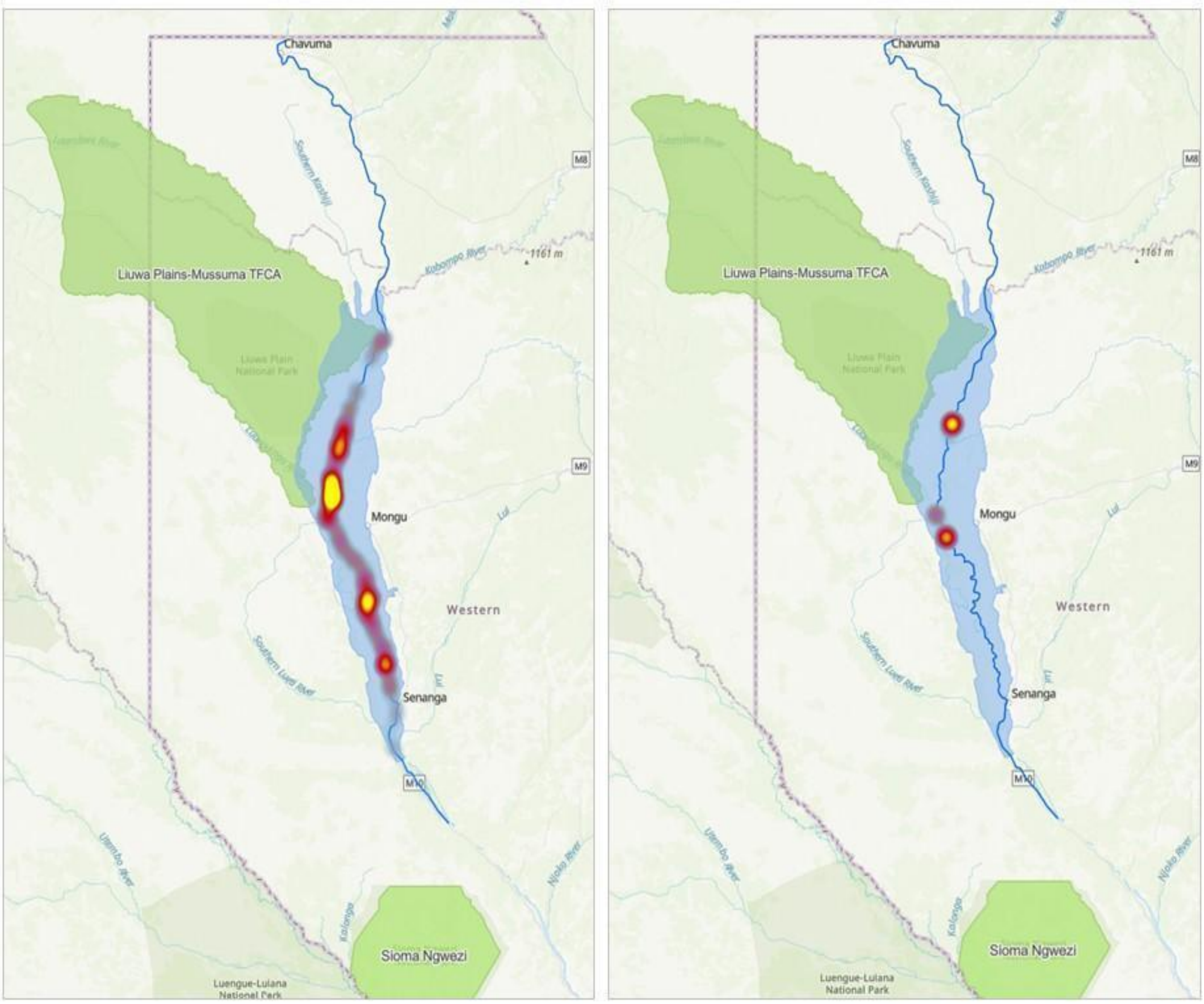

Figure 28. The distribution of reed cormorants (left) and African skimmers (right).

Whiskered Terns (N = 434) were also abundant in the Barotse Floodplain (Figure 29). Overlapping the floodplains on the western side is the Liuwa Plains-Mussuma Transfrontier Conservation Area (TFCA) — the only known breeding site in Zambia for Whiskered Terns[50]. Grey-headed gulls were also common in the floodplains (N = 892). These gulls are usually found in large colonies within and outside breeding season. They breed inland in reedbeds or marshes, laying eggs in floating nests[51].

[50] Gula, J., Martin, C., Mungole, A. & Botha, A. 2022. Large nocturnal roosting aggregations and mass movements of Whiskered Terns in Liuwa Plain National Park, Zambia. Afrotropical Bird Biology: Journal of the Natural History of African Birds. 2(1):1–3.
[51] Mcinnes, A. 2006. Biology of the Grey-headed Gull *Larus cirrocephalus* in South Africa.

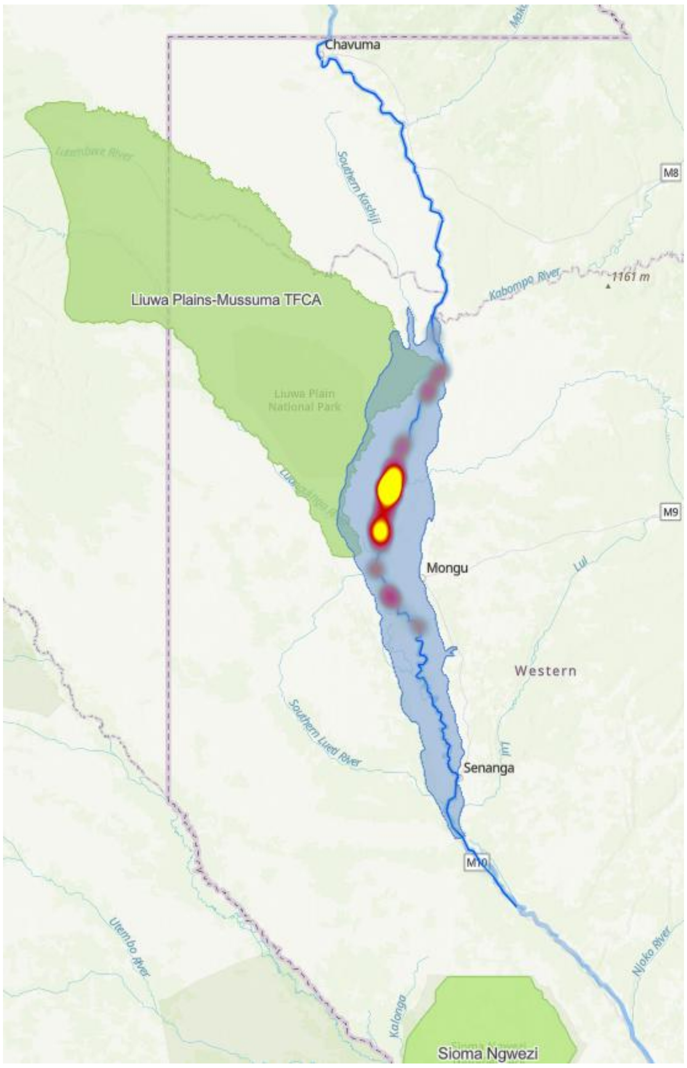

Figure 29. The distribution of gulls and terns.

The Barotse Floodplains demonstrated a significantly higher density of birds (115.24 birds/km) than the Bangweulu Wetlands (4.91 birds/km) or the Lukanga Swamps (11.27 birds/km). When the large colonies of openbills are removed from the analysis, the density of birds is 22.36 birds/km) — still ~5 times greater than the Bangweulu wetlands and double that of the Lukanga Swamps. As a result, even accounting for seasonal variation, it is likely that the Barotse Floodplain hosts the largest population of wetland birds anywhere in Zambia.

All of these ecosystems are recognized as Important Bird Areas by BirdLife international and are designated RAMSAR sites under the International Wetland Convention[52,53]. However, the Barotse Floodplain has no management plans or protected areas to date. The lack of conservation areas in the floodplains is particularly concerning as it is under pressure from intensive and illegal fishing practices and increasing floodplain cultivation (see *Human Activity* section). Moreover, the increased variability of rainfall due to climate change is anticipated to exacerbate these pressures as local communities intensify land conversion for agriculture and focus on fisheries for income generation[54]. The Barotse Floodplain has more than twice the number of buildings compared to the Bangweulu Wetlands. (see *Google Buildings RS Analysis*). It is therefore imperative to prioritize the conservation of the Barotse Floodplain and implement

[52] Zambia Wildlife Authority. 2006. Information Sheet on Ramsar Wetlands - Zambezi Floodplains. Ramsar. 7(1990):1–13.

[53] Zambian Wildlife Authority. 2008. Information Sheet on Ramsar Wetlands - Bangweulu Wetlands. 7:1–17.

[54] Milupi, I. & Sampa Moonga, M. 2020. Transmission mechanisms of Traditional Ecological Knowledge and sustainable management of natural resources among the Lozi-speaking people in Barotse floodplain of Zambia. Multidisciplinary Journal of Language and Social Sciences Education. 3(2):216–228.

measures to mitigate these threats, ensuring the protection of this vital habitat and the diverse avian communities that depend on it.

Figure 30. A colony of African openbills.

Barotse Floodplain to Sioma Town

Below the Barotse Floodplain, the Zambezi River flows through a dry deciduous forest dominated by Rhodesian Teak (Baikiaea plurijuga). The seasonal flooding in this region suppresses tree growth, causing the Baikiaea forest to give way to western Zambezian grasslands. Moreover, disturbance factors such as fire, logging and agriculture suppress tree growth and maintain these grasslands. This region has a high building density and many croplands (see the *Google Buildings RS Analysis* and *WorldCereal Cropland Analysis*). The high disturbance and transformed land reduced the habitat available for wetland-associated birds. Consequently, only 0.3% of birds observed during this expedition were in this region.

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 detection of threats to riverine ecosystems. For this purpose, all non-avian wildlife along the river was recorded, including the number of individuals and the side of the river on which they were observed.

Results and Discussion: Wildlife

The diversity of non-avian wildlife on this expedition was very low, with only four species of animals observed (Table 11, Figure 31). The most common species observed were vervet monkeys (N = 20) and spotted-necked otters (N = 17). In total, 62 individual animals were counted along the transect, amounting to a wildlife density of only 0.11 animals/km. This is extremely low compared to other rivers in the region. For example, the stretch of Zambezi from Sioma to Livingstone had a wildlife density of 1.27 animals/km. Moreover, the Middle Zambezi, between Lake Kariba and Luangwa, has a wildlife density of almost 24 animals/km. For more information on the distribution of each wildlife species, see *EarthViews web application*.

Table 11. The abundance of all the wildlife species observed on the Zambezi River Transect from Chavuma to Sioma.

Wildlife Species	Count
Vervet monkey	20
Spotted necked otter	17
Hippopotamus	16
Water monitor	9
Total	62

The low abundance of wildlife observed on this transect is likely due to the combined interaction of high-water levels and human activity. The former of these likely caused the animals to move inland, whereas human activities including land conversion for agriculture may have reduced wildlife populations, particularly on the eastern bank of the floodplain. Although low numbers of wildlife were observed on this transect, the presence of wildlife in the area is indicated by the Liuwa Plains-Mussuma TFCA. This area, which overlaps with the Barotse Floodplain, hosts Africa's second-largest wildebeest migration[55].

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[56]. Moreover, AIPs reduce water quality by increasing evaporation rates and reducing stream flow and dilution capacity[57]. The continuous monitoring of alien invasive plants allows for detection of threats to riverine ecosystems. For this purpose, all alien invasive plant species within the Zambezi River, and its banks were identified and their extent recorded.

Results and Discussion: Alien Invasive Plants

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[55] Naidoo, R., Chase, M.J., Beytell, P., Du Preez, P., Landen, K., Stuart-Hill, G. & Taylor, R. 2016. A newly discovered wildlife migration in Namibia and Botswana is the longest in Africa. Oryx. 50(1):138–146.

[56] Vilà, M. et al (2011) Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters.

[57] Schachtschneider, K. et al (2012) Impacts of invasive alien plants on water quality, with particular emphasis on South Africa. Water S.A.

This expedition recorded four species of invasive alien plants, including *Mimosa pigra, Eucalyptus globulus,* and *Salvinia molesta*. The most common invasive species was *M. pigra*, estimated to cover 98 m^2 — this low coverage suggests that the species is still in the process of establishment. The Kabompo River is a significant contributor of *M. pigra* to the upper Zambezi. All other species were also recorded at low densities and patchy distributions along the river (Figure 32).

These patchy distributions and low densities indicate that alien plant invasions are in their early stages of establishment. Immediate implementation of an invasive species eradication program is crucial to curb the spread of established AIPs in the river. Furthermore, regular monitoring and detection of AIPs should be integrated into ongoing river assessments to track the proliferation of these species. See *Appendix 1* for information on WWF Zambia and Birdwatch Zambia's current AIP removal programme.

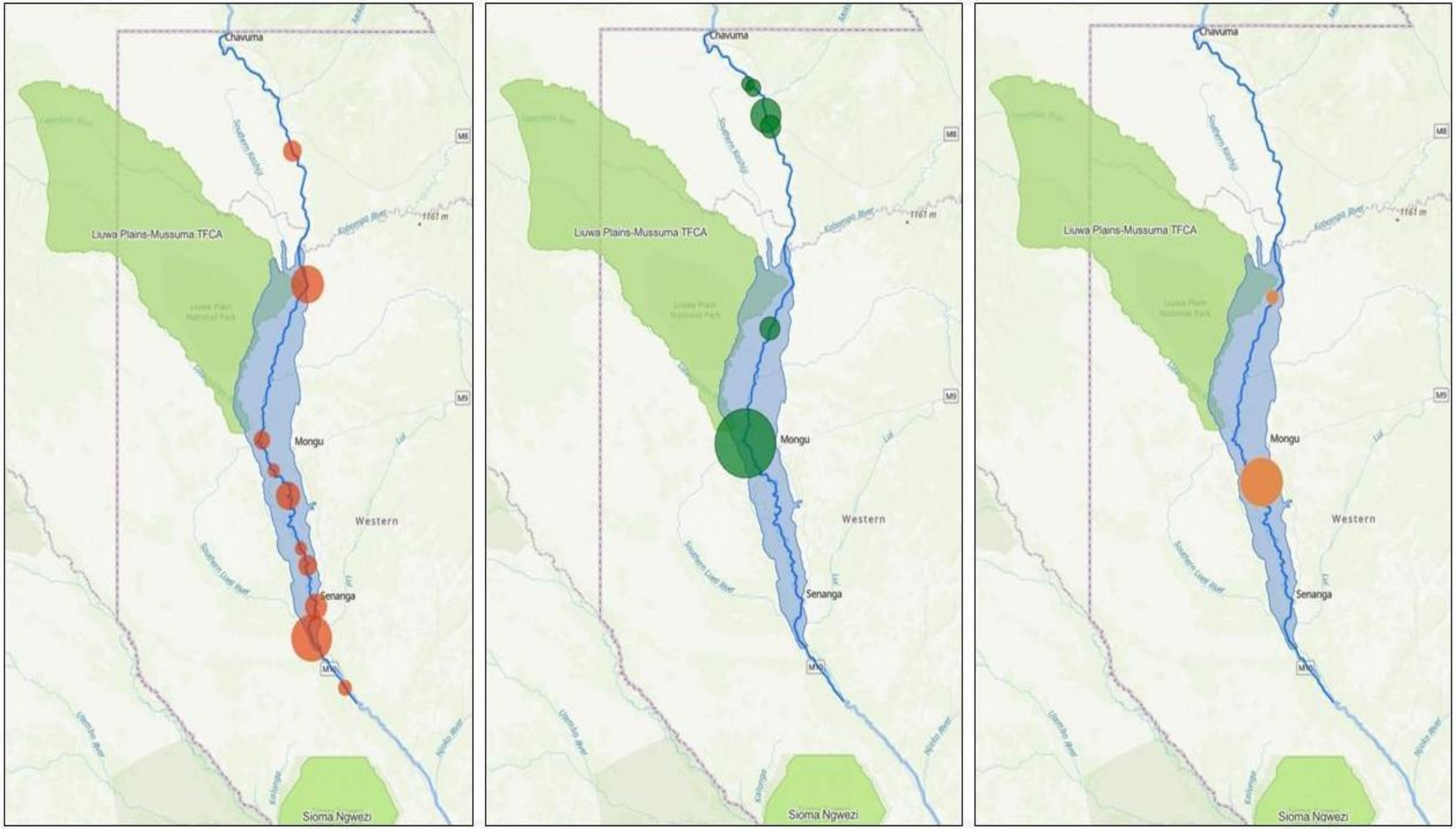

Figure 32. The distribution of Eucalyptus globulus (left), Mimosa pigra (middle), and Salvina molesta (right).

