NATIONAL GEOGRAPHIC

OKAVANGO WILDERNESS PROJECT

WILD BIRD TRUST

REPORT 7

Kavango River Transect, 2021

December 2021

EXECUTIVE SUMMARY

In September 2021, the National Geographic Okavango Wilderness Project (NGOWP) deployed a ten-person team to paddle the length of the Kavango River (487km over 17 days) with three main objectives: 1) repeat the 2017 baseline survey to assess potential change in river health, 2) implement new long term monitoring methodology with the intention of repeating this survey biennially, 3) build local capacity.

The NGOWP specialises in baseline data collection and long term monitoring and is not an academic institution. Thus, this report recommends that local authorities, NGOs and academics set out to verify the findings reported here and seek solutions to preserve the crucial ecosystem services this incredible river offers.

Mapped data are presented in an ESRI web application and 360 degree images of the entire transect can be viewed in an EarthViews web application.

The river was exceptionally low (23.4 m^3/s entering at Katwitwi) exacerbating plastic pollution and poor water quality. Concerning water chemistry values appeared to be linked mostly to commercial agricultural activity. Nitrate levels were well above the acceptable norm posing potential health concerns, especially when the first rains arrive and copious cattle excrement on the river bank adds to the mix. Fortunately, the cleaner waters of the Cuito River do much to clear up the Kavango after the confluence. But the bulk of human population occurs before the confluence and it is strongly recommended that health is monitored closely.

It is encouraging that wildlife (mammals and birds) abundance remained largely unchanged since 2017 and that aquatic macroinvertebrate communities were, for the most part, intact. However, steep increasing trends in human and livestock immigration raise future concerns. Since 2017, there has been a three-fold increase in humans and a five-fold increase in cattle along the Kavango River bank. Land use change analysis reveals rapid urbanisation along the Namibian river bank with agriculture (commercial and subsistence) being the main cause. Rapid deforestation and overgrazing coupled with exploding alien invasive plant communities raises several concerns involving erosion, loss of biodiversity and general diminishment of river ecosystem services.

Water abstractions along the Namibian side have more than doubled since 2017, the main purpose being agriculture. Several very large abstraction points are under construction, destined to irrigate new green schemes.

Observations of the use of fine-meshed fish netting material, the frequent use of drag nets and the existence of commercial ventures that completely deplete local fish stocks and discard unwanted gill nets (ghost nets) in or next to the river is unlikely to remain sustainable, as outlined in various other reports from varied sources. Barring the rapid establishment of several well-policed no-fishing zones, the fishery is likely to collapse in the coming years.

NGOWP recognises that any remedial recommendations proposed in this report must take the well-being and sustained livelihoods of the surrounding communities into full consideration and that future conservation action must be transparent, inclusive and mutually beneficial to the communities and their environment alike.

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TERMS AND ABBREVIATIONS

Abbreviation	Term
AIP	Alien Invasive Plants
ADCP	Acoustic Doppler Current Profiler
ASPT	Average Score Per Taxon
DDT	Dichloro-diphenyl-trichloroethane
DO	Dissolved Oxygen
EC	Electrical Conductivity
eDNA	Environmental DNA
EU	European Union
KIFI	Kamutjonga Inland Fisheries Institute
MIRAI	Macroinvertebrate Response Assessment Index
NASS	Namibian Scoring System
NGO	Non-Governmental Organisation
NGOWP	National Geographic Okavango Wilderness Project
NGS	National Geographic Society
OKACOM	Permanent Okavango River Basin Water Commission
OPP	Oxygen Partial Pressure
ORP	Oxidation Reduction Potential
RDO	Rugged Dissolved Oxygen
SADC	Southern African development Community
SAIAB	South African Institute for Aquatic Biodiversity
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UNAM	University of Namibia
WBT	Wild Bird Trust

1. INTRODUCTION

1.1 Background of the National Geographic Okavango Wilderness Project

Since 2010, the Wild Bird Trust (WBT) has been conducting annual transects across the Okavango Delta, Botswana, collecting baseline environmental data aimed at monitoring the long-term health of the Okavango Delta ecosystem. Having recognised the importance of upstream conditions in Angola and Namibia, a partnership between WBT and the National Geographic Society was inaugurated in 2015 and named the National Geographic Okavango Wilderness Project (NGOWP). The purpose of this project was to conduct systematic river-based explorations and to conduct baseline ecological surveys of the upper and middle reaches of the Okavango Basin. The exploration component aimed to build awareness around these splendid, yet poorly documented rivers while the baseline data served to create a benchmark against which to measure future ecological change.

In close collaboration with the governments of Angola, Namibia, and Botswana, conservation NGOs and academic institutions, NGOWP quickly went to work starting with the rediscovery of the Okavango source lakes in the Angolan highlands, as well as extensive biodiversity and socio-economic surveys. In May 2015 the NGOWP launched a 'megatransect' river expedition beginning at the Cuito River source lake and ending over 2400km away at Lake Xau, in Botswana, six months later (NGOWP 2017). In March 2016 the team surveyed the full length of the Cuanavale River from its source lake to the confluence with the Cuito River. In May 2017, three-month expedition commenced from the source of the Cubango River down to the confluence with the Cuito River on the Namibian border (NGOWP 2020a), thus completing exploration of all major rivers in the Okavango Basin. In 2018, NGOWP completed yet another megatransect – this time following the course of the Cuando River from source to the Zambian border at Rivungu (NGOWP 2020b). Currently, the NGOWP is working with the Angolan Government to establish, activate and support effective management of new conservation areas proposed for the source lake region in the Angolan highlands.

Figure 1: Major expeditions conducted by NGOWP since 2015

1.2 Expedition Procedures and Safety

To navigate rivers, the NGOWP uses 'mekoro', traditional 18-foot dugout canoe fiberglass replicas. Mekoro have long been the conventional means of transport in the Okavango Basin and are ideal for this kind of river exploration for several reasons: They can be carried by two people; it is possible to stand while paddling; they can be loaded with 500 kg of equipment, and they have an extremely shallow draft. In contrast, motorised aluminium or fiberglass boats are noisy, cannot be carried and have a deeper draft. Typical mokoro configuration comprises 300kg of equipment strategically packed into the middle of the boat leaving enough space for a person on either end. Equipment includes dried foods, personal gear, tents, research equipment, medical kits and kitchenware, topped off with a solar panel that charges a lithium-ion battery. Both people paddle the mokoro but the person at the back is the captain, responsible for speed, steering and safety. Depending on river flow, obstructions and wind, the team can cover 20-40 km per day.

In the mornings the team is usually underway by 09:00, slowly moving down the river collecting scientific observations on digital tablets. The captains, being more experienced, call out observations and the persons in the front record the data. Around 16:00 camp is set on the riverbank to prepare food, upload data and rest for the night. NGOWP has extensive experience with this manner of river exploration and has traversed the length of the Okavango, Cuito, Cuanavale, Kavango and most of the Cubango and Cuando rivers this way, as well as completing 12 crossings of the Okavango Delta (over 11,000km in total).

Figure 2: The expedition team camped at the Kavango / Cuito confluence.

All possible avenues for medical support and general safety have been put into place. Land support vehicles follow the mekoro down river and meet up with them in the evenings whenever possible. All team members have full medical cover, and a medevac protocol is put in place beforehand. At least two team members are qualified in advanced medical aid, and we have access to the telephonic medical oversight and services provided by the NGS and local practitioners. The expedition team carries full trauma, resuscitation, and medical kits. At least one team member is always on standby in the country during expeditions to relay messages and liaise directly with the relevant authorities.

1.3 Study Site Description

The Cubango River has its head waters in central Angola near the town of Huambo from where it flows in a south-easterly direction for about 1000km before entering Namibia. Once the river enters Namibia it is called the Kavango, where it forms the boundary between the Kavango East Region of Namibia and the Cuando-Cubango Province of Angola. When the river enters Botswana it becomes the Okavango forming the 'panhandle' that culminates in an alluvial fan, the Okavango Delta (figure 3).

The average annual rainfall at Rundu is 445mm peaking in January and February (Namibia Meteorological Services 1997). The river undergoes an annual pulse that typically peaks in April at Rundu at about 6m river height and ebbs down to about 3m in October (Strohbach2013). During peak flow, the Kavango typically discharges 400-600m^3/s into the Okavango River at the Botswana border (Bauer et al 2014).

Figure 3: The Okavango Basin spans the countries of Angola, Namibia and Botswana. The Kavango section (darker blue) of the river forms the border between Angola and Namibia

In 2011, the Kavango East region had a population size of 136,832 of which 61,900 people lived in Rundu and the remaining 55% lived alongside the Kavango River at a population density of between 10 to 40 people per km^2 (Mendelsohn & el Obeid 2003). There is a striking difference in population density between the Namibian and Angolan side of the river, in that the Angolan side is far less populated than the Namibian side due to the war (Mendelsohn & el Obeid 2003). The Kavango has the highest average household size in the country (6.0 persons per household), and in general has some of the poorest people in the country (Mendelsohn et al. 2006).

The livelihoods of people are typically sustained by subsistence agriculture, livestock and small-scale fishing, meaning that most people rely heavily on the river and its adjacent vegetation. The resultant overexploitation of the land has led to significant deforestation and land degradation, especially in recent years. The area mainly affected is the valley bottom which is predominantly used for agriculture. About 90% of the valley bottom has been altered, leaving only a few patches of natural vegetation in place (Strohbach 2013).

Figure 4: A Google Earth image showing extensive agricultural development along the Kavango.

The floodplains are mainly used for grazing as well as fishing during the late flood season. Overgrazing and the destruction of riparian vegetation have a big impact on the spawning fish communities. There is a paucity of scientific research on the impact of these land uses along the Kavango River, a basic literature survey follows:

Hocutt et al (1994) investigated the biological basis of water quality assessment and recommended that water quality monitoring strategies that include management and sustainable use of resources are adapted. Hocutt and Johnson (2001) reported the first seasonal fish survey along the Kavango. Their data supports the flood pulse concept which assumes that the seasonal flooding is the major driver of fish distribution in floodplains. Aust et al in 2009 studied the impact of crocodiles on rural livelihoods and found that human-crocodile conflict is greater than previously thought and could have an impact on conservation objectives in the area. Strohbach 2013 looked at the vegetation of the Okavango River valley in Namibia. He concluded that the vegetation is a vital ecosystem service provider but its functioning and resilience remains poorly understood. Tweddle and Hay in 2013 composed a transboundary management plan for the Okavango basin. In 2015 Bauer-Gottwein et al attempted to develop an open source software for hydrological forecasting and water resource management in the Kavango basin. Their results showed that the predictions are best for short lead times between 4 and 7 days. Vushe et al (2014) investigated the land use change and nutrient water quality of the Kavango. They found that irrigated area increased by over 100% between 1990 and 2012 and forests, shrubs and grassland have decreased over 11% over the same period. Their study showed that land use change had a low impact on the river itself. Taylor et al in 2017 compared fish assemblages and food-web structures. They found that fish assemblages in the Kavango river changed according to the flood pulse. Jacobs et al 2019 studied the movement behaviour of tigerfish for planning freshwater protected areas. They concluded that fresh water protected areas can be a useful management tool. For example, a 10km stretch of river under protection could protect at least 50% of tiger fish for threequarters of the time.

1.4 Team Members and Expedition Timing

The team consisted of 11 people including four Namibians, three Motswana, and four South Africans. The expedition commenced on 30 August near Katwitwi and ended 18 days later on 17 September at KIFI near the border of Mahangu Game Park. The expedition was arranged and based in Namibia and thus the team overnighted exclusively on the Namibian side.

Figure 5: The NGOWP 2021 Kavango expedition team near the start of the transect.

Table 1: Kavango 2021, expedition team members

	Gobonamang "GB" Kgetho GB is the NGOWP lead poler and a member of the Seronga Polers Trust. GB has crossed the Okavango Delta every year since 2010 with project leader Steve Boyes and is an exemplary ambassador of the Okavango Delta and the baYei community. He has a keen interest in the culture and history of indigenous communities. GB's vast experience in navigating mekoro down difficult waterways and past wild animals keeps the team safe and fully aware at all times.
	Bernardrd "BT" Thumeletso BT is the son of legendary Thumeletso "Water" Setlabosha. BT manages all camp amenities during expeditions and he is also a mokoro captain, which means BT is exceptionally busy. Back in Maun, where he spends much of his time off expedition, he manages and maintains expedition equipment and assists with many other things. BT is also becoming increasingly involved as a research assistant. He was involved with the installation of a hydrometric monitoring station on the Thamalakane River and during the 2021 Kavango expedition he assisted Rob Taylor with aquatic invertebrate surveys.
	Boniface "Bonny" Kangayi Bonny was born and raised on the Kavango River in Namibia. He grew up in a small village and first worked as a thatcher. His hard work and unwavering quest for knowledge got him a job at Ngepi River Camp as a river guide. For several years he guided guests through Andara, a beautiful section of the Kavango River full of rapids and elephants. The NGOWP came to hear of Bonny's abilities and knowledge and hired him as a river guide and mokoro captain for the 2021 Kavango expedition.
	Götz Neef Namibian-born Götz joined the NGOWP in 2015 as the Research Manager. Since then he coordinates all the data and samples collected by the project. During expeditions he works with the various specialists and research assistants undertaking sampling, trapping, and data recording. During the 2021 Kavango expedition, he took on the role of expedition leader, taking ultimate responsibility for the team.
	Martha George Martha is a fisheries biologist from Kamutjonga Inland Fisheries Institute (KIFI) in Namibia where she is currently pursuing her master's degree. She is passionate about freshwater fisheries with a particular interest in fish health, pollutants and the management and sustainability of fisheries resources. On the Kavango expedition, she was assessing pollution of heavy metals and pesticides using tigerfish as an indicator species.
	Scott Buckley Scott has worked with the NGOWP since 2017 and had the difficult task of providing backup for the river team and providing them with resupplies. Scott is accustomed to working in difficult and remote locations and is an excellent problem solver. On the Kavango expedition, he mirrored our movements on land in a vehicle doing his best to stay as close to the team as possible.

	Maryna Story Maryna is a technical consultant, researcher and programme manager, conducting analytical assessment, scheduling, and reporting related to natural resource management, spatial development, livelihoods, disaster risk management and climate change measurement, adaptation and mitigation. The European Union is rolling out a long-term programme that requires integrated management of governance systems and operational processes across the three OKACOM Member States and Maryna is the Team Lead since October 2018, managing and providing programmatic and logistical support to a specialist team of experts that implement a range of activities within the Programme. In this role she is the primary liaison between the EU Delegation & OKASEC, and the Technical Assistance team. This requires ongoing management of programme risks and identification of positive solutions to technical and financial challenges.
	Rainer von Brandis Rainer achieved his Doctorate degree in Conservation in 2012 and has over 25 years of experience in research and monitoring. Rainer largely designed the sampling procedures and protocols and, during the 2021 Kavango expedition, he ensured that data were collected consistently and accurately down the full length of the transect
	Darryn February Darryn is a Namibian born Storyteller. With 8+ years in the creative industry, and 5 years as an acting professional, he is well versed in all aspects of the world of visuals from conceptualization to capturing visuals and creating the final product in post-production. In 2017 Darryn won a short film award which had him placed in Cardiff, Wales under veterans of the creative industry as part of a story telling initiative. In 2018 Darryn began his post at a creative agency called Hashtag Media Namibia as an intern in the production department, he worked his way up the ranks to eventually assuming the position as Production Manager. Currently he is pursuing a Bachelors in Journalism and Mass Communication in Bhopal, India.
	Robert Taylor Rob Taylor studied ecology completing his BSc at the University of KwaZulu-Natal, Pietermaritzburg and his MSc through the University of Witwatersrand, Johannesburg. As a research technician for the South African Environmental Observation Network Rob worked on alien plant mapping and long-term ecological monitoring projects in and around the Kruger National Park. Rob then worked as a wetland and aquatic specialist for 2 years conducting wetlands and river health assessments throughout southern Africa. Since 2018 Rob has been working as an ecologist in the Okavango. He has particular passions for aquatic plants and invertebrates.
	Simon Johnson Simon is a Technical Director of JG Afrika, and Engineering and Environmental Consultancy, and a registered Professional Natural Scientist in the field of Hydrological Sciences. He has been involved as a water resources specialist on several transboundary water resource planning and development, flood modelling and flood risk system development and climate change impact assessment projects across the SADC region. His passion lies in the understanding and protection of river basins and their populations in an African context, as well as the generation of user-friendly understandable information to assist decision makers in the water resource management space. Simon joined the team for a few days to gain first-hand experience of the Kavango river and to provide some valuable insight into its hydrological complexities.

1.5 Expedition Objectives

The aim of the expedition was to traverse the entire length of the Kavango River starting near the Angolan border (Katwitwi) and ending near the Botswanan border (Mohembo), a distance of 487km.

Specific objectives included:

- Repeat the 2017 survey using identical methods and materials.
- Introduce additional methodologies in line with recent technological advances.
- Give OKACOM team members as well as local students, river guides and storytellers an opportunity to participate in an effort to build regional capacity and collaboration.

1.6 Survey Design

In 2017 the expedition team's objective was to collect baseline data along a continuous transect to assess general river health. As the team slowly paddled downstream, all wildlife, birds, humans, water abstractions, fishing activities, water borne vessels and livestock were counted, water quality was measured using a multiparameter sonde and a permanent record of riparian habitat was created using a 360-degree camera at 1-minute intervals (NGOWP 2020a).

