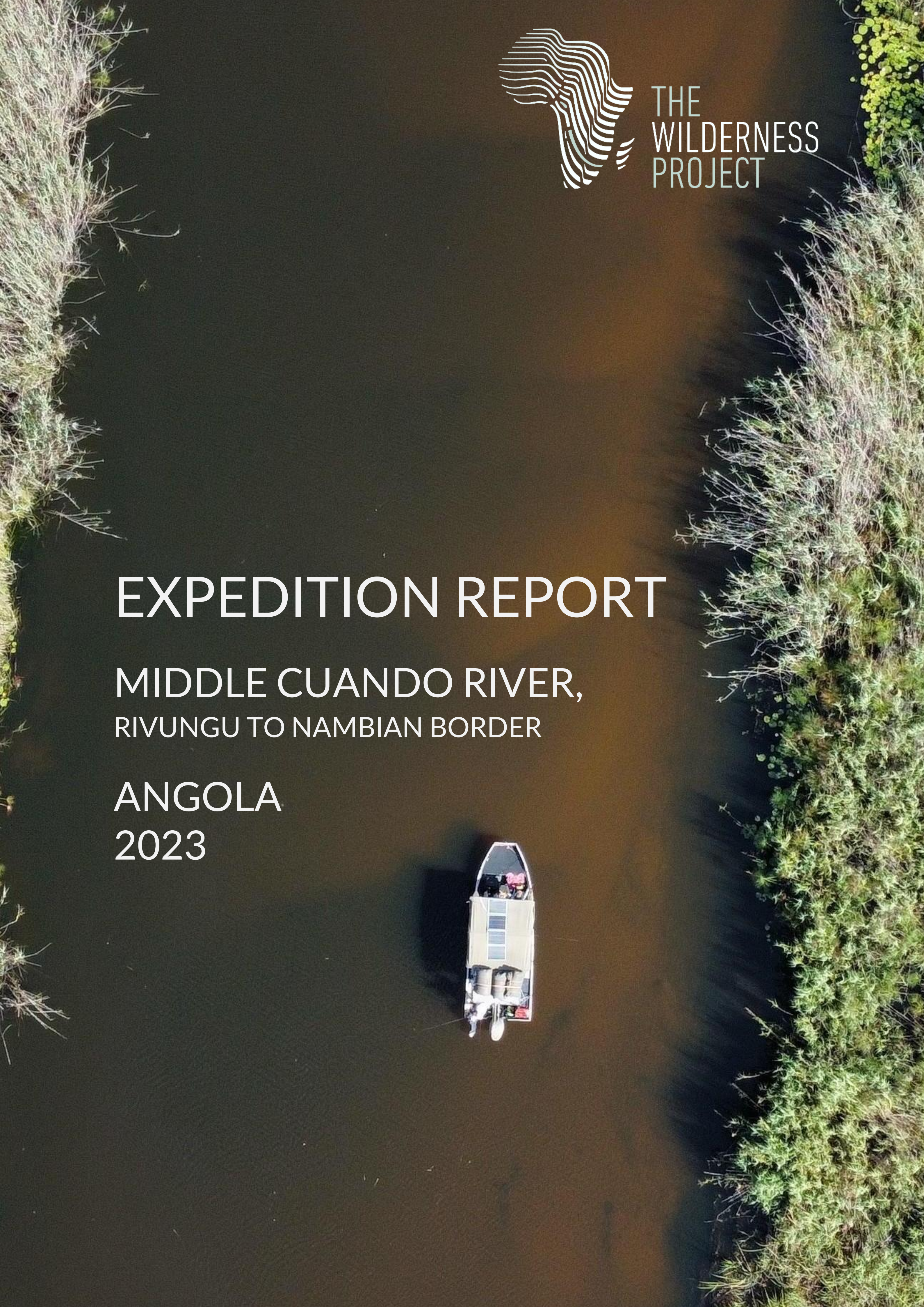

THE WILDERNESS PROJECT

EXPEDITION REPORT

MIDDLE CUANDO RIVER,

RIVUNGU TO NAMBIAN BORDER

ANGOLA
2023

ABOUT THE WILDERNESS PROJECT

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

ACKNOWLEDGEMENTS

Our research transects would be impossible without the collaboration of our various partners, who enable information-sharing, provide local advice, and grant permissions wherever we work. For their continued support along the Cuando River, we thank Fundação Lisima, African Parks 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 Cuando River.

thewildernessproject.org

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The Wilderness Project (2023) Expedition Report: Middle Cuando River, Rivungu to Nambian border, Angola.

thewildernessproject.org

EXECUTIVE SUMMARY

In March–April 2023, The Wilderness Project (TWP) surveyed the middle Cuando River in Angola, covering 556 km from just south of Rivungo to the Namibia border. This expedition aimed to complete the 2018 transect of the upper Cuando River, which was halted due to safety concerns from high hippo densities. Using the same methodologies employed on the 2018 transect, data relating to human activity, biodiversity, water quality and hydrology were collected along the way. This report discusses the findings of the expedition. All data are presented as interactive web-maps in an ESRI web application with 360-degree images of the entire transect viewable in an EarthViews web application.

Key Findings:

People and the river

The middle Cuando River ranks among the **least densely populated** of the rivers surveyed by TWP. Expansive wetlands hinder the development of permanent settlements, resulting in a **low human density (0.13 people/km)** and **sparse infrastructure (one settlement every ~22 km)**. However, satellite analysis indicates increasing encroachment of croplands and settlements along the floodplain fringes. This growing human presence could impact riverine ecosystems and wildlife corridors.

Biodiversity

The middle Cuando River remains a **crucial wildlife corridor** within the Kavango-Zambezi Transfrontier Conservation Area (KAZA TFCA), facilitating seasonal migrations between Angola, Namibia, and Zambia. The highest wildlife densities were recorded near the Namibian border, with **hippos (N=137) and crocodiles (N=72)** being the most common large species. Wetland bird diversity was high, with **3,834 individuals from 53 species** observed, including the little bee-eater (N=880), African openbill (N=659), and blue-cheeked bee-eater (N=488). **Papyrus** was distributed along the entire middle Cuando River, playing a key role in maintaining water quality, regulating hydrological flows, and supporting biodiversity. **Invasive plant species** were recorded along the river, with *Salvinia molesta* and *Ricinus communis* establishing in multiple locations.

Fish Diversity and eDNA Analysis

The river supports a diverse fish assemblage. By sampling at just 12 sites, a total of **45 fish species were detected**, including a potential record of the Ghost Stonebasher (*Paramormyrops jacksoni*) — a species not observed in nearly 60 years. Environmental DNA (eDNA) analysis detected 32 genera from 15 families, with the most common families being Mormyridae, Cichlidae, and Alestidae. These findings suggest the middle Cuando River hosts a **rich and possibly unique fish community**, emphasizing the need for continued monitoring and conservation efforts.

Water Quality and Hydrology

Water quality in the Cuando River remains good, with key parameters such as temperature, conductivity, pH, and dissolved oxygen levels remaining within acceptable limits. Hydrology measurements revealed that the **Cuando River's discharge gradually decreased** from 29.1 m^3/s to 23.9 m^3/s along the transect. This downstream reduction is attributed to channel morphology, extensive floodplain evapotranspiration, and seepage into the basin's permeable sands.

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1. INTRODUCTION

1.1 Background of The Wilderness Project

The Wilderness Project (TWP) is a non-profit organisation that supports research and conservation of 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, Lungwebungu, 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 government 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.

1.2 Expedition Objectives

In 2018, the National Geographic Okavango Wilderness Project (NGOWP) planned to survey the entire length of the Cuando River, from its source in the Angolan highlands to the Namibian border[1] (Figure 1). However, the expedition was halted near Rivungo due to the dangers posed by high hippo densities. As a result, the primary objective of the 2023 Cuando River expedition was to complete a transect downstream from Rivungo to the Botswana border, covering 556 km.

Along this transect, researchers on the expedition aimed to collect biodiversity, human impact, water quality and discharge data. By documenting the expedition using survey forms and a series of 360° images, TWP aimed to identify areas of conservation significance, thereby contributing to the sustainable management of the river.

1.3 Study Site Description

The Cuando River — also known as the Kwando River — is one of the few undisturbed, naturally connected rivers in southern Africa[2]. Originating in the Angolan Highlands Water Tower[3], it flows southeast for ~220 km along the Zambian border, before crossing Namibia's Zambezi Region and terminating in the Linyanti Swamps on Botswana's border (Figure 1). Within the Linyanti Swamps, water from the Cuando River occasionally mixes with that from the Okavango Delta via the Selinda Spillway.

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[1] National Geographic Okavango Wilderness Project. 2020. Report 5: Scientific Exploration in Angola During 2018.

[2] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.

[3] Lourenco, M. & Woodborne, S. 2023. Defining the Angolan Highlands Water Tower, a 40 plus-year precipitation budget of the headwater catchments of the Okavango Delta. Environmental Monitoring and Assessment. 195(7).

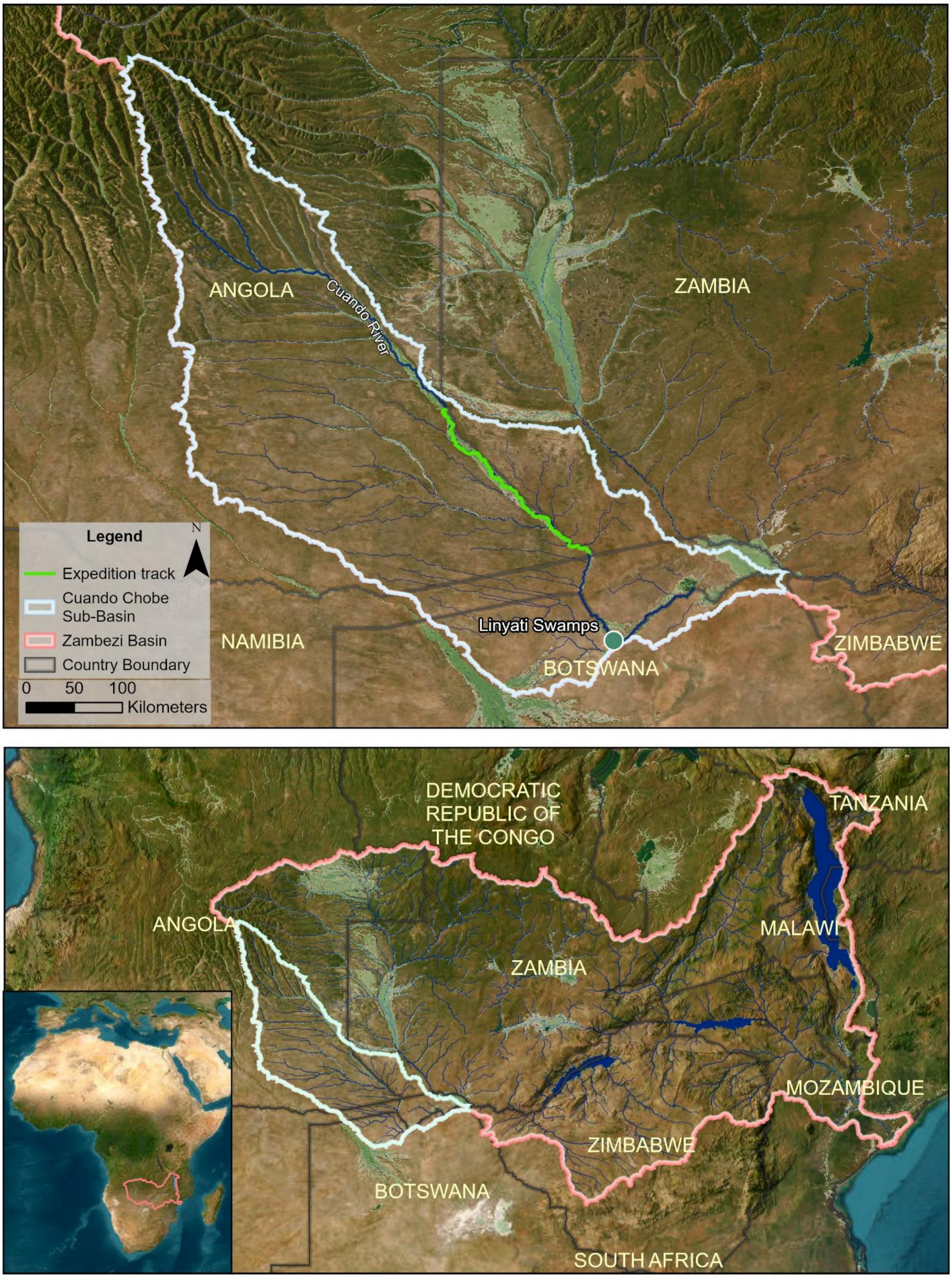

Figure 1. Originating in the Angolan Highlands Water Tower, the Cuando River flows in a southeasterly direction along the Angolan Zambian border. The top map highlights the Cuando Chobe River Basin and the expedition track, while the bottom map provides a broader view of the Zambezi Basin.

The upper Cuando River receives 1,000–1,200 mm of rainfall annually, but this decreases to 600–800 mm by the time it reaches the Linyanti Swamps. Consequently, surface-water contribution of the southern

Cuando Basin to the flow of the river is negligible. To this end, the Cuando River acts as a linear oasis through an area of dry sandy woodland that extends for more than a hundred kilometres on either side of the river. Even during heavy rains here, most rainwater seeps into and disappears in the deep, porous sands that characterise the entire Basin[4]. Water that does reach the lower reaches of the Cuando supports a vast seasonal wetland ecosystem that links the Okavango and Zambezi systems. For a detailed discussion of the hydrology of the Cuando River, see the Cuando State of the Basin Report[5].

The middle and lower Cuando is buffered by dense Phragmites reeds and mixed papyrus stands that restrict access to the river (Figure 3). These grow on a 10–15 km-wide marsh that occasionally narrows, giving way to gallery forests and grasslands. However, these are rarely visible from the main channel (Figure 2).

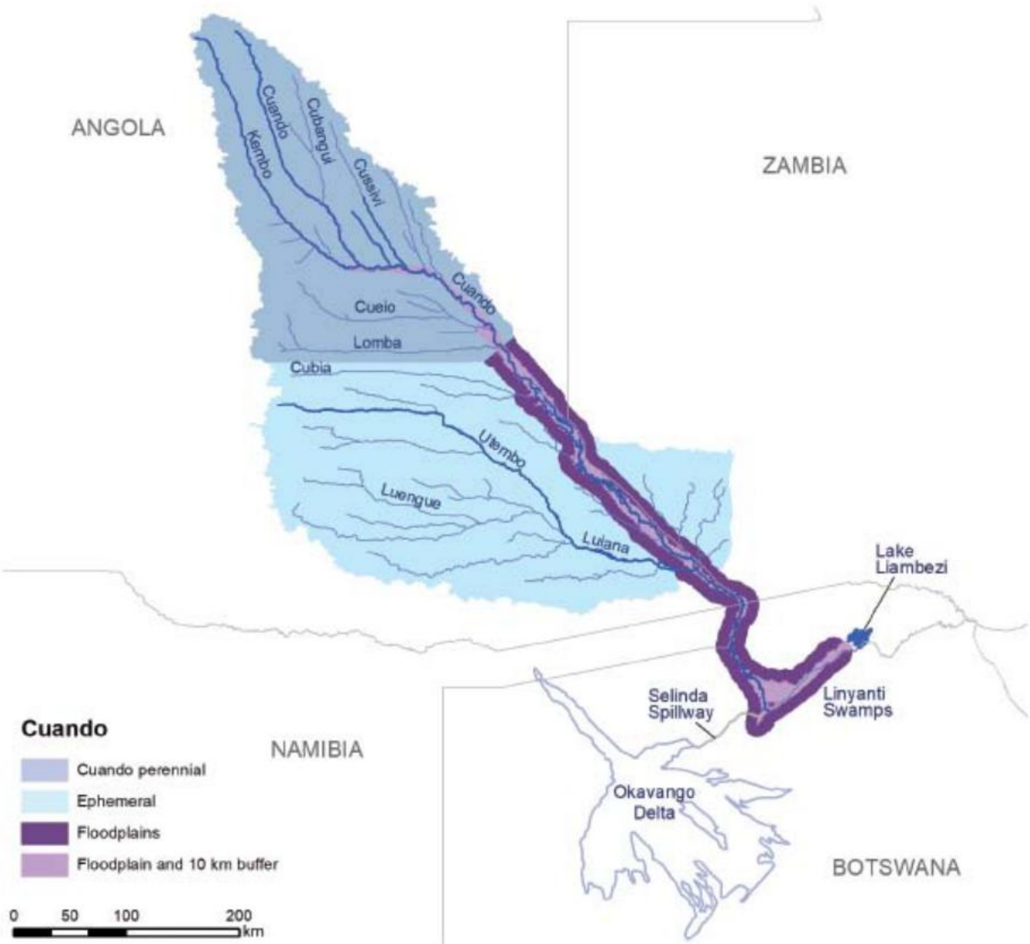

Figure 2. The hydrologically active part of the Cuando River basin[6]. Using the criterion of surface flow, the Cuando River Basin can be categorised into perennial, ephemeral, dormant and shared sections. The perennial and ephemeral parts correspond roughly with what are called the upper and lower parts of the river basin in Angola.

[4] Stadtler, C., Margane, A., Schildknecht, F., Schäffer, U. & Wrabel, J. 2005. Investigation of the Groundwater Resources in the Eiseb Graben in Namibia with TEM Soundings.
[5] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.
[6] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.

Figure 3. Dense semi-aquatic vegetation along the Cuando River.

Socio-economic characteristics

The middle Cuando Basin has few settlements, but towns along the river in Angola are expanding at an estimated rate of ~10% per year[7]. As populations grow, the demand for crop fields, grazing areas and other natural resources grows, placing pressure on the river's natural ecosystems. As a result, it is essential to establish a baseline of human activity, biodiversity, water quality and hydrology that can be used to measure change in this unique ecosystem.

Protected Areas and relevant partners

The middle Cuando River lies entirely within the Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA). The KAZA TFCA is the largest transfrontier conservation area globally, spanning large areas of Angola, Zambia, Namibia, Botswana, and Zimbabwe (Figure 4). A key objective of the KAZA TFCA is to restore transboundary wildlife migration via wildlife dispersal areas (WDAs). These promote healthy populations of large animals and secure the provision of ecosystem benefits to communities living within the KAZA landscape. As a result, the Cuando WDA is identified as an important wildlife corridor at the centre of the KAZA TFCA.

[7] Mendelsohn J, Martins A. 2018. River catchments and development prospects in south-eastern Angola. RAISON.

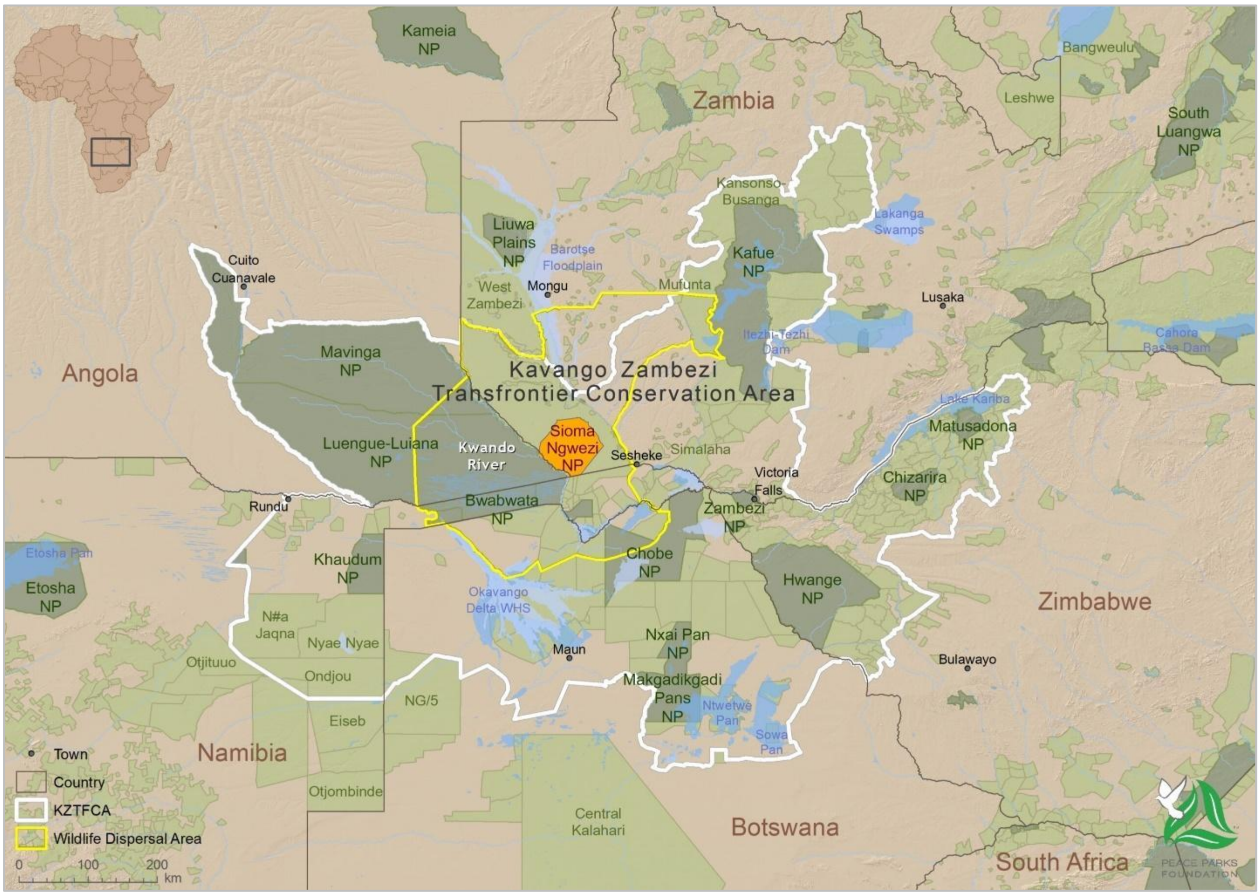

Figure 4. The Cuando Wildlife Dispersal Area (outlined in yellow) within the greater Kavango–Zambezi TFCA (outlined in white), alongside the Luengue-Luiana and Sioma Ngwezi National Parks. Recent initiatives have also expanded the KAZA TFCA northward to include the Liuwa Plains-Mussuma TFCA.

Cuando Wildlife Dispersal Area

The Cuando WDA consists of Luengue-Luiana National Park (Angola), Sioma-Ngwezi National Park (Zambia), and Mudumu and Bwabwata National Parks (Namibia), along with their associated conservancies, concessions and game management areas. This WDA is unique as its unfenced, allowing unrestricted wildlife movement. Elephants from Chobe disperse through Namibia's Zambezi region, along the Cuando River, into Luengue-Luiana National Park and Sioma-Ngwezi National Park. This maintains the genetic integrity of these populations and promotes the use of ancestral migration pathways that are intricately linked to the evolution of the KAZA landscape.