Fire

Methods: Fire

To determine the extent of fires along the Zambezi River from Sioma to Livingstone, all recent and ongoing fires within 100 m of the riverbanks were counted. In addition, the following information about the fires was gathered:

- 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. 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 occurred was noted.

Results and Discussion: Fire

A total of 30 fires were recorded, with a total burn extent of 3.6 km along the riverbanks. Four of these fires were observed actively burning, while the majority were recently burnt, showing no signs of regrowth. The fires were predominantly concentrated in the biogeographic regions before and after the floodplain, with a notable absence within the Barotse Floodplain (Figure 33). This pattern can be attributed to the floodplain's inundated vegetation being less susceptible to fires, in contrast to the other two regions where the vegetation is dry and more susceptible to burning. For example, many fires were observed in grassland areas, as this vegetation provides an abundant fuel source for fires to propagate (Figure 34). Satellite-based analysis of fires in the river basin can be viewed in the Fire Analysis section.

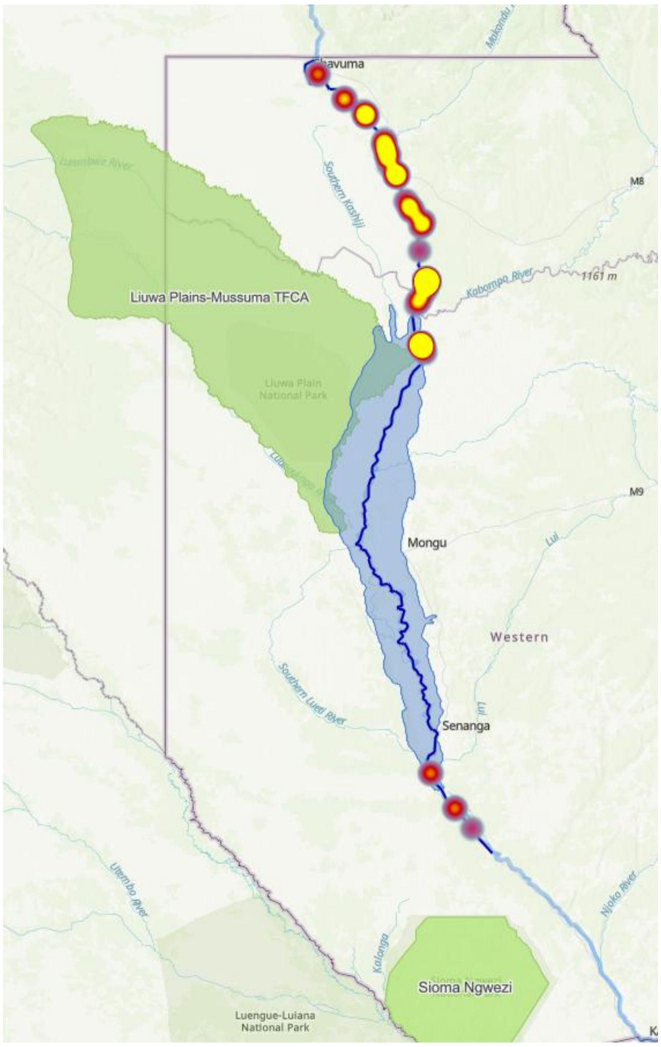

Figure 33. The distribution of fires along the Zambezi River from Sioma to Livingstone. Most fires were concentrated in the first biogeographic region.


Figure 34. A recently burned area with evidence of burn scars and smoke.

3. FIXED SITE MONITORING

Fixed Point Aerial Photography

Aerial photography was conducted at research sites every ~10 km along the river using a drone. In total, aerial photographs were taken at 55 sites. 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, thereby providing evidence against which future changes to the river and the surrounding floodplain vegetation can be compared. A collation of the birds-eye photographs taken from 200 m elevation is presented in *Appendix 3*. The complete database of aerial photography is available upon request.

Water Quality

Methods: Water Quality

Water quality parameters were analysed at 57 sites along this stretch of the Zambezi River using an InSitu Aqua Troll multi-parameter sonde. The sonde measures pH, oxidation-reduction potential (ORP), total dissolved solids (TDS), turbidity, dissolved oxygen (DO), conductivity, salinity, resistivity, temperature, and water density (see *Appendix 5* for the description of parameters). The InSitu multi-parameter sonde was calibrated according to the manufacturer's instructions prior to undertaking the water quality survey along the river transect.

Results and Discussion: Water Quality

The water quality parameters (i.e., water temperature, specific conductivity, total dissolved solids (TDS), pH, dissolved oxygen (DO) and turbidity) from this Zambezi River expedition are below the maximum contamination levels (MCL), indicating overall good river water quality [58]. However, there is spatial variability in the measured parameters along the river, with a notable variation in water quality at site 18 — the confluence of the Kabompo River (Figure 35).

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

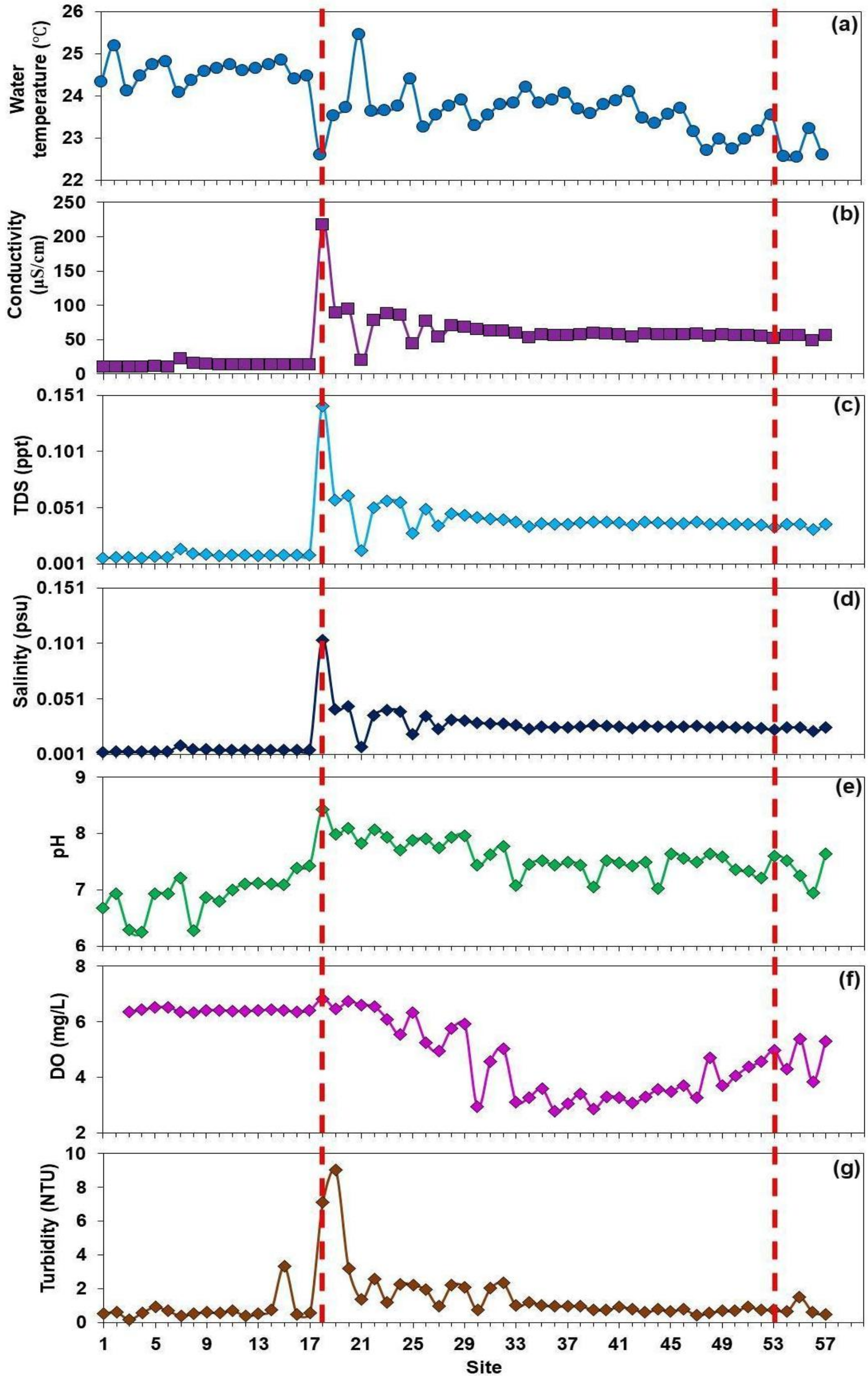

Figure 35. Spatial plots of the river water temperature (a), specific conductivity (b), total dissolved solids (TDS) (c), Salinity (d), pH (e), dissolved oxygen (DO) (f) and turbidity (g) measured along the Zambezi River (Chavuma to Sioma section). The first red dashed line represents the beginning of the Barotse Floodplain and the confluence of the Kabompo River, and the second red dashed line is the end of the Barotse Floodplain.

Temperature

Water temperatures along this section of the Zambezi River ranged between 23°C and 25°C with an average of 24 ± 0.7°C. The river water temperatures decreased along this transect, with the lowest temperatures recorded at the end of the survey (Figure 36). This progressive decrease in the water temperatures can be attributed to river water cooling during transit in the cold winter weather in May.

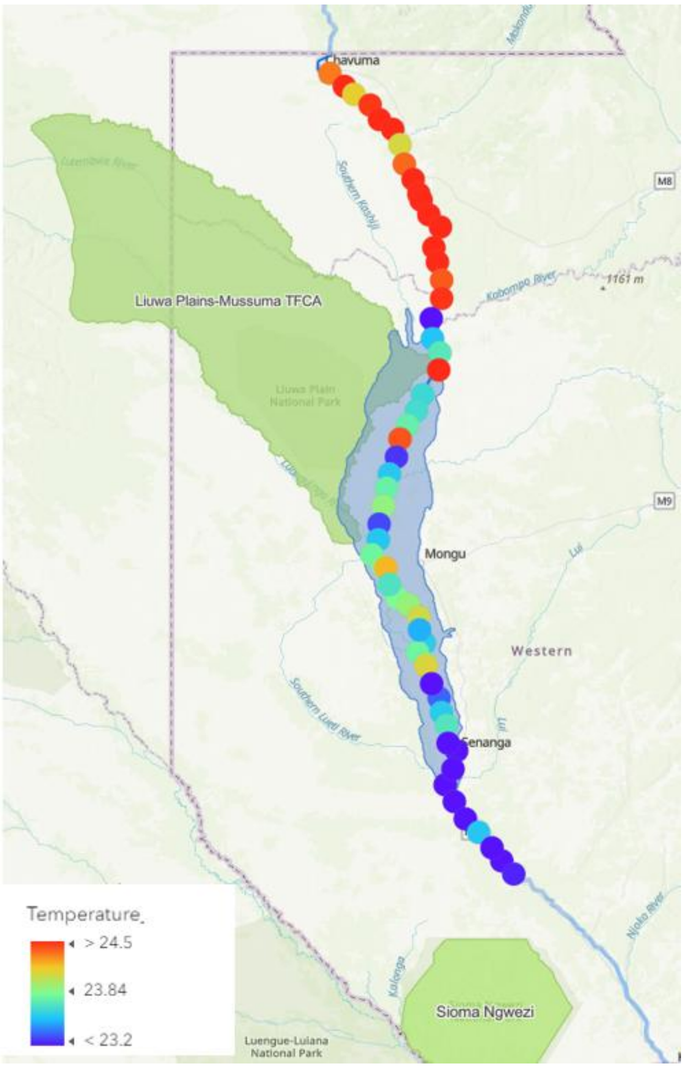

Figure 36. The distribution of water temperature along the Zambezi River.

Conductive dissolved ions

Specific conductivity, TDS and salinity represent conductive dissolved ions in the river water from mineral salts and chemicals. Some of these dissolved ions in water are associated with pollutants. As expected, conductivity, TDS and salinity exhibited similar spatial behaviour along the transect (Figure 35). The conductivity, TDS and salinity were low at the beginning of the survey from site 1 to site 17, followed by a sudden increase at site 18 — at the Kabompo River confluence— after which the conductivity, TDS and salinity decreased.

Additionally, there was a higher TDS concentration in the upper reaches of the Barotse Floodplain between Lukulu and Mongu compared to the lower reaches between Mongu and Senanga. This is due to the upper reaches receiving groundwater discharge, reinforcing that the Barotse Floodplain is groundwater-dependent[59].

There were also perturbations in the dissolved ion concentrations between sites 18 and 26, as reflected by slightly fluctuating conductivity, TDS and salinity (Figure 37 and Figure 38). These perturbations appear to be attenuated by potential inflow from the Njamba area near site 26 and inflow from the Angolan highlands through a tributary joining the Zambezi River at Kalabo. This attenuation and buffering of the river chemistry by inflow from tributaries is evidenced by the relatively stable conductivity, TDS and salinity readings after site 26 (Figure 35).

[59] Banda, K., Ngwenya, V., Mulema, M., Chomba, I., Chomba, M. & Nyambe, I. 2023. Influence of water quality on benthic macroinvertebrates in a groundwater-dependent wetland. Frontiers in Water.