In 2021, the team's research objectives were to repeat the 2017 baseline survey and to include new long term monitoring parameters based on recent advances in conservation technology. To draw a meaningful comparison between 2017 and 2021, we collected the baseline data using identical methods and procedures used in 2017. To add the new monitoring parameters, we established 49 fixed site monitoring sites roughly equidistant from each other along the length of the river (figure 6). At all 49 sites the team stopped to measure water quality and deploy a drone to capture fixed-point photos of the river and its surrounds. Nine of the 49 sites were 'intense' monitoring sites where the team also conducted a rapid bio-assessment of the ecological river condition using the Namibian Scoring System (NASS) and collected eDNA samples to detect fish diversity, dangerous pathogens and invasive species such as Nile tilapia and crawfish. We also used an Acoustic Doppler Current Profiler (ADCP) to measure water discharge at the start of the transect, half-way to the Cuito River confluence and at the confluence. Lastly, we deployed an acoustic recorder and a fyke-net at random sites (overnight camps) to determine bat and fish diversity respectively.

In 2017, the team started at the source of the Cubango near the town of Huambo and ended in Namibia at the Cuito river confluence. In 2021 the team remained in Namibia starting at Katwitwi on the Angolan border and ending near Mohembo on the Botswanan border. Thus, we exclude data collected after the Cuito confluence in all instances where 2017 data are compared to that of 2021.

It's important to note that the expedition followed the main stream of the river, always moving forwards along the path of least resistance. We did not explore backwaters or oxbow lakes.

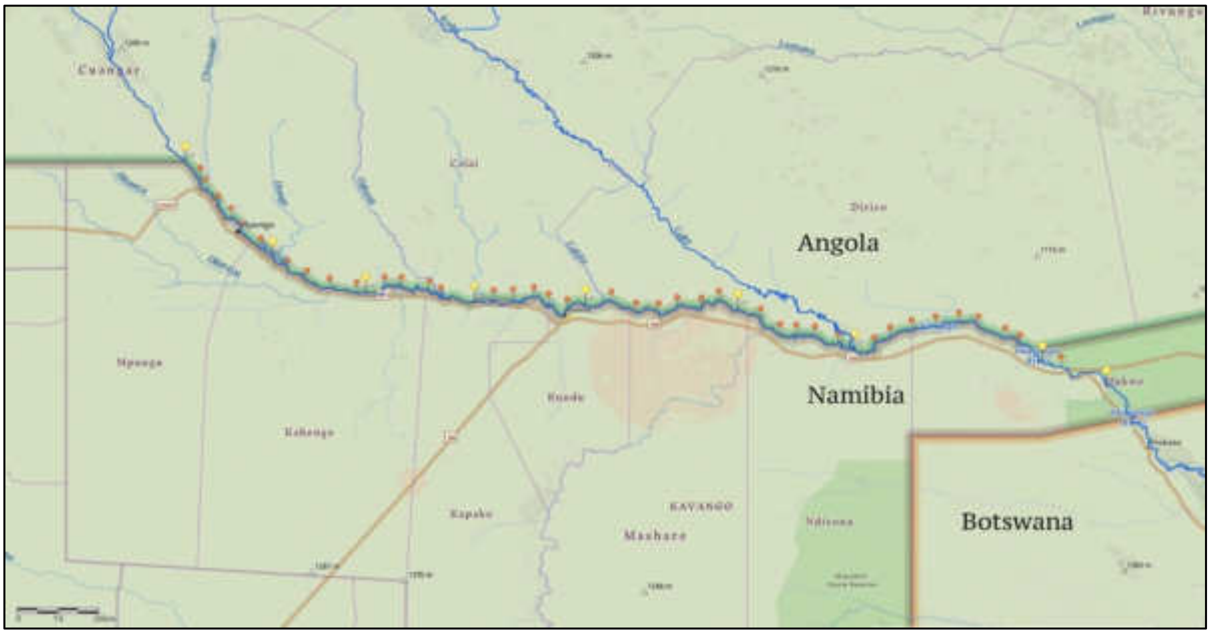


Figure 6: 49 permanent monitoring sites along the Kavango river where NGOWP will collect fixed point drone imagery and water quality parameters biennially. At the 'intense' monitoring sites (yellow pins only), eDNA samples are also collected and rapid ecological river condition assessments (NASS) are conducted.

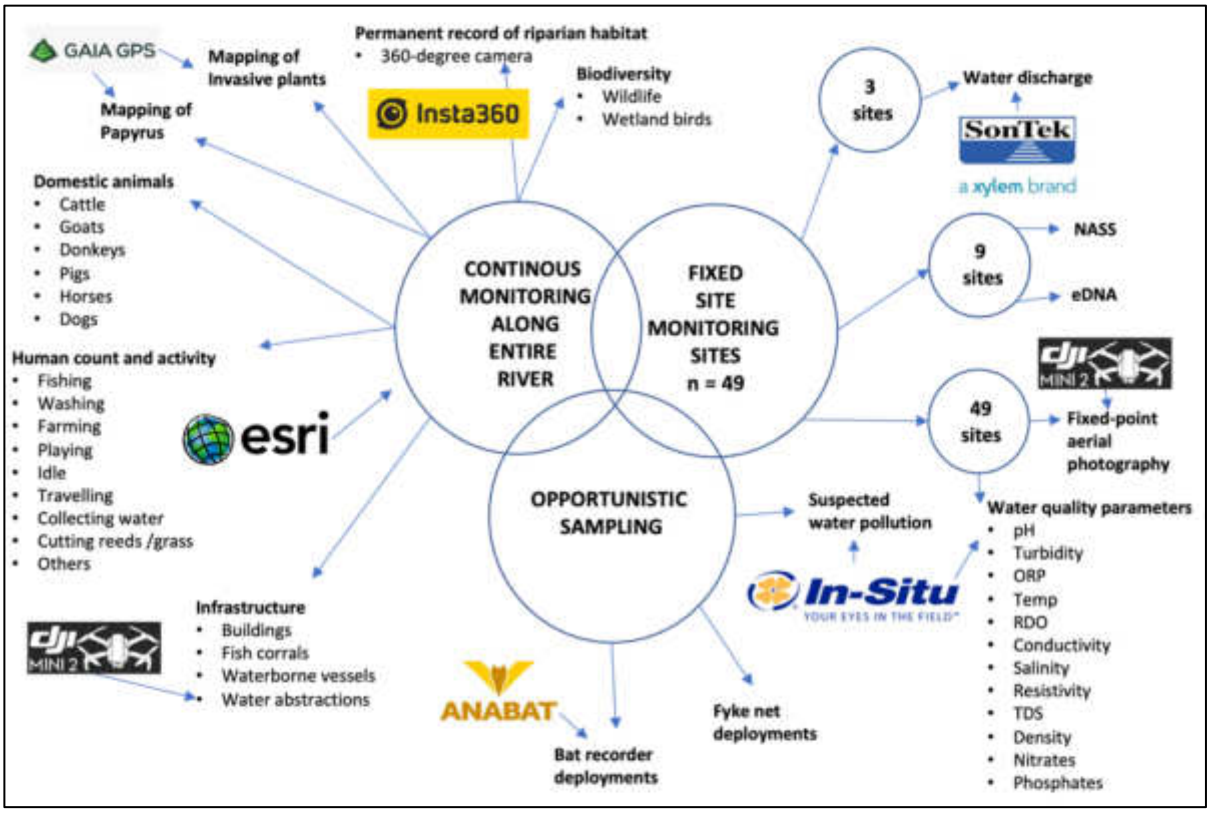


Figure 7: The various types of data that were collected along the continuous river transect, at the 49 fixed site monitoring sites and at opportunistic monitoring sites along the Kavango River.

1.7 Survey Limitations and Potential Data Bias

There are several limitations and biases involved when collecting data as described in section 1.6 above. These often limit statistical confidence and require due consideration when making management decisions. Hence, it is recommended that figures presented in this report are considered estimates and indices of change as opposed to precise values. Our findings intend to 'raise a red flag' based on perceived thresholds of potential concern that are intended to illicit detailed investigations by relevant scientists, academics and recognised local authorities.

Survey Limitations and potential data bias include:

- Ideally, such a survey should be repeated several times a year at different flow states and climatic conditions. The 2017 expedition occurred in June and the 2021 expedition occurred in September which potentially affects comparison of certain data categories.
- River morphology changes over time and occasionally the survey team digressed from the original track in 2017 by using different channels between islands.
- Humans and livestock cross over the river freely making comparisons of conditions on the two banks difficult. Indeed, the river was so low in 2021 that humans and livestock could walk across the river at most places. In 2017 when the river was higher, mekoro were used for humans while livestock couldn't cross.
- The expedition follows the main stream of the river, always moving forward along the path of least resistance. It is not feasible to explore backwaters or oxbow lakes and therefore these are excluded from the analysis. Impacts on backwaters and oxbows are likely higher than on the main stream of the river and thus our figures presented here should be considered conservative.
- The team only counts what is visible within 100m or so of the river edge. This measurement is an estimation and is affected by vegetation density and river bank height.
- Survey time is restricted to daytime hours only between 08:30 and 16:00. Some days are longer or shorter than others depending on many variables.
- Prevailing weather, team health, rapids, sharp corners in the river, sand banks and the presence of hippos can introduce observer bias.

Figure 8: The team paddling steadily downstream while recording observations on human activities, infrastructure and biodiversity and stopping frequently at fixed monitoring sites to collect eDNA samples and conduct habitat and water quality assessments.

2. CONTINUOUS MONITORING ALONG THE ENTIRE RIVER TRANSECT

The team travelled downstream 25km per day on average between the hours of 08:30 and 16:00, continuously collecting data on biodiversity, human activities, infrastructure, domestic animals and vegetation, all the while recording 360 degree images at one-minute intervals. Those sitting at the back of the mekoro, referred to as observers, constantly scanned the river and its banks (<100m from water's edge) and vocalised their sightings to the team. Individual observers were responsible for filtering and confirming specific categories of sightings and then relaying these to the recorder seated at the front of their mokoro. The recorders used a smartphone to ingest the data into Survey123 (ESRI) from which the data uploaded to a cloud database for safekeeping. Survey123 forms were created beforehand and set to automatically assign geolocation, date and time to each entry, the recorder also indicated which side of the river each sighting occurred.

2.1 Human Count and Activities

Methods: Human counts and activities

People living along the Kavango depend heavily on its water for drinking, washing and watering crops and livestock. People make use of natural resources such as fish, reeds, grass, firewood and often clear riparian vegetation to plant crops on the fertile banks. Livestock are plentiful and consequently, people cut down natural vegetation to build enclosures around their agricultural fields and homesteads. Long term monitoring of the number of people interacting with the river as well as their specific activities provides important socioeconomic data as well as provide an indication of the trajectory of general river health.

All humans interacting with river and its riparian vegetation were counted without taking age, sex or ethnicity into account.

Activities were categorized and recorded as follows:

- Fishing: We counted people fishing with nets, traps, hook and line or other means. This also included unmanned, deployed fishing nets. Undeployed gear lying on the riverbank or in mekoro were not counted. Nets were further classified into "gill nets, "drag nets" and "mosquito nets". Gill nets were any gill nets that were set or in the process of being set or retrieved. Drag nets were recorded when groups of people dragged gill nets through the river actively netting fish. Mosquito nets were recorded when people employed mosquito nets or shade netting to encircle structures or vegetation in the river and then sifting it or using it as a drag net in the shallows.
- Washing: This included people in the process of washing their bodies or clothes.
- Farming: People tilling, sowing, harvesting, watering, building enclosures around their farms or any other farming related activity were counted. Crop types were not noted.
- Playing: People swimming, playing games, etc
- Idle: Inactive people

- Traveling: People travelling on foot or in a waterborne vessel. Vehicles were not counted as we were often close to main roads.
- Collecting water: Only people collecting water by hand were counted. Any use of pumps was counted as an abstraction (see below).
- Cutting reeds or grass: Any people encountered that were cutting, bundling, carrying or storing bundles of reed and grass
- Others: Any other activities were noted and counted.

Figure 9: Examples of human activities along the Kavango river (top to bottom, left to right): Playing, Farming; Collecting reeds; Washing; Fishing; Collecting water.

Results: Human counts and activities (ESRI web app)

A total of 4547 people were counted between Katwitwi and Mohembo in 2021, most of whom were on the Namibian side of the river (Namibia = 3294, Angola = 1253). In 2017, 1190 people were counted between Katwitwi and the Cuito confluence compared to 3792 in 2021 – constituting a more than three-fold increase in four years (appendix 1.1 & 1.2). Activities remained much the same with 37% of all people using the river to wash their bodies and clothes (figure 10).

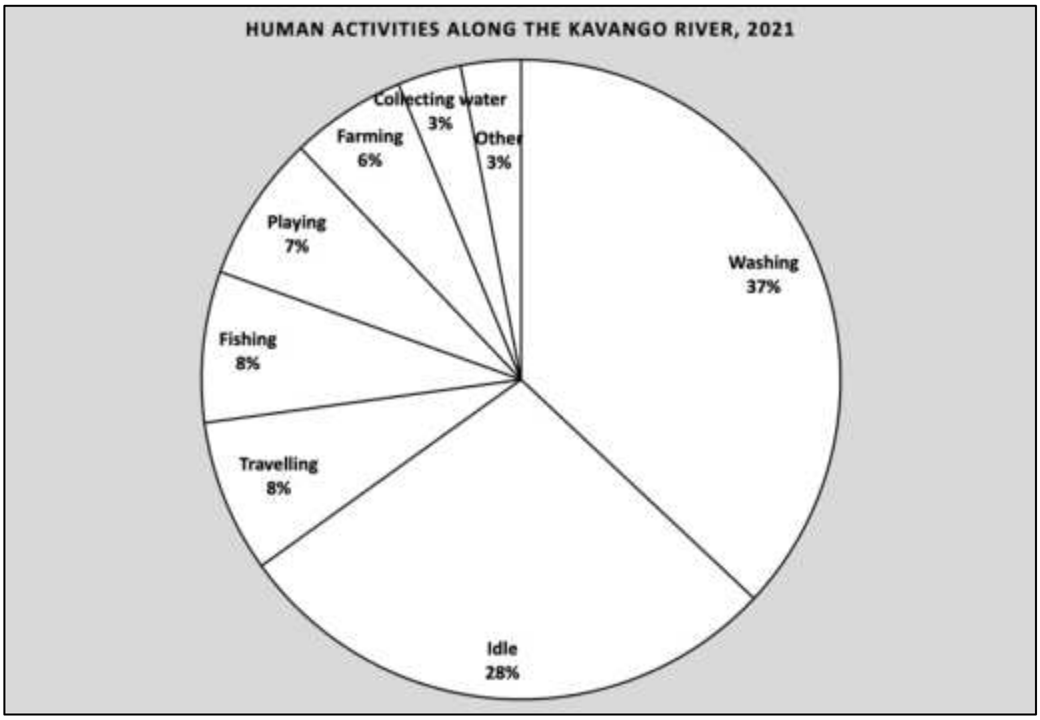


Figure 10: Proportion of human activities observed along the Kavango River

Human density was strongly associated with towns and inversely proportional to the distance from the main road (B8). That is, the further river meandered from the road, the fewer people were around.

Of the 347 people busy fishing, 53% were using nets, 34% hook and line and 13% traps. There were 75 set gill nets varying in length from 10-150m. Nets were encountered throughout the transect, although less so closer to Katwitwi (appendix 1.4). Near the towns of Shitemo and Mukwe, where there was pronounced gill netting activity, we noticed many seemingly abandoned nets lying in mekoro, on the river bank or tangled around objects in the river. At Shitemo village, high gill netting pressure was evident in both 2017 and 2021 (appendix 1.3)

Drag netting was recorded 22 times (appendix 1.5) with 2-10 people working nets up to 100m in length (either holding the net or chasing fish towards it). On 17 occasions we witnessed mosquito nets being used (appendix 1.6) either as drag nets in shallows or to encircle aquatic vegetation, rip it out and then sieve it for fish.

Although the number of set gill nets counted between Katwitwi and the Cuito confluence in 2017 (67) was very similar to that of 2021 (70), the average length of nets has increased significantly. Also, the use of drag nets, mosquito nets, cast nets, hand nets and other new fishing methods has increased considerably.

Figure 11: Mosquito nets are used as drag nets or used to sieve aquatic vegetation (top left and right). Gill nets are often dragged through the river by groups of people (bottom left). Discarded gill nets become 'ghost' nets that indiscriminately continue to kill fish (bottom right).

Discussion: Human counts and activities

There has been significant immigration of humans to the Kavango River since 2017. Living closer to the river provides improved access to water for drinking, sanitation, subsistence agriculture, protein (fish) and watering/grazing for livestock. Influxes of humans to inland waterbodies typically comes with issues related to deforestation, natural resource depletion, pollution and overgrazing and requires careful management of land use practices, municipal service delivery and natural resources.

The tendency for fewer people to be around when the river departs notably from the main road (B8), provides immediate conservation opportunities. Given the rapidly expanding population around the river, this window of opportunity may be short lived.

Current fishing practices are unsustainable and better enforcement of regulations is required. Especially concerning is the apparent increase in the use of drag nets and fine-meshed material such as mosquito nets and shade netting as this impacts heavily on fish recruitment. Also concerning is the excessive gill netting pressure at specific sites where many nets had been staggered close to each other to create impenetrable barriers for fish across the river. At Shitemo and Mukwe, the sheer number of nets both in and out of the water and the fact that they were all similar in appearance, suggested commercial ventures that are unlikely to be aligned with fisheries regulations.