Silowana Complex

Within the Cuando WDA lies the Silowana Complex (also known as the Sioma Ngwezi Management Complex), which consists of the Zambezi West Game Management Area and Sioma Ngwezi National Park (SNNP)[8]. The SNNP is situated in the southwestern corner of Zambia, bordering Namibia to the south and Angola to the west. In 2004, African Parks withdrew funding for the SNNP after recognising that wildlife populations were critically low, making restoration efforts highly challenging at that time. They determined that translocation as a rescue strategy was not feasible, and settlements along the Cuando River had cut off the primary water source from the park's interior. They found that approximately 3,000 people had settled in the park inland from the middle Cuando River. Their settlements, livestock, and agricultural activities severely limited wildlife access to the floodplain and the river's water to the west. With less than 500 mm of annual rainfall, the park had no water during the dry season, making access to the river crucial for wildlife survival[9].

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[8] WWF. 2024. The Silowana Complex.
[9] African Parks Foundation. 2003. Annual Report 2003.

In 2024, the Department of National Parks and Wildlife (DNPW), in collaboration with the Barotse Royal Establishment (BRE), Peace Parks Foundation and WWF Zambia, agreed to co-manage the Sioma Ngwezi Management Complex. This ongoing agreement aims to restore and protect the greater SNNP landscape, which includes managing human-wildlife conflict and encouraging sustainable resource utilisation in the area for the next 20 years.

Luengue-Luiana National Park

The Luengue-Luiana National Park borders the western bank of the middle Cuando River. Wildlife populations in this park are recovering following unregulated hunting during the Angolan Civil War, however, ongoing poaching remains a concern, particularly along the Cuando River[10]. In 2021, Panthera, with the support of local partners, worked closely with authorities to identify and secure high-priority conservation areas in the Luengue-Luiana National Park. These areas were subsequently demarcated as intensive protection zones and are now actively patrolled by game guards from the surrounding villages. In addition to Panthera's efforts, the Government of Angola signed a 20-year management agreement with African Parks to rehabilitate, manage, and finance Luengue-Luiana National Park.

1.4 Expedition Safety

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

1.5 Research Design

During the 556 km transect, survey data and 360° imagery were collected continually, with other data at fixed points (
Table 1, Figure 5). Survey data included human activity, agriculture, infrastructure, biodiversity and fire. In addition, every ~10 km, water quality was analysed, and aerial fixed-point images were recorded. At ~50–75 km intervals, eDNA samples were collected and a benthic macroinvertebrate survey was conducted. At night, an acoustic bat recorder was deployed, along with several traps for freshwater fish and crustaceans. Finally, where suitable sites were identified, fish sampling was conducted using a dip net and discharge measurements were recorded using an acoustic doppler current profiler (ADCP).

Table 1. Summary of the data collected along the Cuando River transect. Data collection is arranged according to collection frequency.

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

[10] Funston, P., P, H., Petracca, L., MacLennan, S., Whitesell, C., Fabiano, E. & I, C. 2017. The distribution and status of lions and other large carnivores in the Luengue-Luiana and Mavinga National Parks, Angola.

Every Night	• Acoustic bat recording • Trap and net deployments for fish and invasive crayfish
Opportunistic	• Fish sampling • Discharge measurement

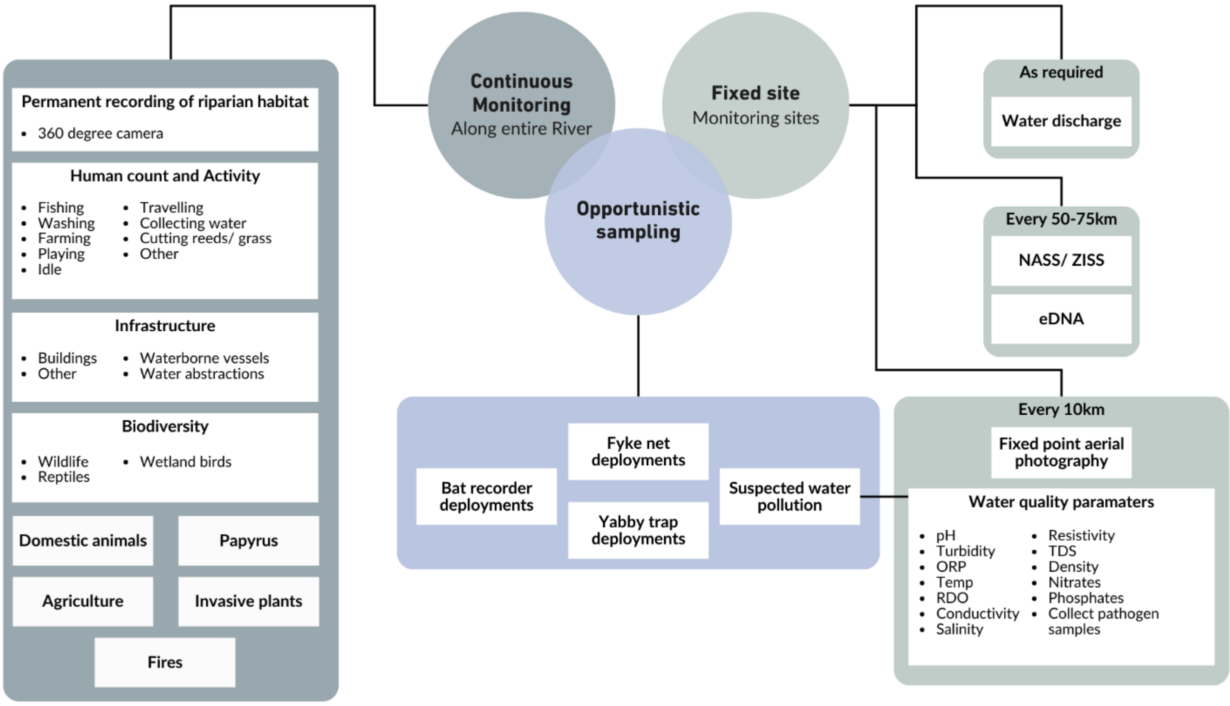

Figure 5. Summary of the data collected on the river.

1.6 Survey Limitations and Potential Data Bias

It is important to note that there are several limitations and potential biases involved with data collection on rivers. These 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 that are specific to the Middle Cuando River expedition include:

- Oxbow lakes and backwaters were excluded from the survey as the expedition followed the main river channel.
- Observers could only count what was visible from their vessels, meaning some wildlife and human activities may have gone undetected.
- Vegetation density, riverbank height, weather conditions, team health, rapids, sharp river bends, and sandbanks may have obscured observations or introduced observer bias.
- Survey time was restricted to daytime hours between 08:30 and 16:00. Some days were longer or shorter than others, depending on many variables.
- The invertebrate D-net was lost early in the expedition, affecting ZISS surveys, which had to be conducted with a modified fish dip net. This significantly impacted data quality, and ZISS scores should be interpreted with caution.
- Unlike the 2018 expedition, which used a self-propelled mokoro, this survey was conducted with a motorized boat. The noise of the motor may have influenced wildlife and bird sightings.

2. CONTINUOUS MONITORING

The process of collecting survey data on the transect involved two parties: the observer and the recorder. The observers visually scanned the river and its banks for relevant observations within 100 m from the river-edge. Sightings of relevance were then relayed to the recorders who used a smartphone to input the data into Survey123 (ESRI). Information obtained for each sighting included the count, the side of the river, and other important notes. From Survey123, data 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.

2.1 Human Activity

Methods: Human Counts and Activity

The presence or absence of people along the middle Cuando River provides an indication of the utilization of the river and associated resources. To this end, all people active within the riparian zone of the river were counted without considering age, sex or ethnicity. An outline of the activities documented on the Cuando River is provided below. Going forward, long-term monitoring of the number of people interacting with the river is recommended to provide an indication of the trajectory of general river health.

- **Inactive:** People present within the riparian zone but not actively engaged in any of the activities below.
- **Travelling:** People moving on foot, by motorbike, or in a waterborne vessel. For analysis purposes, all parked watercraft (mokoros and motorized boats) are discussed separately.
- **Herding livestock:** People controlling, feeding, gathering, moving, or tending to livestock.
- **Washing:** People washing their bodies or clothes in the river.
- **Cutting Reeds:** People harvesting reeds from the riverbanks.
- **Fishing:** All unmanned but deployed fishing equipment is discussed below.

Results and Discussion: Human counts and activity

This stretch of river is among the least densely populated of all the rivers surveyed by TWP to date, with 72 people recorded along the 556 km transect (0.13 people/km) (Table 2). This finding aligns with the 2018 NGOWP Cuando River survey, which reported a similar density of 0.13 people/km upstream. For comparison, the density of people on a 2023 transect of the Kavango River (located ~220 km away along the Angola/Namibia border) was over 100 times higher (14.10 people/km)[11].

Table 2. Summary of human activity on the Cuando River.

Activity	Number of People
Inactive	57
Travelling	9
Herding Livestock	3
Washing	2
Cutting Reeds	1
Total	72

[11] National Geographic Okavango Wilderness Project. 2023. Kavango River Transect 2023.

Most people were inactive (79%), while the remaining 21% were engaged in travelling (13%), herding livestock (4%), washing (3%), or cutting reeds (1%). Human activity was clustered near river access points, particularly around Shangombo/Mainha (near the start of the survey) and just before the river exits Angola near the Namibian border. These clusters corresponded with increased observations of parked vessels, fishing gear, water abstractions, crops, and livestock (Figure 6).

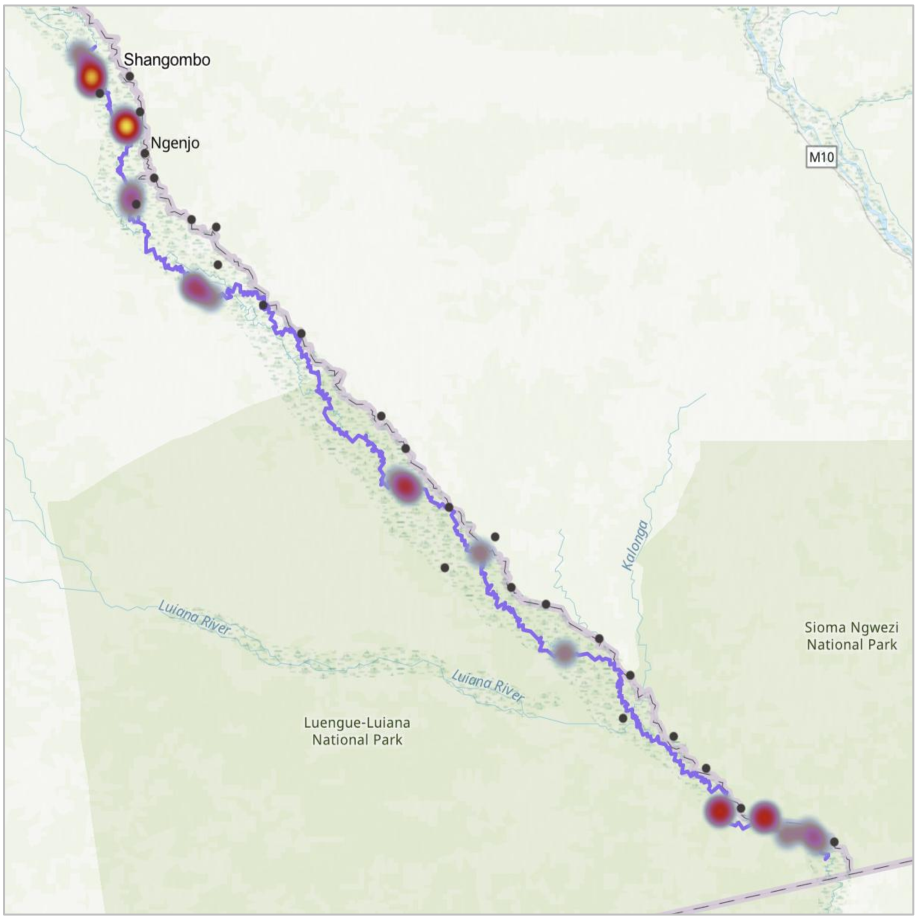

Figure 6. Distribution of people along the Cuando River. Villages are indicated with black dots.

Travel

Mokoros (N=46) and motorised boats (N=8) were the primary means of transport along the river (Table 3). No other means of transport — such as on foot, motor vehicles, and paddle boats — were observed on the river, presumably because of limited road access to the river. Most vessels were parked along the banks of the river and were not in use at the time of the survey (Figure 7).

Table 3. Modes of travel observed along the Cuando River.

Vessel	Count
Mokoros	
In use	2
Not in use	44
Sub-total	46
Motorised boats	
In use	7

Not in use	1
Sub-total	8
Total	54

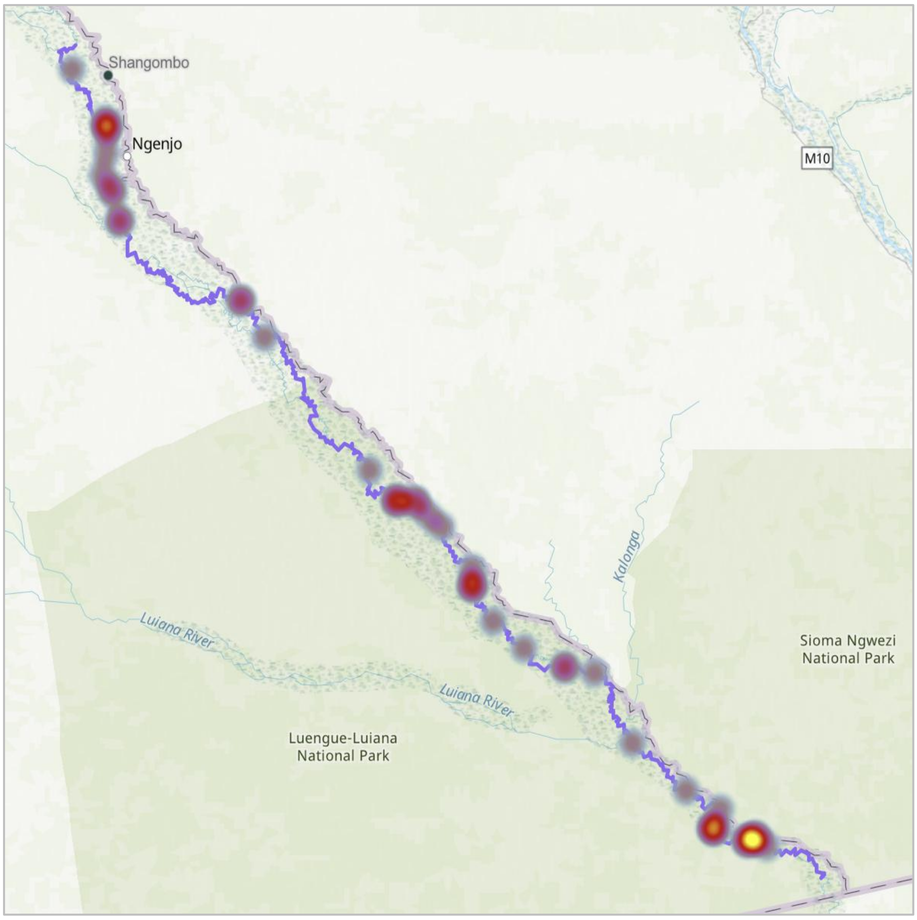

Figure 7. Vessels parked along the Cuando river.

Fishing

No people were actively fishing at the time of the survey. However, this does not provide a comprehensive picture of fishing pressure, as nets and lines are typically left unattended. To address this limitation, all unmanned and deployed fishing gear was recorded. Nets were the most common means of fishing (N=10) with only one unmanned rod and line observed. Most fishing equipment was concentrated in the first half of the transect, particularly near Rivunga (Figure 8). These results indicate that fishing pressure along the Cuando River is low, particularly relative to other rivers in the region.

It is possible that fishing effort is concentrated in backwaters, floodplains, and oxbow lakes — areas not captured during the survey. As a result, fisheries assessments should incorporate interviews with local fishers to develop a comprehensive understanding of fishing activity along the river.

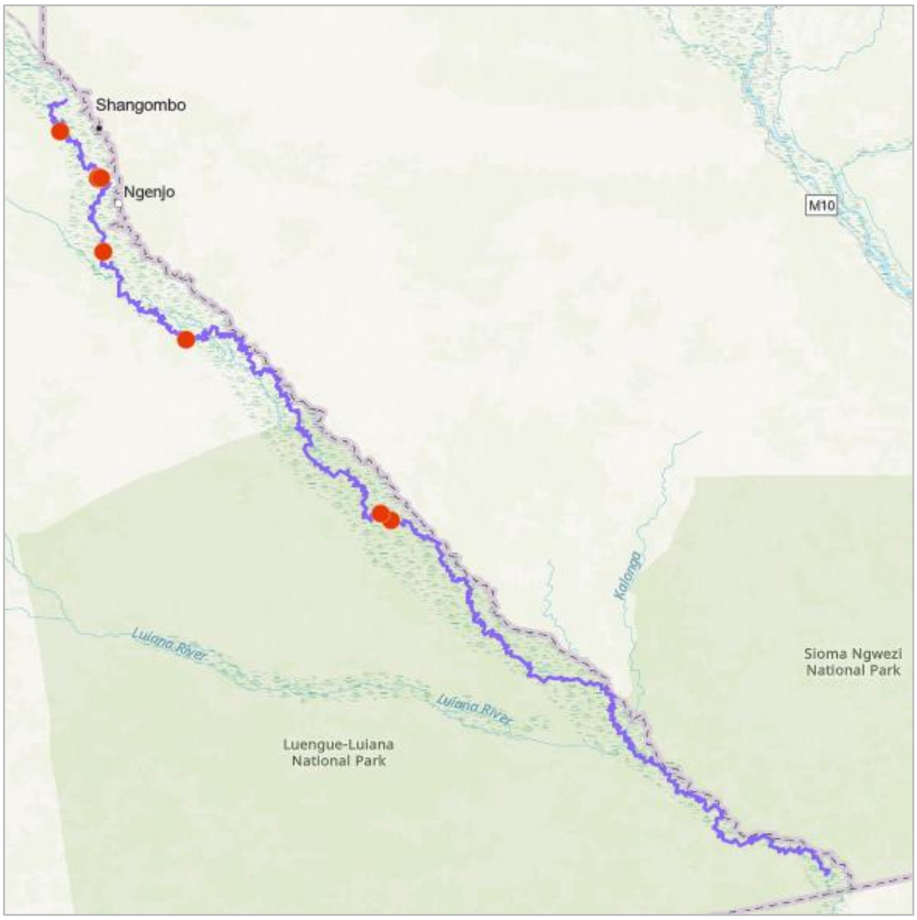

Figure 8. Fishing nets along the Cuando River.

2.2 Infrastructure

Methods: Infrastructure

The quantity, type and distribution of infrastructure along a river offers insights into the level of development in the riparian zone and the ways in which river resources are utilised. Infrastructure in the river and along its banks was categorised and recorded as follows:

- **Water abstractions**: The circumference and location of each water abstraction pipe were recorded.
- **Bridges:** Locations where structures were built across the river to aide travel.
- **Seasonal camps**: Temporary structures made from thatch, fronds, and wood, often constructed below the river's high-water mark.
- **Villages:** Defined as groups of three or more buildings in close proximity.
- **Huts:** Single buildings or pairs of structures.

Results and Discussion: Infrastructure

Villages (N=13) and huts (N=12) were the most common types of infrastructure (Table 4, Figure 9). Their combined density is just ~0.05 settlements/km (or one settlement every ~22 km). This finding is further supported by land-use and land-cover (LULC) analysis, which indicates that human settlements cover just 0.01% of the Cuando-Chobe basin (*see Land-use and Land-cover (LULC) Change Analysis*).

Other infrastructure included seasonal camps (N=5), water abstractions (N=3), and a pedestrian bridge

(N=1). The low infrastructure density is largely due to expansive floodplains, which limit the development of permanent settlements along the river. Consequently, most development occurs on the fringes of the floodplain, beyond the observers' view (see *Google Open Building Analysis*).

Table 4. The type and abundance of infrastructure along the Cuando River.

Type	Count
Villages	13
Huts	12
Seasonal Camps	5
Water Abstraction	3
Bridge	1
Total	34

Figure 9. A village near the Cuando River.

Seasonal Camps

Seasonal camps along the Cuando river were uncommon, averaging one every ~110 km (Figure 10). This is in stark contrast to other regional rivers, even those in seasonally flooded wetlands. For example, wet-season surveys recorded higher seasonal camp densities along the lower Lungwebungu River (one every 13 km) and the Chambeshi River (one every 2 km). This scarcity of seasonal camps along the Cuando River suggests a sparsely distributed population with low levels of wet-season resource use in the riparian zone.

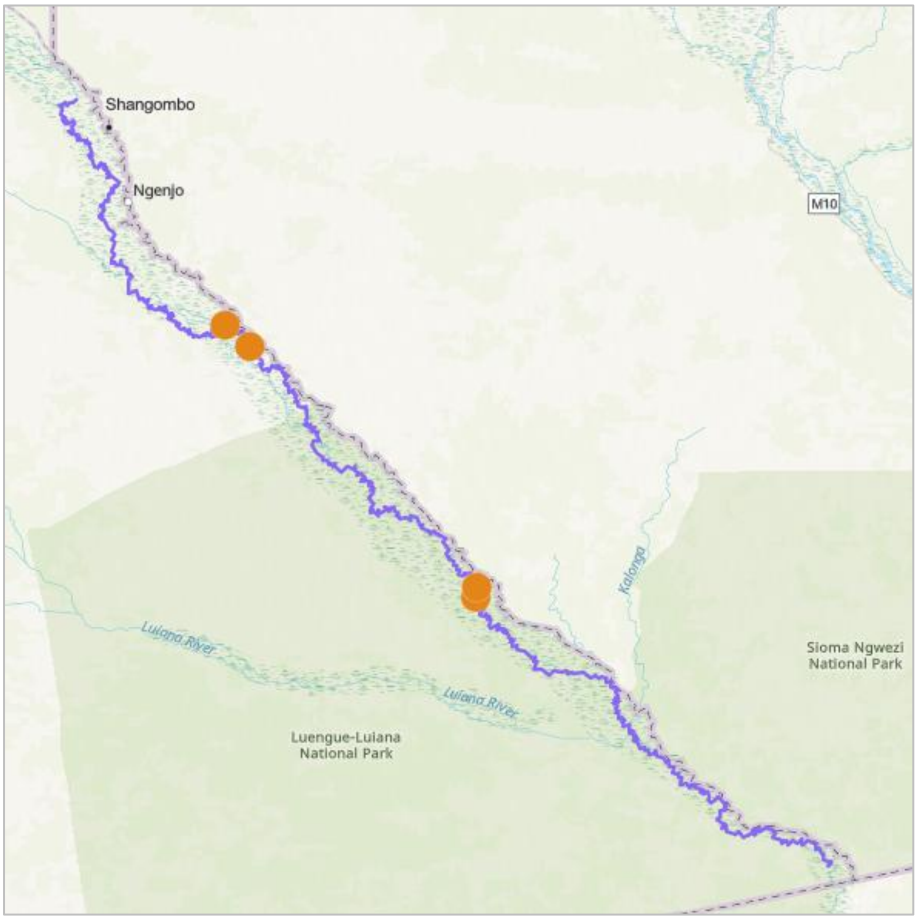

Figure 10. Seasonal camps observed along the Cuando River.

Water abstractions

There were just four water abstractions along the Middle Cuando River, all of which were located in Angola (Figure 11). The purpose of these abstractions was likely for small-scale crop irrigation

Rural settlements and small towns along the river, such as Rivungo, rely on the Cuando as their primary water source. Water demand in the region is expected to increase with population growth and potential future agricultural developments. Given these pressures, continuous monitoring of water abstractions and seasonal flow variations is necessary to assess long-term impacts and ensure sustainable water use in the Middle Cuando River.