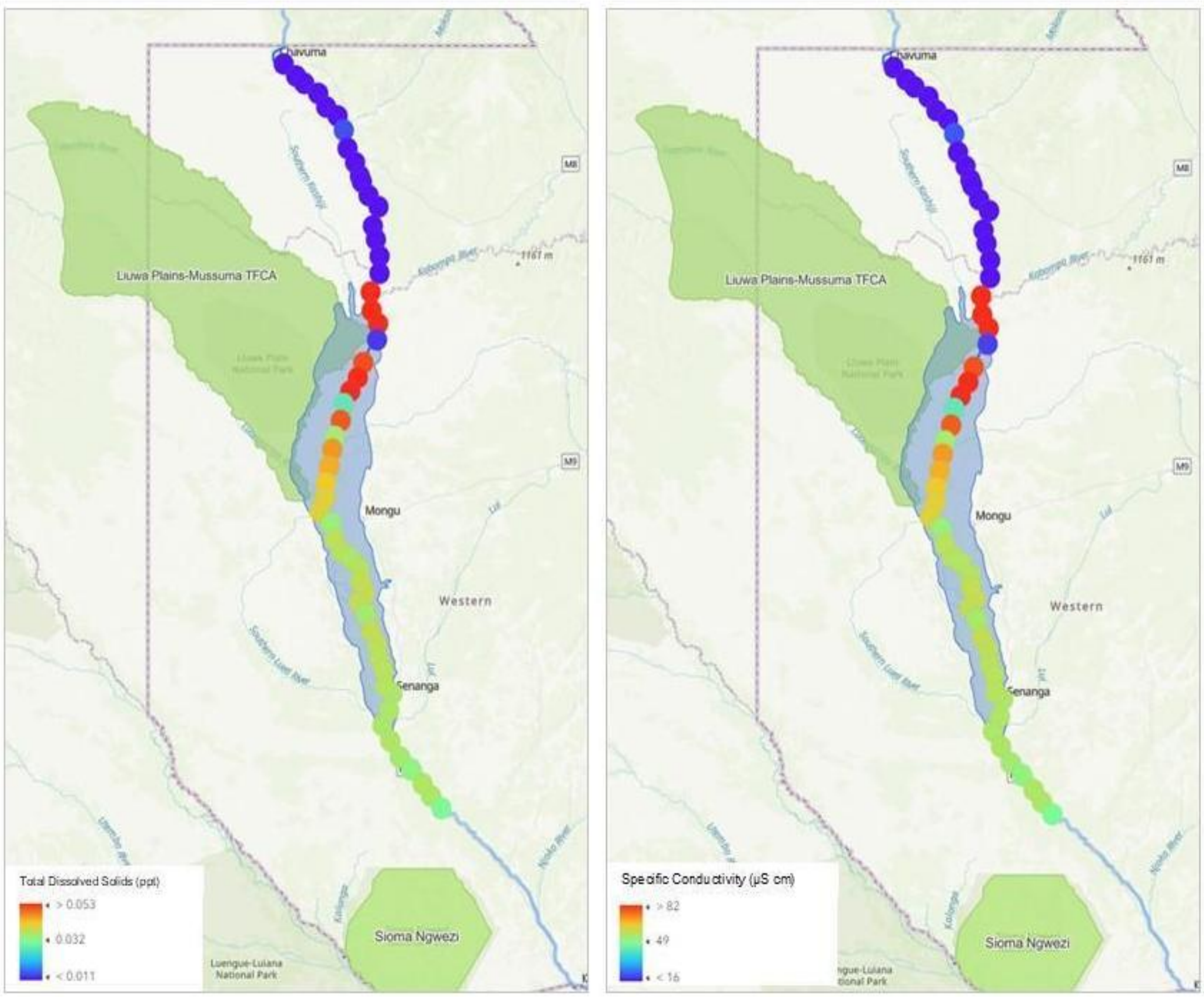

Figure 37. The total dissolved solids (left) and specific conductivity (right) along the river transect.

pH and Dissolved Oxygen

The pH of the river fluctuated between 6.2 and 8.4 (Figure 35). The pH was highest at site 18. The dissolved oxygen (DO) was higher at the beginning of the transect and decreased at site 22. The DO slightly increased towards the end of the survey (Figure 35, Figure 38). The variability in the DO is likely governed by changes in the flow velocity along the transect, with rapid flow being associated with greater aeration (hence higher DO) compared to slower flow. Turbidity was relatively low throughout the survey, except for sites 18 and 19 near the Zambezi-Kabompo confluence, where there could be a contribution of sediment, which increases the turbidity of the river water at these locations.

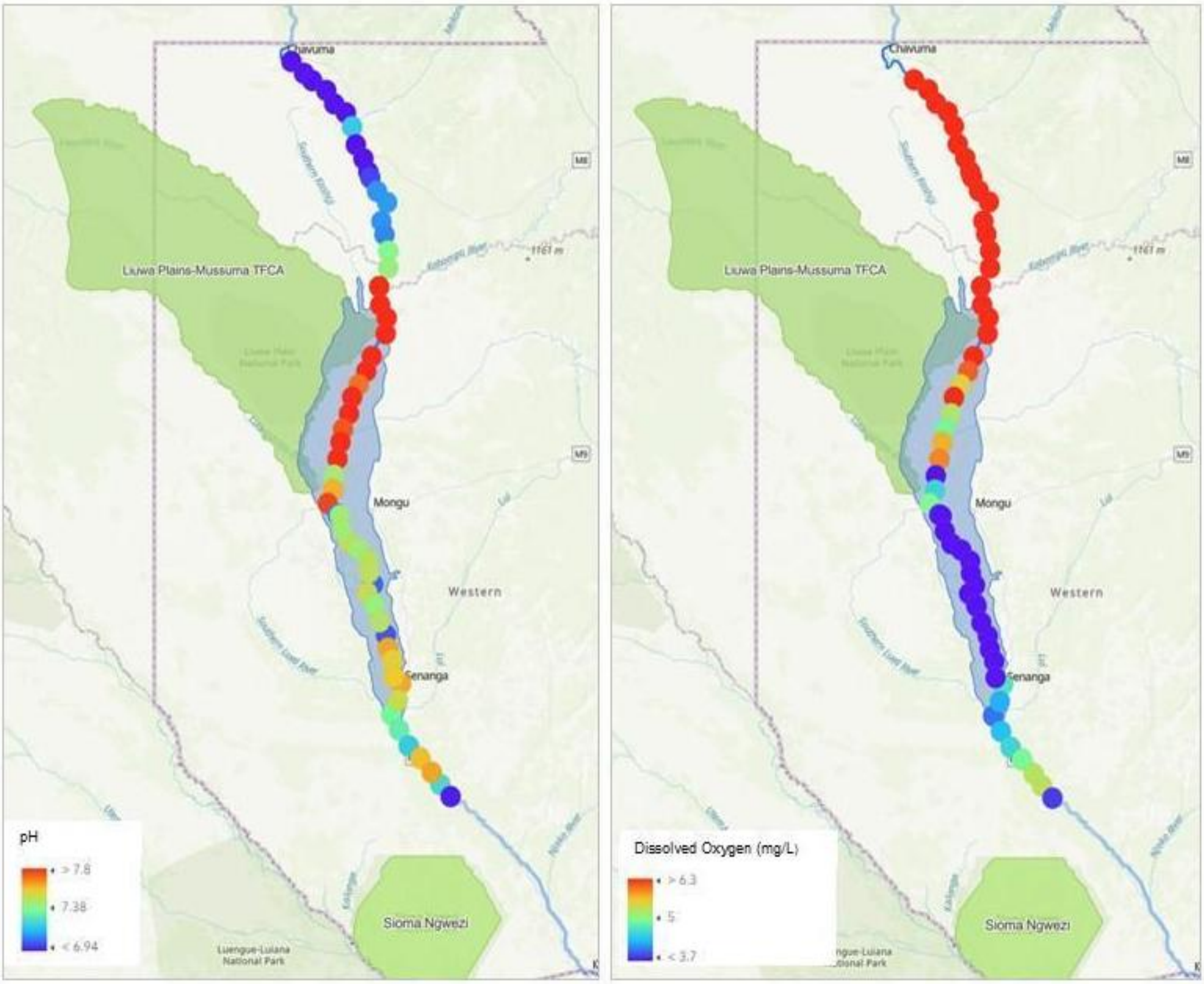

Figure 38. The pH (left) and dissolved oxygen (right) along the Zambezi River transect. Note the drastic increase in pH at the Kabompo River confluence.

Influence of the Kabompo River on water quality

Site 18 is located at the Zambezi River and the Kabompo River confluence. The Kabompo River drains the northwestern portion of the watershed between Northern Zambia and the Democratic republic of Congo and joins the Zambezi River after it flows out of Angola. The Kabompo River is affected by deforestation and land degradation due to intensified mining[60]. In the last decade, there has been accelerated population growth, mainly in the northern parts of the river, which is rich in minerals such as copper, uranium, gold and silver with the potential for oil and gas existence. Several large- and small-scale mines have either started to mine or are prospecting.[61]

In rivers surrounded by mines, stream water and sediment pollution results from the surface and subsurface runoff of excessively heavy-metal-laden solid and liquid wastes. Acid mine drainage (AMD) is particularly concerning to such rivers. Besides transporting elevated concentrations of heavy metals and metalloids, AMD alters the river water chemistry by increasing the pH[62]. Additionally, AMD elevates TDS, conductivity, and salinity, further degrading water quality and impacting the suitability of water for various

[60] Kampata, J.M.J., Rientjes, T.H.M. & Timmermans, J. 2013. Effects of Land Cover Change on the Hydrologic Regime of Kabompo River Basin, Zambia. ESA Living Planet Symposium. 2013:1–6.

[61] Mwiza, M. 2012. Application of remote sensing using a GIS based soil water assessment tool (SWAT)to estimate river discharge in the Kabompo river basin-Zambia. University of Zambia PhD Thesis.

[62] Ouma, K.O., Shane, A. & Syampungani, S. 2022. Aquatic Ecological Risk of Heavy-Metal Pollution Associated with Degraded Mining Landscapes of the Southern Africa River Basins: A Review. Minerals. 12(2).

uses. Consequently, it is likely that the high levels of pH, TDS, conductivity and salinity at site 18 result from mining pollution in the Kabompo River.

The Barotse Floodplain plays a crucial role in naturally filtering and improving the water quality of the Zambezi River. As the river meanders through the floodplain, suspended sediments and contaminants are deposited, while natural wetland processes help absorb and break down pollutants. This filtering effect is evident in the way water quality parameters return to near-background levels downstream, even after the polluted waters of the Kabompo River enter the Zambezi. The floodplain's ability to mitigate pollution underscores the importance of conserving its hydrological and ecological integrity, particularly in light of increasing upstream pressures from mining and land use changes.

Our findings highlight that although the Zambezi River along the Chavuma-Sioma section currently has good water quality, attention should be paid to the role of mining pollution in modifying the river chemistry. Similar future investigations aimed at monitoring the river water quality will be instructive in constraining minor and major shifts in the river chemistry due to anthropogenic pollution and other factors. The findings further underscore the critical role of inflow from tributaries (e.g., tributary from Angola) in attenuating and buffering the river chemistry of the Zambezi River along this Chavuma-Sioma section, such an important component to note, especially under the ongoing climate change that may reduce precipitation and flow in the area. See *EarthViews web application* to view the distribution of all water quality parameters.

Environmental DNA

Methods: Environmental DNA

Triplicate eDNA samples were collected from the river water at eight fixed monitoring sites by filtering up to one litre through a 0.22 µm Sterivex™ filter with a sterile 50 ml piston syringe (Figure 39). 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 to 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[63,64,65]. 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[66,67]. Samples were amplified using the polymerase chain reaction (PCR), using MiFish

[63] 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.

[64] 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.

[65] 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.

[66] Miya, M., 2022. Environmental DNA metabarcoding: a novel method for biodiversity monitoring of marine fish communities.

[67] 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.

primers. Following sequencing, the DNA sequencing data was processed by filtering low-quality reads to generate Amplicon Sequence Variants (ASVs)[68]— unique DNA sequences that were identified through amplification. ASVs were assigned taxonomic identities, which form Molecular Operational Taxonomic Units (MOTUs) — clusters of DNA sequences based on similarity thresholds [69]. 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[70]. 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)[71].

Figure 39. eDNA sample collection using a piston syringe.

Although this report does not present the sequencing results, all sequences generated contribute to a growing eDNA reference library for the region. These data are available upon request and may support future assessments of freshwater biodiversity and conservation planning in the basin.

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[68] 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.

[69] 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.

[70] Tamura, K., Stecher, G., and Kumar, S., 2021. MEGA11 :Molecular Evolutionary Genetics Version 11. *Molecular Biology and Evolution*, *38*, 3022–3027.

[71] 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.

Aquatic Macroinvertebrates

The Zambian Invertebrate Scoring System (ZISS) is a standardized, rapid, field-based bioassessment tool assessing aquatic macroinvertebrate fauna at a 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 heathier and more diverse aquatic habitats. Additional metrics for comparison include the total number of taxa recorded and the average score per taxon (ASPT).

Methods: ZISS

The ZISS assessments were conducted at eight intensive sampling sites along the Zambezi River transect (Figure 40). These sites were spaced 50–75 km apart. An invertebrate d-net was used to sweep marginal and aquatic vegetation for the ZISS assessments. The total number of taxa, 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 further identification verification.

Figure 40. The ZISS sampling sites along the Zambezi River from Chavuma to Sioma.

Results and Discussion: ZISS

The mean ZISS score on the Zambezi River was 68, with a large range of ZISS scores from 39–121. The average number of taxa was 14, and the average score per taxon (ASPT) ranged from 4.08–5.59 (Table 12). The ZISS scores within the Barotse Floodplain were generally higher than those of sites outside the floodplain. This can be attributed to the floodplains containing a higher diversity of benthic macroinvertebrate habitats, which support more diverse macroinvertebrate communities.

Previous studies on the Barotse Floodplain have demonstrated that temperature and pH significantly influence ZISS scores in Barotse Floodplain[72]. Indeed, the low ZISS scores at sites 1, 2, and 8 coincide with low pH values (< 6.9) and areas of temperature extremes (see *Water Quality* section). These sites also correspond to areas of agricultural hotspots and towns. Anthropogenic disturbances stemming from infrastructure development and agricultural practices can significantly impact ZISS scores by altering river habitats. Moreover, infrastructure can disrupt natural flow regimes and habitat structures, while agricultural runoff can influence sedimentation, contributing to reduced macroinvertebrate diversity and lower ZISS scores.

The macroinvertebrates within the Barotse Floodplain respond to salinity and flood pulse dynamics[73]. Salinity in this system was attributed to mineralisation due to water-rock interactions[74] in the groundwater system, which subsequently discharges to the surface water. A dry season survey is needed to fully understand the macroinvertebrate community composition and their response to the varying environmental conditions in the floodplain.

Table 12. ZISS Survey Results. Habitat types: aquatic vegetation (AV), marginal vegetation in current (MVIC), marginal vegetation out of current (MVOC). ZISS = Zambian Invertebrate Scoring System. ASPT = Average Score Per Taxon.

ZISS Site	Latitude	Longitude	ZISS Score	# Taxa	ASPT
1	-13.18417	22.8295	39	9	4.33
2	-13.65699	23.13523	53	13	4.08
3	-14.18386	23.18311	95	17	5.59
4	-14.72024	23.0391	60	11	5.45
5	-15.29277	22.97507	60	14	4.29
6	-15.72584	23.15801	60	13	4.62
7	-16.09971	23.29653	121	23	5.26
8	-16.64311	23.55674	54	11	4.91
AVERAGE			**68**	**14**	**4.82**

4. OPPORTUNISTIC SAMPLING

[72] Banda, K., Ngwenya, V., Mulema, M., Chomba, I., Chomba, M. & Nyambe, I. 2023. Influence of water quality on benthic macroinvertebrates in a groundwater-dependent wetland. Frontiers in Water.
[73] Banda, K., Ngwenya, V., Mulema, M., Chomba, I., Chomba, M. & Nyambe, I. 2023. Influence of water quality on benthic macroinvertebrates in a groundwater-dependent wetland. Frontiers in Water.
[74] Banda, K., Mwandira, W., Jakobsen, R., Ogola, J., Nyambe, I. & Larsen, F. 2019. Mechanism of salinity change and hydrogeochemical evolution of groundwater in the Machile-Zambezi Basin, South-western Zambia. Journal of African Earth Sciences.