2.2 Abstractions

Methodology: Abstractions

Water abstractions have obvious direct influences on the flow regimes of rivers affecting magnitude, frequency, duration, timing and rate of change of flows. Abstractions often have the largest impact on the hydrologic regime as they can substantially reduce flows and other aspects of the natural flow regime resulting in a number of responses including channel incision, bed armouring, or aggradation and disruption of ecosystem services downstream.

Abstractions were defined as any pipe with a submerged inlet leading up to an endpoint where water is either stored or dispensed. Pipes leading from the river that ended abruptly or could not be traced to an endpoint were disregarded. The circumference of each abstraction pipe was measured using a pliable measuring tape and a drone (DJI mini2) was deployed to determine abstraction purpose categorised as: agriculture, homestead, lodge, municipal, factory, construction site and other. It was also noted which side of the river the abstraction was on and whether the pump was running or not.

Pipe circumference was later converted to diameter and divided into four categories: Small (3-5cm), medium (6-30cm), large (30-100cm) and extra-large (101-357cm) (figure 12). For extraction sites with multiple pipes, diameters were summed.

To determine the best estimate of the percent contribution of a category to overall total abstraction, an 'index of contribution' was devised by summing pipe diameters for each category listed above and multiplying by the proportion of occasions where abstractions were actively pumping water at the time.

Figure 12: Typical large (left), medium (centre) and small abstractions along the Kavango River.

Results: Abstractions (ESRI web app)

A total of 377 abstractions were identified of which all, except 5, where on the Namibian side (appendix 2). Abstractions were distributed all along the river except in places where the river departed notably from the main road (appendix 1.8).

Agriculture was by far the highest contributor to overall abstraction (74%) (figure 13). Commercial 'Green schemes' accounted for 59%, followed by other smaller-scale agriculture (15%). Municipal extractions and private residences accounted for 6% each, lodges and a fish farm contributed 4% each and the remainder comprised a hospital, construction sites, brickmaking factories and a few chicken farms.

There was a direct relationship between abstraction size and the number of instances when they were actively pumping (table 2). That is, the larger the abstraction the more time they tend to spend pumping.

Despite there only being 7 extra-large abstractions, they contribute an estimated 47% to overall water abstraction (table 2). In contrast, small abstractions -of which there are 227- only extracted approximately 9% of the water, mainly to service small-scale agriculture and private residences. Together, large and extra-large abstractions (n=30) contributed to an estimated 80% of abstracted water and all but three of these were for the purpose of commercial agriculture. The remaining three included Rundu municipal water treatment, Nankudu Hospital, and Mpungu fish farm.

Since 2017, the number of abstraction between Katwitwi and the Cuito confluence increased from 89 (appendix 1.7) to 223 (table 3). Notably, small abstractions increased more than 3-fold. Seven new large commercial abstractions have been built, or are in the process of being built (table 4, figure 14)

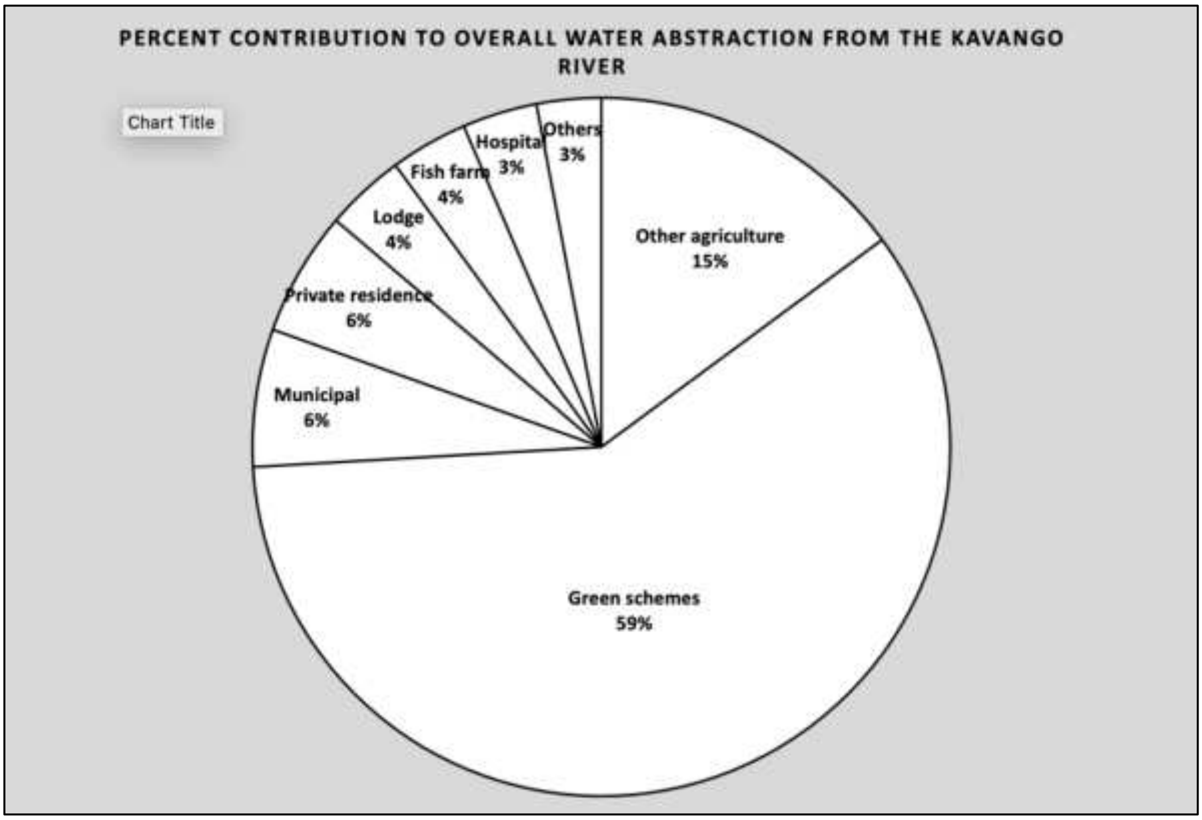


Figure 13: Percent contribution of the various water abstraction categories along the Kavango River in 2021

Table 2: Percent contribution to total water abstraction of the various abstraction sizes.

Abstraction size	Count	Tot. diameter (cm)	% Pumping	Percent contribution
Xlarge (100+)	7	1479	40	47%
Large (31-99cm)	23	1235	34	33%
Medium(6-30cm)	120	965	15	11%
Small (3-5cm)	227	1057	11	9%

Table 3: Number of abstractions recorded in 2017 versus 2021

Abstraction Size	2017	2021
Large (31cm+)	20	26
Medium (6-30cm)	44	67
Small (3-5cm)	25	130
	89	223

Table 4: New x-large and large abstractions since 2017

Country	Lat	Long	Name	Purpose	Tot. pipe diam. (cm)
Namibia	-17.825036	18.95621	Musese	Green scheme	245
Namibia	-17.877608	19.8989872	? E of Rundu	Green scheme	118
Namibia	-17.54213	18.5361814	Nkurenkuru	Green scheme	83
Namibia	-17.613027	18.6158427	Mpungu fish farm	Fish farm	57
Namibia	-17.729623	18.7381947	Nankudu hospital	Hospital	55
Namibia	-17.420163	18.4484534	? near Katwitwi	Other Agriculture	50
Angola	-17.821716	19.2724362	? Cafuma river	Green scheme	50

Discussion: Abstractions

A substantial increase in the number of water abstraction sites has occurred over the last four years, especially in the ‘small’ category which is congruent with the recently high rate of human immigration to the river. It must be noted that our river survey did not include backwaters or oxbows and that our count of 377 abstractions is likely a significant under-count given that, on the occasion when we did visit backwaters for purposes of camping, we noted many abstractions.

The predominant purpose of small abstractions was for small-scale farming and private residences. In these cases, water is pumped into a raised water drum (generally 1-5 kl in size) and only re-filled when empty using predominantly petrol-driven pumps that appear to be shared by the community. Hence, these abstractions were not often in use and can be considered negligible next to the larger commercial extractions.

When the pipe inlet diameters of all abstraction pipes are converted to surface area and summed, it totals 10.8m^2. Since the surface area of the river profile shortly before the Cuito confluence is 208m^2 (calculated with ADCP), then it can be inferred that; provided all the abstractions were switched on at the same time and assuming that pump flow rate was equal to average river flow rate (0.09m/s) then river discharge would drop by at least 5.2%.

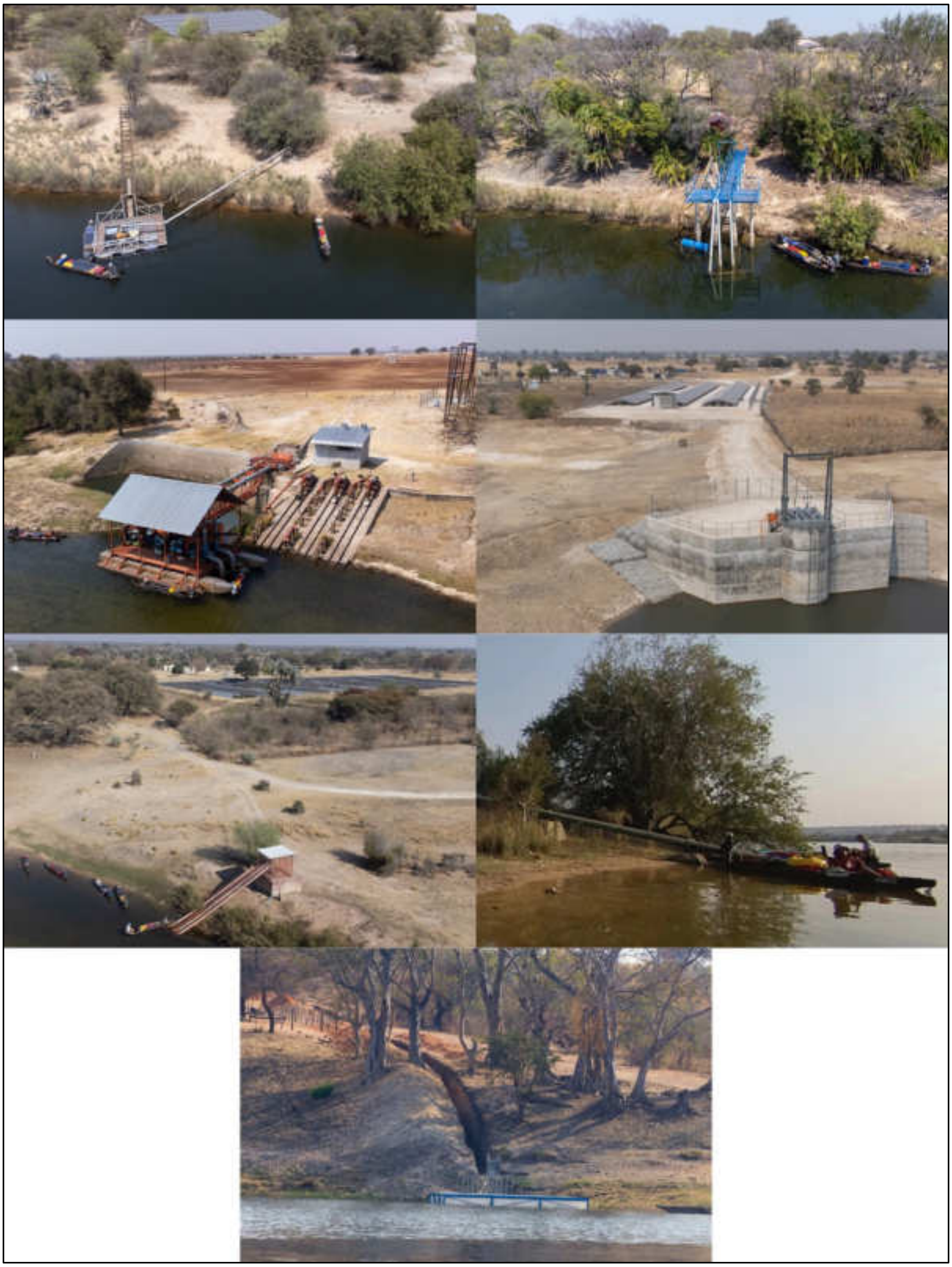


Figure 14: New large abstractions (>30cm pipe diameter) along the Kavango River since the previous survey in 2017. Top to bottom and left to right: Nkurenkuru green scheme; Farm near Katwitwi; Musese green scheme; new green scheme east of Rundu; Mpungu fish farm; Nankudu hospital; new Angolan green scheme near Cafuma river.

2.3 Other Infrastructure

Methods: Other Infrastructure

Other Infrastructure both in the river and along its banks was categorized and recorded as follows:

- Waterborne vessels: All water craft including mekoro, fiberglass canoes, motorised boats, barges or other vessels.
- Lodges: Lodges are often built against or over the water's edge and have jetties, septic tanks and water abstractions.
- Fish corrals: Local inhabitants build circular corrals using rocks to trap fish. We considered the frequency and distribution of these corrals as a potential means of monitoring fishing pressure going forward.
- Dredges: Dredging changes river morphology, sedimentation, damages species composition and alters species habitat. We counted and photographed all dredges that we passed.

Results: Other infrastructure (ESRI web app)

Wooden mekoro are the primary means of travel on the Kavango river. Large, straight indigenous trees are cut down for this purpose. We counted 1481 mekoro of which the majority (1088) were parked on the Namibian side. This constitutes an increase of 15% since 2017. Mekoro were relatively evenly distributed along river although they were less frequent closer to Katwitwi (appendix 1.9). Fewer motorised boats and barges were counted in 2021, probably because many have been removed from the river given its current low flow.

We counted 36 lodges (appendix 1.10), several of which appeared dilapidated or mothballed. Four new lodges were under construction, all in the lower stretches of the river after Andara. Only two lodges were on the Angolan side, although both appeared to be abandoned projects.

Given that fish corrals only work at certain river heights (very low) and in places where the riverbed is rocky, they were locally abundant but limited to specific areas. Specifically, the first 50km after Katwitwi and a 20km stretch near Mashare (appendix 1.11).

We encountered 3 dredges, 2 of which were mining building sand and the other was pumping the slurry through a sieve (figure 15).

Figure 15: Dredgers were used to mine building sand from the Kavango river (left) or to sift it for unknown reasons (right).

2.4 Livestock

Methods: Livestock

We counted all livestock and noted on which side of the river they were using Survey123 (ESRI). Free-roaming cattle are known to have serious impacts on river ecosystems:

- Erosion, from overgrazing and trampling, causes increased sediment runoff and destabilises river banks.
- High levels of nitrates, phosphates, ammonia and potentially dangerous pathogens from copious manure leech into the river when it rains.
- Channel morphology is affected by cattle wading through papyrus and other aquatic vegetation.
- Yet, their most concerning impact on the Kavango River is that people cut down riparian vegetation and use it for fencing material to prevent livestock from entering their fields and homesteads.

Results: Livestock (ESRI web app)

Domestic animals along the Kavango included cattle, goats, donkeys, dogs, horses, pigs and sheep with the former being by far the most abundant (table 5).

Cattle were more abundant in the west, between Katwitwi and Rundu, especially in places with more expansive and lush floodplains (appendix 1.13). In the east, there was a hotspot near the town of Mukwe.

The number of livestock counted along the section between Katwitwi and the Cuito confluence increased from 2342 in 2017 (appendix 1.12) to 11396 in 2021 constituting a five-fold increase.

Table 5: Livestock counted during the 2021 Kavango transect.

	Angola	Namibia	Total
Cattle	5378	7097	12475
Goats	230	812	1042
Donkeys	32	96	128
Dogs	16	85	101
Horses	3	11	14
Pigs	18	29	47
Sheep	0	5	5
Total	5677	8135	13812

Discussion: Livestock

Livestock, mostly cattle, roam freely and are omnipresent along the Kavango relying on the river and its banks for water and food. Numbers have clearly increased immensely since 2017. Cattle were often seen crossing the river going to and fro between the banks, often feeding on the Angolan side where favourable grazing prevails. Ear-tagged cows from Namibia were frequent on the Angolan bank and we conservatively estimate that more than 80% of the cattle counted originate from Namibia.

In places, trampling and overgrazing are clearly evident and copious dung and urine (figure 16) is sure to have a negative impact on water quality with an anticipated spike at the onset of the rains. It must be noted that the onset of the rainy season in the Kavango region does not coincide with the annual flood, which typically arrives several months after originated in the Angolan highlands. Therefore, water pollution from cattle excrement will take some time to flush from the system and, given already high nitrate and pH readings, an imminent healthcare concern may arise.

The compounding effect of rapid, concomitantly increasing human and cattle populations is resulting in swift deforestation of indigenous vegetation in the riparian zone and subsequent loss of biodiversity. Because of overgrazing, cattle and hippos attempt to feed on crops, thereby forcing people to construct fences around their plots. Indigenous trees (notably Waterberries) are primarily cut down for this purpose, making space for exotic invasive plants (figure 16). In places, dense stands of giant sensitive weed (*Mimosa pigra*) have taken over, unfortunately its thorny nature makes this plant difficult to work with and therefore it is not readily used for fencing. The consequent speedy replacement of indigenous riparian vegetation with invasive cohorts will result in significant loss of biodiversity and severely diminish the ecosystem services offered by this river.

Figure 16: Copious cattle dung litters the river bank (top right); Indigenous trees are cut down to build fences around crops to keep cattle out (bottom).