Figure 11. Water abstractions on the Cuando River. Observations within 3 km are clustered.

2.3 Agriculture

Methods: Agriculture

All agricultural activity along the river was recorded, including the scale of the activity and the side of the river on which it was taking place. 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

There was limited agriculture observed along the mainstem of the Cuando River due to the expansive floodplain. Most of the agriculture was at the beginning of the transect, near Shangombo/Mainha, where the mainstem of the river channel borders dryland (Figure 12).

Crops
A total of 33 subsistence-scale farms were identified, cultivating seven different crops. Maize was the most common crop, followed by banana, mango, and cassava (Table 5). The distribution of agriculture corresponded with the distribution of water abstractions (Figure 11, Figure 12). The total distance of crop cover along the banks of the Cuando River was ~1.7 km, representing 0.31% of the transect (Table 5). This indicates that the river's marginal vegetation is intact, however, it is important to note that the extensive

floodplains are largely unsuitable for agriculture, except in particularly dry years. As a result, aside from Shangombo, most agriculture is concentrated inland, around floodplain margins and along the western boundary of Sioma-Ngwezi National Park—a pattern confirmed by the *WorldCereal Cropland Analysis*.

Table 5. Crop Agriculture on the Cuando River. For distribution of individual crops see [ESRI web application](#).

Crop Type	Distance Along the River Edge (m)
Maise	1,625
Cassava	70
Beans	20
Mango	20
Banana	19
Papaya	15
Sugarcane	10
Total	1,799

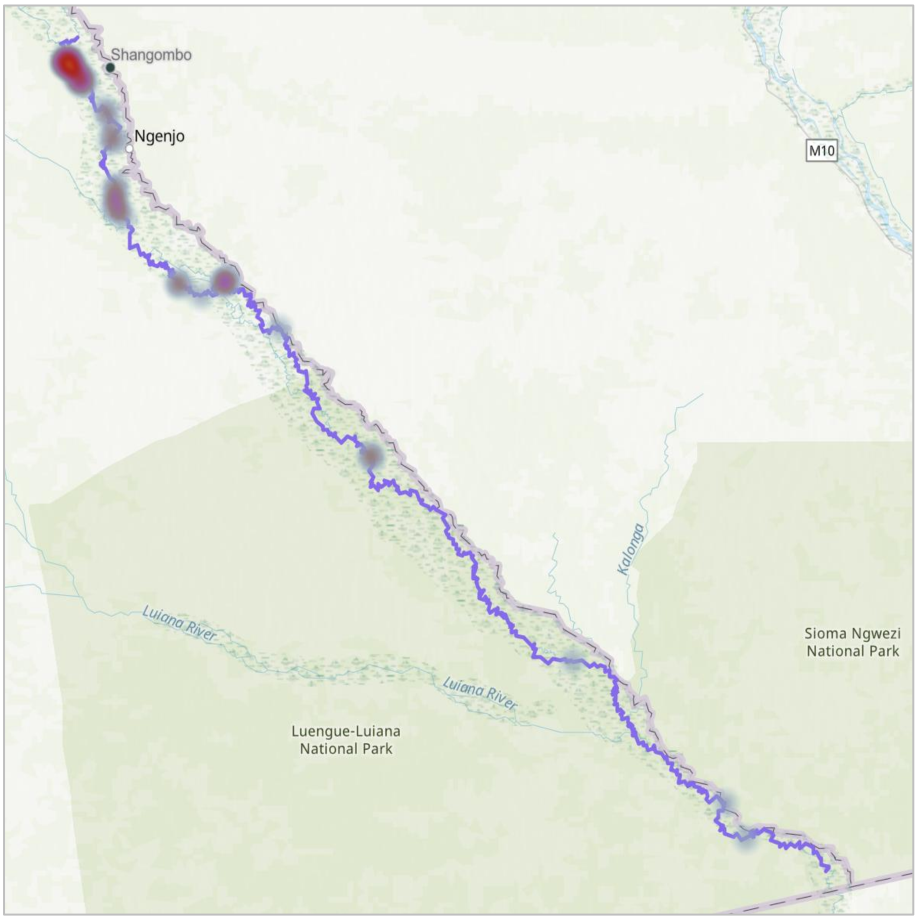

Figure 12. The distribution of crop agriculture along the Cuando River.

Livestock

Livestock densities were low along the transect (~0.2 cattle/km), with only 120 cattle across six herds and a single goat recorded. Interestingly, despite higher human population densities near Shangombo/Mainha, no cattle were observed in that area (Figure 13). The distribution of livestock is closely tied to habitat; all cattle were observed in areas where the river directly touches the mainland, without a floodplain. To this end, it is likely that most cattle graze inland where the floodplain margins and grasslands — identified in the *Land-use and Land-cover (LULC) Change Analysis*— offer suitable pasture.

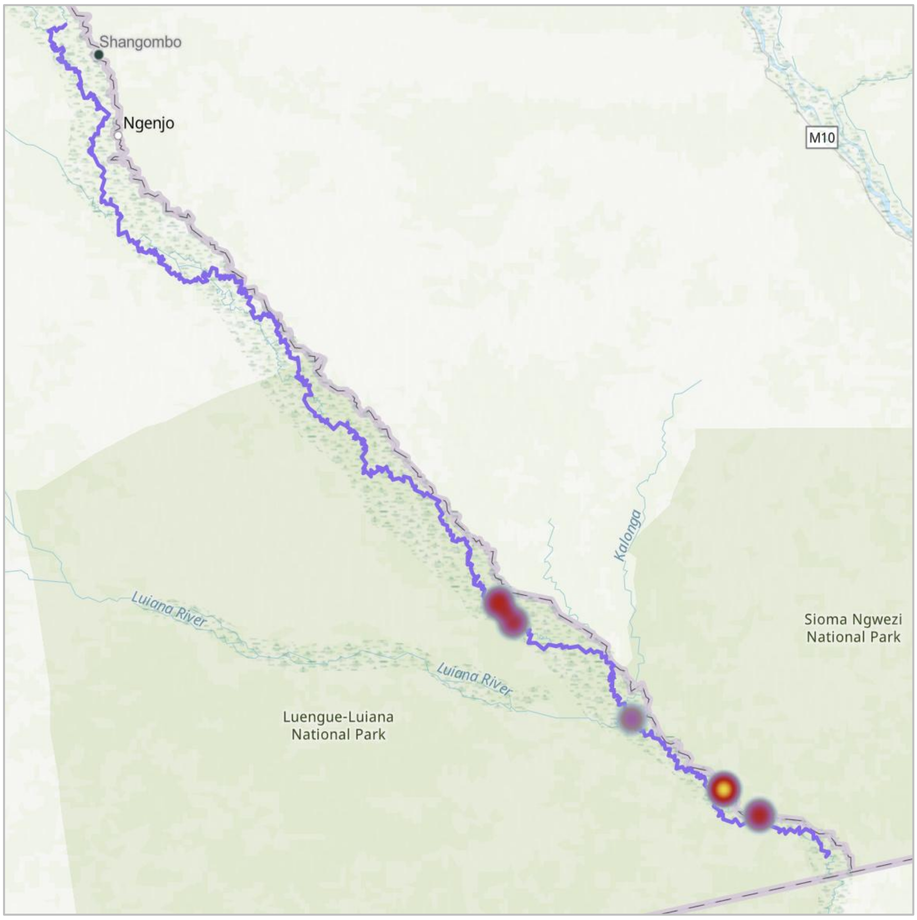

Figure 13. Distribution of livestock along the Cuando River.

2.4 Wetland-associated birds

Methods: Wetland-associated birds

Long-term monitoring of biodiversity can provide important insights into river health, eco-tourism opportunities and the potential for human-wildlife conflict. Birds in particular serve as reliable indicators of disturbance and ecosystem health[12,13], 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 Cuando River, and its riparian vegetation were counted.

Results and Discussion: Wetland-associated birds

A total of 3,834 birds (6.9 birds/km) belonging to 53 different species were recorded along the middle Cuando River (Table 6, Figure 14). The most common species were the little bee-eater (N = 880), followed by the African openbill (N= 659) and the blue-cheeked bee-eater (N=488) (see Appendix 2 for all bird species counts). Several species were only observed once, including, the giant kingfisher, the long-crested eagle, and the western banded snake eagle (see *ESRI web application* for all bird guild distributions).

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[12] Fraixedas S, Lindén A, Piha M, Cabeza M. et al., 2020. A state-of-the-art review on birds as indicators of biodiversity: Advances, challenges, and future directions. Ecological Indicators, 18.

[13] Mugatha SM, Ogutu JO, Piepho HP. et al., 2024. Bird species richness and diversity responses to land use change in the Lake Victoria Basin, Kenya. Sci Rep 14, 1711.

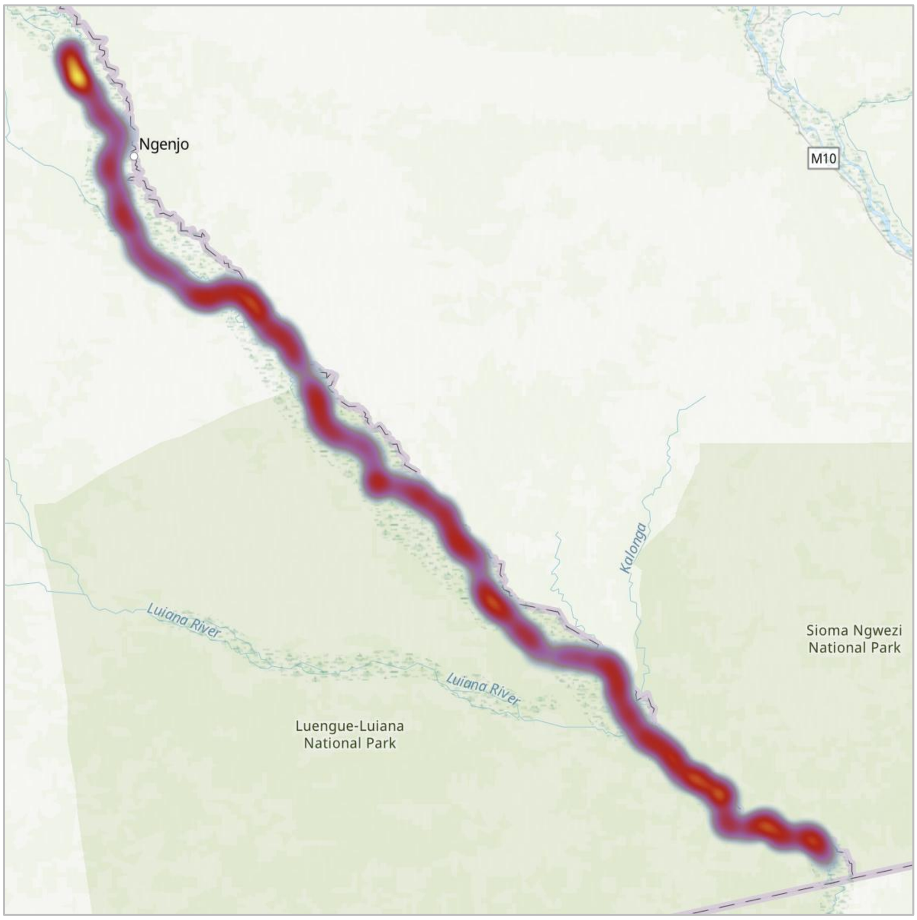

Figure 14. The distribution of all wetland birds on the Cuando River.

Table 6. Bird abundance by guild along the Cuando River.

Guild	Count	% of Total Count
Bee-eaters	1,745	45.5
Storks	662	17.3
Diving Birds	303	7.9
Anatidae	280	7.3
Lapwings/Thick-Knees	229	6.0
Ardeidae	205	5.3
Kingfishers	187	4.9
Rallidae	77	2.0
Hamerkop	44	1.1
Raptors	32	0.8
Ibis	17	0.4
Gulls and Terns	15	0.4
Small Wading Birds	0	0.0
Other	38	1.0
Total	3,834	100.0

The abundance of wetland-associated birds is strongly influenced by habitat quality and food availability. The middle Cuando River, with its dense floodplain and relatively stable flow throughout the year, supports a productive and consistent wetland ecosystem. This hydrological stability ensures that food resources and habitats remain available[14], allowing wetland bird populations to persist without extreme seasonal fluctuations that are characteristic of more variable river systems.

The high abundance of bee-eaters suggests a rich supply of flying insects along the river. Bee-eaters are specialized aerial insectivores, preying on bees, wasps, and dragonflies[15], which are typically abundant in well-vegetated riparian zones. The Cuando's slow-moving water, standing pools, and lush floodplain vegetation provide ideal breeding conditions for these insects. Since the river's flow remains relatively constant, insect populations are likely sustained year-round, offering stable foraging conditions for bee-eaters.

Similarly, the African openbill was the second most abundant species recorded, representing a significant contribution to the stork guild count. Openbills primarily feed on aquatic snails and bivalves[16], which thrive in slow-moving water with dense vegetation — conditions that are prevalent in the middle Cuando floodplain. The high abundance of this species suggests that the floodplain is ecologically productive and supports a complex aquatic food web (Figure 15).

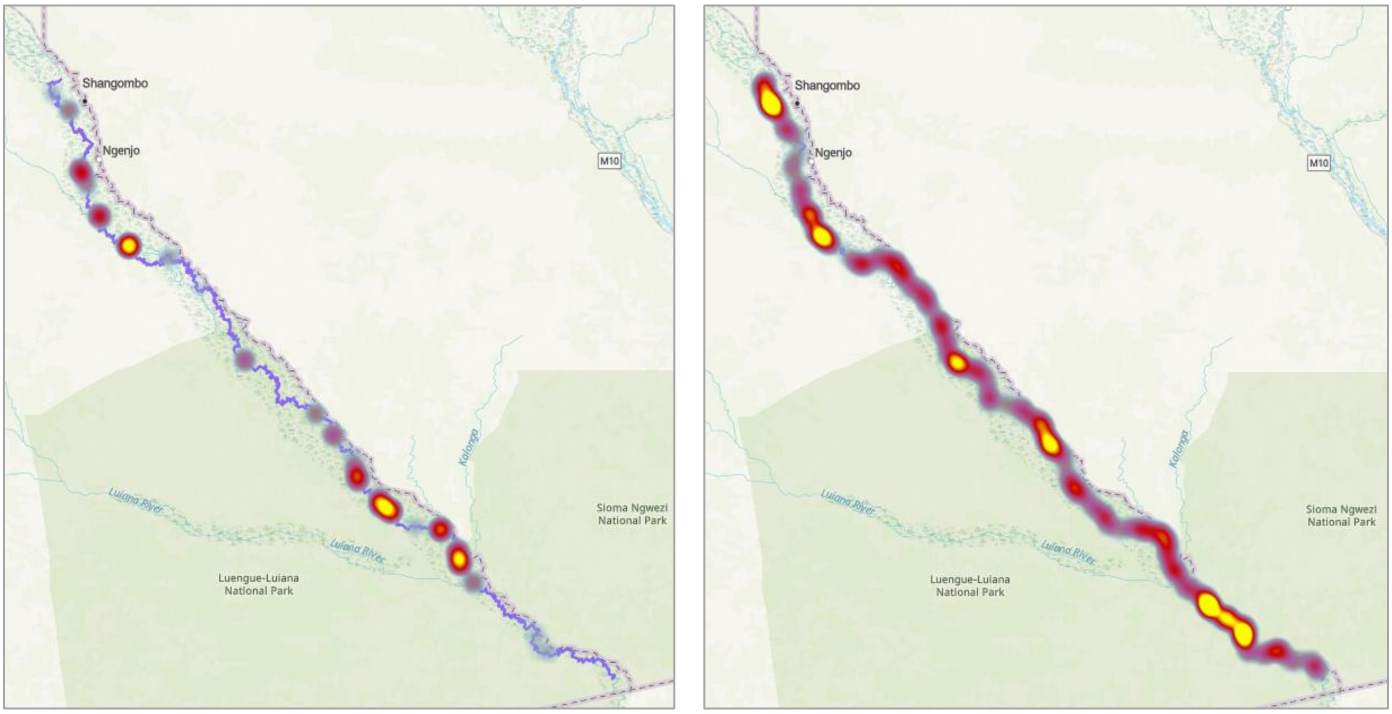

Figure 15. The distribution of African openbills (left) and bee-eaters (right).

Diving birds, including species such as reed cormorants, were also well-represented along the river (Figure 16). The presence of diving birds suggests that the Cuando maintains healthy fish populations and aquatic invertebrates, which serve as essential food sources[17]. Moreover, the undisturbed floodplain provides a safe resting and breeding area for these birds, supporting their abundance along the river. The consistent hydrology of the river likely ensures a stable prey base, reducing seasonal food scarcity and supporting a thriving community of wetland-dependent species.

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[14] Green, P.T. & Adams, J.R. (2023) *Temporal variation in habitat quality shapes the distribution of wetland birds*. *Ecological Studies*, 29(4), pp. 255–270.
[15] Birds of the World (2025). *European Bee-eater (Merops apiaster) – Food habits*. Cornell Lab of Ornithology.
[16] BirdLife International (2025) Species factsheet: African Openbill (*Anastomus lamelligerus*).
[17] Wilson, H., Carter, D.J. & Brown, L. (2024) *Wetland characteristics affect abundance and diversity of wintering waterbirds*. *Wetlands and Ecology*, 18(2), pp. 91–106.

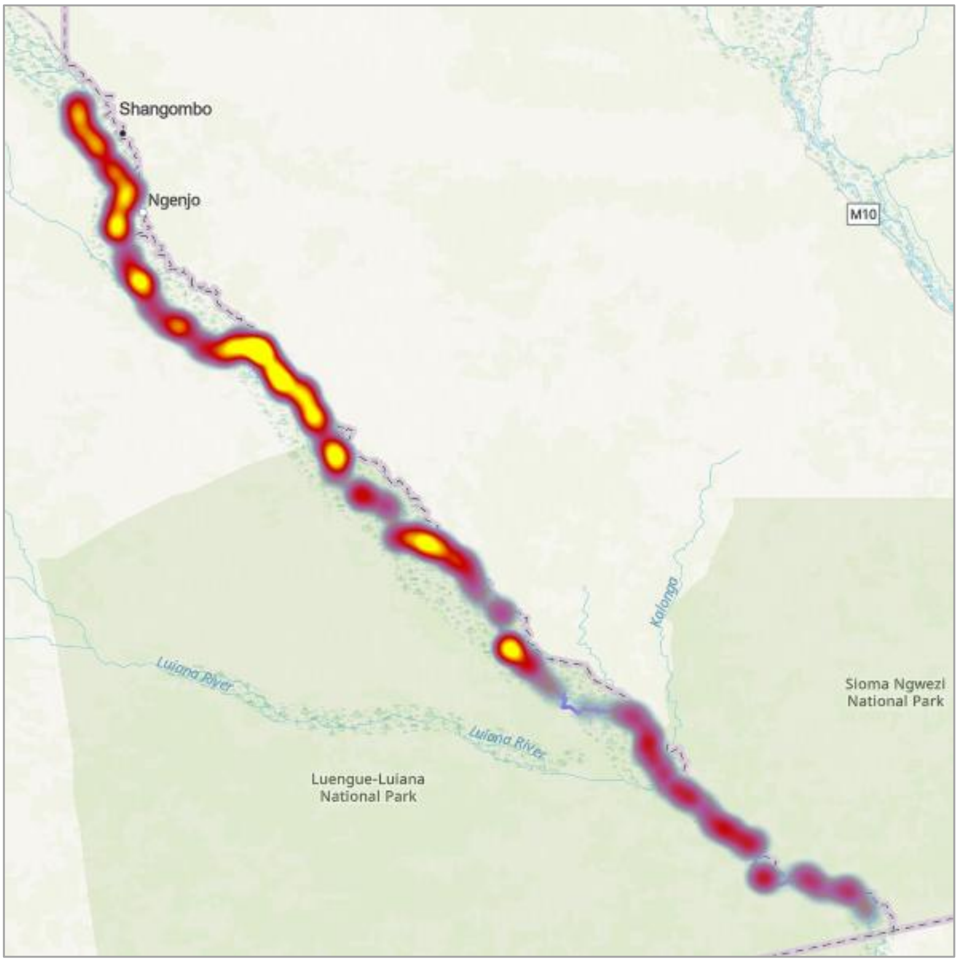

Figure 16. The distribution of anatidae (left) and diving birds (right).

While the middle Cuando River currently supports a thriving wetland bird community, its future is increasingly at risk. Although human population density remains low, rapid settlement growth and agricultural expansion along the floodplain fringes are encroaching on critical wetland habitats (see *Land-use and Land-cover (LULC) Change Analysis*). These developments threaten to disturb nesting sites and foraging grounds for wetland-associated birds. As more people move into these areas, habitat fragmentation and resource competition may disrupt the delicate balance that sustains avian biodiversity. Recognizing these growing pressures, a Strategic Environmental Assessment (SEA) of the Cuando River Basin has identified the Cuando floodplain as a key conservation area[18], highlighting its importance in maintaining biodiversity and ecosystem integrity. Proactive conservation measures, including habitat protection and sustainable land-use planning, will be essential to ensure that the middle Cuando River continues to serve as a refuge for wetland bird populations.

2.5 Wildlife

Methods: Wildlife

Long-term monitoring of biodiversity can provide important insights into river health, eco-tourism opportunities and the 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 within the Cuando River and its riparian vegetation were counted.

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[18] Southern African Institute for Environmental Assessment. n.d. Strategic Environmental Assessment for the Cuando River Basin.

Results and Discussion: Wildlife

A total of 279 individual animals from six species were recorded, equating to a wildlife density of 0.50 animals/km (Table 7). This is considerably higher than the densities of wildlife on the Upper Cuando River (0.07 animals/km). The most common animals were hippos (N=137), followed by crocodiles (N=72) and red lechwe (N=60).

Table 7. Comparison of wildlife abundance between the 2018 (2463 km) and 2023 (556 km) Cuando expeditions. (Note: These expeditions covered different sections of the river; direct comparisons should be made cautiously.)

Species	2018 (animals/km)	2023 (animals/km)
Common duiker	0.001	0.00
Common reedbuck	0.002	0.00
Crocodile	0.013	0.13
Hippopotamus	0.009	0.25
Lechwe	0.002	0.12
Malbrouck	0.004	0.00
Oribi	0.001	0.00
Sitatunga	0.005	0.01
Spotted hyaena	0.001	0.00
Spotted-necked otter	0.004	0.00
Water monitor	0.030	0.01
Total	0.070	0.50

Wildlife sightings generally occurred where the main river was adjacent to dry land. In addition, the southernmost stretch of the surveyed region, near the Namibian border, had the highest wildlife density — with several groups of red lechwe and hippopotamus (Figure 17). This wildlife hotspot is likely linked to the proximity of the Cuando Wildlife Dispersal Area (WDA), which allows unrestricted movement between Angola and Namibia. The lack of physical barriers between the two countries further facilitates cross-border migration and connectivity within the Kavango-Zambezi Transfrontier Conservation Area (KAZA TFCA).