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 contribute to scientific understanding of river processes and 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 five sampling sites. These included measurements of flow rates, depth and river profile. The ADCP was deployed on average every ~100 km and at places of interest, including bridges (Figure 41). Sites considered suitable for ADCP sampling include 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.

On sections where the river was narrow, the ADCP was pulled across the river from the opposite bank, however, for broader sections of the river, the ADCP was towed from a bridge or deployed behind a mokoro and paddled perpendicular across the stream. A minimum of two ADCP transects were conducted per site until the coefficient of variation between transects was < 0.05.

Figure 41. The sites where the ADCP was used to measure river discharge. ADCP was deployed at the start and end of the expedition, as well as around the confluences of the Kabompo and Lungwebungu rivers. Due to the scale of the map and the proximity of sites at the Kabompo and Lungwebungu rivers, they appear as one point.

Results and Discussion: Water Discharge

The discharge of the Zambezi River increased by 1,128 m^3/s from site 2 to site 3, indicating a significant additional inflow into the Zambezi River (Table 13). A large contributor to this increase is the inflow from the Kabompo River (318 m^3/s) and the Lungwebungu River (194 m^3/s) to a lesser extent. Additional flow possibly comes from the release of water from the pan-belt bounding the western and eastern catchments of the Barotse floodplain[75].

Tributary contribution

The Zambezi River and its tributaries influence the annual inundation of the Barotse Floodplain such as the Lungwebungu and the Luanginga emanating from the Lungwebungu and Luanginga Basins in Angola as well as the Kabompo River from the Kabompo Basin in Northwestern Zambia. Much of the discharge into the Barotse Floodplain is from upstream in Angola and Northwestern Zambia, which receives an average of above 1000mm of rainfall.

To measure the Lungwebungu and Kabompo Rivers' relative contribution to flow in the Zambezi system, discharge was measured at the relative confluences. During the dry season (May 2023), the Kabompo River contributed 27% to the flow of the Zambezi River, whereas the Lungwebungu contributed 16%. In repeat measurement, during a subsequent wet-season expedition (March 2023), the Lungwebungu River flowed at 335.7 m^3/s, and the Zambezi was at 1,471.1 m^3/s. Therefore, the Lungwebungu River contributes ~20% during the wet season. No wet-season measurement was taken at the Kabompo confluence. However, the average discharge measured at the gauging station near the Zambezi River basin outlet in March was 664.6 m^3/s[76] (see hydrograph of the Kabompo sub-basin in *Appendix 10*). Therefore, it is possible that the Kabompo River's contribution increases to ~45%.

By contributing a further ~43-65% to the flow of the Zambezi River directly upstream of the Barotse Floodplains, the Kabompo and Lungwebungu Rivers have a direct and tangible impact on the seasonal flood pulse and year-round inundation of this system.

Pan-belt

The pan-belt surrounding the Barotse Floodplain supports no significant watercourses, but the perennial pans and wide, grassy dambos maintain a high-water table. This grassy cover in the dambos helps reduce evaporation and surface runoff, improving their ability to retain water. Furthermore, some dambos receive groundwater recharge, which helps maintain a high-water table in the areas surrounding the floodplain[77] .

Consequently, the pans and dambos bordering the Barotse Floodplain provide a natural storage area for excess water during periods of high discharge — such as during the rainfall season (see *Study Site Description*). This floodplain storage capacity helps spread the river's discharge over time, preventing sudden spikes and leading to a more regulated flow downstream. As a result, the discharge rate measured downstream increases as water stored in the floodplain gradually drains back into the river.

The pan-belt constitutes a significant control over the hydrology of the upper Zambezi River. The ecological integrity of these biogeomorphological landforms and, consequently, the hydrology of the Barotse Floodplain is likely to be sensitive to the destruction and losses of the capping plant cover – by excessive burning, overgrazing and deforestation. Effective management and conservation of these

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[75] Moore, A.E., Cotterill, F.P.D., Main, M.P.L., & Williams, H.B. (2022). The Zambezi: Origins and Legacies of Earth's Oldest River System. Large Rivers Research and Assessment.

[76] Beilfuss, R. (2012). A Risky Climate for Southern African Hydro: Assessing Hydrological Risks and Consequences for Zambezi River Basin Dams. International Rivers.

[77] Moore, A.E., Cotterill, F.P.D., Main, M.P.L., & Williams, H.B. (2022). The Zambezi: Origins and Legacies of Earth's Oldest River System. Large Rivers Research and Assessment.

landforms are essential to ensure the continued regulation of river flow and the overall ecological stability of the region.

Table 13. Discharge measurement results.

Site Name	Latitude	Longitude	Q	Area	Mean Speed	Max Depth
1	-13.18417	22.8295	923.4	1,241.3	0.744	6.7
2	-14.31597	23.20708	1,194.2	1,357.1	0.881	5.8
3	-16.64311	23.55674	2,323.1	3,243.7	0.716	4.5
Kabompo River confluence	-14.18386	23.18311	318.1	546.3	0.582	5.6
Lungwebungu River confluence	-14.31682	23.20603	193.8	354.3	0.547	4.6

The ADCP results, coupled with an understanding of the Barotse Floodplain's unique hydrological characteristics, underscore the immense importance of this natural feature in regulating the flow of the Zambezi River, mitigating flood risks, and maintaining the overall ecological resilience of the river system.

Bat recorder deployments

The team deployed a Wildlife Acoustics Song Meter SM4BAT-FS detector to record bat echolocation calls at 15 sites along the river from dusk to dawn each night. The resulting data has been sent to Dr Siena Weier and Prof. Peter Taylor as part of a more extensive bat diversity study.

Fish Sampling

Methods: Fish sampling

Fish sampling was conducted at 14 sites on the Chavuma–Sioma transect (Figure 42, see *Appendix 7* for a summary of fish sampling sites). Primary sampling techniques included a fyke net, trap, cast net and dip net. Captured fish were identified to the species level, anaesthetized in clove oil, photographed, and preserved in 10% Formalin (Figure 43). Tissue samples were extracted for two representatives per species and stored in 95% ethanol for subsequent DNA analysis and to develop a reference library for eDNA analyses. Fish specimens were transported to the American Natural History Museum (AMNH) for identification verification, genetic analysis and to be accessioned into their collection.

Figure 42. Fish sampling sites.

Figure 43. Expedition team sampling fish specimens on the Zambezi River.

Results and Discussion: Fish sampling

A total of 348 fish were collected, representing at least 33 species. The most common species were *Synodontis sp.* (N = 56), *Pollimyrus marianne* (N = 39), *Enteromius afrovernayi* (N = 28), and *Schilbe intermedius* (N = 28). A complete list of the species captured from sampling efforts is presented in *Appendix 8*, and some species' photographs are presented below (Figure 44).

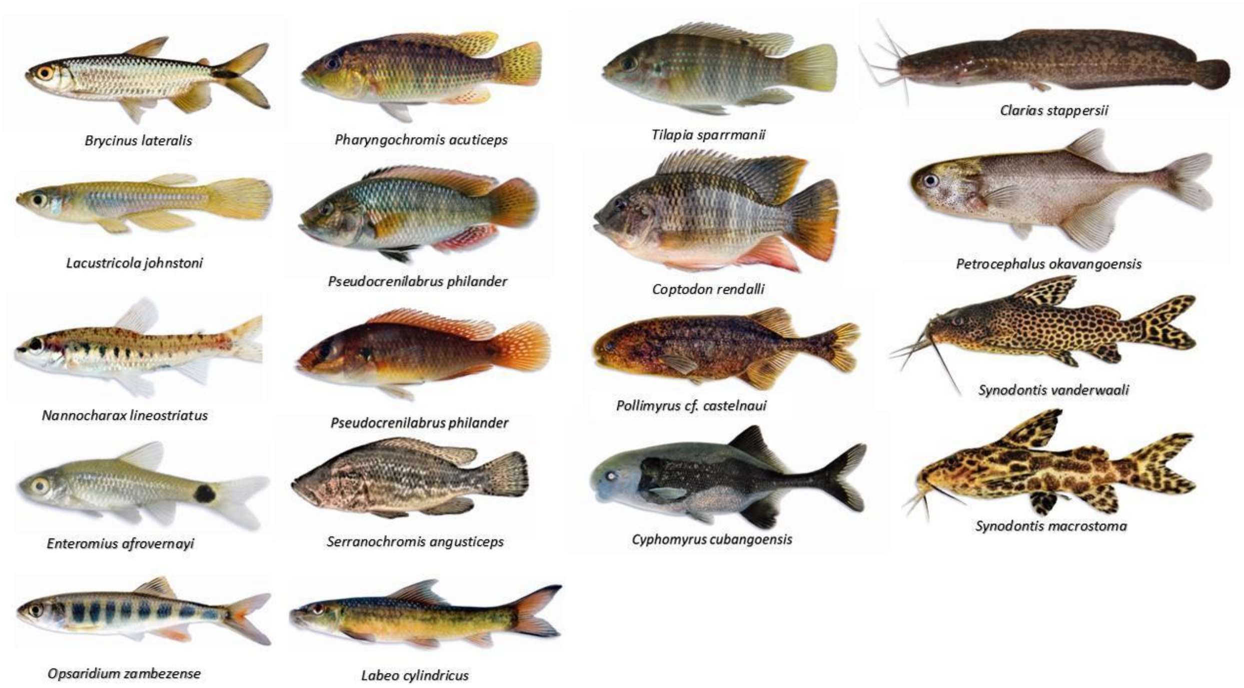


Figure 44. A few of the fish species found on this expedition.

Invasive Crayfish Survey

The Australian redclaw crayfish — *Cherax quadricarinatus* — is a freshwater crustacean native to northern Australia and Papua New Guinea. While its rapid growth, adaptable diet, direct development, and tolerance for varying environmental conditions such as temperature, pH, and dissolved oxygen levels make it a valuable species for aquaculture, these characteristics also contribute to its highly invasive nature. As a result of its high aquaculture value, this species has been introduced to various regions across the globe[78].

To assess the presence of invasive crayfish *Cherax quadricarinatus*, a yabby trap was baited with dry dog food and set overnight at 15 sites along the river transect. *C. quadricarinatus* is known to be widely distributed in the Zambezi River, and was detected at three sites, two of which were within the Barotse Floodplain (Figure 45, Figure 46).

[78] CABI. 2019. *Cherax quadricarinatus* (redclaw crayfish).

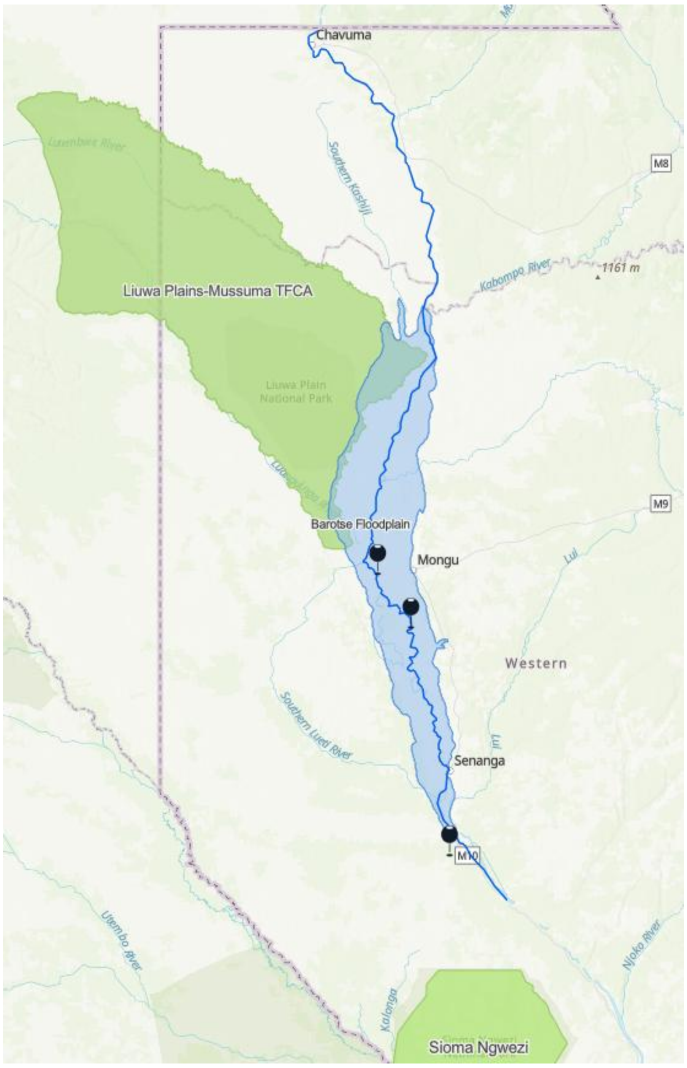


Figure 45. Locations where *Cherax quadricarinatus* were detected.

Invasive Crayfish implications

Cherax quadricarinatus was first reported in the Kafue River in 2001, followed by their sighting in Lake Kariba in 2002. Victoria Falls — a natural barrier — prevented the unassisted spread of these crayfish from Lake Kariba into the Upper Zambezi River system. However, in 2014, they were found in the Barotse Floodplain[79]. Since, a high proportion of egg-carrying females have been captured in the Barotse Floodplain, highlighting the presence of a well-established breeding population. Consequently, there are concerning implications for the potential dispersal of this invasive species both upstream and downstream from the Barotse Floodplain[80].

Cherax quadricarinatus exhibit polytrophic and generalist feeding behaviours, leading to direct predation on native species and indirect impacts through the transmission of parasites and diseases. Their presence often results in habitat alterations and the depletion of aquatic macrophytes. Beyond environmental consequences, crayfish invasions can incur economic costs through damage to agricultural infrastructure, scavenging of fish catches, and the destruction of fishing gear, ultimately threatening food security in

[79] Madzivanzira, T.C., South, J., Wood, L.E., Nunes, A.L. & Weyl, O.L.F.(2020). A review of freshwater crayfish introductions in Africa.Reviews in Fisheries Science and Aquaculture, 29(2), 218–241

[80] Madzivanzira, T.C., South, J., Ellender, B.R., Chalmers, R., Chisule, G., Coppinger, C.R., Khaebeb, F.H., Jacobs, F.J., et al. 2021. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in the Zambezi Basin. Aquatic Conservation: Marine and Freshwater Ecosystems. 31(11):3156–3168.

affected areas[81].

Given these challenges, the consumption of invasive *Cherax quadricarinatus* can serve as a viable alternative food source, alleviating some ecological pressures caused by their invasion. By promoting their harvest for consumption, communities can benefit economically while simultaneously contributing to the management of this invasive species. Recent research has highlighted the crayfish's nutritional value and suitability for human consumption, suggesting that turning *C. quadricarinatus* into a resource—rather than solely a threat—could support both livelihood diversification and ecological management efforts[82].