2.5 Mammal And Avian Biodiversity

Methods: Mammal And Avian Biodiversity

Long term monitoring of birds and mammal abundance and distribution can provide important insight into river health, tourism potential and potential human wildlife conflict. We recorded all sightings of wildlife (medium to large mammals and large reptiles) as well as all wetland birds.

Results: Mammal And Avian Biodiversity (ESRI web app)

Observed mammal species included hippos (n = 563), spotted necked otters (n = 5) and, nearer to Mahango Game Park we encountered impala, kudu, warthog and other common game. Large reptiles including crocodiles (n = 20) and water monitor lizards (n = 12) were relatively uncommon.

Pods of hippo were encountered near Katwitwi, between Rupara and Muveve, Shizogoro, Shitemo, near the Cuit confluence, Mukuvi, Mayara, Diyana and several pods between Mukwe and Kamutjonga (appendix 1.14). In between these pods, in less suitable habitat closer to human habitation, we encountered lone individuals or small groups (<5). Compared to the 2017 survey, we counted almost double the number hippos between Katwitwi and the Cuito confluence (124 vs 254). In 2017, we also encountered hippo pods near Katwitwi and the section around Rupara and Muveve, although little activity was recorded around the confluence.

Elephants were only encountered after dark at Andara and again closer to Mahango Game Park. Shortly after Rupara, where the river departs considerably from the road, we noted fresh signs of elephant.

Figure 17: A pod of hippo on the Kavango River.

A total of 7816 wetland birds, belonging to 50 species, were counted (appendix 1.15). Distributions of major wetland bird groups and other interesting birds can be viewed in appendix 1.16 - 1.34. Those birds for which more than 100 were counted, are displayed in figure 18. Wetland bird 'hotspots' were always in places where the river departs notably from the road: between Rupara and Muveve; Kapako; Nyangana; and Mukuvi (appendix 1.15). In 2017, fewer ducks and small herons were seen between Katwitwi and the Cuito confluence, but many more lapwings and jacanas were counted in 2021 (figure 19). Other interesting observations included (figure 20):

- Collared pratincole and Common greenshank were absent in 2017
- Common sandpiper, Black-winged stilt, Reed cormorant and Swamp boubou were much more abundant in 2021
- Red-winged teal were absent in 2021
- African darters were far more abundant in 2017

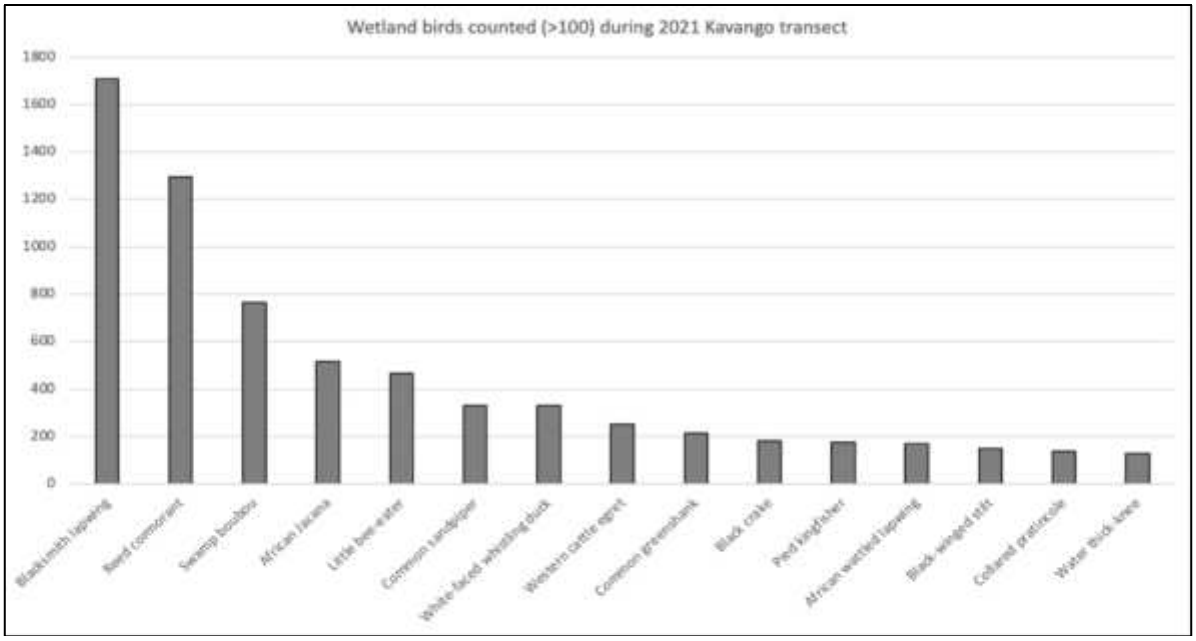


Figure 18: Most common wetland birds counted during the 2021 Kavango transect.

Figure 19: A colony of Carmine Bee-eaters (left), African Skimmers (right) on the Kavango River.

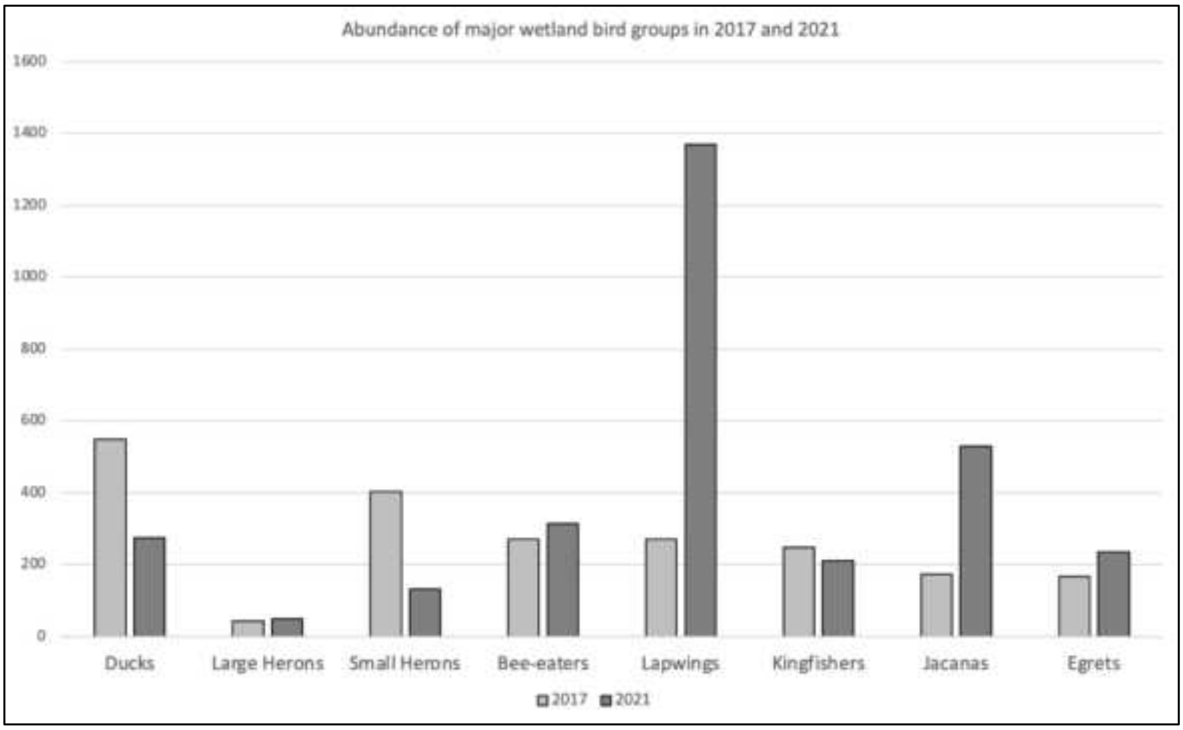


Figure 20: Comparison of abundance of major wetland birds groups in 2017 and 2021

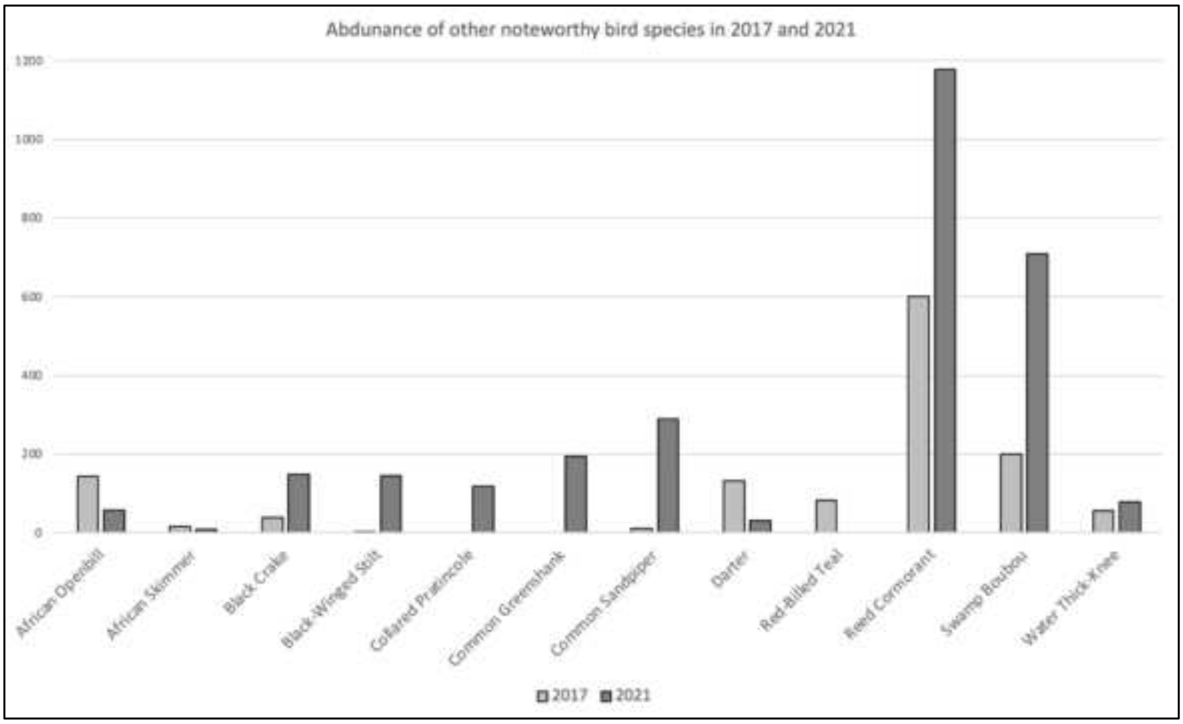


Figure 21: Comparison of abundance of other noteworthy bird species in 2017 and 2021.

Discussion: Mammal And Avian Biodiversity

Despite ending our transect before Mahango Game Park (where hippos are prolific), our count of hippos was 563, considerably more than estimated in the literature (NNF & WWF). Moreover, our count is likely an underestimate of true numbers as we likely missed several lone individuals as they typically did not make their presence known to passers-by, preferring instead to remain quiet and submerged as much as possible. The distribution of hippo pods was strongly related to human presence. That's is, pods were restricted to places furthest away from human habitation, an important consideration when planning protected areas.

Similarly to hippos, wetland birds were also concentrated in areas furthest from human habitation. Several species of migratory birds were present in the August 2021 transect but missing or recorded in very low numbers in the June 2017 transect - this is expected as these summer migrants (the Common Greenshank, Common Sandpiper, and the Collared Pratincole) typically arrive in the region in July/August. The small number of Common Sandpipers observed in June 2017 were likely overwintering subadults.

Several bird species recorded are regionally resident but nomadic within the region. Many Reed Cormorant move towards the coastal regions over winter and back to the inland waters in summer - this explains the observed increase from June 2017 to August 2021. Additionally, Black winged Stilt, Black Crake, and both species of Jacana respond to flooding of ephemeral pans and with the falling water levels in August these species would have returned to the river to seek water.

White-faced duck and Red-billed teal were less abundant than in 2017. These species are regionally nomadic with movement based on rainfall and the availability of shallow water bodies and submerged and floating aquatic vegetation. Similarly, the African Openbill is highly nomadic moving to favourable habitats likely resulting in the decrease observed.

African Darter are resident and largely sedentary making them good indicators for the system health. There is an observed decline in abundance between 2017 and 2021. This species feeds largely on medium sized fish (predominantly cichlids) and occasionally on frogs. A decline in this size-class of fish will likely result in a decline in African Darters. Additionally, they are reliant on clear water as visual hunting is done underwater, increases in turbidity result in a decline in this species. The observed decline in this species could be due to a combination of overfishing and increased turbidity – however more data is needed to confirm this. Like Darters, the large and small heron species are resident and largely sedentary. Large herons are predominantly fish eaters while the smaller herons are more opportunistic eating small fish, frogs and invertebrates. The Goliath Heron targets large fish and competes directly with fishermen with overfishing being a major threat to this species. Small herons showed a decline from 2017 to 2021. Whilst large herons showed little change the species composition switched from more Grey herons towards more Black-headed herons which has a more diverse diet including birds and small mammals.

The Egrets have increase slightly in abundance largely due to increases in cattle egrets which eat mostly insects disturbed by grazing cattle, which have increased five-fold since 2017.

African Skimmers showed a slight decline which is worrying for this near threatened species. The low water levels in August should have favoured this species by providing exposed sandbanks on which to roost. However, a lot of human, livestock and dog activity on the sandbanks would prevent roosting and breeding.

The lapwings (largely represented by Blacksmith Lapwings in this system) adapt well to man modified habitats and their range and abundance has been shown to increase with human development. In addition to this there is some movement of Blacksmith Lapwings from central Africa down to the Okavango region in the summer months. The combination of local movements and the growth of human settlements in the area could have resulted in the observed increase in lapwings.

The increase in Swamp Boubou was unexpected and unexplained. This sedentary species eats invertebrates and favours riparian woodland, papyrus swamp and tall reedbeds. It could potentially be benefiting from the increased alien invasive thickets of Mimosa growing along the river banks.

Kingfishers, bee-eaters and Thick-knees did not show much variation between the years.

Figure 22: Wetland birds flying over the Kavango River.

2.6 Mapping Of Invasive Plants

Methods: Mapping of Invasive Plants

Alien Invasive Plants (AIPs) outcompete native vegetation for space, water, nutrients and sunlight - modifying vegetation structure, reducing biodiversity, and compromising ecosystem function. Resulting impacts include:

- a reduction in grazing for livestock and wildlife;
- increased soil erosion where ground cover is out-competed;
- reduced crop yields through competition;
- increased animal mortality through the ingestion of poisonous plant material;
- increased fire frequency and intensity due to increased fuel loads;
- a reduction in groundwater due to water thirsty species;
- a loss of habitat for animals;
- a loss in aesthetics; and
- an overall increased vulnerability to environmental change.

AIPs are introduced regionally by anthropogenic means. Seeds are dispersed with the movement of contaminated building materials or fodder, or in the tread of vehicles or shoes. AIPs may also escape from gardens or from crops or plantations. Earthworks, agriculture or other disturbances to the soil or natural plant community provide a window of opportunity for the dispersed seeds to germinate and grow. Once established, AIPs can disperse naturally by wind, down rivers, in animal droppings after being ingested, or on the fur, feathers or hooves of animals.

Using Survey123, we recorded the location (including which side of the river), species and extent (% cover or number of individuals). For each species, We assigned a score of 1-5 (low-high) in terms of its potential invasiveness (a), potential ecological impact (b) and current prevalence (c). Then, we calculated an Index of Potential Concern for each species: *a * b + c.*

Results: Mapping of Invasive Plants (ESRI web app)

Sixteen AIP species were recorded on the Kavango River transect (table 6). Of these, eight species are listed as major invasive species occurring in Namibia (Bethune et al. 2004, indicated with an asterisk*). The indices of potential concern suggest that *Mimosa pigra, Leuceana leucocephala* and *Xanthium strumarium* are currently the three most concerning invasive species along the Kavango. The two Daturas (*D. ferox* and *D. stramonium*) are also of concern despite currently being present in low numbers.

Table 6: Alien invasive plants recorded along the 2021 Kavango River transect Indicating their Index of Potential Concern.

Species	**Current prevalence**	**Potential invasiveness**	**Potential ecological impact**	**Index of potential concern**
Mimosa pigra (Giant sensitive plant)	5	5	5	30
Leucaena leucocephala (Wonderboom)*	2	5	5	27
Xanthium strumarium (large cocklebur)	2	5	5	27
Datura ferox (Large thorn apple)	1	5	5	26
Datura stramonium (Common thorn apple)*	1	5	5	26
Senna occidentalis (Coffee senna)	4	5	4	24
Argemone ochroleuca (White Mexican Poppy)*	3	5	4	23
Senna obtusifolia (Sicklepod)	2	5	4	22
Opuntia sp. (Prickly pear)*	2	4	4	18
Agave sp. (Sisal)*	1	4	4	17
Acanthospermum hispidum (Star bur)	1	5	3	16
Ricinus communis (Caster oil)*	3	4	3	15
Cascabela thevetia (yellow oleander)	1	4	3	13
Bidens pilosa (Black Jack)	1	4	2	9
Eucaliptus sp. (Gum tree)	3	1	4	7
Melia azedarach (Syringa)*	2	2	2	6

By far the most abundant species recorded was the semiaquatic weed *Mimosa pigra* (Giant Sensitive Plant). The Giant Sensitive Plant is a shrub which forms dense thorny thickets (figure 23). It is fast growing and thrives in floodplains and watercourses and its seeds spread by floating down the river. It outcompetes natural vegetation and diminishes crops and grazing lands (Witt et al. 2020). This species was continuously present along the banks of the Kavango River for most of the transect (appendix 1.35). Percent cover ranged from 1 to 50% coverage with the highest cover recorded where the natural vegetation had been extensively disturbed by agriculture and heavy grazing closer to large towns, especially Rundu and Nkurenkuru. Mimosa infestations were far more prevalent on the Namibian river bank (n = 112) than Angola (n = 23). Also, fewer of the other remaining invasive species were noted on the Angolan side.