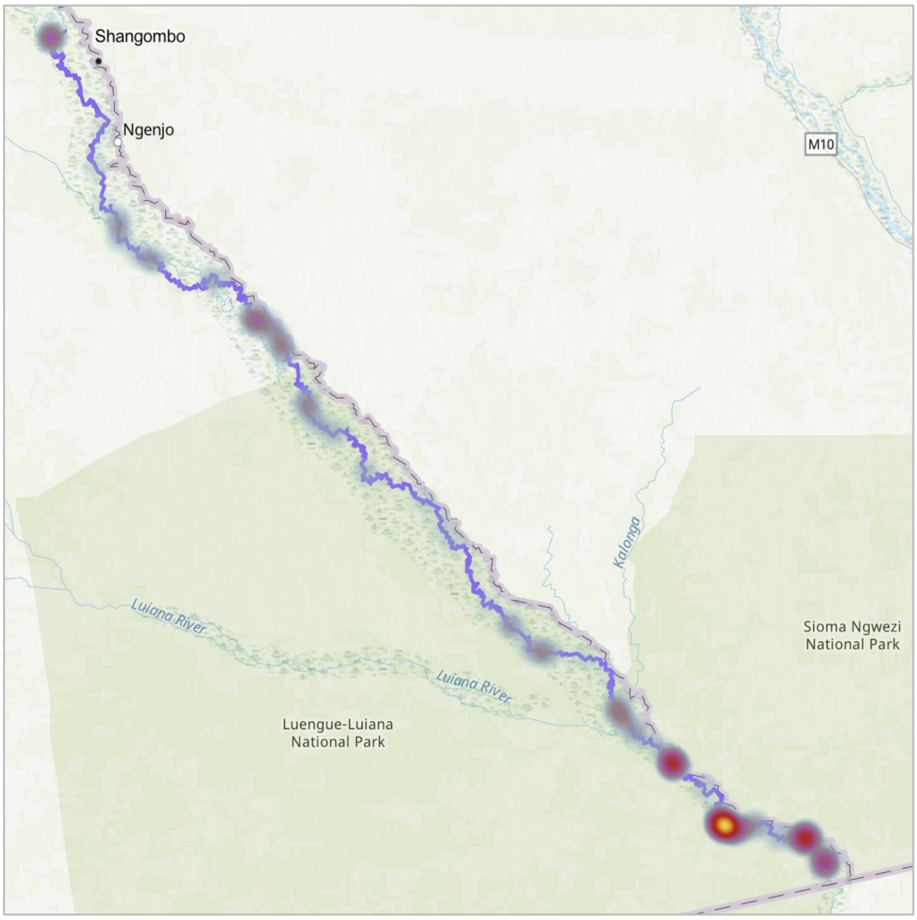

Figure 17. The distribution of wildlife along the Cuando River.

Cuando River as a wildlife corridor

Corridors are important for the connectivity of wildlife populations as they promote genetic diversity and provide avenues for seasonal and episodic migration in response to rainfall and flooding[19]. The Cuando WDA is particularly important to elephants as it allows their dispersal from high-density areas in Northern Botswana to low-density areas in Angola and Zambia (Figure 18)[20]. Historically, elephants migrated through this corridor to reach the highlands of Angola, which provided a seasonal refuge during the dry months in northern Botswana. However, this migration route was disrupted during the Angolan Civil War, and elephant populations have only recently begun to re-establish movement patterns in the region.

[19] Eakin, E. 2017. The effectiveness of wildlife corridors in biological conservation, a case study of the African elephant (*Loxodonta africana*) in Tanzania. (2014).

[20] Chase, M.J. & Griffin, C.R. 2011. Elephants of south-east Angola in war and peace: Their decline, re-colonization and recent status. African Journal of Ecology. 49(3):353–361.

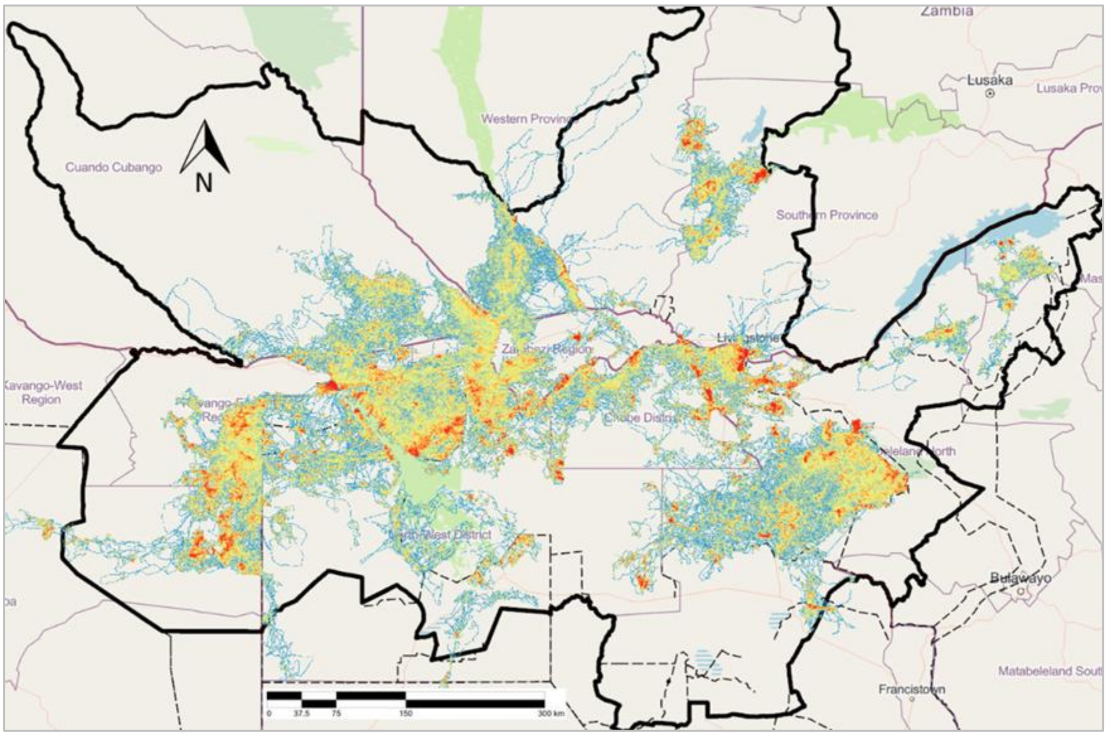

Figure 18. The intensity of elephant use within the Kavango-Zambezi Transfrontier Conservation Area (KAZA TFCA) is mapped using 500-meter grid cells, based on GPS tracking data from collared elephants. Warmer colours on the map indicate areas of higher elephant activity[21]. Notably, elephant movement intensity within the Cuando Wildlife Dispersal Area (WDA) highlights its importance as a key migratory corridor.

Although the corridor has promoted connectivity across the KAZA TFCA, wildlife crime remains a major challenge within the Cuando WDA. In Sioma Ngwezi National Park, poaching reduced the elephant population from approximately 900 in 2004 to just 48 in 2015[22]. That same year, a survey of Luengue-Luiana National Park found many fresh elephant carcasses along the middle Cuando River, indicating prevalent elephant poaching[23]. This emphasises the need for increased law enforcement and protection of wildlife populations along the Cuando River. If elephants are unable to move safely through southeast Angola and southwest Zambia, the potential for the KAZA TCFA to connect elephant populations across southern Africa will be significantly diminished.

Human-wildlife conflict on the Cuando river

Human settlement in south-eastern Angola has increased rapidly in recent years (see *Land-use and Land-cover (LULC) Change Analysis*). The Cuando-Cubango province in southeast Angola was sparsely settled prior to the Angolan Civil War, however, between 1995 and 2014, the number of people has increased by ~75% to 534,000[24]. As a result, settlements and croplands are increasingly prevalent throughout both Sioma Ngwezi and Luengue-Luiana National parks (see *Google Open Building Analysis* and *WorldCereal Cropland Analysis* sections). In many areas, these croplands and settlements have blocked access of wildlife to the Cuando River.

This is particularly concerning as the Cuando River is one of the main water sources within Sioma Ngwezi National Park during the dry season. Additionally, blocked corridors force animals into villages or croplands,

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[21] KAZA TFCA. 2023. Policy Brief: Elephant movements and connectivity in the Kavango-Zambezi Transfrontier Area. (January).

[22] Schlossberg, S., Chase, M.J. & Griffin, C.R. 2018. Poaching and human encroachment reverse recovery of African savannah elephants in south-east Angola despite 14 years of peace. PLoS ONE. 13(3):1–15

[23] Funston, P., P, H., Petracca, L., Maclennan, S., Whitesell, C., Fabiano, E. & I, C. 2017. The distribution and status of lions and other large carnivores in the Luengue-Luiana and Mavinga National Parks, Angola.

[24] Angolan National Institute of Statistics. 2014. Definitive results of the Angolan census.

exacerbating human-wildlife conflict. As ongoing climate change influences where and how people and wildlife access water, human-wildlife conflict along the Cuando River will likely worsen[25]. To this end, The Wilderness Project commends ongoing efforts to define and protect the Cuando WDA, particularly within the Luengue-Luiana and Sioma Ngwezi National Parks[26].

2.6 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[27]. Moreover, AIPs reduce water quality by increasing evaporation rates and reducing stream flow and dilution capacity[28]. 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 middle Cuando River, and its banks were identified and their extent recorded.

Results and Discussion: Alien invasive plants

Three species of AIPs were detected along the Cuando River (Table 8). These were *Cassia* species, *Ricinus communis,* and *Salvinia molesta* (Figure 19). The exact species of Cassia is inconclusive, but based on its location, it is likely *Senna pendula* or *Senna bicapsularis*. Cassia was uncommon, whereas *R. communis* and *S. molesta* had established populations along the river, with multiple patches of varying extent (Figure 20).

Table 8. Invasive aliens plants along the middle Cuando.

Common name	Scientific name	Number of plants	Coverage (m^2)
Cassia	*Cassia sp.*	1	-
Castor oil bush	*Ricinus communis*	22	-
Giant salvinia/Kariba weed	*Salvinia molesta*	-	27

[25] Eakin, E. 2017. The effectiveness of wildlife corridors in biological conservation, a case study of the African elephant (*Loxodonta africana*) in Tanzania. (2014).
[26] Funston, P., Petracca, L., Maclennan, S., Whitesell, C., Fabiano, E. & I, C. 2017. The distribution and status of lions and other large carnivores in the Luengue-Luiana and Mavinga National Parks, Angola.
[27] Vilà, M. et al (2011) Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters.
[28] Schachtschneider, K. et al (2012) Impacts of invasive alien plants on water quality, with particular emphasis on South Africa. Water S.A.

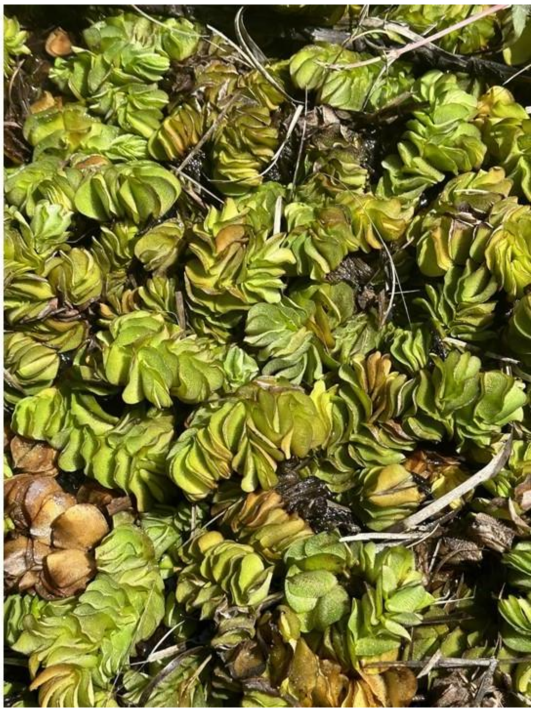

Figure 19. Ricinus communis (left) and Salvinia Molesta (right).

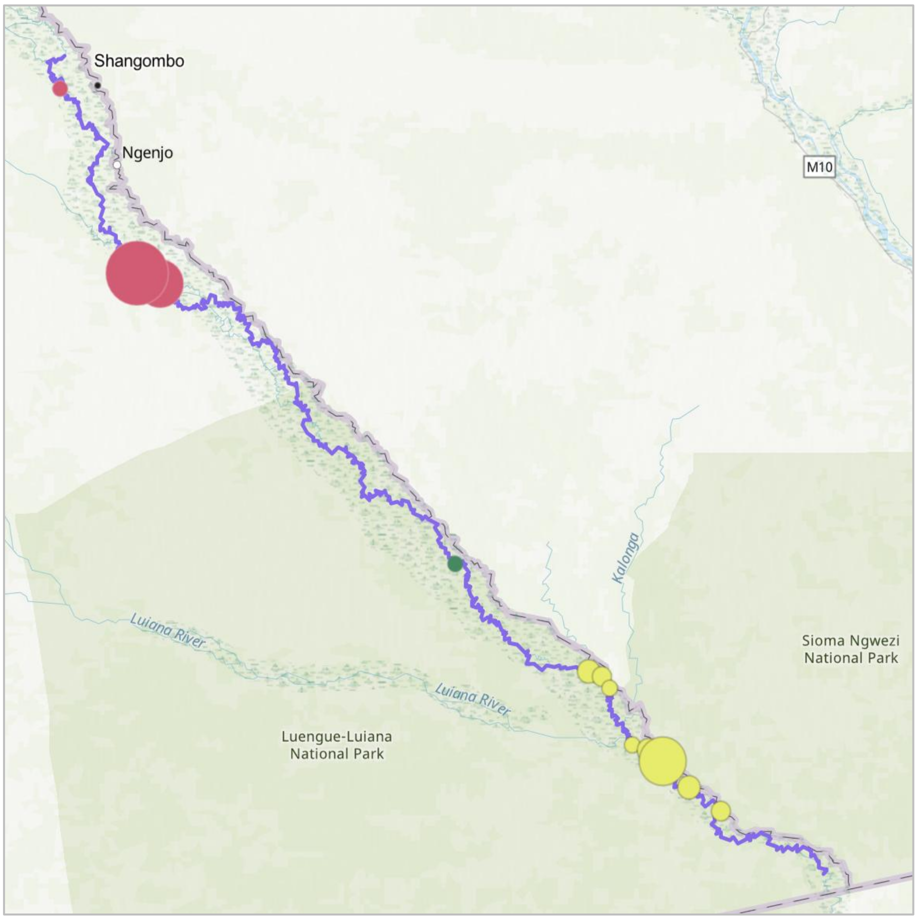

Figure 20. Relative locations and extent of the three invasive species found along the Cuando. Salvinia molesta is represented by yellow dots, the castor oil bush in red dots and the Cassia in green.

Salvinia molesta is a highly invasive aquatic weed and is considered one of the world's worst alien invasive species[29]. It can double in area within days, forming thick mats that block sunlight, deplete oxygen levels, and degrade water quality[30]. Additionally, *S. molesta* can clog human infrastructure, obstruct transport across water bodies, and significantly impact local fisheries by reducing habitat quality for native fish species.

The distribution of *S. molesta* was associated with the presence of dense hippo pods in the southern section of the transect. Hippos are known to transport the weed on their backs between waterbodies and thereby act as an effective means of dispersal for the invasive species[31]. This relationship suggests that *S. molesta* is likely also present in waterbodies adjacent to the Cuando River. The detection and control of *S. molesta* should be a priority for water management authorities in the region.

While the total area covered by invasive species is low, all three species identified in this survey are highly invasive and potentially cause serious ecological damage to the ecosystem. As a result, it is recommended that an invasive species management program is implemented immediately to prevent any proliferation of established AIPs on the river. This should include ongoing biocontrol measures, such as the use of Salvinia weevils, which were noted on one of the *S. molesta* patches on the Cuando River.

2.7 Papyrus

Papyrus, the world's fastest-growing herbaceous plant, is found in many African wetlands. Papyrus plays a crucial role in controlling nutrient balances and hydrological flows in river systems[32]. It creates vital habitats for numerous species, providing breeding grounds, foraging areas, and shelter. Furthermore, these wetlands play a crucial role in mitigating the effects of climate change by sequestering carbon and regulating water cycles.

Papyrus was distributed along the entire length of the Cuando River transect in 1,600 small patches (Figure 21). The majority of these patches (89%) were located on the Angolan side, whereas papyrus cover was notably lower on the Zambian side of the river. Given that human settlement densities are higher on the Zambian side (see *Google Open Building Analysis*), increased human activity may be contributing to the decline of papyrus in these areas. However, the extent to which papyrus reduction is linked to settlement expansion versus natural hydrological or ecological factors remains unclear and requires further investigation.

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[29] Courchamp, F., The Giant Salvinia (*Salvinia molesta*): the 100th among some of the worst. 2013.
[30] Le Maitre DC, De Lange WJ, Richardson DM, Wise RM & Van Wilgen BW. 2011. The economic consequences of the environmental impacts of alien plant invasions in South Africa. Biological invasions: Economic and environmental costs of alien plant, animal, and microbe species.
[31] Giant Salvinia (*Salvinia molesta*) Ecological Risk Screening Summary. 2018. U.S. Fish & Wildlife Service.
[32] Pacini N, Hesslerová, P. et al. 2018. Papyrus as an ecohydrological tool for restoring ecosystem services in Afrotropical wetlands. Ecohydrology and Hydrobiology. 18(2).

Figure 21. Papyrus along the main channel of the Cuando River.

2.8 Fire

Fire is an important and natural component of many ecosystems, playing a key role in preventing bush encroachment, clearing dead organic material, promoting grass regrowth, and even facilitating the germination of some seeds[33]. In Angola, ~30% of the country's area burns each year, with the highest burn percentage in the northeast and southeast, including the Cuando basin[34].

Methods: Fire

To determine the extent of fires along the Cuando River, 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. Intensity was categorised as follows:
    - *Low:* groundcover 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 was identified; and
- The side of the river was noted.

Results and Discussion: Fire

Fire was present along much of the transect and appeared to be prevalent near Shangombo/Mainha and in two other areas that are not associated with high densities of people (Figure 22). There was a higher abundance of fires outside the Luengue-Luiana National Park, likely in response to human activity (Figure 25). Most of the fires were medium intensity (66%) and weeks to months old.

[33] Cassidy L, Perkins JS, Bradley J. 2022. Too much, too late: fires and reactive wildfire management in northern Botswana's forests and woodland savannas. African Journal of Range & Forage Science, 39(1).
[34] Catarino S, Romeiras MM, Figueira R, Aubard V, Silva JM, Pereira JM. 2020. Spatial and temporal trends of burnt area in Angola: Implications for natural vegetation and protected area management. Diversity, 12(8).

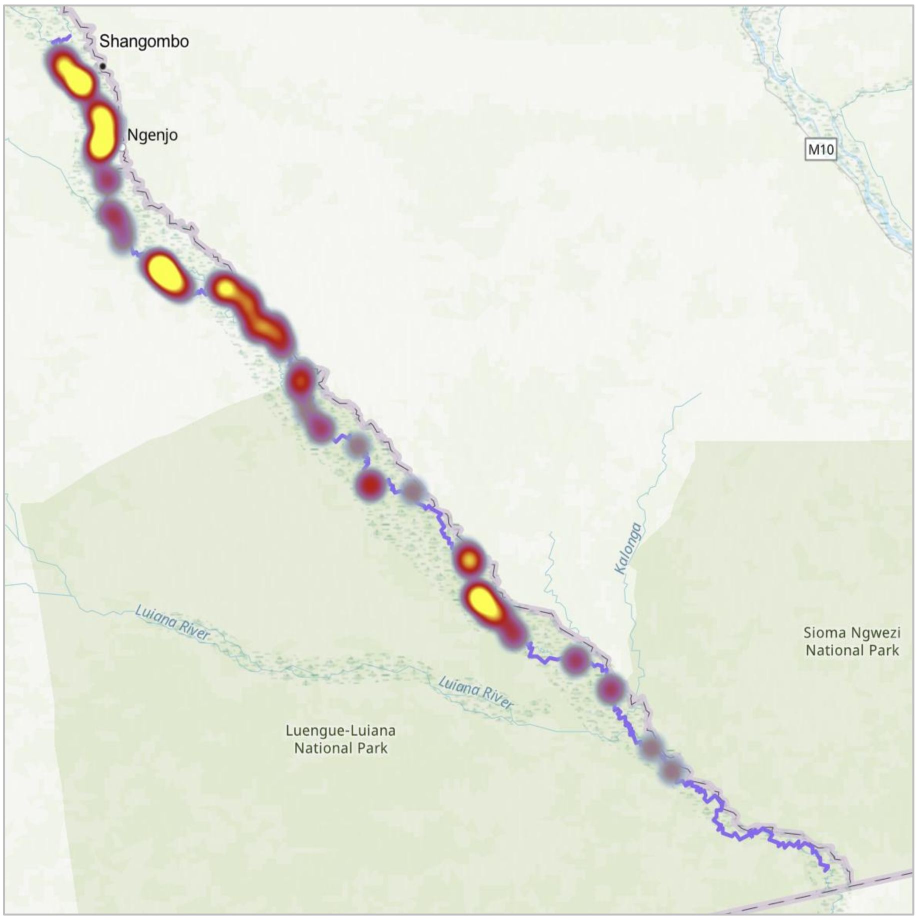

Figure 22. Distribution of fires along the Cuando River.


Figure 23. A recently burned area on the Cuando's riverbank.

Most of the fires observed during the expedition were old burns of low or medium intensity. This is likely because the survey was conducted at the end of the wet season, when the fuel load was limited. However, satellite analysis reveals that the southern Cuando Basin is prone to regular, intense, and large fires[35] (Figure

[35] Huntley, B.J., 2023. Ecology of Angola: Terrestrial biomes and ecoregions (p. 460). Springer Nature.

24). Here, 50% of the landcover burns per annum—a pattern that has persisted for at least the past 20 years[36]. Some of these fires last for several weeks and cover tens of thousands of hectares.

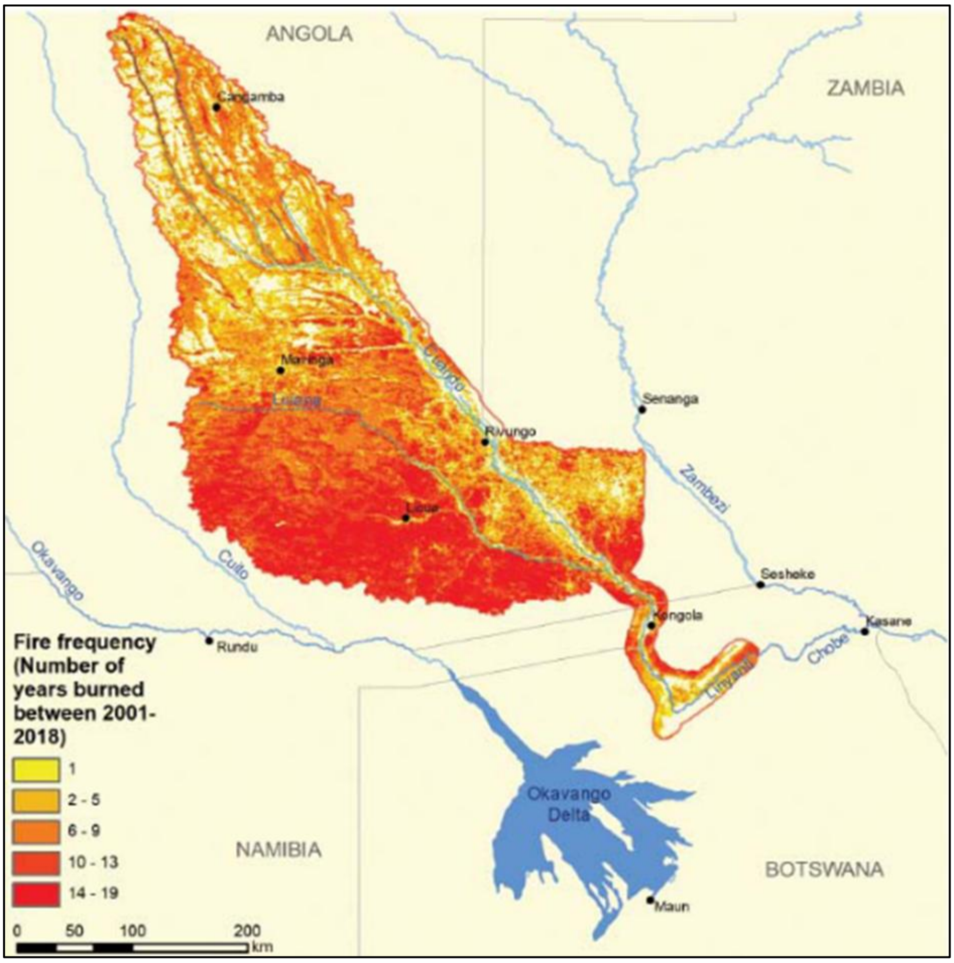

Figure 24. Fire frequency, depicted as the number of fires recorded in the 18-year period from 2001[37].