Numerous projects and research initiatives are currently underway to better understand and manage the impacts of *Cherax quadricarinatus* in the Barotse Floodplain and the wider Zambezi Basin. This includes quantifying the ecological and economic damage caused by this invasive species, particularly its role in damaging gillnet catches and reducing the marketability of fish through scavenging behaviour[83]. Experimental studies have demonstrated the species' high feeding rates on both fish and aquatic vegetation, with clear implications for fisheries productivity and ecological balance[84]. Additionally, pilot studies testing control strategies such as misdirection traps offer promising avenues for mitigating impacts in artisanal fisheries[85]. Continued support for these initiatives will be critical to developing effective, context-specific management solutions and protecting the livelihoods of communities dependent on the floodplain's resources.

[81] Madzivanzira, T.C., South, J., Ellender, B.R., Chalmers, R., Chisule, G., Coppinger, C.R., Khaebeb, F.H., Jacobs, F.J., et al. 2021.

[82] Madzivanzira, T.C., et al. (2023a). Feeding ecology and resource consumption of invasive crayfish under climate-relevant conditions. Environmental Science and Pollution Research.

[83] Madzivanzira, T.C., Weyl, O.L.F., & South, J. (2022). Ecological and potential socioeconomic impacts of two globally-invasive crayfish. NeoBiota, 72, 25–43.

[84] Madzivanzira, T.C., et al. (2023a). Feeding ecology and resource consumption of invasive crayfish under climate-relevant conditions. Environmental Science and Pollution Research.

[85] Madzivanzira, T.C., et al. (2023b). Get it before it gets to my catch: misdirection traps to mitigate against socioeconomic impacts associated with crayfish invasion. Management of Biological Invasions, 14(2), 335–346.

Figure 46. The yabby crayfish caught on this expedition. Note the yabby trap on the top left with a crayfish inside.

5. SATELLITE ANALYSES

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

Methods: LULC change analysis

To generate the LULC change analysis, 300 m resolution land cover classification maps for 1992 and 2020 were extracted from the European Space Agency Climate Change Initiative. These maps provide an estimate of the land cover change for the entire Upper Zambezi Basin Region, ending in Livingstone. Classes from this global land cover product were combined into general change detection classes according to the product's user guidelines. For more information, see *Appendix 9*.

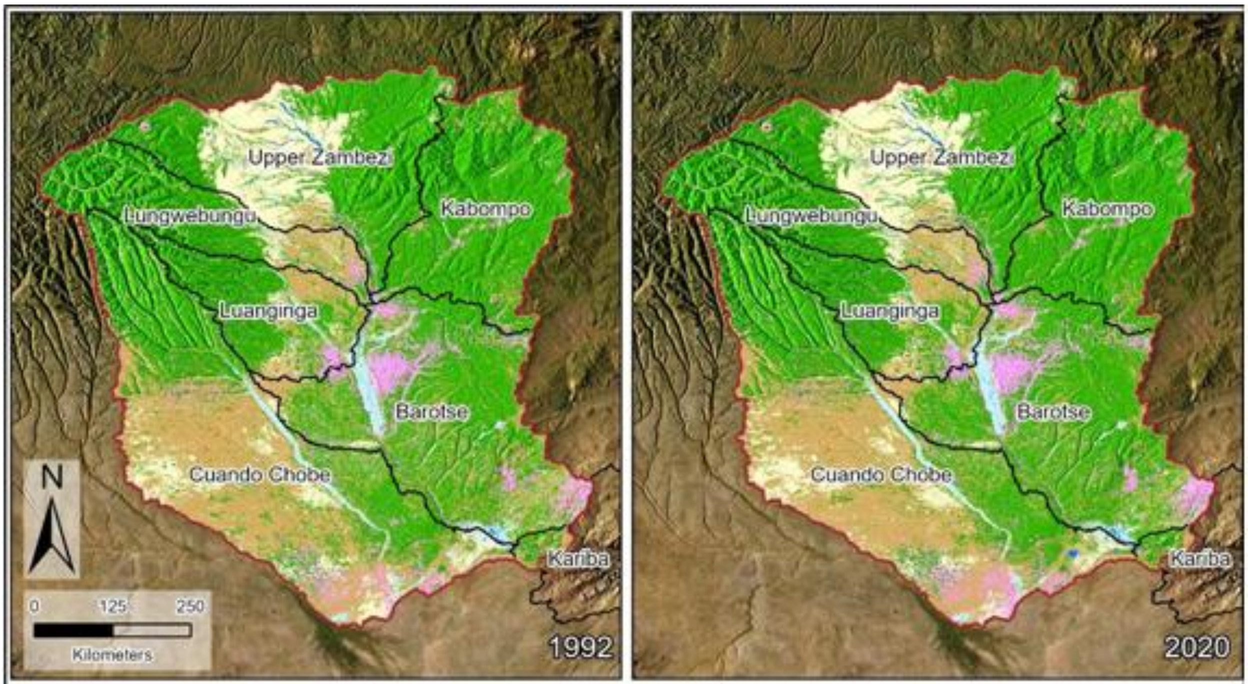
Results and Discussion: LULC change analysis

Vegetation Cover
The Upper Zambezi region features two major landscapes characterized by distinct vegetation cover: the Northern Highlands and the Central Plains (Figure 47). The Northern Highlands consists of a belt of high ground described as forest and woodland, giving rise to the Zambezi and its headwater tributaries in Zambia and Angola, flanking the Central Plains. The Central Plains of the Kameia, Lungwebungu, Luanginga and Barotse Floodplain are described as wetlands, grasslands and shrublands.

Between 1992 and 2020, forest and woodland land cover has expanded by 1.28% or 3,772 km^2. Wetland and water coverage saw minimal change between 1992 and 2020, with wetlands being calculated to have lost 136 km^2 and water having gained 114 km^2. This is because the Liambezi Lake within the Cuando Chobe sub-basin was classified as a wetland in 1992 and water in 2020. Lake Liambezi was refilled in 2009 after a 22-year dry period.

Human land-use cover
Between 1992 and 2020, a net percentage increase in agriculture (7.71%) and settlement (72.72%) occurred, calculated as having gained 88 km^2 and 3 km^2 per year, respectively. Gains in agriculture and settlement are typical across many rivers in Africa. These changes generally result in negative implications for both water discharge and water quality, a concern for the Upper Zambezi. Agriculture is concentrated around the Barotse Floodplain and Kabompo River (Figure 47).

The primary threat to the Upper Zambezi sub-basins is modification and damming. Apart from dams associated with mining on the upper reaches of the Kabompo sub-basin, this region remains undammed and has a small settlement footprint (less than 0.03% of the basin area), resulting in a free-flowing natural state. The significant contributions of the Upper Zambezi (Luena and Kameia), Luanginga, Lungwebungu, Cuando Chobe and Barotse sub-basin floodplains are critical to the ecological and geomorphological functioning of this river, its end users, and its biodiversity.



Legend LULC Class	The Upper Zambezi 1992 (km^2)	The Upper Zambezi 2020 (km^2)	Change (%)
Agriculture	32,093	34,567	7,71%
Forest and Woodland	294,557	298,329	1,28%
Grassland	53,390	52,216	-2,20%
Wetland	13,676	13,540	-0,99%
Settlement	116	201	72,72%
Shrubland	118,240	113,103	-4,34%
Bare/ sparse vegetation	97	98	0,79%
Water	1,538	1,652	7,43%
Total	513,707	513,707	-

Figure 47. The CCI LULC for the Upper Zambezi Region of the Zambezi Basin in 1992 and 2020.

Google Buildings RS Analysis

Methods: Google Buildings Analysis

The Google Open Buildings dataset, which provides building footprints derived from satellite imagery[86], was used to calculate the number and total area of buildings within a 4 km buffer zone around the Zambezi River and Barotse Floodplain. The dataset was clipped to the buffer zone, and area and count data for the buildings within that region were obtained. This dataset complemented and improved the observational data from the survey, offering a more comprehensive understanding of building distribution and size beyond the river's riparian zone. By highlighting human settlements' proximity to these key ecological areas, the dataset also aids in assessing human impact on these critical ecosystems.

Results: Google Buildings Analysis

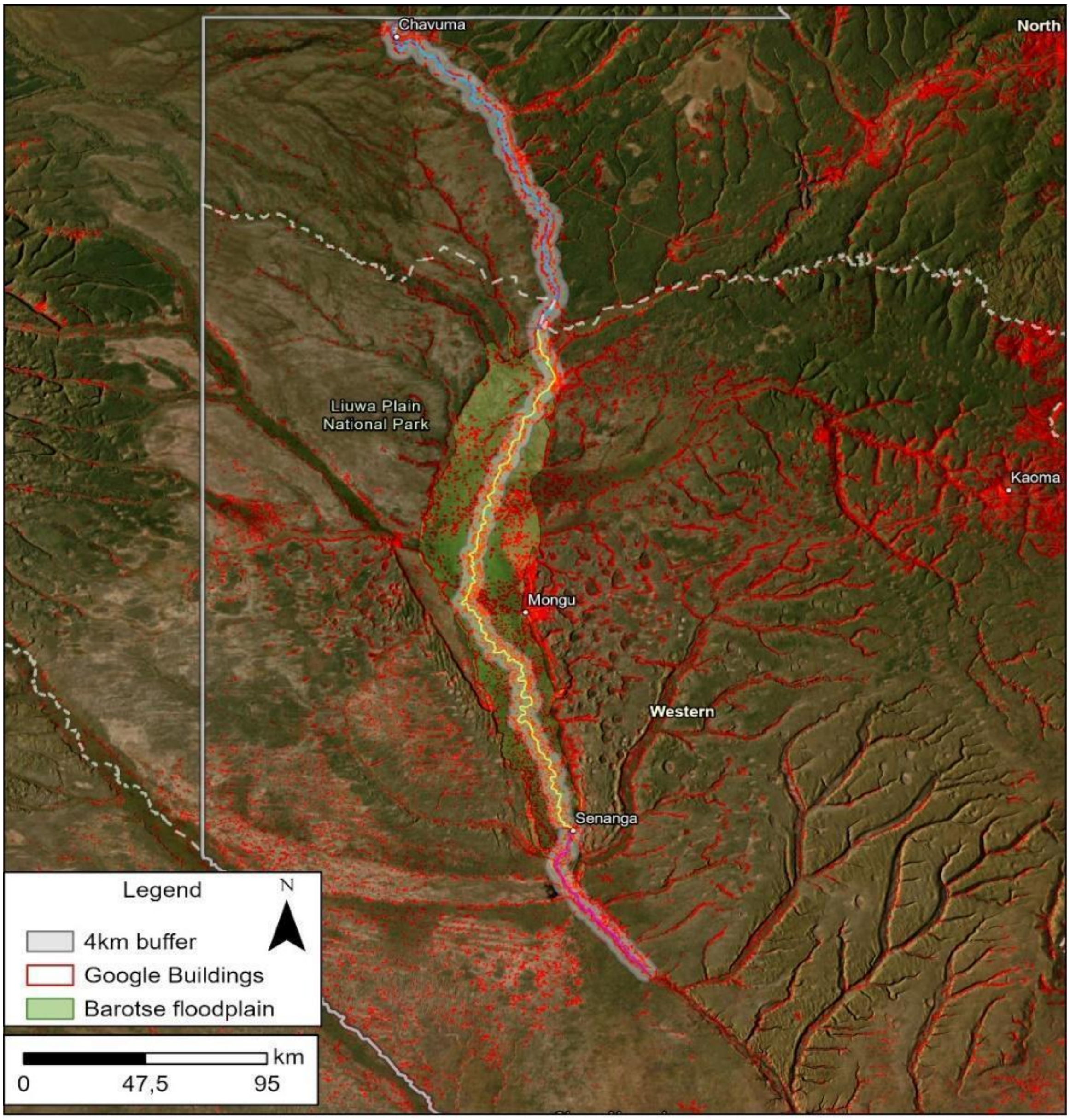
From Chavuma to Sioma, there are an average of 16.93 buildings/km^2, which is significantly higher

[86] Sirko, W., Kashubin, S., Ritter, M., Annkah, A., Salah, Y., Bouchareb, E., Dauphin, Y., Keysers, D., et al. 2021. Continental-scale building detection from high resolution satellite imagery.

compared to the Chambeshi River (6.22 buildings/km^2) and the Lungwebungu River (3.36 buildings/km^2) (Figure 48). The area from Chavuma to the Barotse Floodplain shows the highest building density (0.09%), followed closely by the stretch from the Barotse Floodplain to Sioma (0.08%) (Figure 49). The Barotse stretch of the river, has half the of building density (0.04%) compared to the other two stretches. However, the entire Barotse Floodplain has 14.96 buildings/km^2 primarily clustered along the floodplain edges, which is significantly higher than the Bangweulu wetlands (6.04 buildings/km^2).

The survey data collected during this expedition suggests that infrastructure is concentrated in the Barotse Floodplain. There are two main reasons for this discrepancy between the survey and satellite data: i) villages were not recorded during the survey, and ii) the Google Building analysis may not detect seasonal villages as they use temporary building materials. Consequently, the Google Building analysis indicates permanent infrastructure in the region.

Many villages within the Barotse Floodplain are constructed using temporary materials, allowing structures to be dismantled or relocated in response to the seasonal rise and fall of water levels. As a result, these settlements are often not captured by remote sensing tools like the Google Building analysis. This is consistent with survey observations, which recorded clusters of impermanent infrastructure along the floodplain margins (Figure 49, Figure 50). These patterns reflect more than just environmental adaptation—they are deeply rooted in cultural tradition. The Lozi people have long shaped their livelihoods, settlements, and movement around the annual flood cycle. As waters spread across the plain each year, communities migrate to higher ground, following a practice that is both pragmatic and ceremonial. This seasonal relocation is embodied in the Kuomboka ceremony, which marks the Litunga’s journey from the floodplain capital of Lealui to the elevated grounds of Limulunga.



	Buffer Area (km^2)	Total no. of buildings	No. of buildings/km^2	Total building area (km^2)	Building area (%) within Buffer zone
Chavuma to Barotse	1,432	32,967	23.02	1.33	0.09%
Barotse	2,093	24,633	11.77	0.87	0.04%
Barotse to Sioma	638	12,867	20.17	0.51	0.08%
Barotse Floodplain	8,864	132,648	14.96	5.34	0.06%

Figure 48. A Google building analysis for a 4 km buffer area around the Zambezi River from Chavuma to Sioma.