Figure 23: dense stand of Mimosa pigra (Giant sensitive plant) growing on the banks of the Kavango River.

Other invasive species were more patchy in distribution (appendix 1.36) but were prevalent where soil had been disturbed (or building material imported) at large water extractions, in and around towns and villages and in areas exposed to heavy grazing. The two Datura species, the two Senna species, the White Mexican poppy, and the Large cocklebur were particularly prominent in these disturbed areas and were already spreading downstream. Ideally, better grazing management – to preserve natural riparian vegetation – and the rehabilitation of disturbed soils would be needed to curb the spread of these aggressive invaders.

Figure 24: Earthworks to install large abstractions disrupt the soil and natural vegetation creating a window of opportunity for Alien Invasive Plants. Indicated in the yellow circle are Argemone ochroleuca (White Mexican Poppy) and Senna occidentalis (Coffee senna) growing in the disturbed soil alongside an abstraction point – once established these plants will likely spread downstream.

Some species were recorded in the gardens of homesteads and lodges. Tree species *Cascabela thevetia* (yellow oleander), *Leucaena leucocephala* (Wonderboom), and *Melia azedarach* (Syringa) were all recorded in gardens planted as ornamentals. Other species were being grown as crops including *Ricinus communis* (Caster oil), *Opuntia sp.* (Prickly pear), and *Eucalyptus sp*. (Gums). The prickly pears have been planted as live hedges and have since escaped (Strohbach 2013). Escapee Caster oil plants were also observed on the transect. The Gum trees appeared not to have escaped but need careful monitoring as they have been shown to use much more water than the plant communities they replace.

Figure 25: Xanthium strumarium (left) and Senna occidentalis (right) pictured along the Kavango River. Both species have the potential to create widespread damage along the river banks.

Discussion: Mapping of Invasive Plants

The data collected from this transect will be a useful baseline from which to compare future surveys. The study further highlights the need for a AIP management plan for the Kavango River in order to preserve ecosystem functions and mitigate the spread of AIPs to other regions in the catchment. Special attention should be given to species highlighted in orange in table 6. Further work is also needed to identify potential invaders not yet recorded in the system and put in place measures to prevent their introduction – this should also include potential invasive animals including freshwater crayfish, molluscs and fish all of which are threatening other aquatic systems in southern Africa.

The prevalence of *Mimosa pigra* is concerning given that it appears to be rapidly replacing indigenous riparian vegetation due to deforestation and overgrazing. Management options for this species include fire, herbicides, mechanical and manual removal, however the most cost effective control would be bio-control. Several insects and pathogenic fungi are effective and host specific (Payther, 2005). The stem boring moth *Carmenta mimosa* has been released on the Kafue River floodplains in Zambia to combat *Mimosa pigra* with some success (Witt et al. 2020) and might be an option for the Kavango River.

Given that natural vegetation on the Angolan side was less disturbed by agriculture, Mimosa infestations were far more prevalent on the Namibian river bank (n = 112) than Angola (n = 23). Furthermore, fewer invasive species were recorded on the Angolan side (n = 3) than on Namibia's (n = 15). This is corroborated by the fact that far more people, livestock and infrastructure was observed on the Namibian side.

Infestations of AIPs can be very costly and often impossible to eradicate. For this reason prevention is better than cure. Prevention can be achieved by ensuring that building material is not sourced from contaminated sites. Additionally, minimizing the disturbance of the soil and natural vegetation will reduce the window of opportunity for AIPs to establish. Locally indigenous plants and non-invasive species are best used when creating a garden or rehabilitating a disturbed area.

Leucaena leucocephala had in past years been sold by the Namibian Directorate of Forestry nurseries as a fodder tree, nitrogen fixer, firewood producer and rapid growing shade tree – it is now likely to become a serious invader (Joubert 2009). It is necessary to educate home and lodge owners on the impact of these species and to advocate for their removal. The two Datura species, the two Senna species, the White Mexican poppy, and the Large cocklebur were particularly prominent in heavily disturbed areas and were already spreading downstream. Ideally better grazing management – to preserve natural riparian vegetation – and the rehabilitation of disturbed soils would be needed to curb the spread of these aggressive invaders.

Alien Invasive Plants (AIPs) are a growing threat to the Kavango River (Strohbach, 2013), a threat that if left unchecked, is likely to expand with agricultural or industrial development into the Okavango catchment as well as disperse downstream into the Okavango delta. Strohbach (2013) recorded 28 AIP species in the Okavango ecosystem and warned of their immense encroaching potential and the treat to the riparian and floodplain ecosystems.

2.7 Mapping Of Papyrus

Methods: Mapping of Papyrus

Papyrus (*Cyperus papyrus*) is one of the most efficient and effective natural pollution filters, yet little is known about its distribution, abundance and conservation status in the Okavango Basin. We used a combination of Survey123 and GPS tracking software (Gaia GPS) to map papyrus stands for future reference.

Results: Mapping of Papyrus (ESRI web app)

We started noting small patches less than 50m in length after the Cuito confluence. Later, after the town of Mukwe, we recorded several larger patches up to 1,2km in length (appendix 1.37).

Discussion: Mapping of Papyrus

Since no Papyrus was recorded before the Cuito confluence, the Cuito river clearly feeds the Okavango with Papyrus clones. It's ability to filter and trap pollutants and sediment loads makes Papyrus an integral part of the river ecosystem and needs to be protected at all costs. This plant only becomes naturally prolific as it enters Botswana, yet any stands along the Kavango should be protected and encouraged to expand naturally.

2.8 Permanent Record of Riparian Habitat

Methods: Permanent Record Of Riparian Habitat

Permanent records were created of the riparian habitat using a 360-degree camera (Insta360) at one minute intervals. These images were later assembled on an interactive web map (EarthViews) and made freely accessible to the public.

Results: Permanent Record of Riparian Habitat

A total 6449 pictures were taken along the river and successfully assembled online in a way that they can be viewed in an easy and intuitive manner without needing to sign up or download an app.

Discussion: Permanent Record of Riparian Habitat

These images are an excellent means of conducting long term monitoring of riparian habitat while at the same time providing permanent records of the environment. Using new technology such as artificial intelligence, it has become possible to train software to identify specific objects or habitat types based on a combination of shapes, colours and textures. We plan to assign a PhD student to this task in the coming months.

3. FIXED SITE MONITORING

A fixed-site, trend monitoring network is an approach that uses a set of monitoring sites that remain in place and are monitored over the course of many years. Sampling a specific site along a river once gives a snapshot of the current condition at a moment in time, but sampling in the same fixed location repeatedly over the course of many years gives a picture of how variables change over time. The more frequently samples are taken and the longer the site is monitored, the more reliable the results become. Depending on the rate of change, trends can be detected in a few short years, however it typically takes in the order of ten years or more to detect statistically significant trends in water quality and biodiversity data. This is due to high volatility generated by complex co-variates related to climate and hydrology.

We established 49 randomly stratified fixed monitoring sites along the 486km Kavango River. That is, we randomly selected sites at roughly 10km intervals where we stopped to collect specific data. At all 49 sites we dispatched a drone to collect habitat photos and collected water quality readings. Nine of these sites were referred to as 'intensive sites' where we also collected eDNA samples and conducted a rapid bio-assessment of the ecological river condition using the Namibian Scoring System (NASS). At three of these nine intensive sites, we used an Acoustic Doppler Current Profiler (ADCP) (Sontek RS5) to measure water discharge.

Figure 26: 49 fixed monitoring sites established along the Kavango River in 2021. Yellow pins are intensive sites.

3.1 Fixed Point Aerial Photography

Methods: Fixed Point Aerial Photography

At each fixed monitoring site, a DJI Mini2 drone was deployed to a hight of 300m and aligned to specific coordinates to collect a series of fixed point photographs of the river below and the surrounding landscape at an approximate radius of approximately 3km and at an image resolution of 4000 x 2250 pixels. A series of 18 images were collected at each site, nine at 300m elevation and nine at 100m elevation. At each elevation, the first image was taken straight down. Then, four images (North, East, South, West) were taken at an angle of -20 degrees to the horizon and four images at -45 degrees. This process was repeated at 100m elevation.

Results: Fixed Point Aerial Photography

Fixed point photos were collected at all 49 sample sites. These images were also loaded into the Earthviews database of 360 degree images to provide an updated current aerial perspective (satellite photos in Google Earth or similar programs are often outdated).

Discussion: Fixed Point Aerial Photography

Similar to the land based 360 degree images, these photos provide a permanent record against which to assess changes in habitat quality and land use at high resolution (figure 27).

Figure 27: An image taken with a DJI mini2 drone at 300m elevation in raw format shooting at 4000 x 2250 pixels. The insert is at 300% magnification.

3.2 Water Quality

Methods: water quality

Water quality and chemistry were sampled at each fixed monitoring site using an *InSitu Aquatroll* 600 multi-parameter sonde (Nitrate; pH; Oxidation Reduction Potential; Total Suspended Solids; Dissolved Oxygen; Conductivity; Salinity; Resistivity; Temperature and water density) *Quantofix* Phosphate test strips (Phosphate) and *Apera TN400* (Turbidity).

Sub-samples of the nine eDNA samples are currently undergoing microbial analyses to detect pathogens and their respective loads in the water. Results will be available in the first quarter of 2022.

- High **nitrate** in drinking water can result in restriction of oxygen transport in the bloodstream, is known to cause birth defects and increase risk of thyroid diseases and certain cancers (USGS). Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (excess application of inorganic nitrogenous fertilizers and manures), from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. Nitrate together with phosphates stimulate plant growth often resulting in eutrophication which, in turn, can clog waterways, deplete dissolved oxygen and restrict light penetration into the water. These combined effects can result in rapid release of toxins making the water unfit for human consumption and deadly to biodiversity. World Health Organization (WHO) recommends Nitrate (NO_3) remains below 50mg/L for safe drinking water.

- Phosphates are a common constituent of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent. Similarly to nitrates, they are essential elements for plant life, but when there is too much in water, eutrophication occurs. In contrast to nitrates however, phosphates typically do not compromise health unless present in exorbitant quantities (>1000mg/L). Phosphates get into water in both urban and agricultural settings mostly via surface runoff as they tend to attach to soil particles. Phosphorus is also a major constituent of common detergents, of which copious amounts are discarded into the Kavango river daily. Typically, phosphate should be above 25mg/L to qualify a body of water as eutrophic.
- pH (or hydrogen ion concentration) is a general indicator of water quality that is affected by all manner of contaminants and other changes in water chemistry. pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.) Extremes in pH can make a river inhospitable to life. The pH of most raw waters should lie between 6.5-8.5, above and below that warrants detailed water analyses.
- Turbidity 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) 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) 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) 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- 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.

- **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.

Results: Water Quality (ESRI web app)

General comments: Five team members fell ill within the first few days of the expedition due to E.coli or Typhoid poisoning from the water, despite making use of a specialised filter. In a few places, always near to green schemes and/or large urban centres, there was a malodorous brown foam on the surface of the water that, when tested, presented levels of phosphate and/or nitrate that were above the recommended standard. This foam dissipates by noon and is likely a product of high phosphates and nitrates. Other frequently encountered pollutants included disposable nappies and sanitary pads (hundreds were counted), plastics, discarded gill nets (ghost nets). Given the low river state at the time of this expedition, reported water quality values are likely exacerbated beyond what they would be at higher levels.

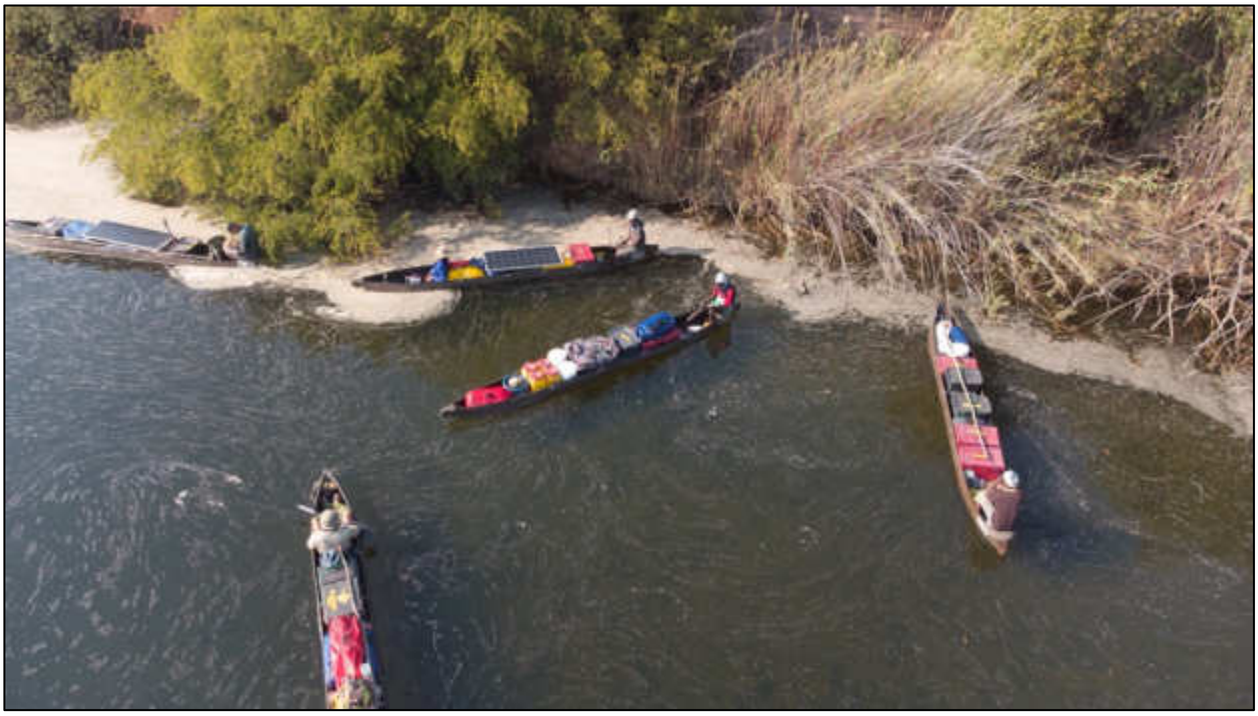


Figure 28: Malodorous foam accumulations along the Kavango River coincided with high Nitrate readings.

Nitrates: Average Nitrate (NO_3) concentration was 67 mg/l (SD = 99, range = 0.04 – 593), well above the recommended standard. There is a clear association with large agricultural schemes with Nkurenkuru, Musese and Shadikongoro being likely sources (appendix 1.38).

Phosphates: Average phosphate was 4.28 mg/L, (SD = 3, range = 0-10), well below the recommended guidelines. Sites where it was highest coincided in most cases with large agricultural schemes. (appendix 1.39) pH: pH was on the high side with a mean of 8.4 (SD = 0.26, range = 7.9-8.7). In places, values were above the recommended norm of 8.5 indicating potential pollution that could result in a loss of biodiversity. High pH was strongly associated with high nitrates that are congruent with large agricultural schemes (appendix 1.40).

Turbidity and Resistivity: These two variables represent particles in the water that are not able to conduct current and are thus mostly organic. Average turbidity was 2.74 NTU (SD = 1.4, range = 1-6) and showed a steady increase down river. After the Cuito confluence, turbidity increases by more than two-fold (appendix 1.41), which was expected given the high volume of water ($79m^3/s$) flowing into a low volume ($18m^3/s$) Kavango at the confluence. Similarly, resistivity more than doubled after the confluence (appendix 1.43).

EC, Salinity and TDS reduced markedly once mixed with the Cuito (appendix 1.42, 1.44, 1.45). These variables are all indicators of inorganic particles, potential pollutants, as they represent those particles able to conduct electrical current.

Dissolved oxygen saturation (appendix 1.49) concentrations were within safe limits along the entire river (mean = 89, SD = 6, Range = 85-112) as well as ORP (mean = 128, SD = 18, range = 80 – 168) (appendix 1.47), Density and Temperature (mean = 22.3, SD= 1.3, range = 19.6 -26) (appendix 1.48, 1.50).

Discussion: Water Quality

At its current flow rate and state, the Kavango river is nearing pollution levels that will negatively impact its ecosystem services. Nitrates are especially high and if they remain as such, serious health implications should be expected including birth defects, thyroid disease, cancers and other issues. High pH, EC, salinity and TDS suggest the presence of other pathogenic and chemical pollutants that are similarly hazardous. As for the river ecosystem, the current level of pollution will eventually diminish biodiversity and fish stocks and we should expect severe eutrophication, especially in the backwaters.

Water quality tests conducted at the confluence of the Kavango and Cuito show that the latter is much healthier (figure 29) meaning that the dilution effect afforded by the Cuito is somewhat of a saving grace downstream of the confluence. Much depends on future precipitation in the upper Cubango catchment, annual floods should do much to clean up the river temporarily, although this often has adverse effects on downstream regions and pollution should be avoided in the first instance. Nevertheless, if another year of poor rainfall besets the Cubango catchment, the consequences on peoples' livelihoods and the environment alike will likely be dire along the Kavango.