Fire and Water Quality

Fires may adversely affect rivers by exposing them to ash and contaminants and by consuming vegetation that retains soil and regulates water. If vegetation has not yet regrown, rainstorms following a wildfire can wash significant amounts of ash, sediment, nutrients, and pollutants into rivers. However, the fires observed along the river had a negligible impact on water quality (see *Water Quality*). This is likely because 89% of the burns already demonstrated regrowth of vegetation that helps to retain soil and prevent runoff.

[36] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.

[37] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.

3. FIXED SITE MONITORING (EVERY 10KM)

Every 10 km, a fixed research site was conducted that included water quality analysis and an aerial drone survey. This amounted to a total of 58 research sites along the transect (Figure 25). When combined with continuous survey data, water quality and aerial surveys allow for the identification of land-use, development and pollution sources within the riparian zone.

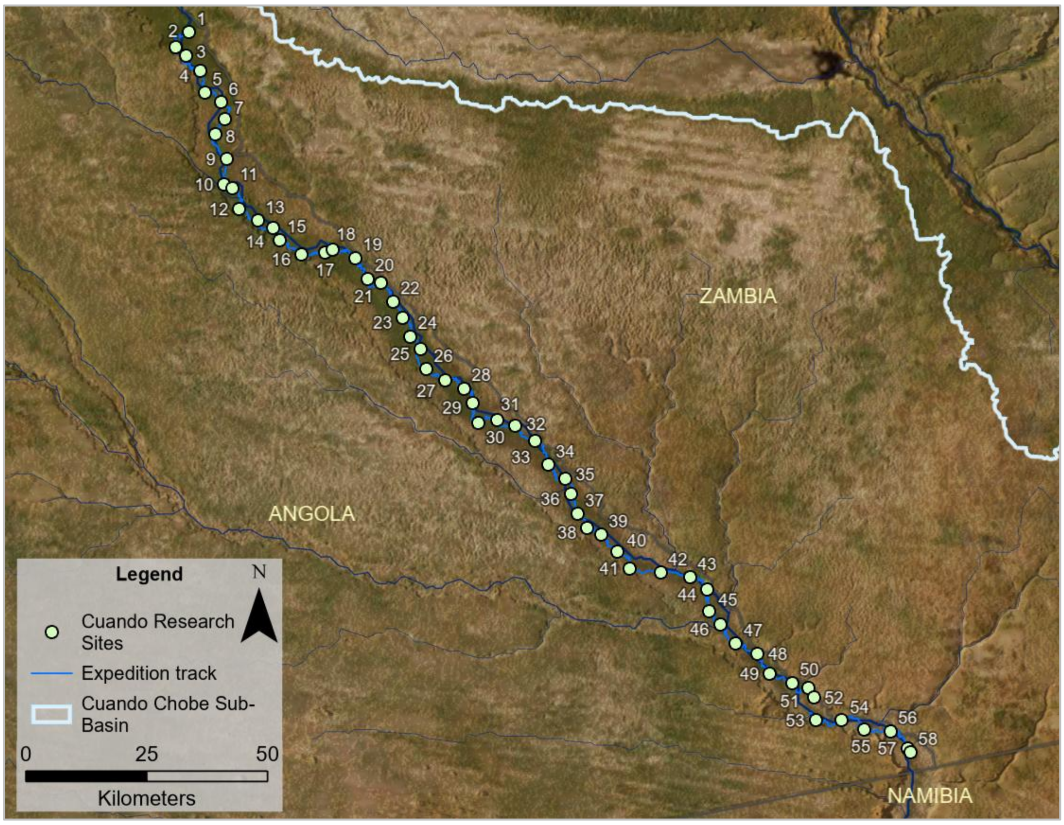

Figure 25. The locations of the 58 fixed-point monitoring sites.

2.9 Fixed Point Aerial Photography

Aerial photography was conducted at 58 sites research sites along the river using a drone. A series of 18 images were collected at each site: nine at 200 m elevation and nine at 100 m elevation (Figure 26). At each elevation, the first image was taken straight down (Figure 26). 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. The full database of aerial photography is available upon request.

Figure 26. Fixed point aerial photographs taken from 100m height, taken at 10 km intervals along the river.

2.10 Water Quality

Methods: Water quality

Water quality was analysed along the Cuando River using an InSitu Aqua Troll 600 multi-parameter sonde (Figure 27), which measures pH, oxidation-reduction potential (ORP), total suspended solids (TDS), turbidity, dissolved oxygen (DO), conductivity, salinity, resistivity, temperature and water density (see Appendix 3 for the description of parameters). The sonde was calibrated according to the manufacturer's instructions prior to undertaking the water quality survey along the river transect.

Figure 27. InSitu Aqua Troll 600 multi-parameter sonde.

Results and Discussion: Water quality

All water quality parameters were well below the maximum contamination levels (MCL)[38], indicating good overall water quality in the middle Cuando River. However, several parameters exhibited spatial and temporal variations (Figure 31). For example, temperature fluctuated between 24.2–26.0°C, depending on the weather conditions and the time of day. Additionally, channel morphology and water residence time likely contributed to temperature variations along the river.

Specific Conductivity
Specific conductivity, which reflects the concentration of dissolved ions in river water, increased downstream from 101.5 to 163.2 µS/cm (Figure 28). This downriver increase in dissolved ions can be attributed to the progressive evaporation of river water during transit, resulting in the evapoconcentration of ions downstream. The specific conductivity of the Cuando River was much greater than that of nearby rivers, such as the Lungwebungu River (6–15 µS/cm). There are three key reasons for this: i) rainfall is low in the southern Cuando River, so potential evaporation always exceeds rainfall; ii) the lower reaches receive a small water contribution from tributaries; and iii) the large floodplains in the lower reaches increase sunlight exposure, boosting evaporation, while abundant reeds and papyrus enhance transpiration[39].

[38] WHO. 2008. Guidelines for drinking-water quality. Volume 1. Geneva.
[39] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.

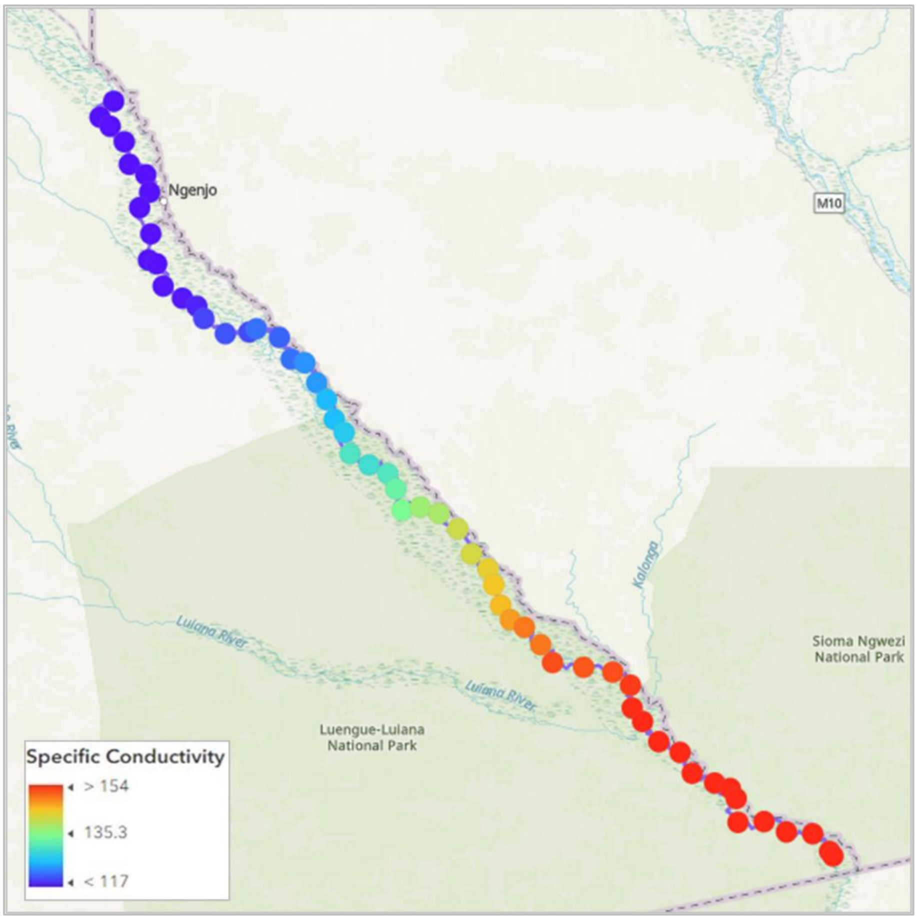

Figure 28. Specific conductivity of the Cuando River.

pH and Dissolved Oxygen

The pH remained relatively stable along the river, ranging from 7.1 to 7.5 (Figure 29), with minor variations likely influenced by local hydrological conditions. The average DO of the Cuando River (3.68 mg/L) was significantly lower than that of the nearby Lungwebungu River (7.88 mg/L). One likely explanation is that the Lungwebungu River has a much higher discharge (55.4 m^3/s) than the Cuando (26.5 m^3/s). Faster-flowing water enhances aeration, allowing for greater oxygen exchange between the river and the atmosphere[40].

At site 12, where the Uefo and Cuando Rivers meet, there was a sudden drop in pH, DO, and water temperature (Figure 30, Figure 31). The drop in these parameters at site 12 suggests that the inflow from the Uefo River altered the water chemistry. The parameters quickly returned to baseline levels downstream, confirming that the change was localized to the Uefo's influence. Similarly, turbidity dropped sharply at sites 5 and 22 (Figure 31). However, unlike site 12, there were no major tributaries nearby that could explain this change, suggesting that additional unknown factors may be influencing water clarity at these locations.

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[40] Dou, B., Hosseini, Y., Lee, C., Rosenberg, C. & Wu, N. 2018. The Relationship Between Stream Discharge and Dissolved Oxygen Levels at Canyon Creek, and Implications Towards Salmon Performance. The Expedition. 8(2003):1–20.

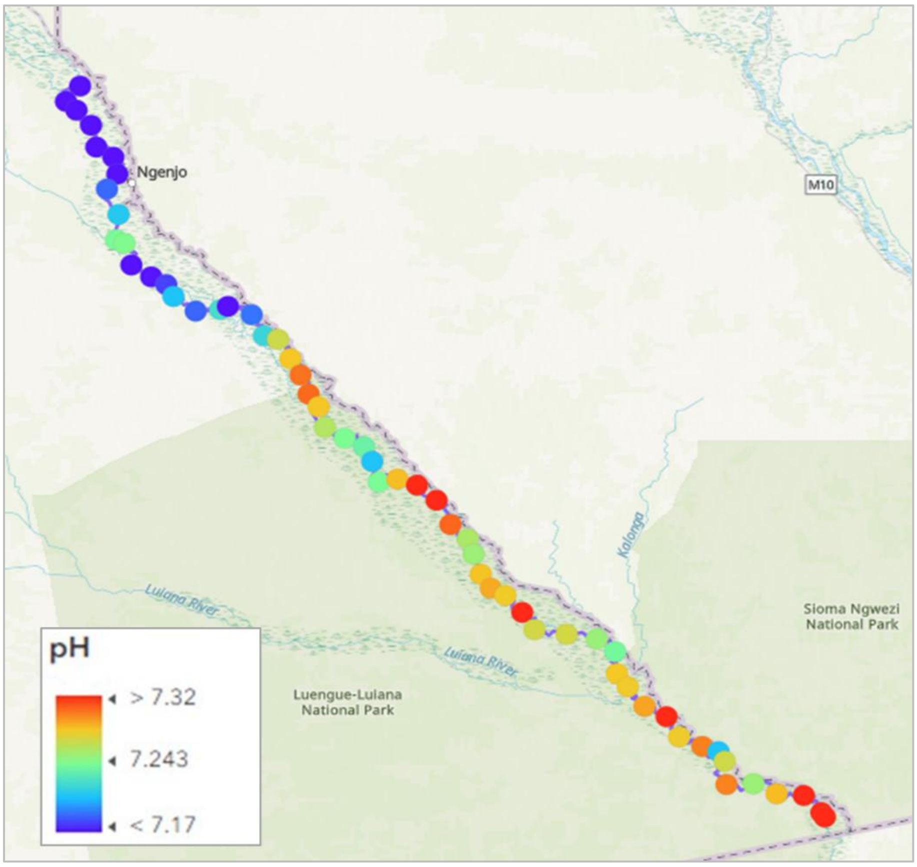

Figure 29. The pH of the Cuando River. Note site 12 below Ngenjo.

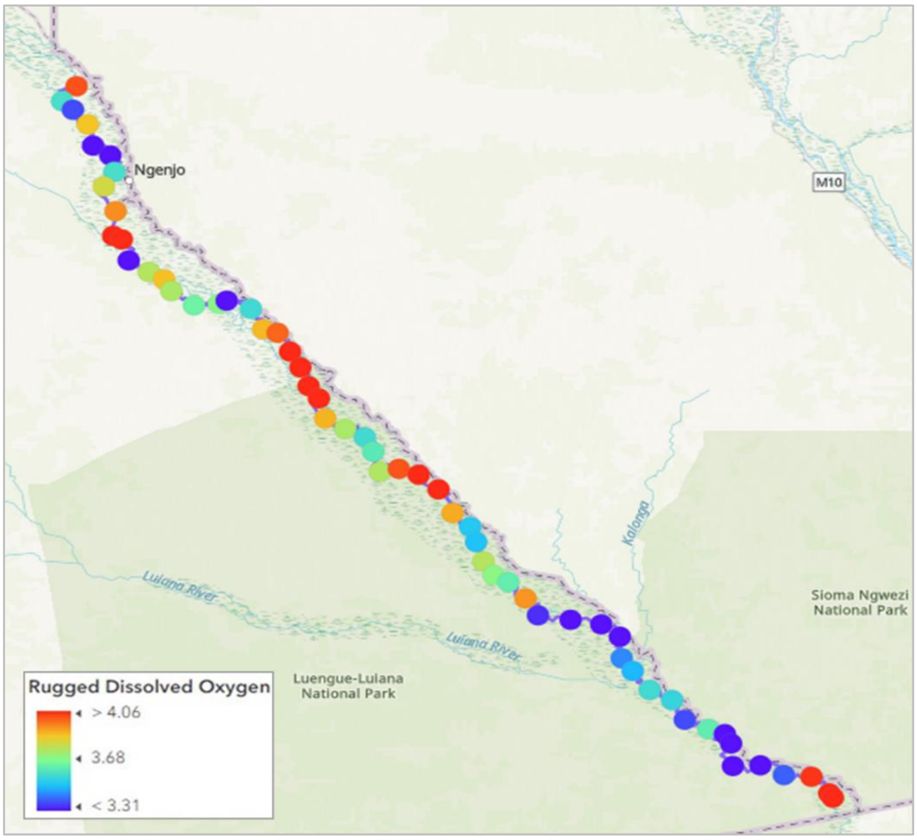

Figure 30. The DO of the Cuando River. Note site 12 below Ngenjo.

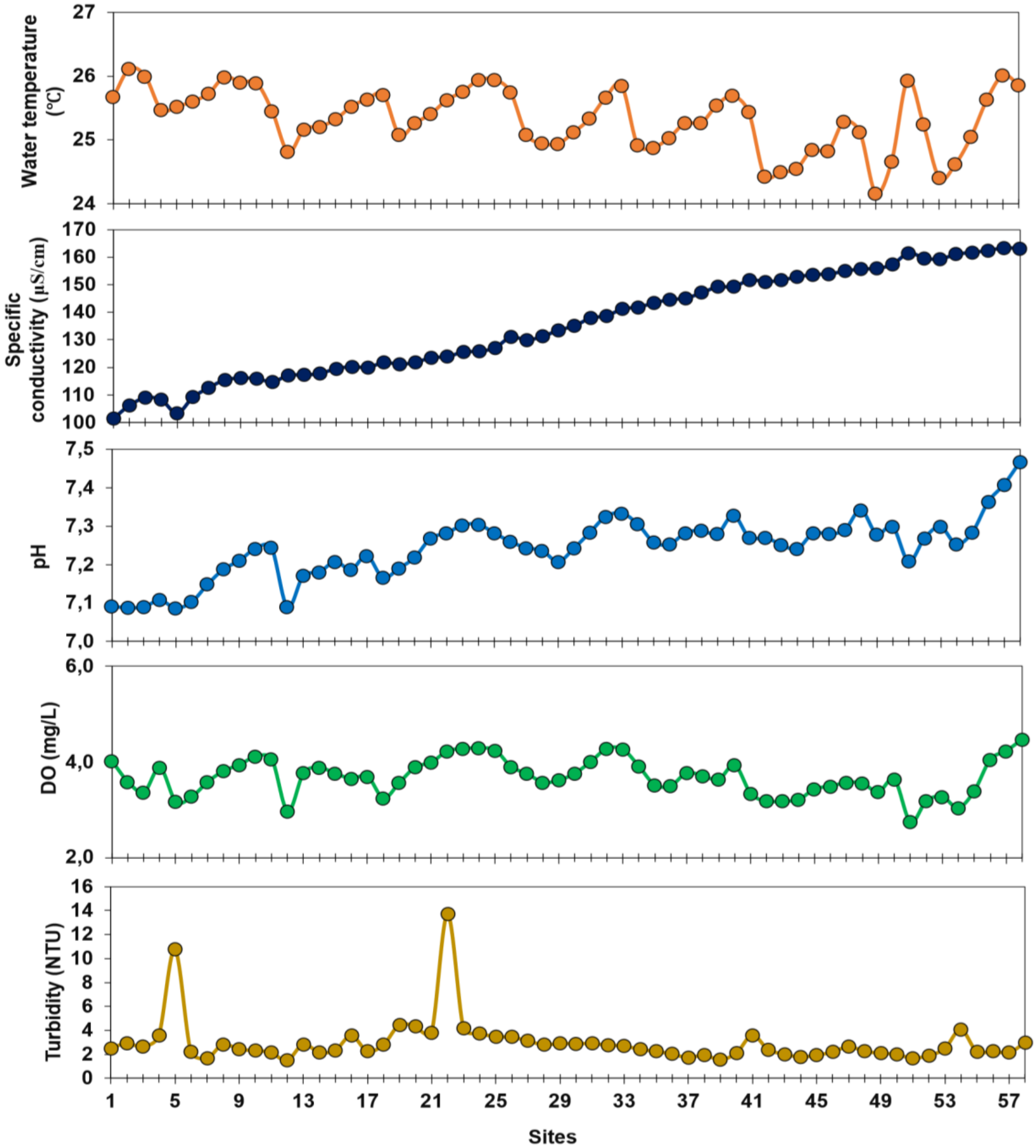

Figure 31. Spatial plots of water temperature, specific conductivity, pH, dissolved oxygen (DO) and turbidity measured along the Cuando River.

The data from the Cuando expedition provides a snapshot of the factors affecting the river's water chemistry (see *ESRI web application* for the distribution of all water quality parameters). To gain a more comprehensive understanding of these processes, continuous monitoring with the sonde should be complemented by water source partitioning techniques, including the analysis of major ions and stable water isotopes from samples.

1. FIXED SITE MONITORING (EVERY 50 – 75 KM)

Site monitoring consisted of collecting environmental DNA (eDNA) samples and conducting a benthic macroinvertebrate survey every 50–75 km along the transect. A total of 7 intensive research sites were sampled, representative of all river sections and habitats (Figure 32).

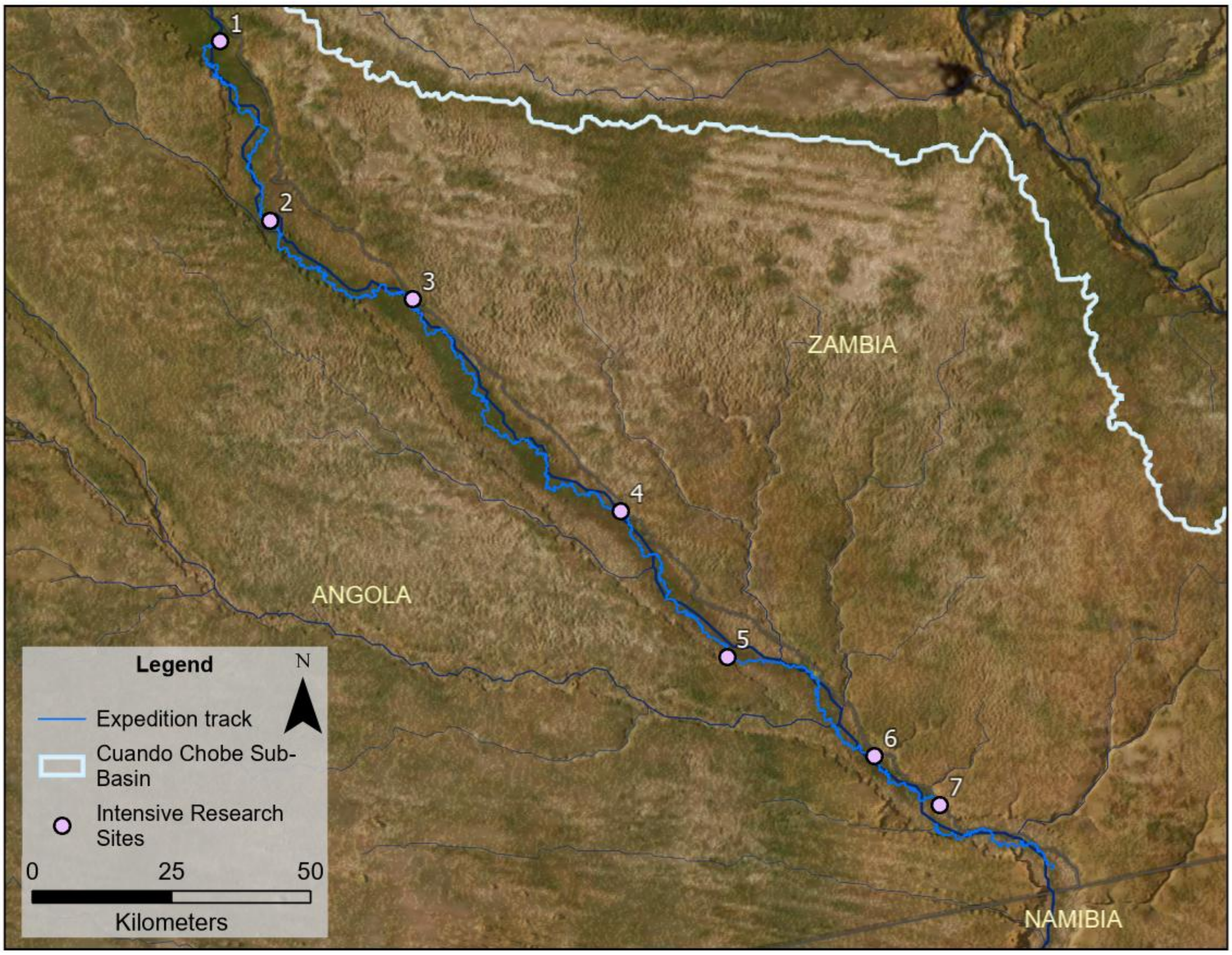

Figure 32. The locations of the 7 intensive research sites.