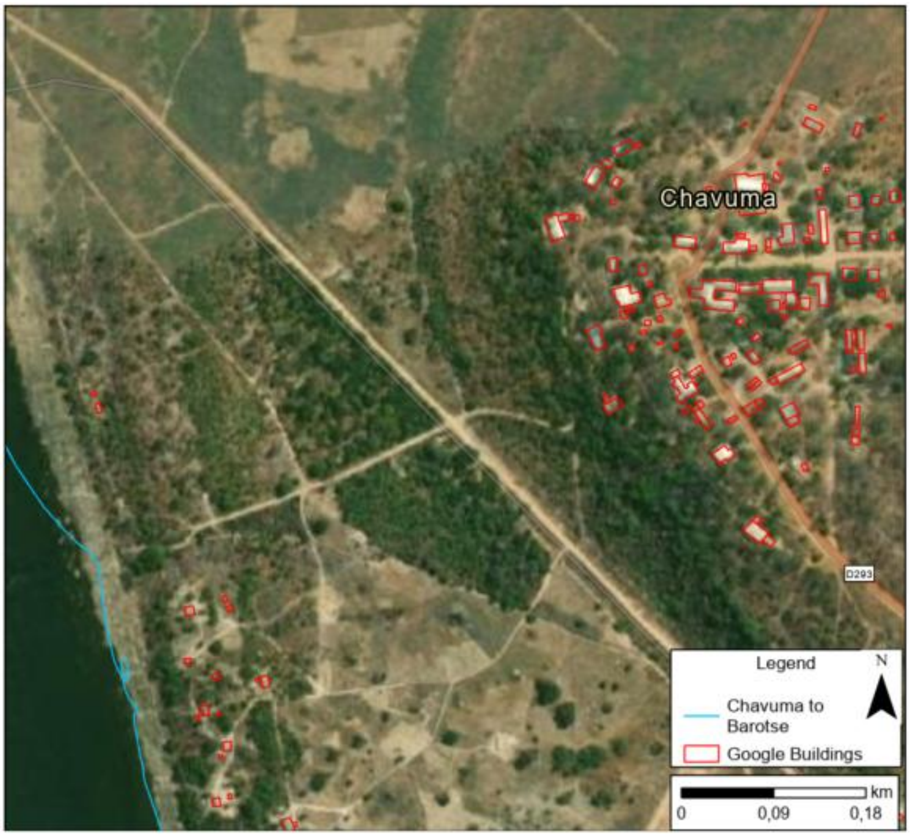


Figure 49. The Google Buildings for Chavuma Town.

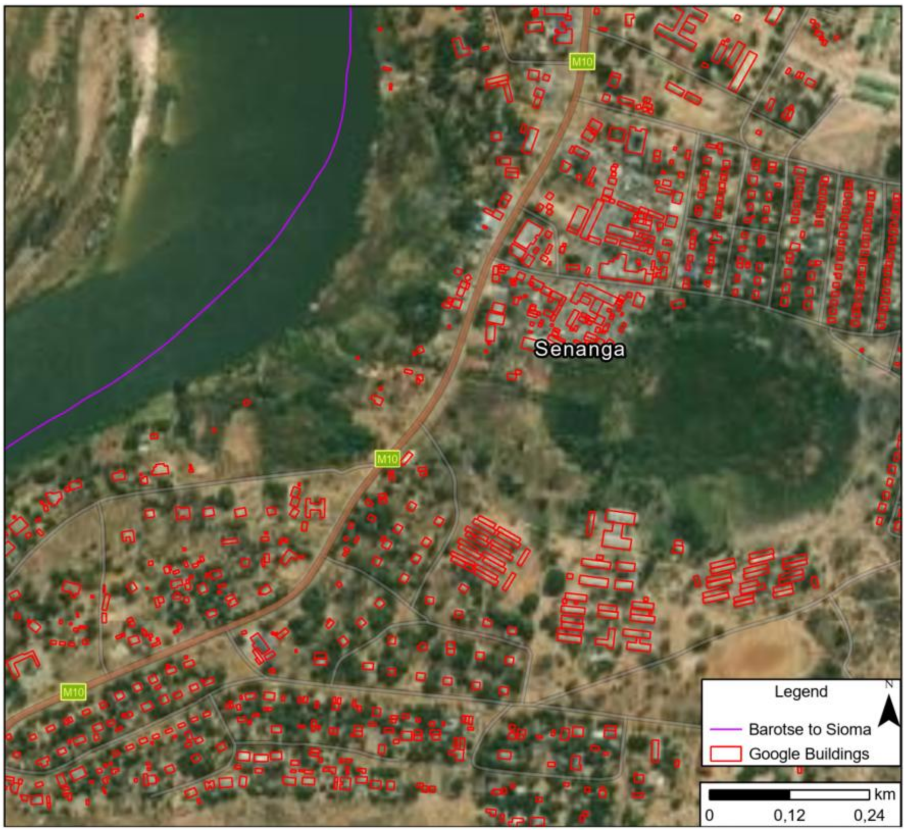


Figure 50. The Google Buildings for Senanga Town

WorldCereal Cropland Analysis

Methods: WorldCereal Cropland Analysis

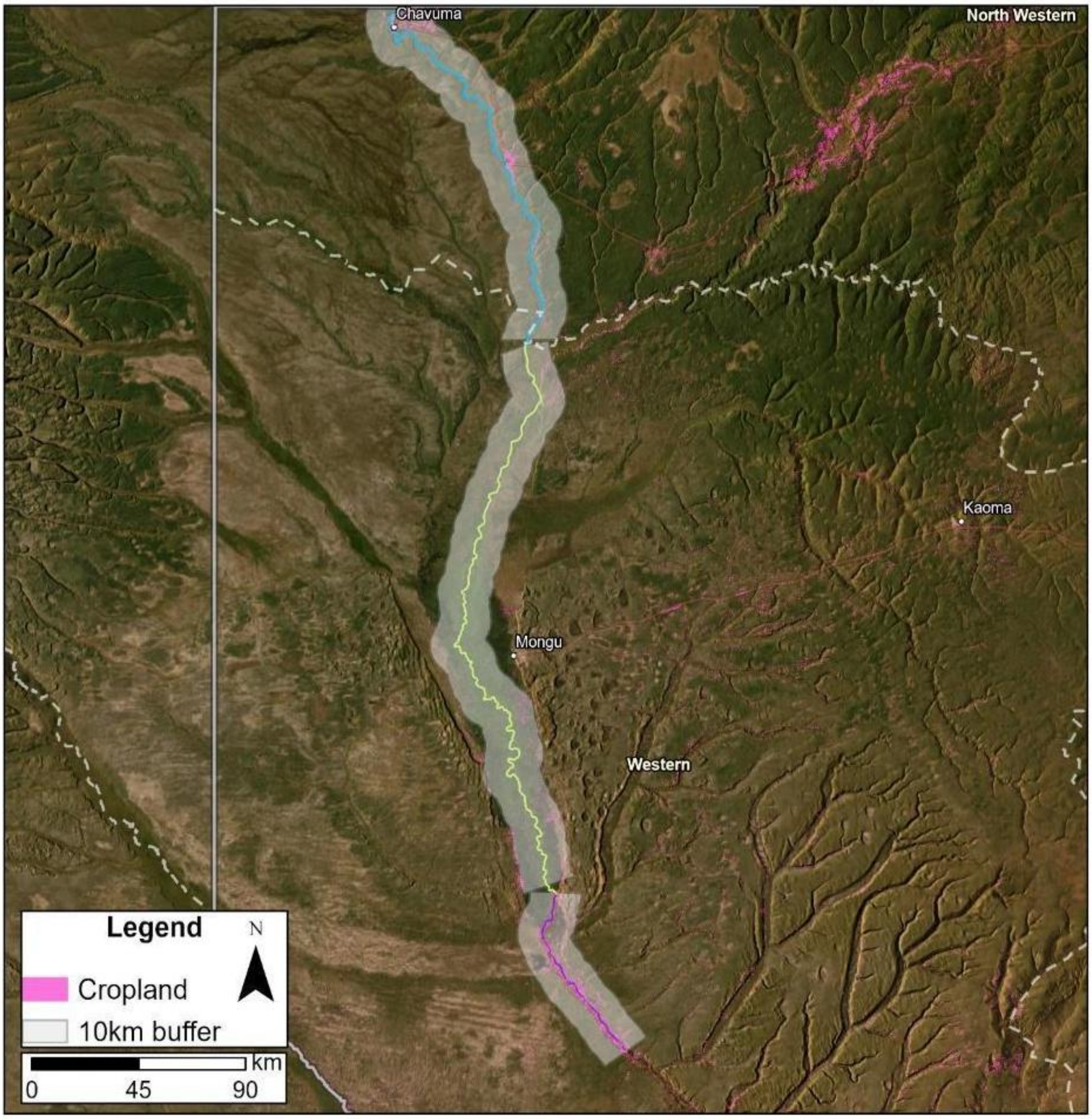
WorldCereal is an open-source system — developed under the European Space Agency's initiative — that provides comprehensive, seasonal, and reproducible maps of global crop extents[87]. In this analysis, WorldCereal data was used to calculate the extent of cropland within a 10 km buffer zone around the three biogeographic regions of the Zambezi River from Chavuma to Sioma. The total cropland area within this buffer zone was determined by summing the areas of identified croplands.

Results and Discussion: WorldCereal Cropland Analysis

There are 158.33 km^2 of cropland within 10km of the Zambezi River from Chavuma to Sioma. From Chavuma to the Barotse Floodplain, the croplands cover 1% of the buffer zone (Figure 51 and Figure 52). In the Barotse Floodplain, croplands are primarily located on the fringes — as seen in the *Land-Use and Land-Cover Change Analysis 2019-2021*— with some croplands present on islands within the floodplain (Figure 51). From the Barotse Floodplain to Sioma, croplands become more common along the main river channel and on the islands within the river (Figure 52). This stretch of river has 4 times more cropland area within the buffer zone compared to the other two regions (Figure 51).

These results correspond to the survey data which demonstrated that crop agriculture was prevalent outside of the Barotse Floodplain. However, due to droughts, subsistence maize farming may become more prevalent in the Barotse Floodplain, where floodplains can provide a reliable water source, mitigating the impacts of the region's seasonal rainfall variability (see *Agriculture* section).

[87] Van Tricht, K., Degerickx, J., Gilliams, S., Zanaga, D., Battude, M., Grosu, A., Brombacher, J., Lesiv, M., et al. 2023. WorldCereal: a dynamic open-source system for global-scale, seasonal, and reproducible crop and irrigation mapping. Earth System Science Data. 15(12):5491–5515.



	Buffer Area (km^2)	Total cropland area (km^2)	Cropland area (%) within buffer area
Chavuma to Barotse	3352	41.88	1%
Barotse	4878	58.20	1%
Barotse to Sioma	1518	58.30	4%

Figure 51. The WorldCereal Cropland Analysis with a 10km buffer zone of the Zambezi River.

MODIS Fire RS Satellite Analysis

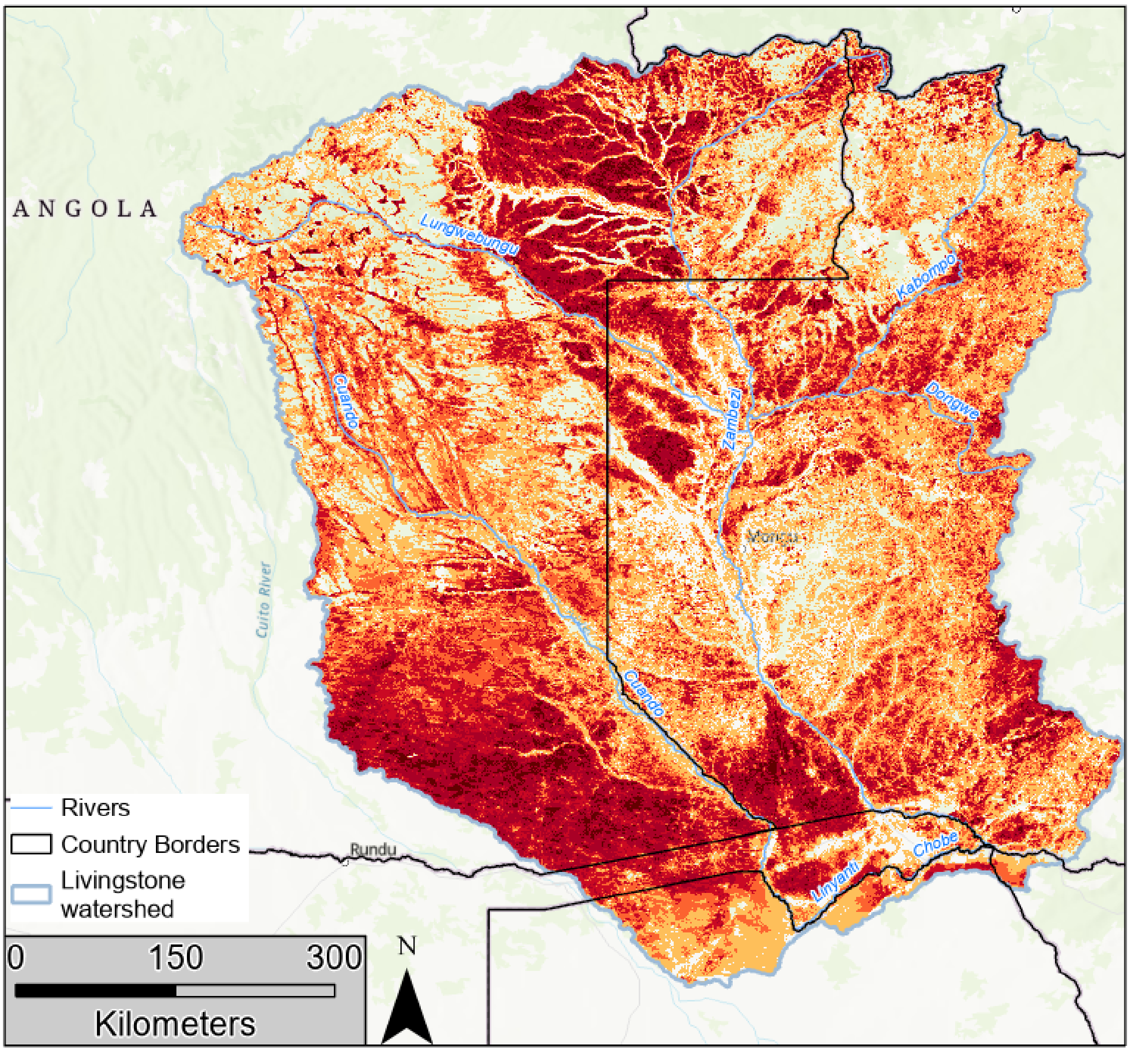
Methods: MODIS Fire RS Satellite Analysis

The 2000–2023 burn frequency of the Upper Zambezi Basin was extracted from the MCD64A1.061 MODIS Burned Area Monthly Global 500 m product. A total of six burned area frequency categories were included in the analysis (ranging from no burn to burnt yearly). A limitation of this data set is that the size of burn areas must be greater than 500 m to be recorded, so this product may not identify some smaller fires.