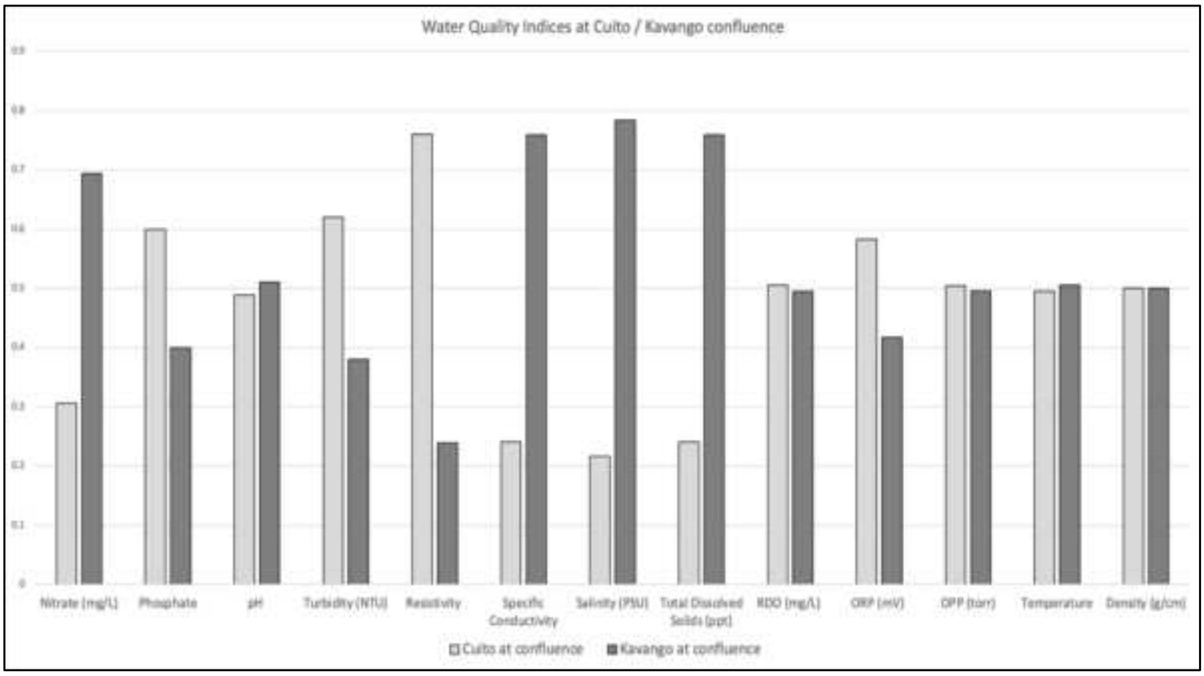


Figure 29: Comparison of water quality readings from the Cuito and Kavango Rivers near their confluence.

Figure 30: Plastic pollution with alien invasive plant Mimosa pigra in the background.

3.3 Environmental DNA

Methods: Environmental DNA

eDNA samples were collected at 9 sites along the Kavango river in Namibia in order to look at fish, invasive species and microbial communities in the river. Living organisms constantly shed DNA material that can be isolated by filtering water samples and extracting the DNA in a specialised laboratory. Once extracted, the DNA can be compared to an existing barcode reference database to identify the fish species that were present within the vicinity where the sample was collected. This barcode database was created in 2019 by collecting tissue samples from the SAIAB collection of Okavango fishes (in collaboration with Prof. Paul Skelton) and sequencing these.

Triplicate samples of ± 750ml of water at each of the sampling sites were taken. The water was filtered through a 0.22μm Sterivex filter and stored in an ATL buffer for long term storage. Samples were then sent to the eDNA laboratory at Stellenbosch University where the DNA was extracted. PCR conditions for using the MIFish primers have been optimized from a previous study done in 2019 in the Okavango Delta. Once the samples have been sequenced they will be compared to the reference database which includes over 200 samples of fish. The microbial communities will be assed using general 16S sequencing by the Microbiology lab at Rhodes University. Importantly, samples will also be scrutinised for the presence of Nile tilapia (*Oreochromis niloticus*) and the red Crawfish (*Cherax quadricarinatus*) both of which are serious invasive species know to devastate river ecosystems.

Results and Discussion: Environmental DNA

Analysis currently underway at Stellenbosch and Rhodes University.

Figure 31: Expedition leader Götz Neef collecting a eDNA sample along the Kavango River

3.4 Aquatic Macroinvertebrates

Methods: Aquatic Macroinvertebrates

Aquatic macroinvertebrates can be useful indicators of aquatic ecosystem health and are frequently used in biomonitoring assessments. Aquatic macroinvertebrates are ideal indicators as they are visible to the naked eye, easy to identify, have relatively rapid life cycles – indictive of current conditions – and are largely sedentary – indicative of local conditions (Dickens & Graham 2002). The Namibian Scoring System (NASS) is a standardized, rapid, field-based bioassessment tool assessing aquatic macroinvertebrate fauna at a family level to determine the heath of perennial rivers in Namibia (Palmer & Taylor 2010). The tool, based on the South African Scoring System, can be used to assess ecological state, spatial and temporal trends, emerging problems, impact of developments, set objectives, predict changes and determine the ecological reserve (Dickens & Graham 2002).

NASS scores the health of a site based on sensitivity scores related to the macroinvertebrates recorded there. The higher the score the heathier and more diverse the aquatic habitats are. Additional metrics for comparison includes the total number of taxa recorded, and the Average Score Per Taxon (ASPT). Healthy and diverse aquatic habitats will host a high diversity of aquatic taxa. As such interpretation of data must be made in relation to the naturally available habitat - its quality, quantity and diversity.

The deterioration or loss of habitat can be the result of alien species encroachment, trampling or overgrazing, organic and inorganic pollutants, soil erosion, reduced or modified flows, or direct habitat removal for construction.

During the recent survey of the Kavango River, NASS assessments were conducted at the 9 intensive sampling sites (figure 26). These samples provide a baseline against which subsequent surveys can be compared, providing quantifiable data on the ecological health of the river system. To complement the NASS data, water quality was recorded at each site.

Results: Aquatic Macroinvertebrates

Sites sampled along the Kavango River achieved NASS scores ranging from 180 to 220 where all habitats were present and 74 to 148 where stones were limited or missing (appendix 3). The numbers of taxa ranged from 29 to 31 where all habitats were present and 12 to 23 where stones were limiting. The Average Score Per Taxon (ASPT) – considered the most consistent and reliable indices (Dickens & Graham 2002) – ranged from 6 to 7.3 where all habitats were present and 5.3 to 6.7 where stones were limited or missing.

Site 1, at Katwitwi, scored very high and is a good reference to compare what taxa should occur where all the aquatic habitats are well represented (table 7). This site experiences few anthropogenic impacts and represents a near natural state. Site 2 is a lower scoring site but representative of what taxa occur where the stone habitat is missing or limited. Sites 3, 4, and 5 appeared to be the most impacted sites assessed, scoring low on two or more of the indices used (NASS Score, No. of Taxa, and/or ASPT). Site 6 was one of the highest scoring sites. Site 7, downstream of the confluence with the Cuito River, was a very low scoring site but this was not unexpected considering the limited habitats available combined with strong flows. Site 8 and 9 were low to moderate scoring - not unexpected considering the limited stone habitats available.

Table 7: The NASS score, Number of taxa recorded, and the Average Score Per Taxon (ASPT) for each for each of the sites sampled.

	Site No.	NASS Score	No. of Taxa	ASPT	Notes
All habitats well represented	1	220	31	7.10	
	5	180	30	6.00	Stones covered in algae
	6	211	29	7.28	
Missing or limited stone habitat	2	121	23	5.26	Stone habitat missing
	3	100	19	5.26	Stones represented by bedrock out of current only
	4	101	18	5.61	Stone habitat missing
	7	74	12	6.17	Stone habitat missing, additional inputs from Cuito
	8	148	22	6.73	Stones limited to bedrock in and out of current
	9	115	20	5.75	Stones limited to several stones in a gabion structure

There were two groups of sites which were represented by comparable habitats thus allowing for upstream/downstream comparisons. The first group (sites 1, 5 and 6) was well represented by all habitats. The second group (sites 2, 3, 4, 7, 8, and 9) was missing or had a poor diversity of stone habitats. Both groups are representative of the Kavango River which has both rocky, fast flowing stretches and long reaches with a base substrate of sand and mud. Site 5 had similar number of taxa as sites 1 and 6 but scored a lower NASS score and ASPT. Site 5 is downstream of Rundu and has extensive agriculture (both commercial and subsistence). It is likely that this site has been affected by anthropogenic impacts. Site 5 had a high diversity of taxa as it had a very high diversity of habitats, however the taxa recorded were low scoring and included worms and several flies. Further downstream at site 6, where the river perhaps had a chance to recover again, a better score was recorded. An interesting comparison here is the Nitrate concentration which increased from 0.4mg/L at site 1 to 74.9mg/L at site 5 before dropping to 25.9mg/L at site 6 suggesting some form of nutrient enrichment in the vicinity of site 5.

Sites 3 and 4 were low scoring sites also likely do to impacts of agriculture and human settlements in the area. Some recovery in the condition of the river is evident at Site 8 near Andara. This site is downstream of a long reach of river with very few anthropogenic impacts. Compared to the other upstream sites with limited stone habitats it scored well.

Discussion: Aquatic Macroinvertebrates

The 9 sites sampled were representative of habitats found on the Kavango River in Namibia. Unfortunately, limited work has been done on Namibian rivers to determine ecological health scores for NASS assessments. Comparisons to the SASS scores from similar ecoregions of South Africa suggest that the Kavango recorded moderate to high scores (considering the aquatic habitats present). The data do however suggest moderate negative impact at some sites and ongoing monitoring will be important going forward. The sample sites selected will work well for the ongoing monitoring planned for the river and should detect further impacts. Sensitive taxa (figure 32) were found at most of the sites. We would expect a decline in occurrence and abundance of some of these taxa should conditions worsen.

Figure 32: Some of the higher scoring, sensitive taxa observed in the Kavango River. Clockwise from top left: Oligoneuriidae (Brush-legged Mayfly), Machadorythidae (Pop-eyed Mayfly), Perlidae (Stonefly), Ephemeridae (Burrowing Mayfly), and Prosopistomatidae (Water spec).

The assessment highlights the river's ability to regenerate. It is very important that stretches of river, such as that near Andara, are allocated some formal protection to allow the river to recover. The value added by demarcating several reaches of river with some level of protection would be immense and the communities neighbouring such protected areas will reap the benefits of a healthy functioning river – cleaner water, more fish and better ecosystem services.

Going forward natural, reference conditions need to be described to inform a Macroinvertebrate Response Assessment Index (MIRAI), standardizing categories of ecological health for the Kavango River. These categories could then be used to measure the impacts of developments and inform mitigative measures.

3.5 Acoustic Doppler Current Profiler

Methods: **Acoustic Doppler Current Profiler**

We used a SonTek RS5 Acoustic Doppler Current Profiler (ADCP) to measure water discharge (m^3/s) at the start of the transect near Katwitwi, at intensive sample site 3 and at the confluence on both the Kavango and the Cuito. The river was too wide to use ropes to pull the ADCP across, so we paddled slowly across the river in a mokoro towing the ADCP (figure 34) while remaining within acceptable limits in terms of sampling speed and trajectory.

Results: **Acoustic Doppler Current Profiler**

Water discharge decreased steadily as we moved down river starting at $23.4m^3/s$ at Katwitwi and ending at $18.3m^3/s$ at the confluence. The Cuito River was delivering $79.8m^3/s$ at the confluence, thus currently contributing 80% of the water that enters the Okavango river at Mohembo. Our automated discharge meter (Sommer RQ30) at Divundu bridge further downstream was reporting in the region of $90m^3/s$ at that time, which is congruent with the results from the ADCP (assuming that a ~10% loss between the confluence and Divundu bridge is correct).

Discussion: **Acoustic Doppler Current Profiler**

The Kavango river is currently at an exceptionally low level with just over $20m^3/s$ entering Namibia. This is due to a shortage of rainfall in the upper catchment. Given the lack of available groundwater data, it is not possible at this stage to account for the 22% loss of discharge between Katwitwi and the confluence.

Figure 33: Discharge rates along the Kavango River calculated using ADCP between 30 August (Katwitwi) and 17 September (confluence), 2021.

Figure 34: Sontek RS5 ADCP in use on the Kavango River.

4. OPPORTUNISTIC SAMPLING

4.1 Assessment of Mercury and DDT in Tigerfish

We hosted Ms. Martha George from the Kamutjonga Inland Fisheries Institute (KIFI) who was investigating mercury and DDT levels in tigerfish from the Kavango River in fulfilment of her MSc through the University of Namibia. The following excerpts were taken from Ms Georges project proposal:

Tigerfish (*Hydrocynus vittatus*) are an important component of artisanal, commercial and recreational fisheries along the Kavango River where they contribute to food security and rural livelihoods (Abbott et al. 2015; Tweddle et al. 2015). Extensive exploitation of tigerfish populations was recently reported for northern Namibia (Cooke et al. 2016) and due to their ecological and economic importance in the region, there is an urgent need for their sustainable management. Currently there is no information on the ecotoxicology of tigerfish, and this lack of knowledge may further constrain the effective management of this species.

There has been an increase in developmental projects along the Kavango River in recent years, including large agricultural green schemes. These projects pose potential hazards in terms of pollution that can affect the wellbeing of the aquatic ecosystem along the Kavango River. Mercury (Hg) and Dichloro-diphenyl-trichloroethane (DDT) are two of the most important pollutants in fish that have been shown to cause severe problems in fish and human health. The tigerfish is the apex predator in the Kavango River and as a result, bioaccumulation may be a potential threat to the life history of this species and there may be a potential hazard to humans by consuming this species.

This study aims to provide a baseline research on the pollutant levels of Mercury and DDT in tigerfish which could provide management recommendations on the health status of fish species along the Kavango River especially considering that they are the main source of food in this region.

At suitable overnight camps, Ms George deployed a gill net to capture tigerfish. Additionally, team members used conventional fishing rods to catch tigerfish at opportune locations. The data is still under analysis and will eventually be published in a peer-reviewed journal.

Figure 35: Ms Martha George collecting a tissue sample to test for mercury and DDT levels in a tigerfish caught in the Kavango River.

4.2 Bat recorder deployments

Bat echolocation recordings were obtained during the early evening activity peak period each night (figure) during the river expedition using a *Wildlife Acoustics Song Meter SM4BAT-FS* detector (Taylor et al. 2018). The data has been sent to Dr Siena Weier and Prof Peter Taylor as part of a larger bat diversity study of the entire Okavango Basin.

4.3 Fyke net deployments

A fyke trap-net was set overnight at each of the 16 camp sites along the river transect (figure). Most captured fish were released as they were easily distinguished to the species level, others that were not discernible were anaesthetized in clove oil and preserved in 10% Formalin. Tissue samples were also extracted and stored in 99% ethanol for subsequent DNA analysis. Samples are housed at the South African Institute for Aquatic Biodiversity (SAIAB). Captured species are presented in table 8.

Figure 36: Overnight sites during the Kavango 2021 expedition.