2.11 Environmental DNA

Methods: Environmental DNA

Triplicate eDNA water samples were collected at four fixed monitoring sites, by filtering as much water as possible, up to one litre, through a 0.22 µm Sterivex™ filter using a sterile 50 ml piston syringe (Figure 33). Once the filtration process was complete, excess water was removed from the filter by pushing air through. To preserve DNA and initiate extraction, 2 ml of ATL lysis buffer (Qiagen) was added to the Sterivex™ filter, after which the ends were sealed with Helapet combi-caps and biofilm. To prevent contamination, fresh surgical gloves were worn between each sampling iteration, and field blanks were processed by filtering one litre of distilled water on two occasions.

Samples were stored at room temperature before being transported to Stellenbosch University for DNA extraction. DNA extraction was conducted in an ultra-clean, DNA-free laboratory using the DNeasy Blood and Tissue Kit (Qiagen) following a modified protocol.[41,42,43]. Surfaces were sterilized with a combination of high-intensity UV exposure (30 minutes) and frequent wiping with a 10% bleach solution. Negative controls

[41] 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.
[42] 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.
[43] 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.

were processed in the lab using Ultra Clean DNA-free water to account for possible contamination.

The 12S rRNA gene was used for metabarcoding, as it is considered an effective marker for fish biodiversity assessments[44,45]. Samples were amplified using the polymerase chain reaction (PCR), using MiFish primers. Following DNA sequencing, low-quality reads were filtered, and Amplicon Sequence Variants (ASVs)[46]—unique DNA sequences derived from amplification—were generated. ASVs were then assigned taxonomic identities, forming Molecular Operational Taxonomic Units (MOTUs) based on similarity thresholds [47]. 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 for unidentified MOTUs, a family-level phylogeny was constructed. Sequences were aligned, and a neighbour-joining tree was built using Kimura two-parameter distances in MEGA software[48]. MOTUs forming a monophyletic group within a single genus were assigned as "Genus sp.", numbered sequentially (e.g., Petrocephalus sp. 1, sp. 2). Similarly, family-level MOTUs were labelled accordingly (e.g., Poecillidae sp. 1, sp. 2)[49].

Figure 33. Filtering water through a Sterivex filter for eDNA collection.

Results and Discussion: eDNA

Environmental DNA (eDNA) metabarcoding has emerged as a powerful method for assessing fish biodiversity in aquatic ecosystems. By analysing DNA fragments found in water samples and grouping similar sequences into Operational Taxonomic Units (OTUs), this technique allows researchers to detect multiple species at once, offering a comprehensive snapshot of the community.

Analysis of the 12S rRNA gene detected 32 genera from 15 families (Figure 34, Figure 35), surpassing the

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

[45] 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.

[46] 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.

[47] 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.

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

[49] 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.

24 genera from 11 families recorded using traditional fish sampling. The most represented families included Mormyridae, Cichlidae, and Poecillidae (Figure 34). Taxonomic composition varied across sites, with Hydrocynus, Marcusenius, and Pollimyrus being the most frequently detected genera (Figure 35).

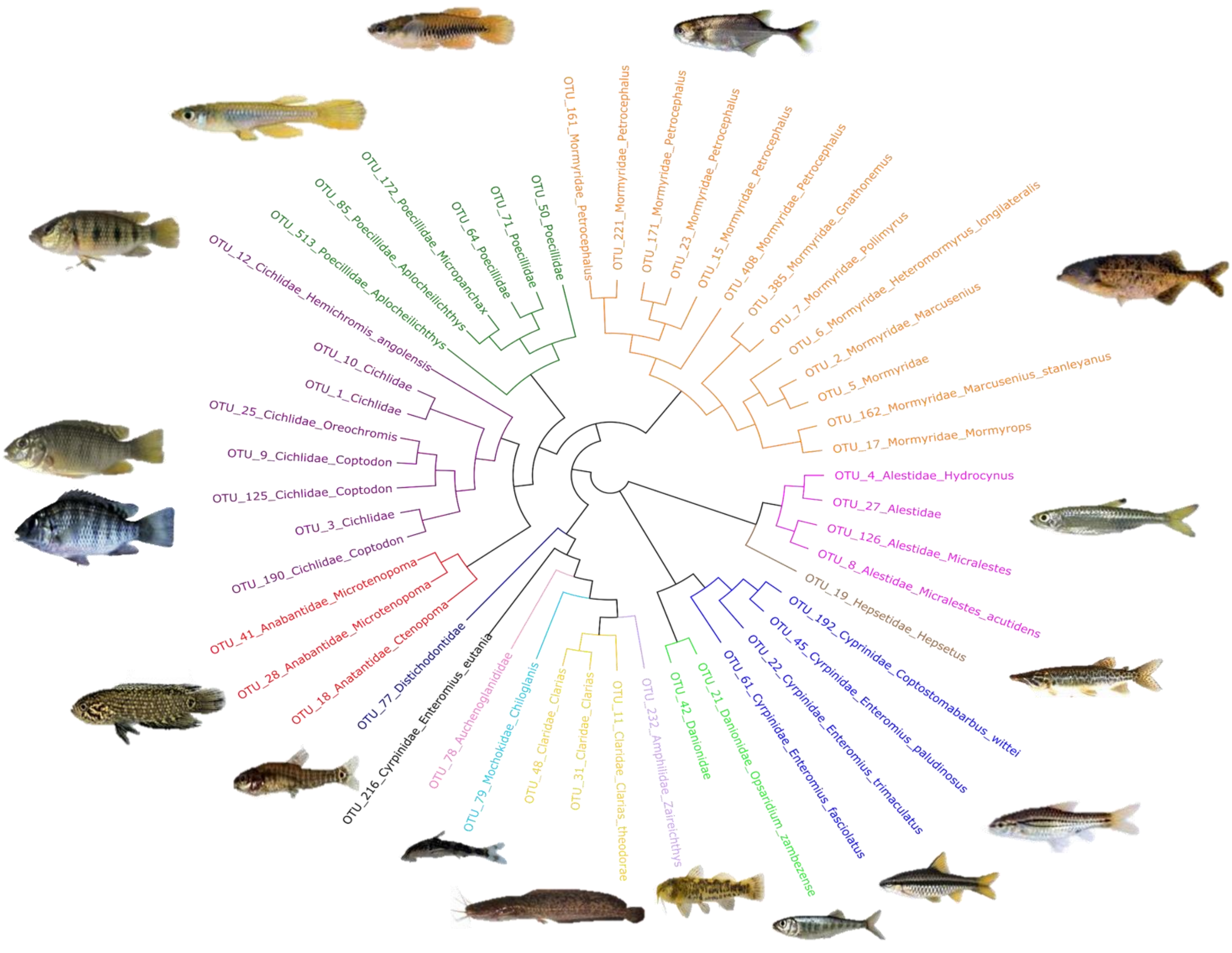

Figure 34. Family-level phylogeny showing most common families detected by eDNA metabarcoding.

The most commonly detected species were *Heteromormyrus longilateralis*, *Microlestes acutidens*, and *Enteromius fasciolatus* (Figure 35). In contrast, the least frequently detected species included *Coptostomabarbus wittei*, *Osparidium zambezense*, and *Chiloglanis*, each exhibiting low OTU abundance (<1000 OTUs) and being recorded at only a few sites (Figure 35). Additionally, no OTUs were detected at site 26, likely due to issues related to sample storage or DNA extraction, which may have compromised the eDNA data from that location.

eDNA vs. traditional sampling methods

On this expedition, eDNA metabarcoding identified species that were not captured during traditional fish sampling. As a result, eDNA metabarcoding may be more effective than traditional techniques for assessing fish biodiversity in river systems. It offers a cost-effective approach, can sample a broader range of habitats, including inaccessible aquatic environments, and has the potential to detect rare or previously undocumented species[50].

Limitations of eDNA metabarcoding

While eDNA metabarcoding is a powerful tool, several limitations must be acknowledged. One limitation of

[50] Jerde, C.L., 2019. Can we manage fisheries with the inherent uncertainty from eDNA. Journal of Fish Biology, 98,

eDNA metabarcoding is its inability to consistently identify species with high accuracy. Some taxa detected through eDNA metabarcoding were only identified at the family or genus level, such as cichlids, Coptodon, Clarias, and Petrocephalus. Several fish species sampled during the survey belong to these genera, suggesting that these detections may correspond to the sampled species (Table 9). Additionally, eDNA metabarcoding identified taxa unlikely to be present in the river, such as Marcusenius senegalensis and certain marine species. These misidentifications likely stem from genetic similarities between closely related species[51].

Greater precision can be obtained using species-specific primers[52] or using multiple genetic markers, which could increase the likelihood of species detection or address shortcomings associated with specific gene regions[53]. To support this, a local reference sequence database is being developed in partnership with the ANHM, focusing on species known or likely to occur in the study area. To this end, several species detected by both methods, such as *Opsaridium zambezense* and *Microlestes acutidens* (Table 9), will serve as voucher specimens to build an eDNA database for the region. This will strengthen the utility of eDNA as a tool while emphasizing the importance of integrating both traditional and genetic methods for comprehensive biodiversity monitoring.

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[51] Shaw, J.L.A., Clarke, L.J., Wedderburn, S.C., Barnes, T.C., Weyrich, L.S., and Cooper, A., 2019. Comparison of environmental DNA metabarcoding and conventional fish survey methods in a river system. Biological Conservation, 197, 131–138.

[52] 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.

[53] Shaw, J.L.A., Clarke, L.J., Wedderburn, S.C., Barnes, T.C., Weyrich, L.S., and Cooper, A., 2019. Comparison of environmental DNA metabarcoding and conventional fish survey methods in a river system. Biological Conservation, 197, 131–138.

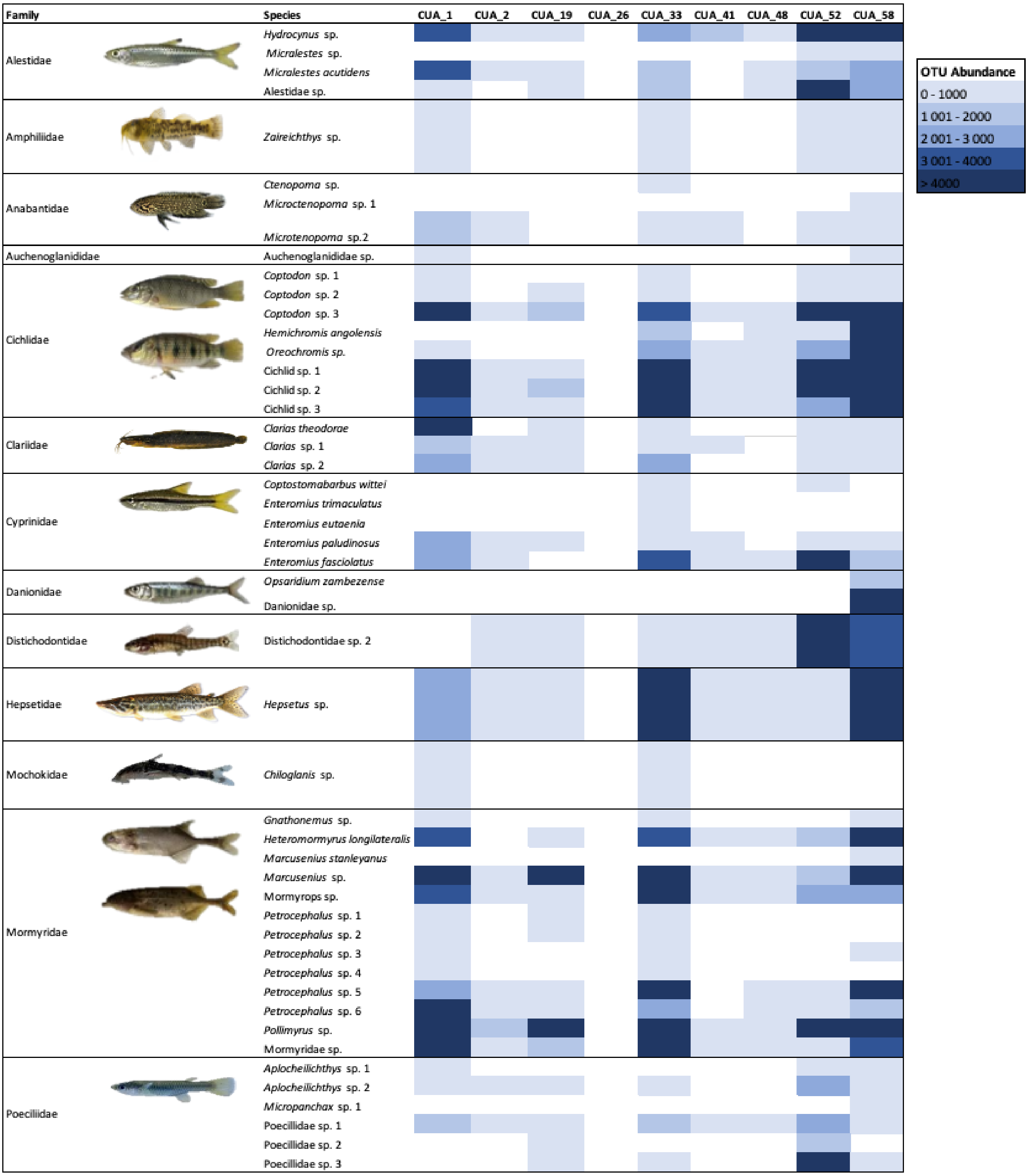

Figure 35. Abundance of OTUs per species across sites in the Cuando River.

Table 9. Fish taxa identified using eDNA metabarcoding and the fish sampling survey that are classified in the same genera.

Family	Identified fish taxa	
	eDNA	Fish sampling survey
Alestidae	*Microlestes acutidens*	*Microlestes acutidens*
	Microlestes sp.	
Anabantidae	*Microtenopoma* sp.1	*Microtenopoma intermedius*
	Microtenopoma sp.2	
Cichlidae	*Coptodon* sp. 1	*Coptodon rendallii*
	Coptodon sp. 2	
	Coptodon sp. 3	
	Hemichromis angolensis	*Hemichromis elongatus*
	Oreochromis sp.	*Oreochromis macrochir*
Clariidae	*Clarias theodorae*	*Clarias sp.*
	Clarias sp. 1	
	Clarias sp. 2	
Danionidae	*Opsaridium zambezense*	*Opsaridium zambezense*
	Danionidae sp.	
Mochokidae	*Chiloglanis* sp.	*Chiloglanis fasciatus*
Mormyridae	*Marcusenius stanleyanus*	*Marcusenius altisambezi*
	Marcusenius sp.	*Marcusenius moorii*
	Petrocephalus sp. 1	*Petrocephalus longicapitis*
	Petrocephalus sp. 2	*Petrocephalus magnitrunci*
	Petrocephalus sp. 3	*Petrocephalus okavangoensis*
	Petrocephalus sp. 4	
	Petrocephalus sp. 5	
	Petrocephalus sp. 6	
	Pollimyrus sp.	*Pollimyrus cuandoensis*

2.12 Aquatic Macroinvertebrates

The Zambian Invertebrate Scoring System (ZISS) is a standardised, rapid, field-based bioassessment tool assessing aquatic macroinvertebrate fauna at a family level to determine the health of perennial rivers in Zambia. Given that no invertebrate scoring system was available for Angola at the time of sampling, the ZISS was used for the Cuando River. 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

Benthic macroinvertebrate assessments were conducted at seven fixed sampling sites (Figure 32). Unfortunately, a critical piece of equipment—the invertebrate D-net—was lost mid-expedition, necessitating the use of a modified fish net for sampling at the final four sites (Figure 36). The use of a modified fish net likely resulted in lower catch efficiency, meaning that macroinvertebrate diversity, ZISS scores, and ASPT values may be underestimated.

Figure 36. ZISS sampling on the Cuando River.

Results and Discussion: Aquatic Macroinvertebrates

The mean ZISS score for the Cuando River was 39.4, with an average ASPT of 5.5 (Table 10). Most sites exhibited relatively consistent scores, except for site 1, which had a notably lower ASPT of 4.3. The ZISS score was fairly low compared to other rivers surveyed in the region. For example, the Angolan section of the Lungwebungu River had a mean ZISS score of 86 and ASPT of 6.0. Besides the equipment limitation, the lower ZISS scores in the Cuando River may also be attributed to homogeneous marginal vegetation, which reduces habitat complexity and limits macroinvertebrate diversity. Unlike rivers with varied riparian vegetation, submerged logs, and diverse substrate types, the Cuando's relatively uniform habitat structure may provide fewer ecological niches for macroinvertebrates, resulting in lower overall diversity.

Table 10. The ZISS data summarised for the nine intensive research sites along the Cuando River.

ZISS Site	Latitude	Longitude	No. of Taxa	ASPT	ZISS Score
1	-16.2738	22.041	4	4.8	19
2	-16.56261	22.12118	6	5.3	32
3	-16.69052	22.35183	9	5.3	48
4	-17.03334	22.68745	6	6.5	39
5	-17.26879	22.85877	4	7	28
6	-17.42824	23.09717	11	5.3	58
7	-17.50704	23.2023	12	4.3	52
AVERAGE			7.4	5.5	39.4

2. OPPORTUNISTIC SAMPLING

4.1 River Discharge

River discharge — the volume of water flowing through a river per unit of time — is a vital indicator 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

We used a SonTek RS5 Acoustic Doppler Current Profiler (ADCP) to measure water discharge (m^3/s) at two sites, including the start and end of the transect (Figure 37). These included measurements of flow rates, depth, river profile and discharge. Navigating slowly in a motorised boat, we towed the ADCP, ensuring adherence to acceptable limits in terms of sampling speed and trajectory (Figure 38).

Figure 37. The ADCP sampling sites on the Cuando River.

Figure 38. The ADCP deployed on the Cuando River.

Results and Discussion: Hydrology

Throughout the river transect, discharge decreased from 29.1 m^3/s to 23.9 m^3/s (Table 11). This reduction in discharge is negligible, as variations in channel morphology and floodplain extent may account for natural fluctuations in volume. However, the general trend of decreasing discharge downstream aligns with broader hydrological patterns observed in the Cuando River, where flow reduction is driven by the combined effects of evapotranspiration losses in the floodplain and the seepage of water into the basin's permeable sands.

Table 11. Acoustic Doppler Current Profiler (ADCP) measurements along the Cuando. Q = discharge.

ADCP Site	Latitude	Longitude	Q (m^3/s)
1	-16.2738	22.04163	29.1
2	-17.5010	23.20066	23.9

These results align with the reported average discharge measurements at Kongola — 27 m^3/s in December and 39 m^3/s in July (Figure 39). Interestingly, the Cuando's discharge is almost four times lower than the adjacent Cuito River (90–195 m^3/s) (Figure 40), despite their upper catchments being similar in size, soils, rainfall, and geomorphology[54]. This difference can be explained by the variations in their lower catchment structures. The Cuito flows through floodplains that are rarely more than 2 km wide, while the Cuando meanders through a floodplain that stretches 15 km wide[55]. The seepage of water through a larger floodplain, and therefore more vegetation, results in significant evapotranspiration losses and slows the flow. This is likely why the Cuando River has much lower discharge volumes.

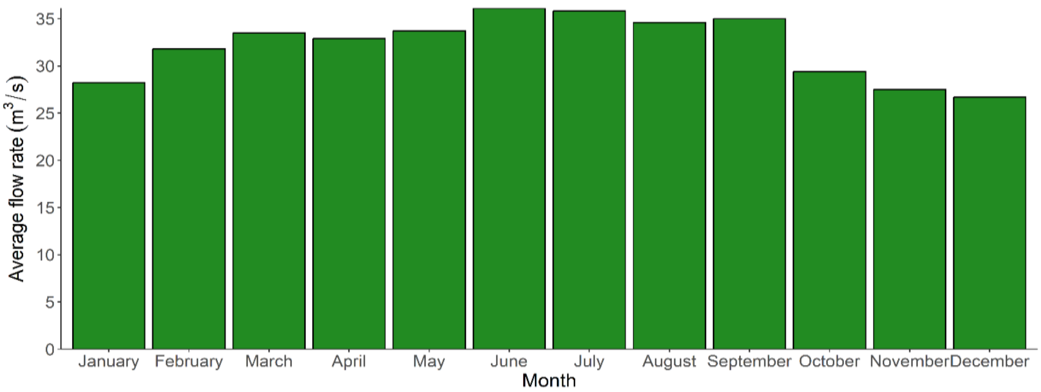

Figure 39. Average annual discharge of the Cuando River at Kongola The annual discharge of the southern Cuando River at Kongola is ~1 billion m^3/year, with typical flows of 25–35 m^3/s

[54] Mendelsohn, J.M. & Martins, A. 2018. River catchments and development prospects in south-eastern Angola. (May):1–106.
[55] Mendelsohn, J.M. & Martins, A. 2018. River catchments and development prospects in south-eastern Angola. (May):1–106.

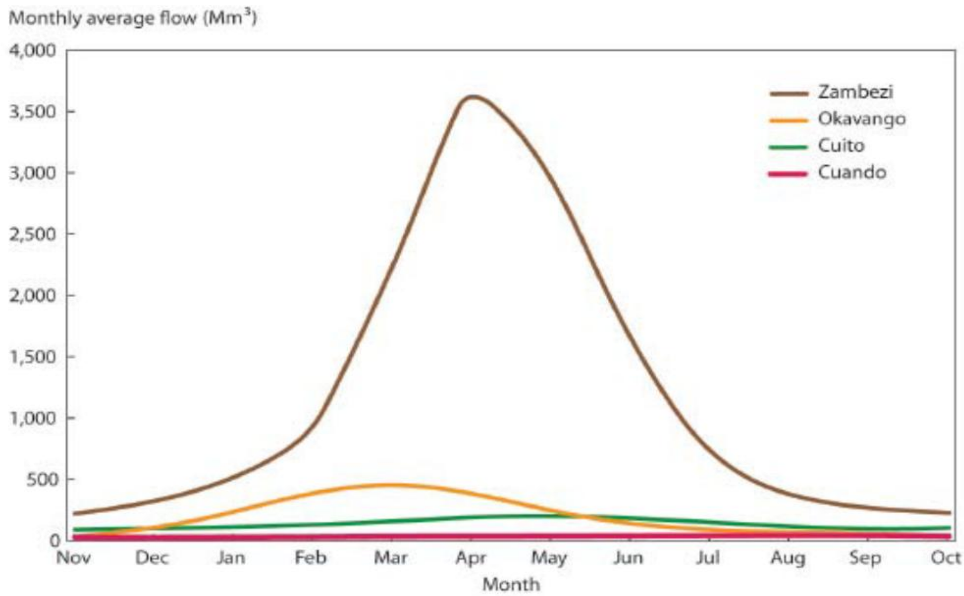

Figure 40. Average discharges in millions of m3/second each month from 2001 to 2019 at Katima Mulilo (Zambezi), Rundu (Okavango), Dirico (Cuito) and Kongola (Cuando)56.