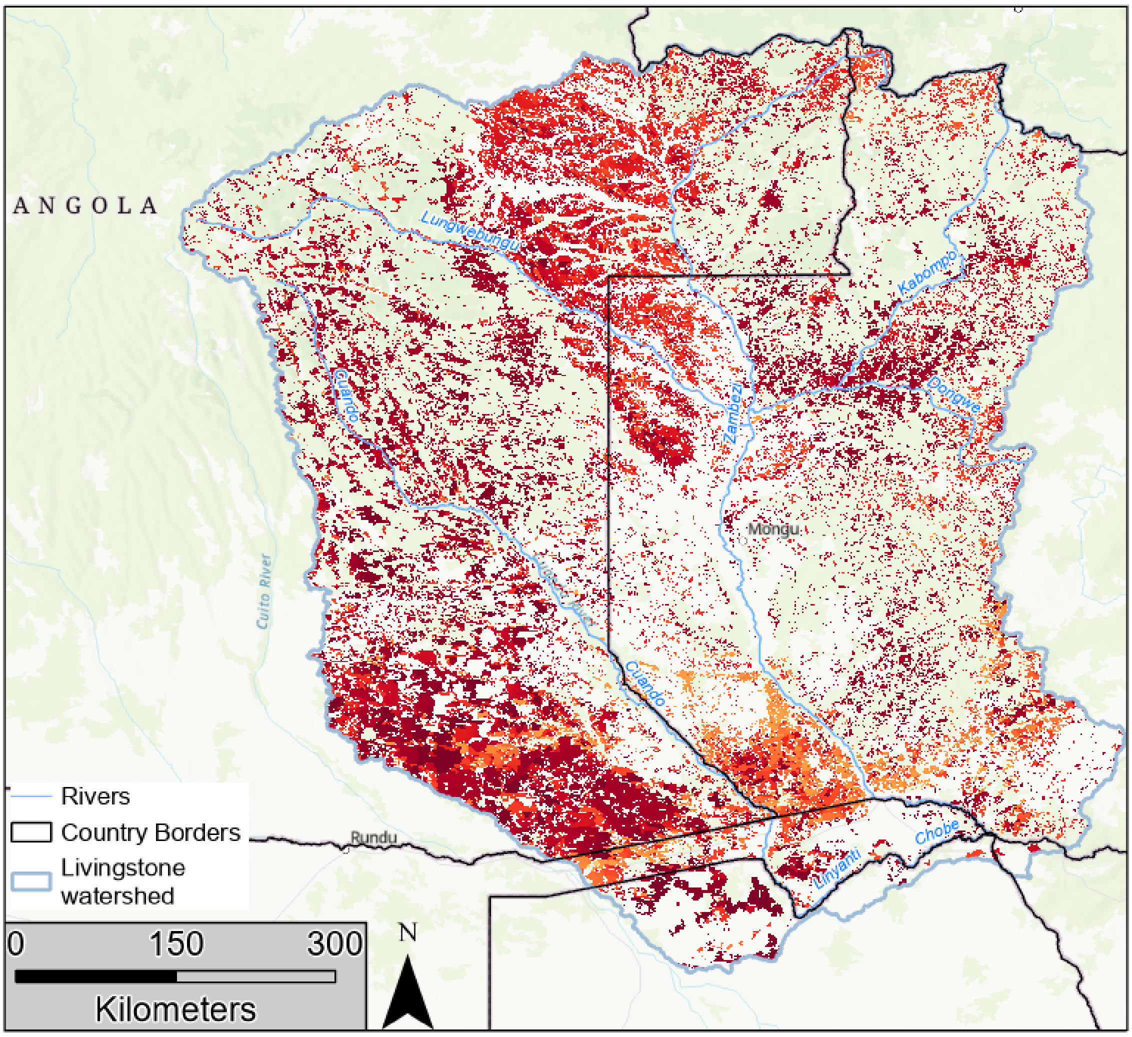
Results: MODIS Fire RS Satellite Analysis

Fire frequencies in this region are closely related to land cover, with vegetation such as grass demonstrating greater burn frequencies. Between 2000-2023, 105,203 km^2 (19 %) of the Livingstone Basin did not have detectable burns (Figure 52). These "No Burn" areas are predominantly within the forest and woodland areas and the Barotse Floodplain. Conversely, the highest burn frequencies (21–23 burns; near-yearly to yearly burns) occurred in areas that are predominantly covered by grassland and shrubland. This corresponds to the areas where fires were observed on this expedition — fires were prominent in the first and third biogeographic regions, with a notable absence within the Barotse Floodplain (see *Fire* section).

For 2023, there was a spatial and monthly variation of areas burnt within the Upper Zambezi Basin (Figure 53). At a basin scale, in four months (June to September), more than 80 % of the basin was burnt, with over a third of the basin burning in August. The Southwestern section seems to burn mainly from September to October, whereas the area between the Zambezi and Cuando Rivers burns mainly from July to September). Given the impact of fire on ecosystems, basin fire management strategies should involve long-term monitoring of monthly burn occurrence to determine the impact of fire in the region and detect any changes in the fire regime.



Legend	Burn Frequency (2000-2023)	Area (km2)	Proportion (%)
	No Burn	105,203	19%
	1-5 Burns	174,835	32%
	6-10 Burns	113,416	21%
	11-15 Burns	77,753	14%
	16-20 Burns	57,899	11%
	21-23 Burns	11,434	2%
	Total Area	540,539	-



Legend		2023 Area (km2)	Burn Proportion (%)
	No Burn	380965	
	January	4	0,00%
	February	18	0,01%
	March	44	0,03%
	April	2393	1,50%
	May	10519	6,58%
	June	29118	18,21%
	July	32023	20,02%
	August	50423	31,53%
	September	30101	18,82%
	October	4901	3,06%
	November	388	0,24%
	December	12	0,01%
	Total Area	159943	

CONCLUSION AND RECOMMENDATIONS

The Barotse Floodplain is a vital ecological feature of the Zambezi River system, serving two critical functions. Firstly, the floodplain acts as a natural hydrological buffer, absorbing and storing water during the wet season and gradually releasing it in the dry season. This process helps maintain perennial flow in the downstream sections of the Zambezi River and plays an essential role in flood mitigation. Secondly, the floodplain is a crucial habitat for bird conservation, supporting approximately 99% of the bird abundance recorded along the Chavuma-Sioma section of the river. Large bird colonies, including up to 15,000 African Openbills, underscore the floodplain's significance for avian biodiversity and ecotourism.

Human activity is abundant along the Chavuma-Sioma stretch of the Zambezi River, particularly in the Barotse Floodplain. Key pressures include illegal fishing practices and increasing floodplain cultivation. Climate change-induced variability in rainfall is expected to exacerbate these pressures as local communities expand land conversion for agriculture and increase reliance on fisheries for income. The Barotse Floodplain also exhibits a high density of buildings—over twice the number recorded in the Bangweulu Wetlands.

During the expedition, Australian redclaw crayfish (*Cherax quadricarinatus*) were recorded at three sites within the floodplain. This invasive species poses a significant threat to native ecosystems by preying on indigenous species, transmitting diseases, and altering habitats. Additionally, three alien invasive plant (AIP) species were recorded—*Mimosa pigra, Eucalyptus globulus*, and *Salvinia molesta*. AIPs are known to cause substantial ecological degradation in African river systems, necessitating continuous monitoring and removal efforts.

Water quality analyses revealed a significant decline in the Zambezi River's water quality at the Kabompo confluence, where mining-related pollution is a growing concern. The Kabompo River is highly exposed to pollutants from mining activities, leading to contamination that affects the broader Zambezi system.

In light of the information presented, the following recommendations for the sustainable management of the Zambezi River and Barotse Floodplain are intended to complement and build upon existing efforts in the region:

1. **Support the Finalization and Implementation of UNESCO status**
   The Barotse Floodplain is a designated Ramsar site and is currently under nomination as a UNESCO cultural landscape. Supporting the finalization and implementation of its UNESCO recognition is an important step toward protecting the floodplain's biodiversity and ecological role. This support could also help strengthen its long-term resilience to increasing development and climate pressures.

2. **Strengthen the Regulation and Monitoring of Fisheries and Agricultural Activities**
   Intensive and unregulated fishing has emerged as a primary threat to biodiversity. WWF's Catch Assessment Survey (CAS)[88] and community-based fisheries governance initiatives have contributed to better monitoring and local regulation of fishing activities, but ongoing support is essential. Encouraging integration of CAS data into policy, investing in capacity-building, and pursuing legal frameworks that reinforce community fisheries management may enhance resilience.

3. **Enhance Cross-Border and Regional Conservation Coordination**
   The floodplain's role as part of the greater Zambezi River system highlights the importance of transboundary cooperation. The Liuwa-Mussuma Transfrontier Conservation Area (TFCA) facilitates

[88] Aquatic Ecosystem Services | Fisheries & Environmental Consulting. (2023). Upper Zambezi Landscape Project - Aquatic Ecosystem Services | Fisheries & Environmental Consulting.

joint management between Zambia and Angola[89], while regional bodies like ZAMCOM and WARMA offer platforms for coordinated water governance[90]. Enhancing Barotse stakeholder representation in these institutions could strengthen local influence over upstream decision-making and promote a basin-wide approach to protecting hydrological function.

In addition, advocating for the designation of the Zambezi River headwaters as a Water Resource Protected Area (WRPA) would safeguard the river's hydrological integrity and ensure that upstream developments do not compromise the ecological health of the Barotse Floodplain.

4. **Expand Monitoring and Management of Invasive Species**
   The spread of invasive species—particularly *Cherax quadricarinatus* (redclaw crayfish) and *Mimosa pigra*—continues to pose a significant threat to the floodplain's native biodiversity and ecological balance. Existing efforts, including community-led *Mimosa pigra* control initiatives spearheaded by BirdWatch Zambia and WWF, and ongoing research into the distribution and ecological impact of redclaw crayfish, represent important steps toward managing these threats. Continued support for these programs—through resourcing, capacity strengthening, and knowledge-sharing—may help sustain their effectiveness and ensure long-term ecological resilience.

5. **Establish Long-Term Community-Based Water Quality Monitoring**
   Given evidence of a decline in water quality at the Kabompo River confluence —systematic water quality monitoring is urgently needed. Building on current efforts, localized monitoring stations managed by communities in collaboration with WARMA could enable more timely responses to contamination. These data would also support adaptive management of pollution risks and help safeguard the floodplain's role as a hydrological buffer.

6. **Promote Sustainable Livelihood Alternatives**
   To reduce unsustainable dependence on fisheries and land conversion, sustainable livelihood options should be prioritized. PIN and WWF initiatives promoting agroforestry, renewable energy, and small-scale enterprises provide valuable models that could be scaled to other areas of the floodplain. Ensuring these alternatives are culturally appropriate, economically viable, and ecologically compatible will be key. Initiatives such as the Simalaha Conservancy and community-managed fish farms offer replicable frameworks that link local development to conservation goals.

[89] Tfcaportal.org. (2025). Liuwa Plains-Mussuma Transfrontier Conservation Area | SADC TFCA Portal.

[90] Zambezicommission.org. (2019). Zambezi Watercourse Commission (ZAMCOM) | The Strategic Plan for the Zambezi Watercourse.

8. APPENDICES

Appendix 1. Past and ongoing initiatives and projects within the Barotse Floodplain.

Project Name	Partners	Description
IUCN Zambezi Basin Wetlands Project (Phase I & II) (1993–2000)	International Union for Conservation of Nature (IUCN); Zambian Government (e.g. Dept. of Fisheries, local authorities); Biodiversity Foundation for Africa	Multi-year initiative conserving the Zambezi Basin's wetlands, including Barotse. Conducted biodiversity and socio-economic studies, valued ecosystem services, and developed wetland management policy recommendations.
AWF "Four Corners" Transboundary Natural Resource Management Project (ca. 1999–2004)	African Wildlife Foundation (AWF); USAID; Wildlife authorities of Zambia, Zimbabwe, Namibia, Botswana; Zambezi Society; Biodiversity Foundation Africa	Linked protected areas and communities across four countries. In Barotse, established aquatic monitoring and fisheries surveys, and formed a working group to manage transboundary resources.
Liuwa Plain National Park Co-Management Initiative (2003–ongoing)	Zambia DNPW; Barotse Royal Establishment; African Parks	Public–private partnership to restore Liuwa Plain NP. Reintroduced species, improved law enforcement, and integrated sustainable land use with community benefit-sharing inside the park.
Kavango–Zambezi Transfrontier Conservation Area (KAZA TFCA) (2011–ongoing)	Governments of Zambia, Angola, Namibia, Botswana, Zimbabwe; SADC; Peace Parks Foundation	Large-scale conservation zone enabling wildlife movement and promoting cross-border habitat protection. In Barotse, supports corridors, anti-poaching, and community-based tourism.
CGIAR Aquatic Agricultural Systems (AAS) Barotse Hub (2012–2016)	WorldFish Center; Dept. of Fisheries; Barotse Royal Establishment; Local NGOs and communities	Pilot project using participatory methods to promote flood-resilient agriculture, improved fishing, and better local governance of floodplain resources.
WWF Upper Zambezi – Barotse Landscape Program (c. 2015–ongoing)	WWF Zambia; Barotse Royal Establishment; International Crane Foundation; Govt agencies; Local communities	The WWF Upper Zambezi – Barotse Landscape Programme, launched in 2018 by WWF Zambia in partnership with WWF Netherlands and DOB Ecology, is a comprehensive conservation initiative aimed at safeguarding the ecological integrity and enhancing the climate resilience of the Upper Zambezi River Basin, with a strong focus on the Barotse Floodplain, Liuwa Plain National Park, and the Kabompo River catchment. The programme's objectives center on sustainable ecosystem management, biodiversity conservation, community livelihood support, and controlling

		invasive species such as Mimosa pigra and the redclaw crayfish (Cherax quadricarinatus). It employs landscape-level planning to guide responsible water and land use, protect against unsustainable development, and promote climate adaptation. Key activities include conducting ecological, hydrological, and socio-economic baseline studies; implementing electronic Catch Assessment Surveys (eCAS) to monitor fisheries and inform sustainable management; and removing invasive species through community-led initiatives that also provide economic opportunities. Fire management is another critical component, blending traditional and scientific approaches to reduce wildfire risks. The programme also supports the preservation of cultural heritage, particularly efforts to gain UNESCO World Heritage Site status for the Barotse Floodplain, recognizing its unique ecological and cultural importance.
Barotse Floodplain Cultural Landscape UNESCO Nomination (2017–2022)	Barotse Royal Establishment; National Heritage Conservation Commission; Ministry of Tourism; WWF Zambia; UNESCO advisors	Attempted World Heritage Site nomination recognizing cultural and ecological value of Barotse. Fostered local heritage appreciation despite 2022 suspension.
Mimosa pigra Eradication and Floodplain Restoration Project (2022–2023)	BirdWatch Zambia; WWF Zambia; Barotse Royal Establishment; Local communities	Physically cleared 9.5 ha of Mimosa pigra. Combined habitat restoration with community training, awareness-raising, and short-term employment.
Enhancing Livelihood Opportunities through Ecosystem Protection Project (2024–2027)	People in Need Zambia; WWF Zambia; Barotse Royal Establishment; Jersey Overseas Aid; Czech Aid	Supports community forest and rangeland management, sustainable energy adoption, and poverty reduction linked to conservation goals.

Appendix 2. Summary of the bird species and count of individuals.

Bird Species	Individuals
African openbill	28,049
Reed cormorant	2,354
Grey headed gull	892
African skimmer	693
White faced whistling duck	603
Little egret	579
Whiskered tern	434
Pied kingfisher	291

White winged tern	167
Squacco heron	146
White crowned lapwing	107
Great egret	71
Spur winged goose	62
Little bee eater	53
Grey heron	51
Other	50
Blacksmith lapwing	49
Western cattle egret	49
Glossy ibis	48
Striated heron	41
Yellow billed stork	39
Purple heron	37
White fronted bee eater	32
African marsh harrier	29
Malachite kingfisher	28
Black winged stilt	25
African fish eagle	22
African pied wagtail	19
Bateleur	19
African wattled lapwing	14
Coppery tailed coucal	14
Slaty egret	13
African sacred ibis	12
Common sandpiper	12
Southern carmine bee eater	11
Black crake	9
Yellow billed duck	9
African jacana	8
European bee eater	7
Water thick knee	6
Woolly necked stork	5
Crowned hornbill	4
Crowned lapwing	4
Giant kingfisher	4
Rufous bellied heron	4
Three banded plover	4
Western banded snake eagle	4
Black chested snake eagle	3
Black headed heron	3
African harrier hawk	2
African pygmy goose	2

African spoonbill	2
Brown snake eagle	2
Hamerkop	2
Lizard buzzard	2
Western osprey	2
Woodland kingfisher	2
African darter	1
Grey headed kingfisher	1
Hadada ibis	1
Lanner falcon	1
Lappet faced vulture	1
Long crested eagle	1
Long toed lapwing	1
Martial eagle	1
Pink backed pelican	1
White backed night heron	1
Total	35,215

Appendix . Drone images taken looking straight down from an altitude of 200m at sites 5, 13, 20, 31, 48 and 57.