Table 8: Fish species captured during nightly fyke net deployments

Name	Common name	Lat	Long
Mastacembelus frenatus	Longtail Spiny Eel	-17.393803	18.421753
Pharyngochromis acuticeps	Zambezi Bream	-17.824053	19.237353
Petrocephalus sp.	Churchhill sp.	-17.881933	20.192292
Enteromius sp.	Barb sp.	-18.028089	20.790697
Nannocharax multifasciatus	Multibar Citharine	-18.028089	20.790697
Serranochromis angusticeps	Thinfaced Largemouth	-17.949355	21.060679
Tilapia sparrmanii	Banded Tilapia	-18.068828	21.460864

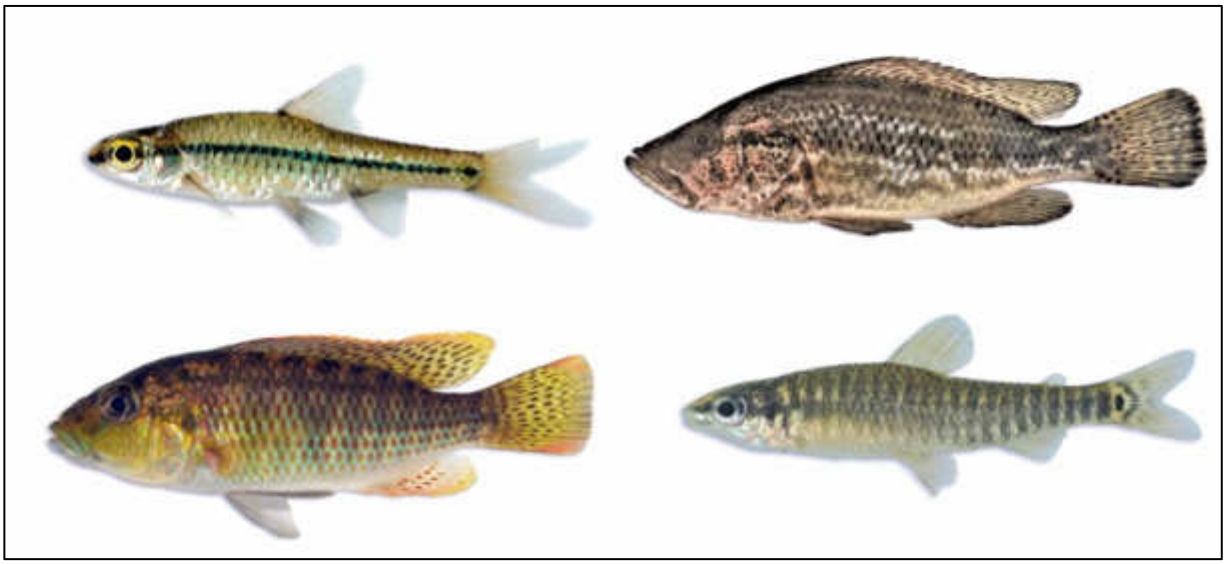


Figure 37: Some fish species recorded during nightly fyke-net deployments: Clockwise from top left, Enteromius sp, Serranochromis angusticeps, Pharyngochromis acuticeps, Nannocharax multifasciatus

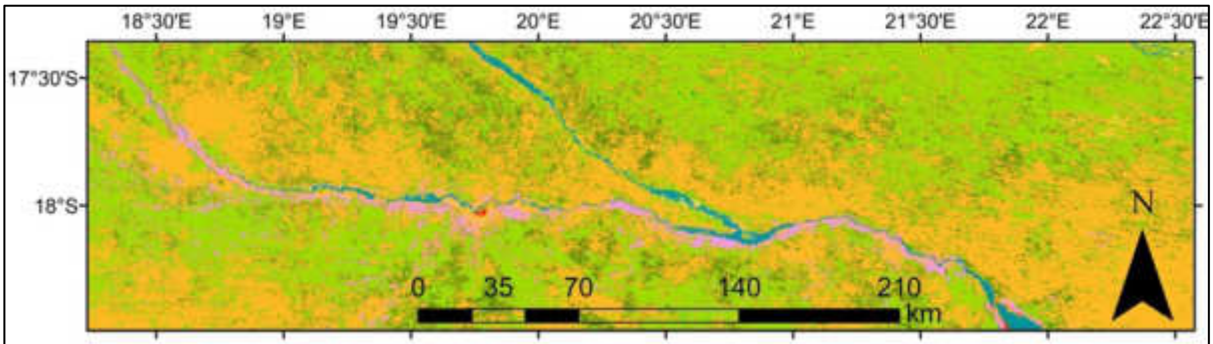
5. LAND USE CHANGE ANALYSIS 2019-2021

Methods: Landcover and Land Use Change Analysis

The Copernicus Global Land Cover Layers: CGLS_LC100 collection 3 product was used to generate a land cover map of the study area (figure 38). The product classification has a 100m resolution and a global accuracy of 80% (Buchhorn et al., 2020). Copernicus Sentinel-2 (S2) satellite data were used to generate land cover RGB optical images of the mapped area at 20m resolution for 2019 and for 2021. The Copernicus S2 MSI: Multispectral Instrument, Level-2A Surface Reflectance dataset is an atmospherically corrected product (ESA, 2021). Clouds from both datasets were removed from the image composites by filtering out images with greater than 5% cloud cover. The change detection data was derived from Google Earth Engine where the 2021 image was subtracted from the 2019 image (figure 39). A difference threshold of 0.35 was used, this represents significant differences in the spectral signature between each classification and hence land cover changes. Using satellite imagery, areas where 'natural' change occurred (floodplains and protected areas) were ignored and areas where change occurred as a consequence of agriculture or other anthropogenic activity were highlighted in figure 39

Results: Landcover and Land Use Change Analysis

The "Cultivated and managed vegetation / agriculture" class skirts the river as it is dependent on its water. Of the 1,618km^2 that this class covers, 69.2% lies on the Namibian side and 30.8% in Angola, this is clearly evident in the resultant landcover map (figure 38). In the land use change analysis, noteworthy difference in the spectral signature was detected in 627Km^2 (0.96% of total area) between 2019 and 2021 (figure 39) most of which took place within 5km of the river bank.



Legend	Copernicus Landcover classes (100 m)	Coverage (%)	Area (km2)
	Shrubs	43,14	28387,9
	Herbaceous vegetation	0,47	308,2
	Cultivated and managed vegetation / agriculture	2,46	1618,3
	Urban / built up	0,04	26,6
	Bare / sparse vegetation	<0,01	0,1
	Permanent water bodies	0,07	46,3
	Herbaceous wetland	1,32	871,3
	Closed forest, deciduous broad leaf	0,14	93,8
	Closed forest, not matching any of the other definitions	0,01	9,6
	Open forest, deciduous broad leaf	37,19	24471,9
	Open forest, not matching any of the other definitions	15,15	9971,8
	Total	100	65805,6

Figure 38: Landcover map for the Kavango River, 2021.

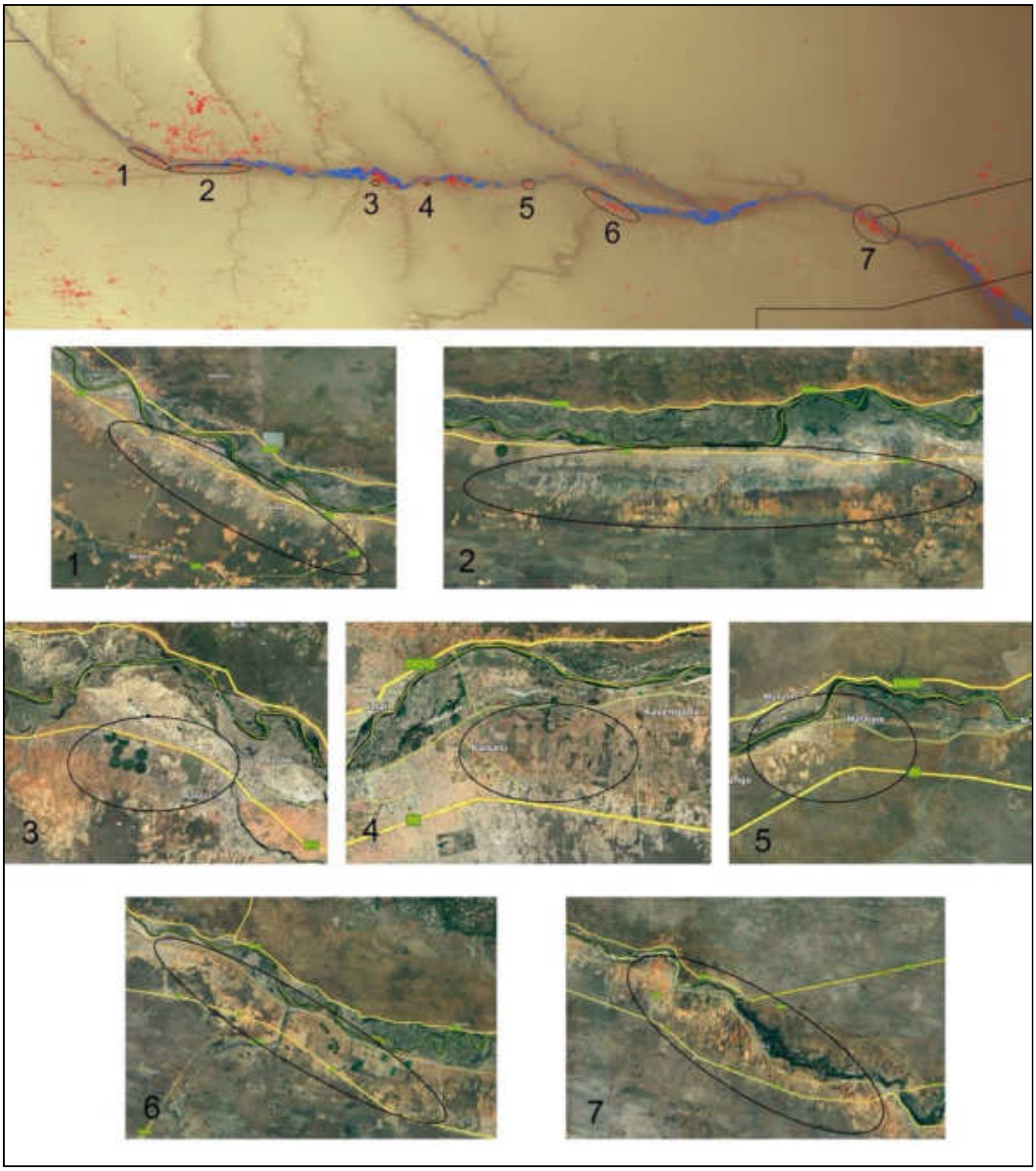


Figure 39: Land use change analysis between 2019-2021 highlights locations along the Kavango River where agriculture is expanding rapidly

Discussion: Landcover and Land Use Change Analysis

Much of the "cultivated land" category in the landcover map belonged to Namibia, where water abstractions have permitted rapid agricultural expansion. In Angola, this class is almost completely limited to within 1km of the river. This makes sense as there are few abstractions and people mostly water their crops by hand. An analysis of land use change over the last 3 years reveals significant agricultural expansion along the Namibian side at green schemes (commercial agriculture) and around certain towns (semi-commercial or subsistence agriculture).

6. RECOMMENDATIONS

This report highlights potential concerns in water quality, water offtake, resource overutilisation, land use practices and unsustainable development along the Kavango River, especially on the Namibian side. We base these concerns on sound data collection procedures and scientific prowess curated during similar transect surveys in the Okavango basin spanning in excess of 11,000km. Nevertheless, survey limitations and bias call for verification of our findings. On January 25, 2022, NGOWP is arranging and hosting a scientific symposium in Windhoek during which these results will be presented to local authorities from the relevant ministries, academic institutions and NGOs. The purpose of the symposium is to present our finds and give other institutions the opportunity to weigh in and suggest what could be done to verify our findings and how they may find solutions to some of the river's problems. NGOWP has secured funding for two fully funded Namibian PhD scholarships and we have invited UNAM's best candidates to the symposium in the hope that some project proposals will be forthcoming.

Sound conservation planning is absolutely essential if the ecosystem services provided by the Kavango River are to be sustained. We suggest commissioning a consultancy whereby a MARXAN analysis is performed. Useful data layers generated by government, NGOs, academic institutions as well as data from this report are combined into a data cube and once ingested by the MARXAN software, will inform on a sound, efficiently zoned conservation strategy. Community inclusion and benefits are essential here.

Apparent high nitrates and other water quality concerns should be verified with detailed water tests in the laboratory. In the meantime, authorities should pay close attention to the health of those drinking directly from the river, perhaps by monitoring the situation in local clinics. Of the ten members in our team, 5 fell ill from drinking the water, even though it was filtered.

Nitrate and other concerning water chemical signatures appear related to green schemes and other large farms. This also requires verification, but in the meantime existing regulations regarding fertilisation should be reviewed and enforced.

Due to the prolonged low flow state of the Kavango during 2021, many people have planted crops or built dwellings on the floodplain or near the river bank. Early flood warning is essential to prevent loss of property or life.

Remote sensed data from satellite imagery is a powerful tool in monitoring future land use change. We recommend a more rigorous analysis than what has been presented in this report and to repeat that exercise on an annual basis.

Despite existing fishing regulations, we noted many instances of illegal fishing and questionable commercial fishery activities. In this regard, the mapped data in this report may be useful to the authorities.

Provisioning of municipal water wherever possible, especially in places where immigration is high will improve people's livelihoods as well as the state of the river. Currently people are forced to drink directly from the river and wash in it, which leads to further pollution.

Human population census data should be gathered more frequently to determine immigration rates and demographics.

The national policy on alien invasive plants should be expanded and include guidelines, regulations and increase awareness (Bethune et al. 2004). *Leucaena leucocephala* had in past years been sold by the Namibian Directorate of Forestry nurseries as a fodder tree, nitrogen fixer, firewood producer and rapid growing shade tree – it is now likely to become a serious invader (Joubert 2009). It is necessary to educate home and lodge owners on the impact of concerning alien invasive species to advocate for their removal

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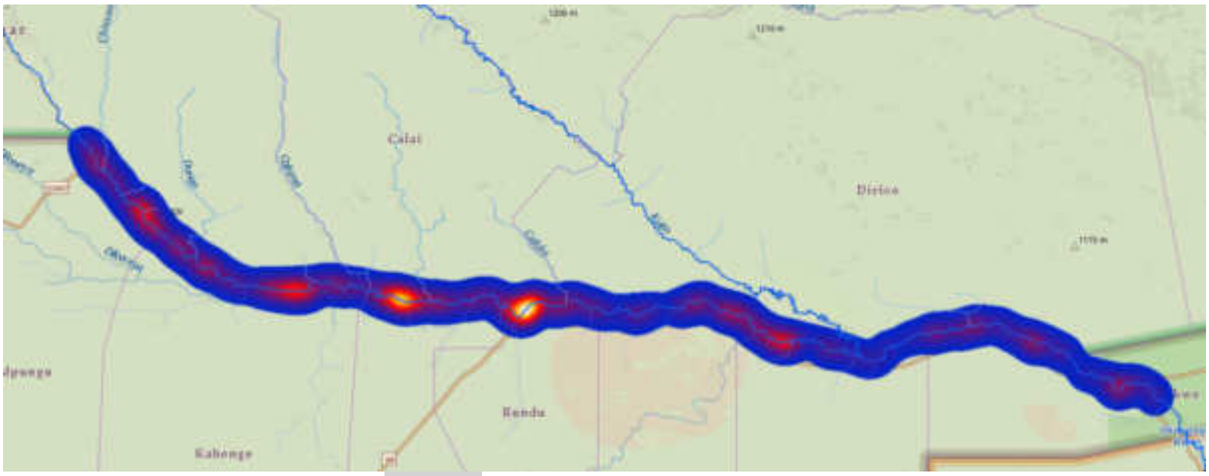
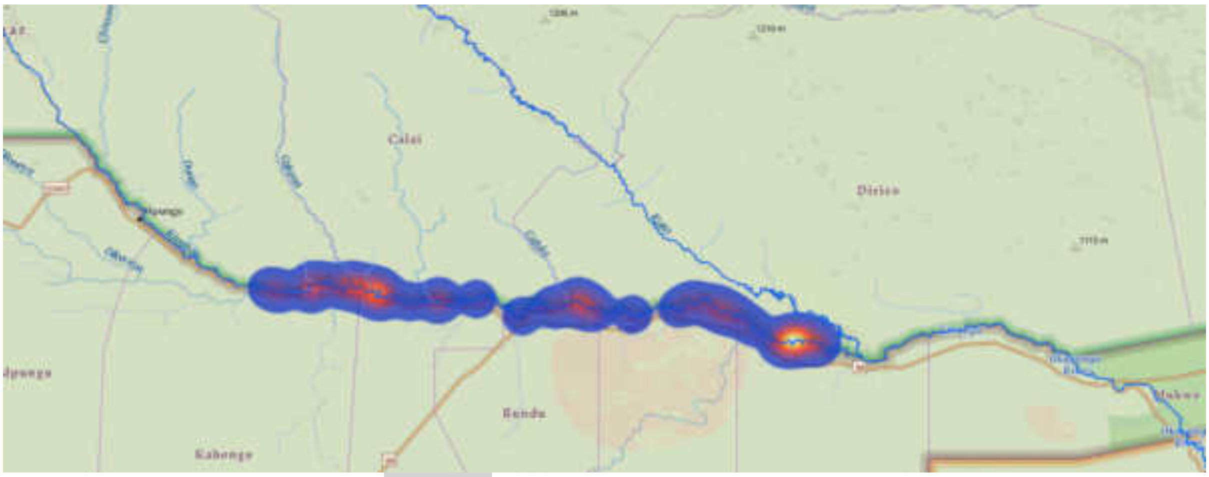
APPENDIX 1: MAPPED DATA

Appendix 1.1: Distribution of people recorded in 2017



Appendix 1.2: Distribution of people recorded in 2021



Appendix 1.3: Distribution of gill nets in 2017

Appendix 1.4: Distribution of gill nets in 2021

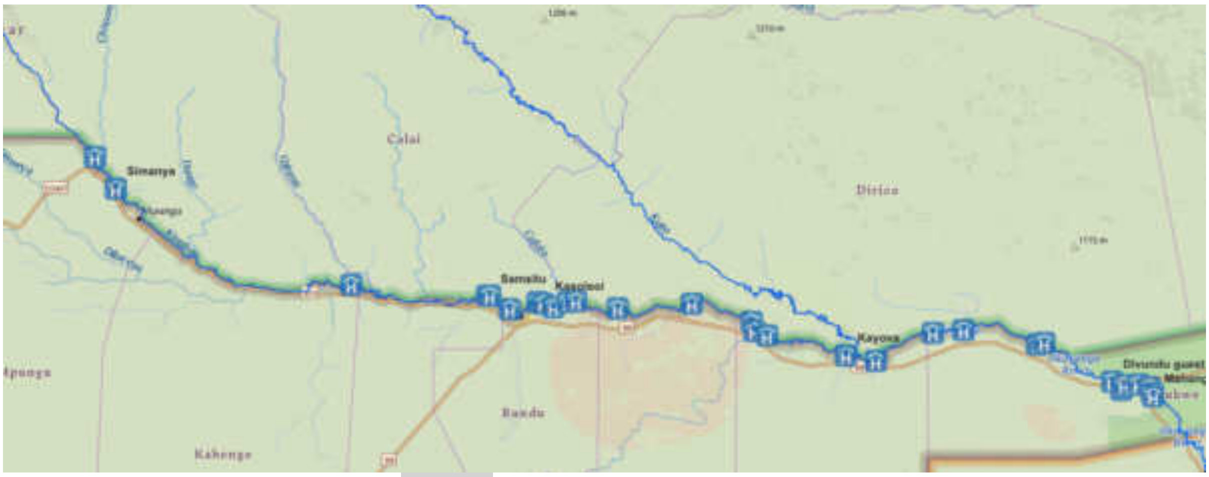
Appendix 1.5: Drag netting observed in 2021

Appendix 1.6: Use of mosquito nets for fishing observed in 2021

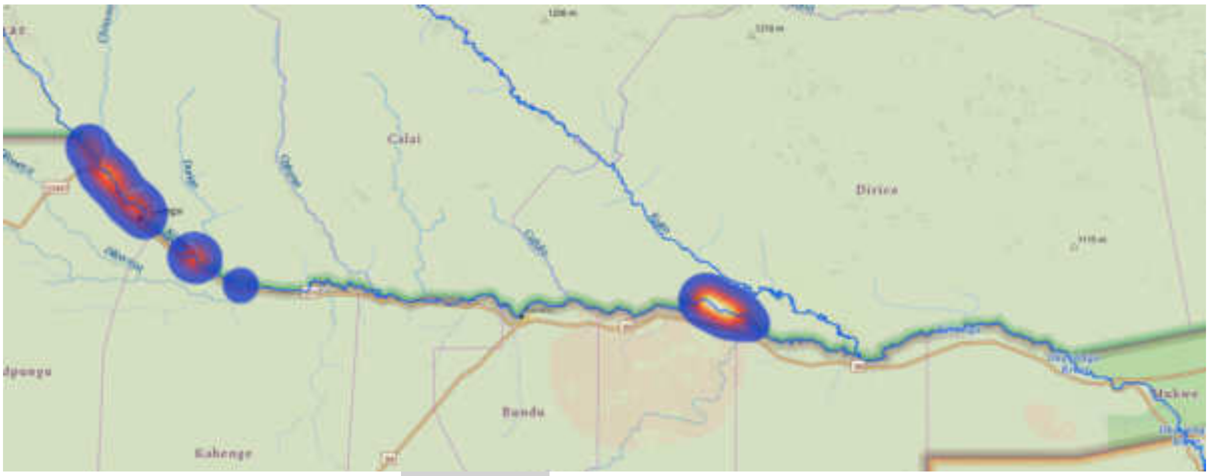
Appendix 1.7: Abstractions recorded in 2017. Red pins = X-Large and Large abstractions, Green pins = Medium and Yellow pins = Small.