The Cuando River maintains relatively stable flow patterns, peaking only during periods of very intensive rainfall (Figure 39). The peak flow occurs about six months (July/August) after the peak rainfall in the upper catchment, reflecting the extremely slow passage of water. This lag indicates that the river system has a large capacity to store water, in wetlands or underground, which is slowly released over time. In the upper basin, the majority of the rainwater seeps into deep, porous sands. The water then percolates down to ~30–100 m before reaching the aquitards (hardpans), which forces it to seep out into tributaries further downslope. This lateral seepage is the predominant form of recharge of the river's water. Consequently, deep sands function like a sponge, absorbing and gradually releasing the water[57].

Climate change projections for the KAZA TFCA indicate a 4.6% decline in total annual precipitation by 2050, averaged across the entire TFCA. In addition, the average annual temperature across the KAZA region is projected to rise by 3°C. In the western areas, including Angola and parts of Zambia and Namibia, temperature is expected to rise more rapidly compared to other parts of the TFCA[58]. This will likely increase evaporation losses from the river, further decreasing the river's limited flow. This underscores the need for proactive water management strategies, including enhanced monitoring and adaptive management practices, to mitigate the impacts of climate change on water resources and ecosystems in the region.

4.2 Bat recorder deployments

The team deployed a *Wildlife Acoustics Song Meter SM4BAT-FS* detector to record bat echolocation calls at four 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 larger bat diversity study.

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[56] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.
[57] Stadtler, C., Margane, A., Schildknecht, F., Schäffer, U. & Wrabel, J. 2005. Investigation of the Groundwater Resources in the Eiseb Graben in Namibia with TEM Soundings.
[58] Beilfuss, R. 2012. A Risky Climate for Southern African Hydro: assessing hydrological risks and consequences for Zambezi River Basin Dams.

4.3 Fish Sampling

Methods: Fish Sampling

A fyke net and a dip net were used to sample fish diversity at 12 sites (See Appendix 5 and Appendix 6). Fish of interest were anaesthetised in clove oil, photographed, and preserved in a 10% formalin solution (Figure 41). Tissue samples were collected for two representatives per species and stored in 99% ethanol for subsequent DNA analysis. In addition, a tissue sample subset was collected to develop a reference library for future eDNA analyses.

Following the expedition, fish specimens were transported to the American Natural History Museum for identification verification and to be accessioned into the ichthyology collection at the institution. It is important to note that the final identification of the specimen is ongoing. Regardless, the fish sampling effort on this expedition significantly contributes to our understanding of freshwater diversity in the Cuando River.

Figure 41. Fish identification on the Cuando River.

Results and Discussion: Fish sampling

A total of 941 specimens, representing 45 species, were collected (Figure 42). The most common species included *Lacustricola johnsoni* (N=227), *Lacustricola mediolateralis* (N=89), and *Pseudocrenulabus philander* (N=82) (Figure 44). A significant finding of this survey was the collection of several specimens of the Ghost Stonebasher (*Paramormyrops jacksoni*) (Figure 43). The identification of these specimens are provisional and pending taxonomic confirmation. The last and only official sighting of the *P. jacksoni* was in 1967 in the Longa River, Angola[59]. There has since been minimal research on this species' abundance, distribution and habitat. Consequently, it has been listed as Data Deficient on the IUCN redlist since 2007[60]. The sighting of this species underscores the importance of ongoing research and monitoring of fish species within the Cuando River to better understand and protect their populations.

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[59] Poll, M. 1967. Contribution à la faune ichthyologique de l'Angola. Companhia de Diamantes de Angola (Diamang), Serviços Culturais No. 75. Lisboa.

[60] Tweddle, D. 2007. Paramormyrops jacksoni. The IUCN Red List of Threatened Species 2007

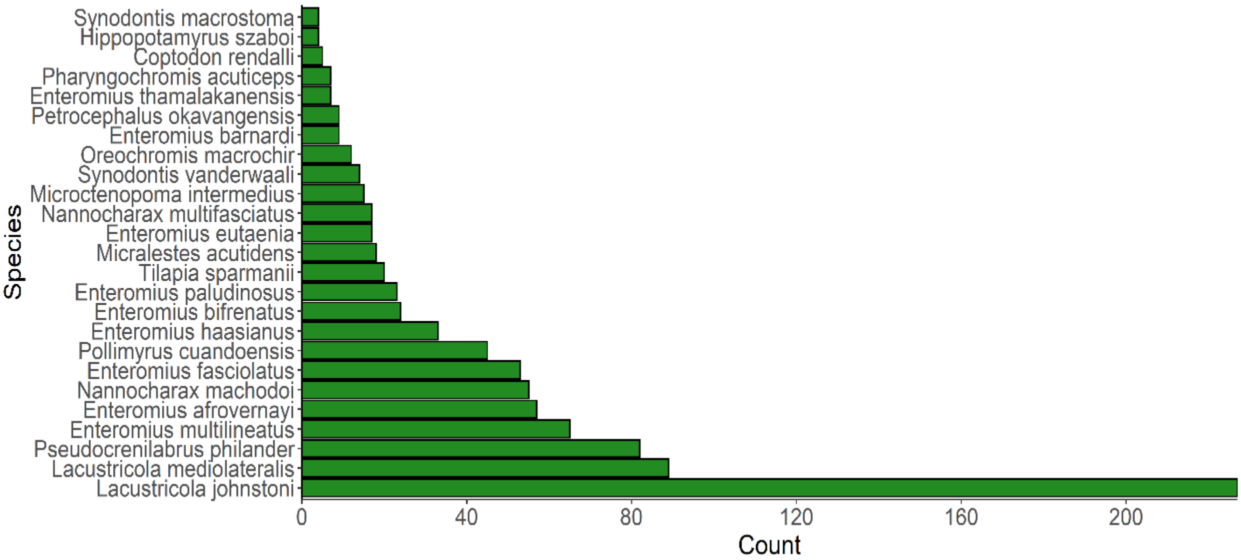


Figure 42. Count of fish species caught on the Cuando River.

Figure 43. The specimen that has been provisionally identified as the Paramormyrops jacksoni (Ghost stonebasher).

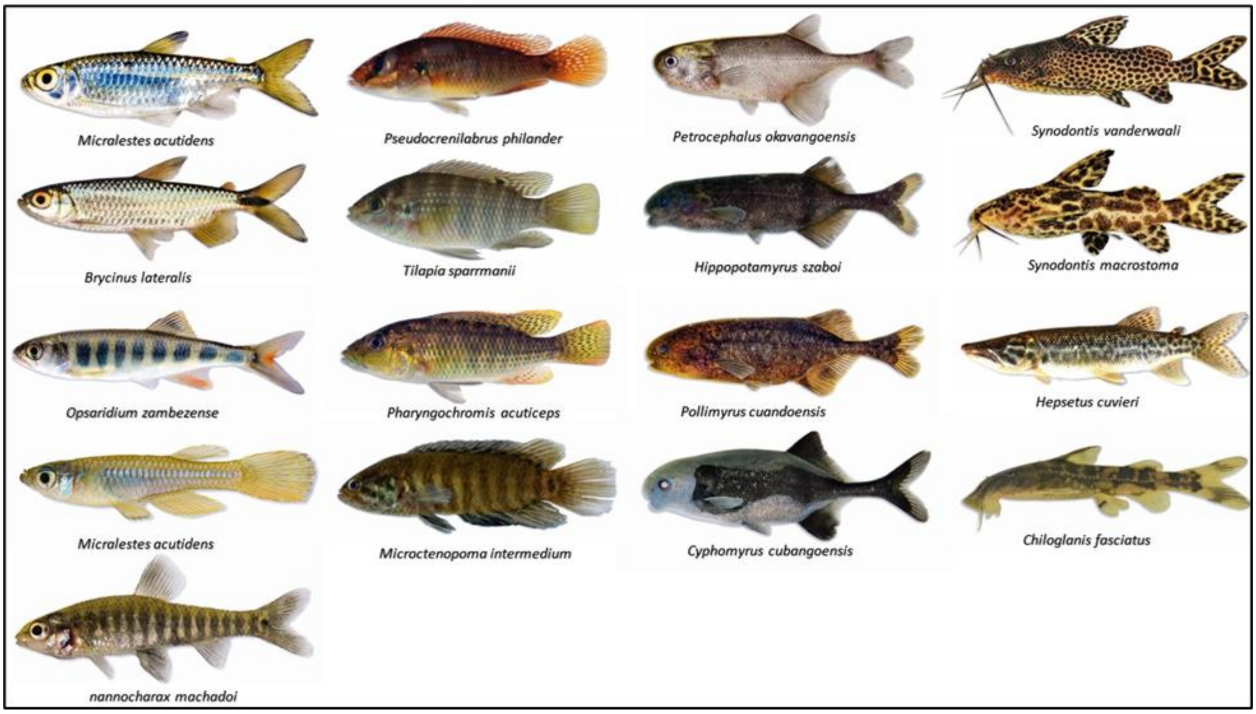


Figure 44. Some of the fish that were collected on the Cuando River.

3. SATELLITE ANALYSIS

5.1 Land-use and Land-cover (LULC) Change Analysis

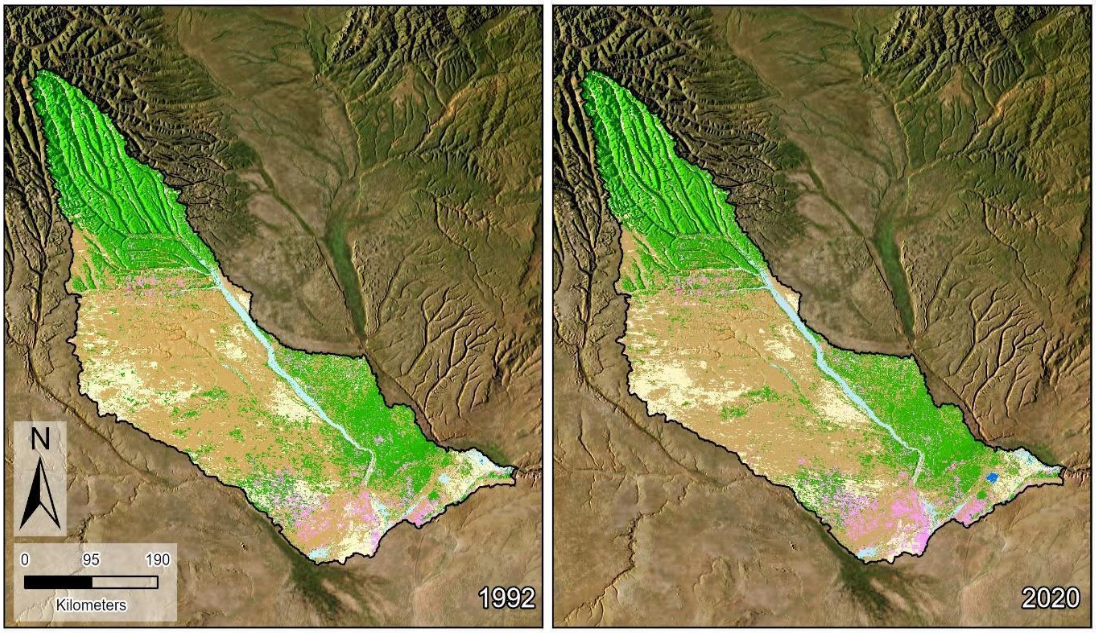
Methods: LULC change analysis

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 Cuando Chobe River Basin. 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 4.

Results and Discussion: LULC change analysis

Wetland and water coverage has seen drastic change between 1992 and 2020, with wetlands calculated to have lost 121 km^2 and water having gained 150 km^2. This is due to Lake Liambezi within the Cuando Chobe sub-basin being classified as a wetland in 1992 and then as water in 2020 (Figure 45). Lake Liambezi refilled in 2009 after a 22-year dry period[61]. The lake is ephemeral, undergoing cyclical phases of flooding and drying. It received inflow in 2010 and 2011 but has not received any since then and is currently receding[62].

[61] Peel, R.A., Tweddle, D., Simasiku, E.K., Martin, G.D., Lubanda, J., Hay, C.J. and Weyl, O.L.F., 2015. Ecology, fish and fishery of Lake Liambezi, a recently refilled floodplain lake in the Zambezi Region, Namibia. African Journal of Aquatic Science, 40(4), pp.417-424.
[62] Peel, R.A., Tweddle, D., Simasiku, E.K., Martin, G.D., Lubanda, J., Hay, C.J. and Weyl, O.L.F., 2015. Ecology, fish and fishery of Lake Liambezi, a recently refilled floodplain lake in the Zambezi Region, Namibia. African Journal of Aquatic Science, 40(4), pp.417-424.



Legend LULC Class	Cuando Chobe 1992 (km^2)	Cuando Chobe 2020 (km^2)	Change (%)
Agriculture	8,923	10,360	16.11%
Forest and Woodland	55,676	54,905	-1.38%
Grassland	18,556	17,876	-3.67%
Wetland	4,203	4,082	-2.88%
Settlement	10	16	69.91%
Shrubland	66,619	66,598	-0.03%
Bare/ sparse vegetation	2	2	0.00%
Water	75	225	198.07%
Total	154,063	154,063	-

Figure 45. The CCI LULC for the Cuando Chobe River Basin in 1992 and 2020. Note that the change in wetlands and water is because Lake Liambezi was classified as a wetland in 1992 and as water in 2020, following a 22-year dry period.

Settlements

Settlement within the Cuando Chobe Basin grew by 69.91%, however, this only accounts for a 6 km^2 increase. The last census within the Cuando Cubango province in Angola estimated a population of 677,430 people in 2022 (only 3.3 people/km^2)[63]. The main reason for this is the short supply of water and soil nutrients, limited access to roads, services and other commercial activity that are available in towns. Despite being small, the population is increasing at rapid rates on the floodplain fringes of the middle Cuando River (*see Google Open Building Analysis*).

Vegetation and Agriculture

Forest and woodland are common in the Cuando River Basin. In the upper reaches, open and closed canopy miombo woodlands are dominant, whereas these are displaced by Baikiaea-Burkea woodlands on deep Kalahari sands in the lower reaches[64]. Within the mid-basin, these two woodland areas are separated by a large expanse of shrubland, interspersed by grassland (Figure 45).

Natural vegetation cover in the Cuando Basin decreased by 1,472 km² from 1992 to 2020. During this

[63] Institute of National Statistics. 2022. Anuário de estatísticas sociais 2015 – 2022.

[64] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.

period, agriculture increased by 1,437 km² — accounting for this change (Figure 45). Most agriculture is in the southern areas of the basin, with a prominent concentration near the main road (B8) that connects Kongola with Katima Mulilo. Conversely, in Angola, the low human population has resulted in limited conversion of land for agriculture.

It is important to note that the low resolution of the LULC analysis only shows agriculture greater than 300 m^2, consequently many small-scale croplands have been missed. To better understand the croplands surrounding the Cuando River, a higher-resolution dataset — WorldCereal —has been used. The WorldCereal Cropland analysis reveals dense croplands on the Zambian side of the middle Cuando River (*see WorldCereal Cropland Analysis below*).

5.2 Google Open Building Analysis

Methods: Google Open Buildings Analysis

The Google Open Buildings dataset, which provides building footprints derived from satellite imagery[65], was used to calculate the number and total area of buildings within a 4 km buffer zone around the upper and middle sections of the Cuando River. 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 and Discussion: Google Open Buildings Analysis

The middle section of the Cuando River contains ~five times more buildings than the upper section (Figure 46). The upper section is sparsely populated due to its poor soils and isolation from roads and essential services. These results are similar to the Lungwebungu River, which had a building area coverage of 0.001% in the upper reaches and 0.008% in the lower reaches of Zambia.

The majority of buildings are located in Zambia along the edges of the floodplain and in the major towns. Most of these settlements are expanding (*see Land-use and Land-cover (LULC) Change Analysis*). Satellite imagery from 2004 to 2018 shows that Shangombo Town in Zambia experienced a 2.9% growth rate, exceeding the national rural average of 2.1% (Figure 47). Towns in south-eastern Angola are growing at rates over 10% per year[66]. This growth can be attributed to the significant number of people returning to these areas after the end of the civil war in 2002, along with the broader trend of rural-to-urban migration. The expansion of these towns along the Cuando River raises concerns, as many settlements have obstructed wildlife access to the river (*see Wildlife section*). Additionally, the increasing demand for agricultural land, grazing areas, and other natural resources could negatively impact the river and surrounding floodplains.

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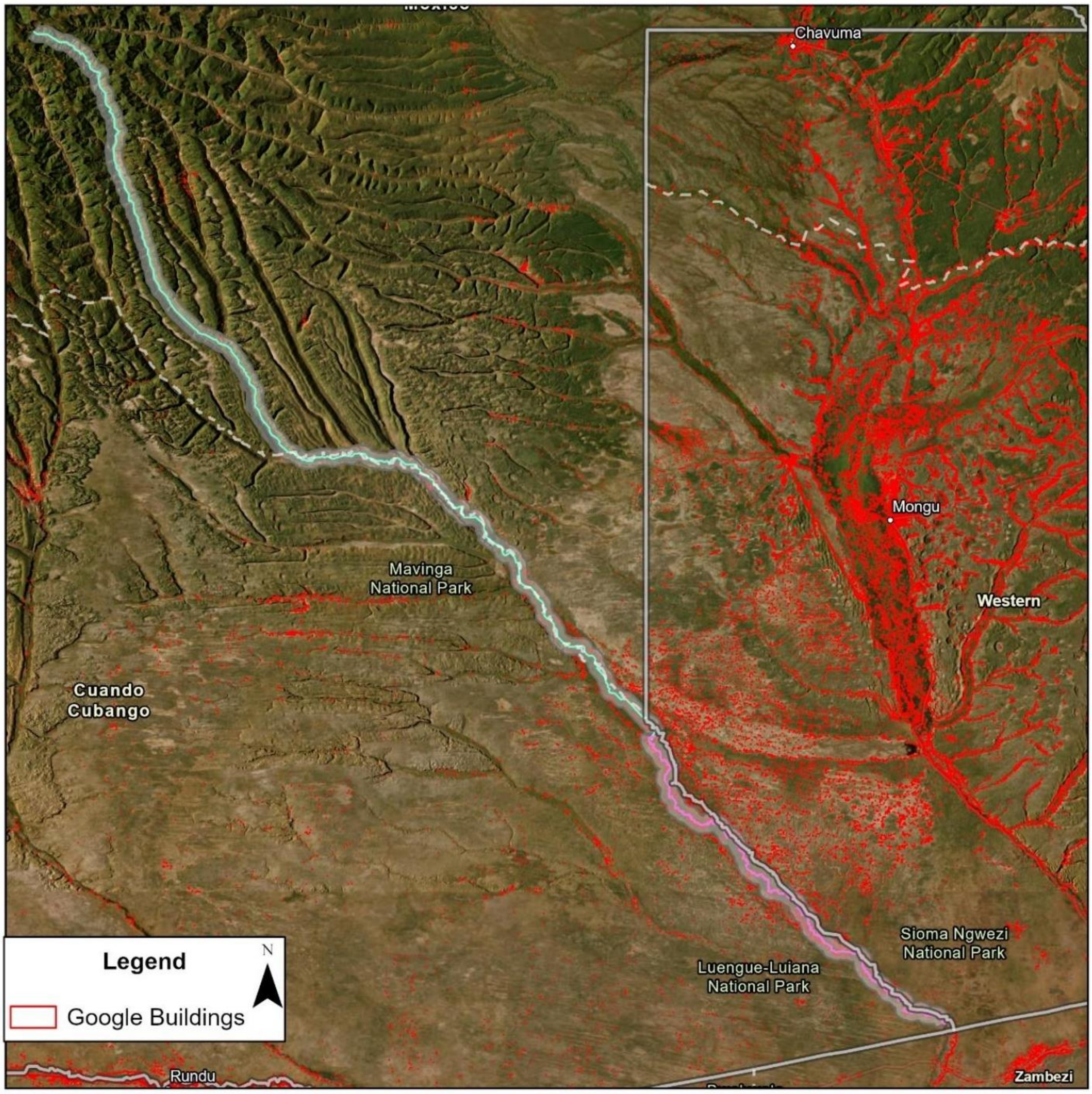
[65] Sirko, W., Kashubin, S., Ritter, M., Annkah, A., Salah, Y., Bouchareb, E., Dauphin, Y., Keysers, D., et al. 2021. Continental-scale building detection from high resolution satellite imagery.

[66] Pallett, J., Mukumbuta-Guillemin, I. & Mendelsohn, J.M. 2022. Cuando state of the basin report. (July):1–96.



Cuando 4km buffer	Buffer Area (km^2)	Total no. of buildings	No. of buildings/km^2	Total building area (km^2)	Building area (%) within Buffer Zone
Upper Cuando	4413	3516	0.80	0.06	0.001%
Middle Cuando	2114	8328	3.94	0.16	0.008%

Figure 46. A Google Open Building Analysis for the upper and middle Cuando River.