Appendix 4. Summary of sampling localities.

Site Name	Date	GPS Coordinates	Sampling Types
Zambezi 1	15 May 2023	-13.01481, 22.70887	Aerial Survey, Water Quality
Zambezi 2	15 May 2023	-13.09412, 22.68404	Aerial Survey, Water Quality
Zambezi 3	17 May 2023	-13.08978, 22.72075	Aerial Survey, Water Quality
Zambezi 4	17 May 2023	-13.14846, 22.78655	Aerial Survey, Water Quality
Zambezi 5/Camp 1	17 May 2023	-13.18417, 22.82950	Aerial Survey, Water Quality, ZISS, eDNA, Flow, Fish, Yabby Trap, Bat Recording
Zambezi 6	18 May 2023	-13.23158, 22.90374	Aerial Survey, Water Quality
Zambezi 7	18 May 2023	-13.29656, 22.94619	Aerial Survey, Water Quality

Zambezi 8	18 May 2023	-13.34034, 23.00641	Aerial Survey, Water Quality
Zam Camp 2	18 May 2023	-13.35897, 23.02472	Fish, Yabby Trap, Bat Recording
Zambezi 9	19 May 2023	-13.40844, 23.03890	Aerial Survey, Water Quality
Zambezi 10	19 May 2023	-13.49553, 23.05896	Aerial Survey, Water Quality
Zambezi 11	19 May 2023	-13.56400, 23.09902	Aerial Survey, Water Quality
Zambezi 12	19 May 2023	-13.62923, 23.12480	Aerial Survey, Water Quality
Zambezi 13/ Camp 3	19 May 2023	-13.65699, 23.13523	Aerial Survey, Water Quality, ZISS, eDNA, Fish, Yabby Trap, Bat Recording
Zambezi 14	20 May 2023	-13.72211, 23.17032	Aerial Survey, Water Quality
Zambezi 15	20 May 2023	-13.77664, 23.22332	Aerial Survey, Water Quality
Zambezi 16	20 May 2023	-13.86879, 23.19354	Aerial Survey, Water Quality
Zambezi 17/Camp 4	20 May 2023	-13.93276, 23.20933	Aerial Survey, Water Quality, Fish, Yabby Trap, Bat Recording
Zambezi 18	21 May 2023	-14.01351, 23.22863	Aerial Survey, Water Quality
Zambezi 19	21 May 2023	-14.09500, 23.22889	Aerial Survey, Water Quality
Zambezi 20	21 May 2023	-14.18386, 23.18311	Aerial Survey, Water Quality, ZISS, eDNA, Flow
Zambezi 20A/Camp 5	21 May 2023	-14.18740, 23.17539	Fish, Yabby Trap, Bat Recording
Zambezi 21	22 May 2023	-14.27436, 23.18706	Aerial Survey, Water Quality
Zambezi 22	22 May 2023	-14.33659, 23.22112	Aerial Survey, Water Quality
Zambezi 23	22 May 2023	-14.41318, 23.21560	Aerial Survey, Water Quality
Zam Camp 6	22 May 2023	-14.44514, 23.18007	Fish, Yabby Trap, Bat Recording
Zambezi 24	23 May 2023	-14.52300, 23.14262	Aerial Survey, Water Quality
Zambezi 25	23 May 2023	-14.59458, 23.11391	Aerial Survey, Water Quality
Zambezi 26	23 May 2023	-14.65977, 23.07395	Aerial Survey, Water Quality
Zambezi 27/Camp 7	23 May 2023	-14.72024, 23.03910	Aerial Survey, Water Quality, ZISS, eDNA, Fish, Yabby Trap, Bat Recording
Zambezi 28	24 May 2023	-14.80019, 23.02346	Aerial Survey, Water Quality
Zambezi 29	24 May 2023	-14.87572, 22.99141	Aerial Survey, Water Quality
Zambezi 30	24 May 2023	-14.93743, 22.97829	Aerial Survey, Water Quality
Zambezi 31	24 May 2023	-15.01851, 22.96298	Aerial Survey, Water Quality
Zam Camp 8	24 May 2023	-15.04876, 22.93776	Fish, Yabby Trap, Bat Recording
Zambezi 32	25 May 2023	-15.09795, 22.94405	Aerial Survey, Water Quality
Zambezi 33	25 May 2023	-15.16736, 22.94033	Aerial Survey, Water Quality
Zambezi 34	25 May 2023	-15.23352, 22.91101	Aerial Survey, Water Quality

Zambezi 35	25 May 2023	-15.28625, 22.96217	Aerial Survey, Water Quality
Zambezi 36/Camp 9	25 May 2023	-15.29277, 22.97507	Aerial Survey, Water Quality, ZISS, eDNA, Fish, Yabby Trap, Bat Recording
Zambezi 37	26 May 2023	-15.36502, 22.99107	Aerial Survey, Water Quality
Zambezi 38	26 May 2023	-15.42467, 23.02607	Aerial Survey, Water Quality
Zambezi 39	26 May 2023	-15.45577, 23.07613	Aerial Survey, Water Quality
Zambezi 40	26 May 2023	-15.50818, 23.12513	Aerial Survey, Water Quality
Zam Camp 10	26 May 2023	-15.51568, 23.12386	Fish, Yabby Trap, Bat Recording
Zambezi 41	27 May 2023	-15.56599, 23.12836	Aerial Survey, Water Quality
Zambezi 42	27 May 2023	-15.62452, 23.15026	Aerial Survey, Water Quality
Zambezi 43	27 May 2023	-15.66454, 23.11898	Aerial Survey, Water Quality
Zambezi 44	27 May 2023	-15.71600, 23.15574	Aerial Survey, Water Quality
Zambezi 45/Camp 11	27 May 2023	-15.72584, 23.15801	Aerial Survey, Water Quality, ZISS, eDNA, Fish, Yabby Trap, Bat Recording
Zambezi 46	28 May 2023	-15.80387, 23.18330	Aerial Survey, Water Quality
Zambezi 47	28 May 2023	-15.86740, 23.21730	Aerial Survey, Water Quality
Zambezi 48	28 May 2023	-15.93140, 23.22760	Aerial Survey, Water Quality
Zambezi 49	28 May 2023	-15.98838, 23.25079	Aerial Survey, Water Quality
Zam Camp 12	28 May 2023	-15.99155, 23.24850	Fish, Yabby Trap, Bat Recording
Zambezi 50	29 May 2023	-16.06729, 23.25763	Aerial Survey, Water Quality
Zambezi 51/Camp 13	29 May 2023	-16.09971, 23.29653	Aerial Survey, Water Quality, ZISS, eDNA, Fish, Yabby Trap, Bat Recording
Zambezi 52	30 May 2023	-16.18139, 23.28059	Aerial Survey, Water Quality
Zambezi 53	30 May 2023	-16.25049, 23.24466	Aerial Survey, Water Quality
Zambezi 54	30 May 2023	-16.32450, 23.28661	Aerial Survey, Water Quality
Zambezi 55	30 May 2023	-16.40042, 23.33660	Aerial Survey, Water Quality
Zambezi 56/Camp 14	30 May 2023	-16.46046, 23.39679	Aerial Survey, Water Quality, Fish, Yabby Trap, Bat Recording
Zambezi 57	31 May 2023	-16.52810, 23.45745	Aerial Survey, Water Quality
Zambezi 58	31 May 2023	-16.58523, 23.50193	Aerial Survey, Water Quality
Zambezi 59	31 May 2023	-16.64311, 23.55674	Aerial Survey, Water Quality, ZISS, eDNA, Flow, Bat Recording

Appendix 5. Water Quality parameters.

Water Quality Parameter	Description

pH (or hydrogen ion concentration)	pH (or hydrogen ion concentration) is a general indicator of water quality that is affected by all manner of contaminants and other changes in water chemistry. pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.) Extremes in pH can make a river inhospitable to life. The pH of most raw waters should lie between 6.5-8.5, above and below that warrants detailed water analyses.
Turbidity	Turbidity is the condition resulting from suspended solids in water (silt, clays, industrial waste, sewage and plankton). Such particles absorb heat in the sunlight, thus raising water temperature, which in turn lowers dissolved oxygen levels. Increases in turbidity can also result from elevated erosion rates due to poor land use practices. Resistivity is a similar measure of turbidity.
Electric Conductivity (EC)	Electric Conductivity (EC) measures the water's ability to carry an electric current and is related to the total dissolved salts or ions in the water. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulphides and carbonate compounds that are often associated with pollutants. Total Dissolved Solids (TDS) and salinity are similar measures to conductivity.
Dissolved Oxygen (DO)	Dissolved Oxygen (DO) Depleted oxygen results in eutrophic conditions that can be detrimental to ecosystem health. Invasive weeds such as water hyacinth and certain algae, reduce available oxygen in the river. Weed invasions and algal blooms often result from fertiliser runoff and other poor land use practices. 80-120% saturation is safe.
Oxidation-Reduction Potential (ORP)	Oxidation-Reduction Potential (ORP) measures the ability of a river to break down waste products, such as contaminants and dead organic matter. In general, the higher the ORP value, the healthier the river is. Safe drinking water should have an ORP of greater than 650mV.
Salinity and its inverse — Resistivity	Salinity and its inverse — Resistivity — are measures of salt content in the water. Salts are highly soluble in surface and groundwater and can be transported with water movement. Increases in salinity are often associated with excessive vegetation clearance (fires), poor land management, irrigation, and industrial practices.
Total Dissolved Solids (TDS)	Total Dissolved Solids (TDS) is measured as a volume of water with the unit milligrams per litre (mg/L), otherwise known as parts per million (ppm). According to the EPA secondary drinking water regulations, 500 ppm is the recommended maximum amount of TDS for your drinking water.
Temperature and Water Density	Temperature and Water Density impacts aquatic organisms in terms of their growth and metabolic rates and their sensitivity to disease, parasites, and toxins. Temperature also affects the rate of photosynthesis and the solubility of oxygen in river water.

Appendix . Screenshots of satellite imagery of Biogeographic Region 3. Although the Land-use land change analysis (see land use change analysis 2019-2021 section) does not reflect agricultural activities in this region, satellite imagery reveals areas with extensive agricultural pastures. This region is highly modified with settlements and agriculture fields (top image), agricultural fields mosaiced with forested areas (middle image), and extensive areas of agricultural fields (bottom image).

Appendix 7. Summary of fish sampling sites and methods.

Site	Sampling Method	GPS	Total Species
1	Fyke	-13.18417, 22.8295	3
2	Fyke	-13.35897, 23.02472	3
3	Fyke + Trap	-13.65699, 23.13523	7
4	Fyke	-13.93276, 23.20933	6
5	Fyke + Dip	-14.1874, 23.17539	11
6	Fyke + Cast net	-14.44514, 23.18007	11
7	Fyke	-14.72024, 23.0391	12
8	Fyke	-15.04876, 22.93776	4
9	Fyke	-15.29277, 22.97507	6
10	Fyke	-15.51568, 23.12386	8
11	Fyke + Dip	-15.72584, 23.15801	4
12	Fyke + Trap	-15.99155, 23.2485	6
13	Trap + Cast Net	-16.09815, 23.29594	6
14	Fyke + Trap	-16.46046, 23.29678	6

Appendix 8. Summary of fish species caught.

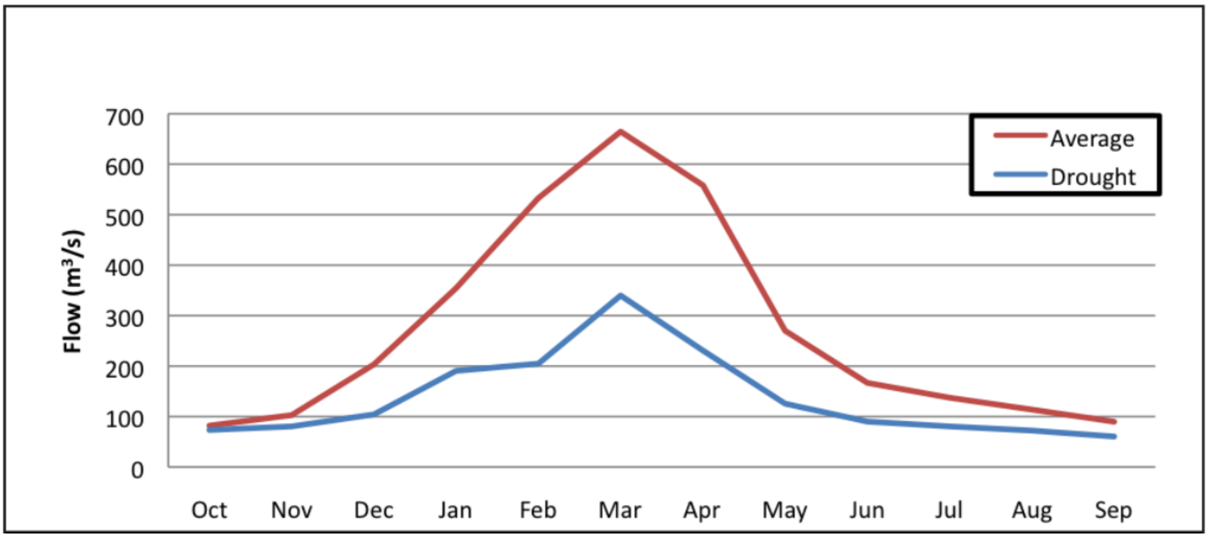
Species	**Number of specimens**
Brycinus lateralis	11
Clarias ngamensis	1
Coptodon rendalli	3
Cyphomyrus cubangoensis	5
Enteromius afrovernayi	28
Enteromius paludinosus	2
Enteromius sp. 'sharp'	6
Hemichromis elongatus	2
Labeo cylindricus	2
Lacustricola johnstoni	5
Marcusenius altisambesi	1
Mastacembelus frenatus	1
Micralestes acutidens	23
Nannocharax lineostriatus	1
Opsaridium zambezense	4
Parauchenoglanis ngamensis	1
Petrocephalus longicapitis	3
Petrocephalus okavangensis	3
Pharyngochromis acuticeps	5
Pollimyrus cf. castelnaui	4
Pollimyrus marianne	39
Pseudocrenilabrus philander	21
Schilbe Intermedius	28
Serranochromis angusticeps	4

Synodontis cf. macrostoma	131
Tilapia sparrmanii	9
Grand Total	**343**

Appendix 9. LULC Supplementary table.

IPCC Classes considered for the change detection (with colour)	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 needleleaved)
	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 10. Mean monthly flows in the Kabompo sub-basin during average and drought years[91].



[91] Beilfuss, R. 2012. A Risky Climate for Southern African Hydro: assessing hydrological risks and consequences for Zambezi River Basin Dams.

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