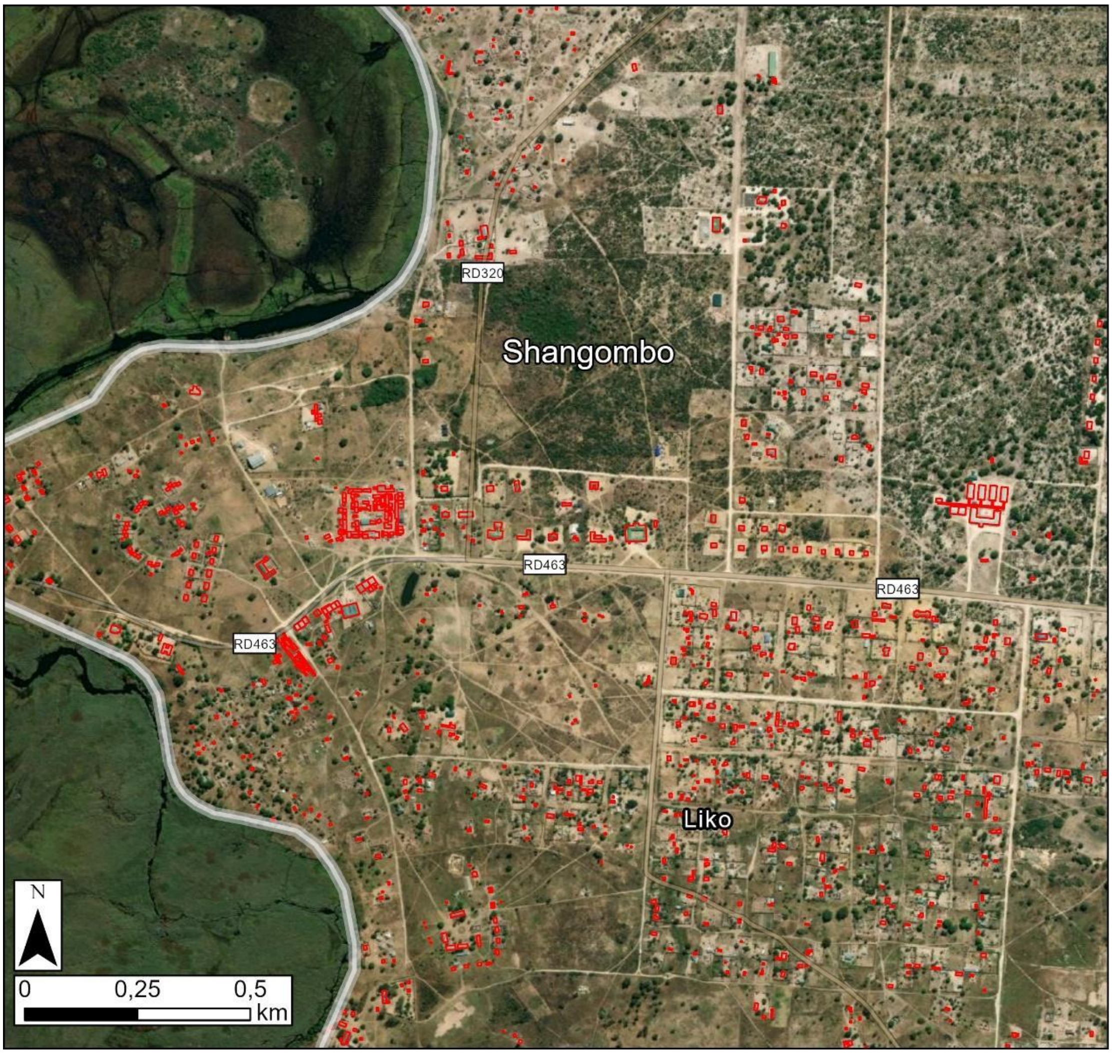


Figure 47. The Google Open Building classification of Shangombo Town.

5.3 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[67]. In this analysis, WorldCereal data was used to calculate the extent of cropland within a 10 km buffer zone around the middle Cuando River. The total cropland area within this buffer zone was determined by summing the areas of identified croplands.

Results and Discussion: WorldCereal Cropland Analysis

There is 120.54 km² of cropland within 10 km of the middle Cuando River. Most of this agricultural activity occurs on the Zambian side, notably within Sioma Ngwezi National Park (SNNP) (Figure 49). In this area, croplands form a dense barrier along the Cuando River, restricting wildlife access to this vital water source (Figure 49). This is particularly concerning, as the Cuando River is one of the main water sources within SNNP during the dry season. Additionally, blocked corridors force animals into villages or croplands, intensifying human-wildlife conflict. In response, SNNP is actively working to establish corridors within these agricultural areas to reconnect the park with the Cuando River (*see Wildlife section*).

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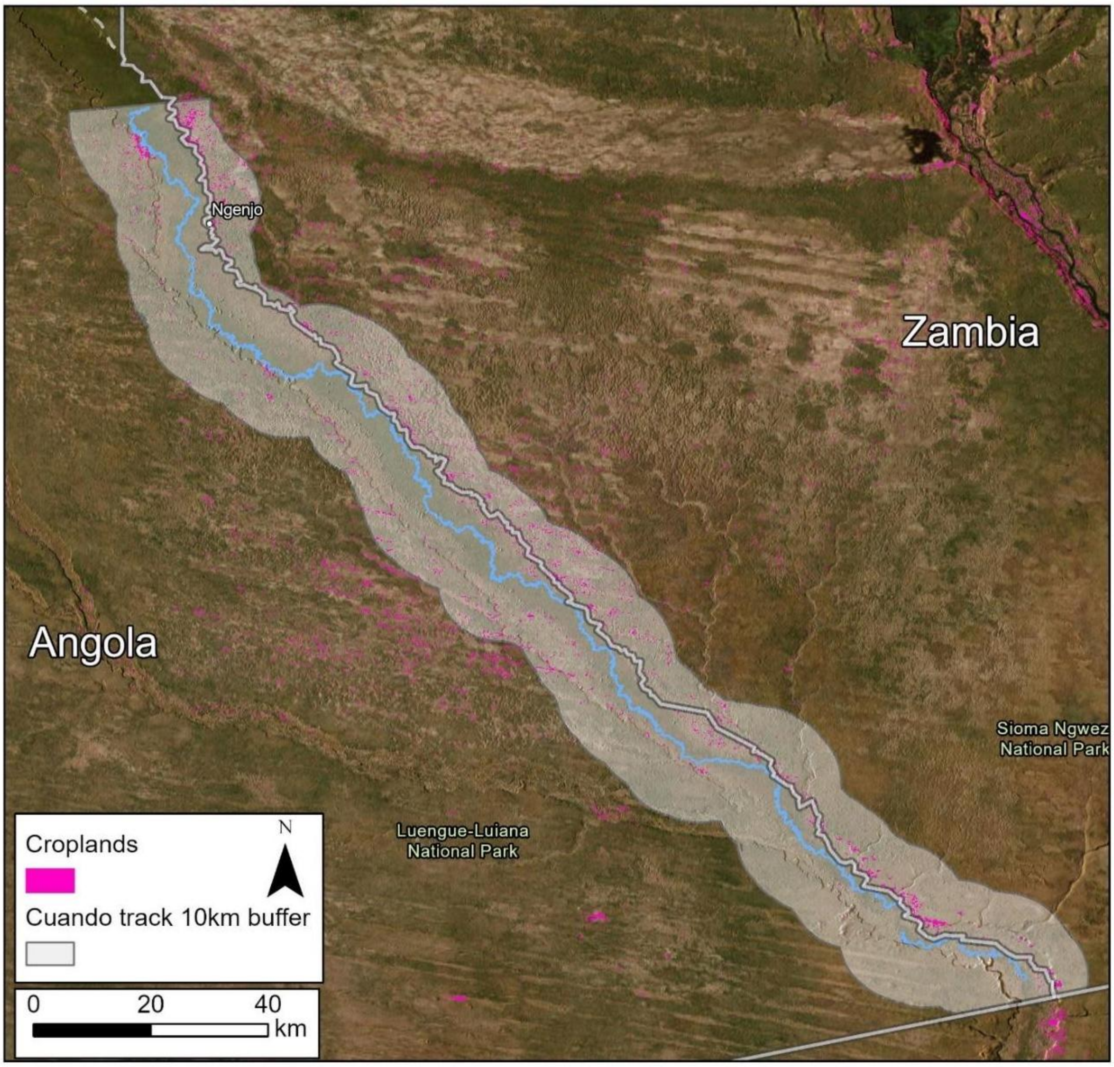
[67] Van Tricht, K., Degerickx, J., Gilliams, S., Zanaga, D., Battude, M., Grosu, A., Brombacher, J., Lesiv, M., et al. 2023. WorldCereal: a dynamic open-source system for global-scale, seasonal, and reproducible crop and irrigation mapping. Earth System Science Data. 15(12):5491–5515.



Cuando 10km buffer	Buffer area (km^2)	Total cropland area (km^2)	Cropland area (%) within buffer zone
Middle Cuando River	4912	120.54	2.45%

Figure 48. WorldCereal Cropland analysis for the middle Cuando River.

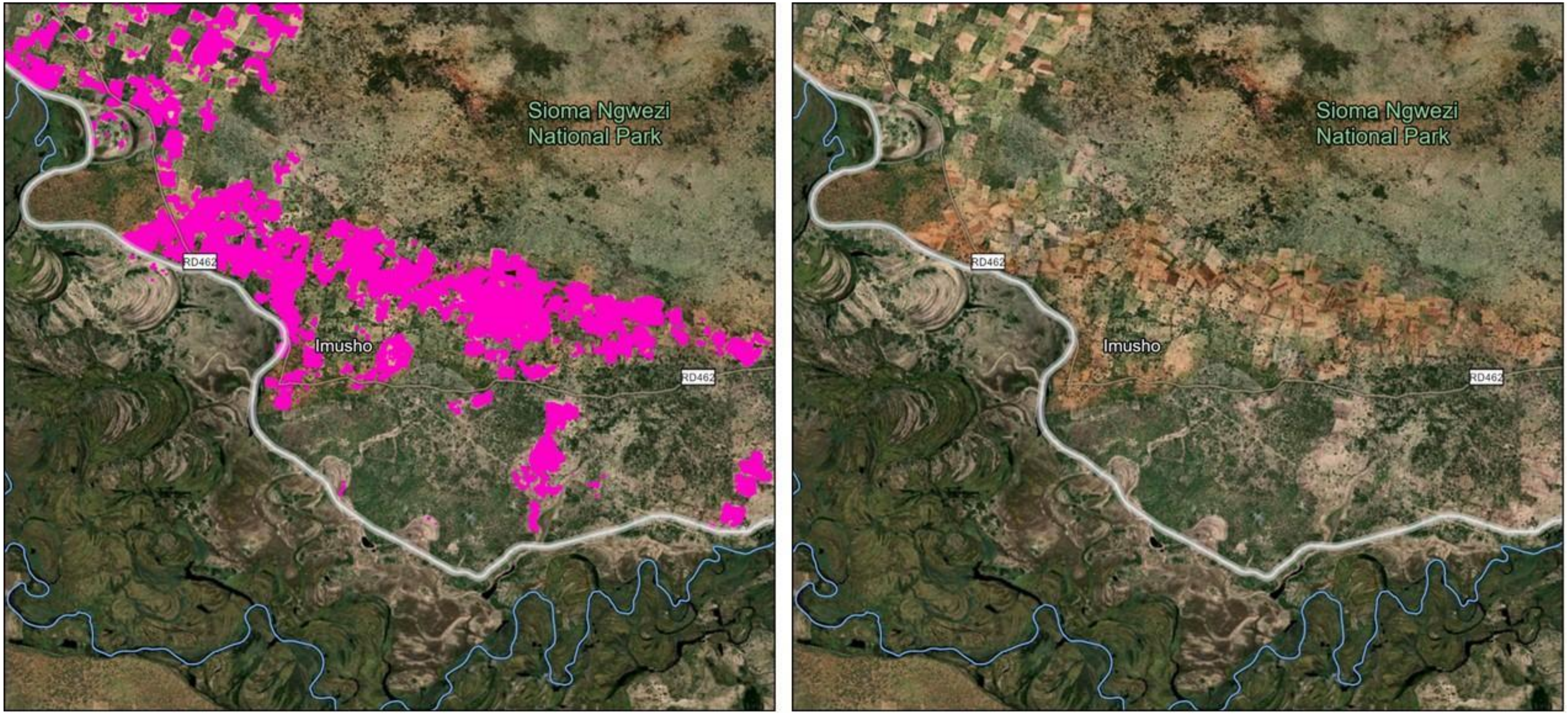


Figure 49. Croplands form a dense barrier along the Cuando River, restricting wildlife from Sioma Ngwezi National Park access to this vital water source. The WorldCereal cropland classification on the left compared to satellite imagery (right).

4. CONCLUSION AND RECOMMENDATIONS

The middle Cuando River remains largely undisturbed, with its expansive floodplains limiting permanent settlements and infrastructure development. As a result, human density along the river is low (0.13 people/km), allowing key ecological processes and biodiversity to persist. However, expanding croplands and settlements along the floodplain fringes could impact wildlife corridors, water quality, and aquatic habitats over time.

The integrity of the river supports high fish diversity, with 941 specimens from 45 species recorded during the survey — despite limited sampling effort. Notably, the possible detection of *Paramormyrops jacksoni* (Ghost Stonebasher) — a species last documented in 1967 — highlights the importance of ongoing monitoring and conservation efforts. Similarly, eDNA analyses identified 15 fish families from 32 genera, further emphasizing the rich biodiversity of the river system.

A total of 3,834 birds (6.9 birds/km) from 53 species were recorded, underscoring the importance of the middle Cuando River's dense floodplain and stable hydrology in sustaining wetland-associated bird populations. While habitat fragmentation could become a concern in the future, much of the region remains intact, continuing to provide critical nesting and foraging areas.

A total of 279 individual animals from six species were recorded, equating to a wildlife density of 0.50 animals/km. This is considerably higher than the densities of wildlife on the Upper Cuando River (0.07 animals/km). The southernmost stretch of the middle Cuando River serves as a crucial corridor, facilitating animal movement between Angola, Zambia, and Namibia. However, restricted wildlife access to the river from Sioma Ngwezi and Luengue-Luiana National Parks threatens regional connectivity and exacerbates human-wildlife conflict as animals are forced into villages and croplands.

Three alien invasive plant species (AIPs) were recorded—*Cassia* species, *Ricinus communis*, and *Salvinia molesta*—with the latter two establishing multiple populations. If left unmanaged, these AIPs could rapidly spread, degrading aquatic ecosystems. *S. molesta*, in particular, can clog human infrastructure, obstruct transport across water bodies, and degrade habitat quality for native fish species.

Water quality in the Cuando River is excellent, with key parameters such as temperature, conductivity, pH, and dissolved oxygen levels well within acceptable limits. At site 12, where the Uefo and Cuando Rivers meet, inflow from the Uefo causes a slight shift in water chemistry, lowering pH, dissolved oxygen, and temperature. However, overall, the river maintains a high standard of water quality, particularly in comparison to other regional waterways.

Hydrology measurements indicate a gradual decrease in discharge from 29.1 m^3/s to 23.9 m^3/s along the transect, influenced by channel morphology, floodplain evapotranspiration, and seepage into the basin's permeable sands. Climate projections for the region predict a 3°C temperature rise and a 4.6% decrease in rainfall by 2050, which may affect seasonal discharge patterns. Continued monitoring will help assess the long-term resilience of the system.

In light of this information, future recommendations for the sustainable management of the middle Cuando River include:

1. Enhancing Aquatic Biodiversity Monitoring and Conservation
    - Conduct a fisheries assessment that includes i) long-term fish biodiversity monitoring with regular eDNA sampling and species inventories, ii) the establishment of fish refuges to protect key species like *Paramormyrops jacksoni*, iii) an evaluation of fishing activities beyond the main river channel, iv) and the use of data to support sustainable management and community-based fisheries governance.

2. Protecting Wetland Habitats for Avian Biodiversity
    - Protect key wetland areas as bird conservation zones to prevent habitat loss.
    - Promote agroecological practices that minimize wetland degradation from agricultural expansion.
    - Conduct long-term bird population monitoring to track species trends and assess the impacts of habitat changes.
3. Strengthening Wildlife Access and Mitigating Human-Wildlife Conflict
    - Support efforts to establish and strengthen wildlife corridors linking Sioma Ngwezi and Luengue-Luiana National Parks to the Cuando River, enhancing habitat connectivity, biodiversity conservation, and ecosystem resilience.
    - Encourage sustainable ecotourism initiatives that benefit local communities while promoting wildlife conservation.
4. Controlling Alien Invasive Plant Species (AIPs)
    - Develop and implement invasive species management plans to control and eradicate *Cassia* species, *Ricinus communis,* and *Salvinia molesta.*
    - Promote early detection and rapid response programs to prevent further spread of invasive species.
    - Engage local communities in invasive species control efforts through training and employment opportunities.
5. Maintaining Water Quality and Hydrological Integrity
    - Improve hydrological monitoring to track evapotranspiration rates, seepage losses, groundwater fluctuations and seasonal discharge fluctuations.
    - Develop climate adaptation strategies to address projected temperature increases and rainfall declines.
    - Conduct regular water quality monitoring to track key parameters such as pH, dissolved oxygen, conductivity, and temperature, particularly at the Uefo confluence and other areas affected by tributary inflows and human activity.

APPENDICES

Appendix 1. Past and ongoing initiatives in the Cuando Basin.

Project	Partners	Description
Water Partnership for a Resilient Kwando Basin	United States Agency for International Development (USAID) and supported by the World Wildlife Fund for Nature (WWF), the Zambezi Watercourse Commission (ZAMCOM) and the Kavango–Zambezi Transfrontier Conservation Area (KAZA).	Aims to strengthen transboundary water governance and inclusive decision-making mechanisms across the four countries that the basin transverses: Zambia, Namibia, Botswana, and Angola
Transboundary Governance of the Cuando; Protecting the Heart of Southern Africa	United States Department of State (USDOS) and supported by the World Wildlife Fund for Nature (WWF); the Zambezi Watercourse Commission (ZAMCOM); and the Kavango-Zambezi Transfrontier Conservation Area (KAZA) Secretariat	To strengthen the transboundary planning, management and governance in the Kwando River Basin in Southern Africa.
Community Engagement in the Cuando-Cubango District	ACADIR (Associação de Conservação do Ambiente e Desenvolvimento Integrado Rural) KCS - Kalahari Conservation Society German Federal Ministry of Economic Cooperation and Development (BMZ)	In the framework of the project, ACADIR will reach target groups in the catchment area of the Cubango-Okavango River in the remote region of Southeast Angola. In three villages, a total of 190 households with a total of 1,115 people from marginalised rural ethnic minorities are defined as direct beneficiaries. The people will be better informed about their rights and their opportunities for water use in the transboundary Okavango River system and will be involved in a campaign to protect the common waters in the Okavango River system in Angola, Namibia and Botswana through the UNESCO World Heritage Convention.
Cuando-Cubango: Energy 2040	The Nature Conservancy	Development, with the constructive engagement of Angola's national and provincial governments, of the Vision Cuando-Cubango: Energy 2040, targeting the electrification plan of the province and the recommendations on the best alternative renewable energy sources and siting to achieve lower-impact renewable energy security in Cuando-Cubango Province while ensuring the sustained provision of ecosystem goods and services by the Okavango River Basin.

Appendix 2. Wetland- associated bird species observed on the Cuando River.

Species	Scientific name	Count
Little Bee-eater	*Merops pusillus*	880
African Openbill	*Anastomus lamelligerus*	659
Blue-cheeked Bee-eater	*Merops persicus*	488
White-faced Whistling Duck	*Dendrocygna viduata*	244
African Darter	*Anhinga rufa*	242
White-fronted Bee-eater	*Merops bullockoides*	242
Blacksmith Lapwing	*Vanellus armatus*	167
Black-crowned Night Heron	*Nycticorax nycticorax*	127
Southern Carmine Bee-eater	*Merops nubicoides*	121
Pied Kingfisher	*Ceryle rudis*	114
Malachite Kingfisher	*Corythornis cristatus*	70
Reed Cormorant	*Microcarbo africanus*	61
African Jacana	*Actophilornis africanus*	47
Hamerkop	*Scopus umbretta*	44
African Wattled Lapwing	*Vanellus senegallus*	32
Swamp Boubou	*Laniarius bicolor*	31
Water Thick-knee	*Burhinus vermiculatus*	28
Western Cattle Egret	*Bubulcus ibis*	27
Black Crake	*Zapornia flavirostra*	24
Spur-winged Goose	*Plectropterus gambensis*	24
Rufous-bellied Heron	*Ardeola rufiventris*	18
Hadada Ibis	*Bostrychia hagedash*	17
European Bee-eater	*Merops apiaster*	14
African Marsh Harrier	*Circus ranivorus*	13
African Pygmy Goose	*Nettapus auritus*	12
Striated Heron	*Butorides striata*	12
African Fish Eagle	*Haliaeetus vocifer*	10
White-winged Tern	*Chlidonias leucopterus*	10
Coppery-tailed Coucal	*Centropus cupreicaudus*	7
Goliath Heron	*Ardea goliath*	7
Purple Heron	*Ardea purpurea*	7
Fan-tailed Widowbird	*Euplectes axillaris*	5
Whiskered Tern	*Chlidonias hybrida*	5
Black-winged Kite	*Elanus caeruleus*	4
Saddle-billed Stork	*Ephippiorhynchus senegalensis*	3
Black-chested Snake Eagle	*Circaetus pectoralis*	2
Cape Wagtail	*Motacilla capensis*	2
Common Moorhen	*Gallinula chloropus*	2
Grey Go-away-bird	*Corythaixoides concolor*	2
Long-toed lapwing	*Vanellus crassirostris*	2
Slaty Egret	*Egretta vinaceigula*	2
Squacco Heron	*Ardeola ralloides*	2
Woodland Kingfisher	*Halcyon senegalensis*	2
Allen’s Gallinule	*Porphyrio alleni*	1
Black-headed Heron	*Ardea melanocephala*	1
Giant Kingfisher	*Megaceryle maxima*	1
Lesser Moorhen	*Paragallinula angulata*	2
Lesser Jacana	*Microparra capensis*	1
Little Bittern	*Ixobrychus minutus*	1
Little Egret	*Egretta garzetta*	1
Long-crested Eagle	*Lophaetus occipitalis*	1
Western Banded Snake Eagle	*Circaetus cinerascens*	1
Western Barn Owl	*Tyto alba*	1

Appendix 3. Description of 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 utilised 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 4. LULC Supplementary Table.

IPCC Classes considered for the change detection (with colour)	LCCS legend used in the CCI-LC maps	
	Code	Description
1. Agriculture	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 5. Results of the opportunistic fish sampling that was conducted on the Cuando River.

Fish sampling site	Latitude (°)	Longitude (°)	No. of Specimen	Number of Species
1	-16.27404	22.04182	6	6
2	-16.27905	22.02383	44	14
3	-16.89965	22.48178	6	4
4	-16.94009	22.55592	11	4
5	-17.03273	22.68311	43	13
6	-17.19323	22.79015	301	17
7	-17.26901	22.85876	1	1
8	-17.27534	22.90598	63	18
9	-17.42786	23.09736	58	12
10	-17.47395	23.12095	199	23
11	-17.50704	23.2023	1	1
12	-17.50988	23.20155	208	13

Appendix 6. The counts of fish species caught on the Cuando River.

Scientific name	Count
Lacustricola johnstoni	227
Lacustricola mediolateralis	89
Pseudocrenilabrus philander	82
Enteromius multilineatus	65
Enteromius afrovernayi	57
Nannocharax machodoi	55
Enteromius fasciolatus	53
Pollimyrus cuandoensis	45
Enteromius haasianus	33
Enteromius bifrenatus	24
Enteromius paludinosus	23
Tilapia sparmanii	20
Micralestes acutidens	18
Enteromius eutaenia	17
Nannocharax multifasciatus	17
Microctenopoma intermedius	15
Synodontis vanderwaali	14
Oreochromis macrochir	12
Enteromius barnardi	9
Petrocephalus okavangensis	9
Enteromius thamalakanensis	7
Pharyngochromis acuticeps	7
Coptodon rendalli	5
Hippopotamyrus szaboi	4
Synodontis macrostoma	4
Lacustricola katangae	3
Marcusenius altisambezi	3
Brycinus lateralis	2
Chiloglanis fasciatus	2
Mastacembelus fasciatus	2
Petrocephalus longicapitis	2
Serranochromis alcrum	2
Serranochromis macrocephalus	2
Clarias sp.	1
Cyphomyrus cubangoensis	1
Enteromius brevidorsalis	1
Enteromius chicapaensis	1
Hemichromis elongatus	1
Hepsetus cuvieri	1
Hippopotamyrus ansorgii	1
Lacustricola chobensis	1
Marcusenius moorii	1
Opsaridium zambense	1
Petrocephalus magnitrunci	1
Serranochromis angusticeps	1

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