Appendix 1.8: Abstractions recorded in 2021. Red pins = X-Large and Large abstractions, Green pins = Medium and Yellow pins = Small.

Appendix 1.9: Distribution of mekoro counted in 2021.

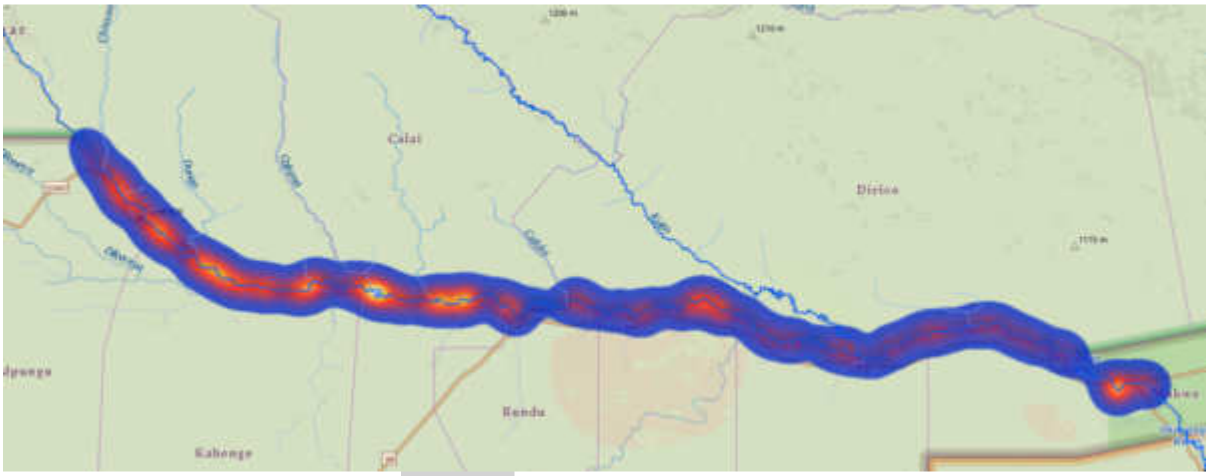


Appendix 1.10: Distribution of lodges observed in 2021



Appendix 1.11: Distribution of fish corrals in 2021

Appendix 1.12: Distribution of livestock in 2017

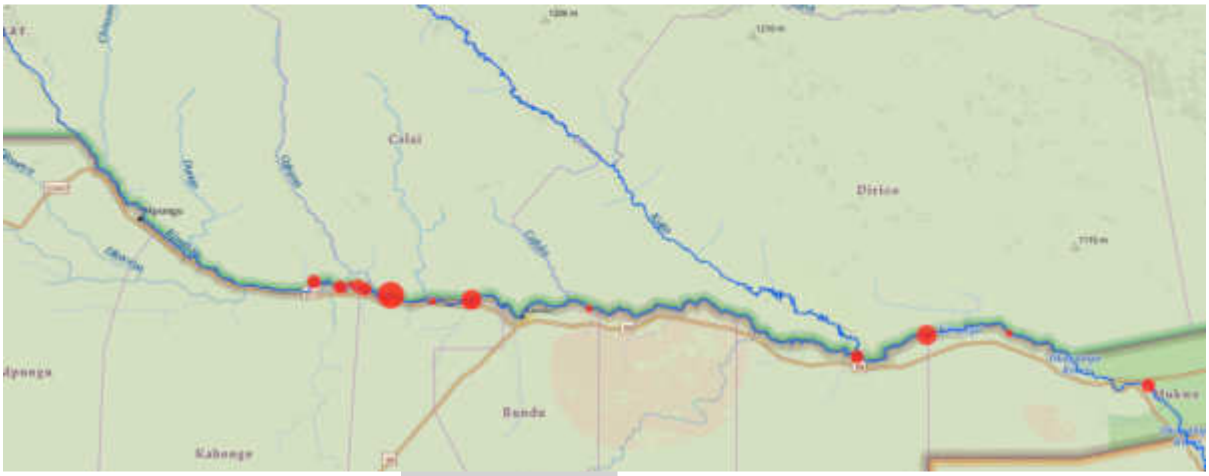


Appendix 1.13: Distribution of livestock in 2021.

Appendix 1.14: Distribution of hippos in 2021

Appendix 1.15: Distribution of all combined wetland birds in 2021

Appendix 1.16: Distribution of African Darter in 2021



Appendix 1.17: Distribution of African Openbill in 2021

Appendix 1.18: Distribution of African Pygmy Goose in 2021

Appendix 1.19: Distribution of African Skimmer in 2021

Appendix 1.20: Distribution of Bee-eaters in 2021

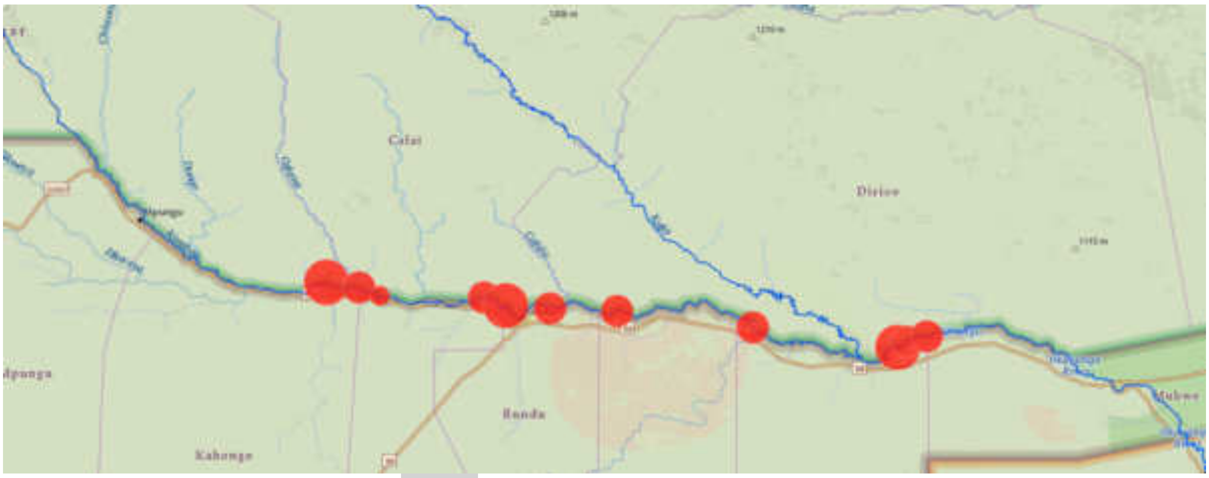
Appendix 1.21: Distribution of Black Crake in 2021

Appendix 1.22: Distribution of Black-winged Stilt in 2021

Appendix 1.23: Distribution of Collared Pratincole in 2021

Appendix 1.24: Distribution of Common Greenshank in 2021

Appendix 1.25: Distribution of Common Sandpiper in 2021



Appendix 1.26: Distribution of Ducks in 2021

Appendix 1.27: Distribution of Egrets in 2021

Appendix 1.28: Distribution of Herons in 2021

Appendix 1.29: Distribution of Jacanas in 2021

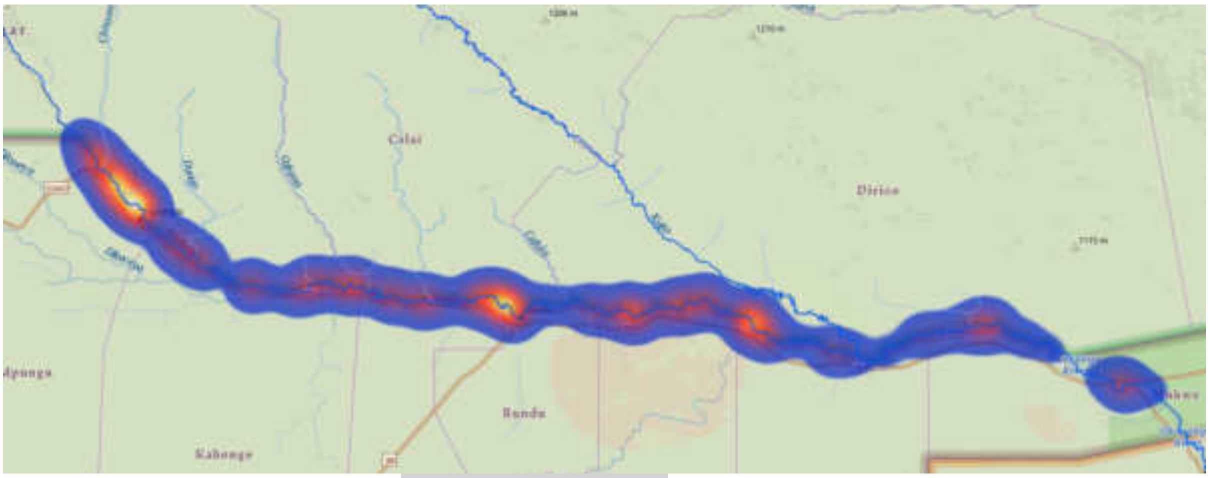
Appendix 1.30: Distribution of Kingfishers in 2021

Appendix 1.31: Distribution of Lapwings in 2021

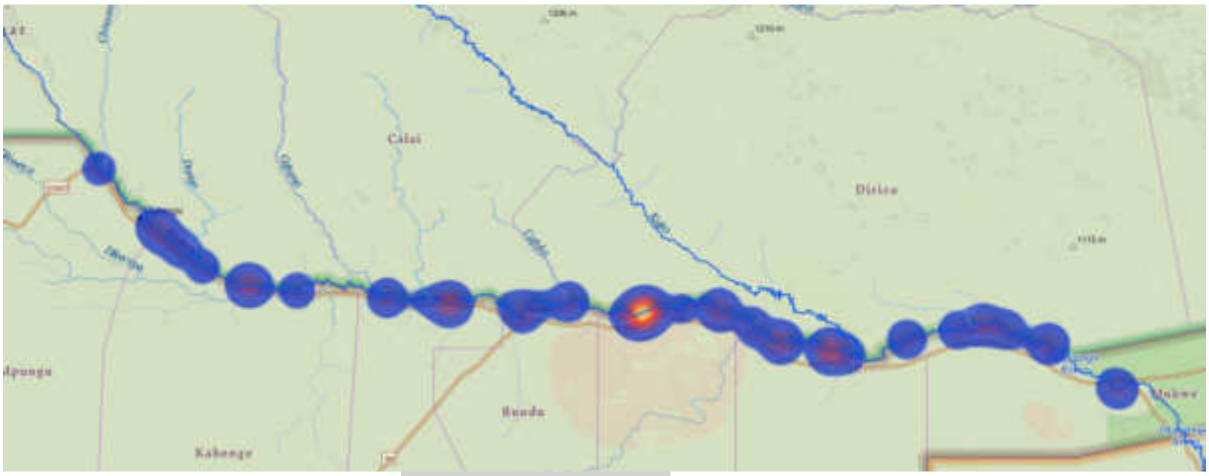
Appendix 1.32: Distribution of Reed Cormorant in 2021

Appendix 1.33: Distribution of Rock Pratincole in 2021

Appendix 1.34: Distribution of Yellow-billed Stork in 2021



Appendix 1.35: Distribution of Giant Sensitive Plant (*Mimosa pigra*) in 2021



Appendix 1.36: Distribution of other invasive plants in 2021

Appendix 1.37: Distribution of Papyrus in 2021

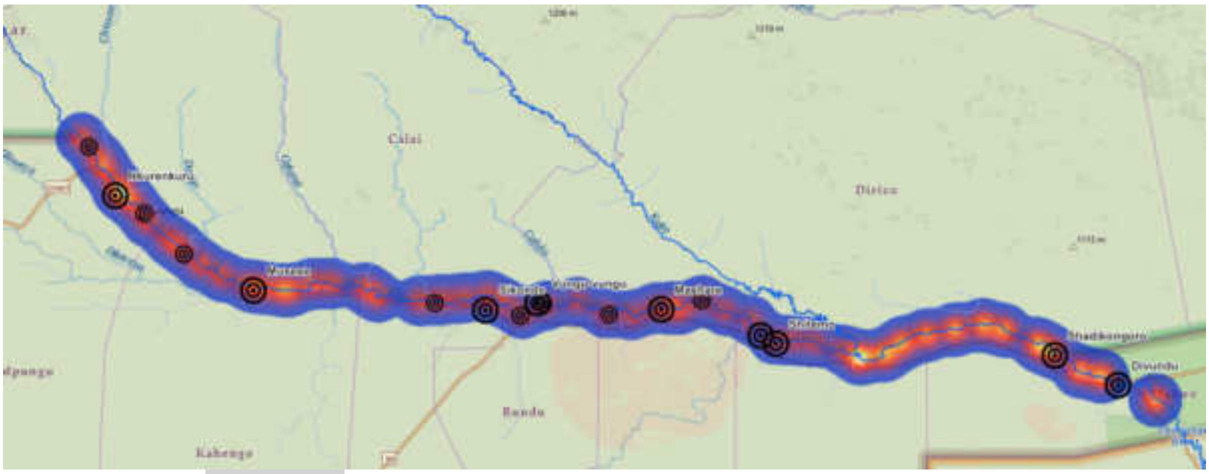
Appendix 1.38: Nitrates. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.

Appendix 1.39: Phosphates. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.

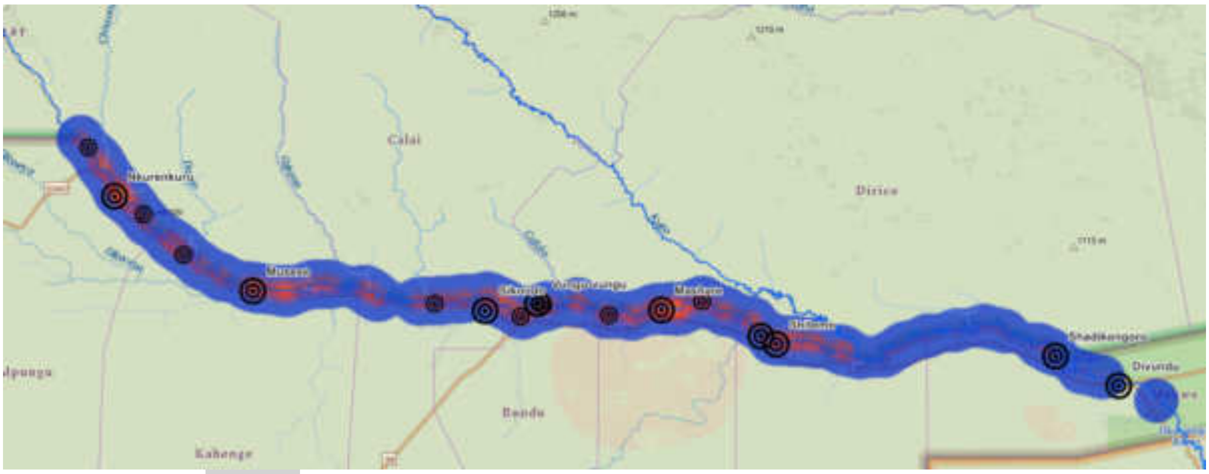
Appendix 1.40: pH. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.

Appendix 1.41: Turbidity. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.

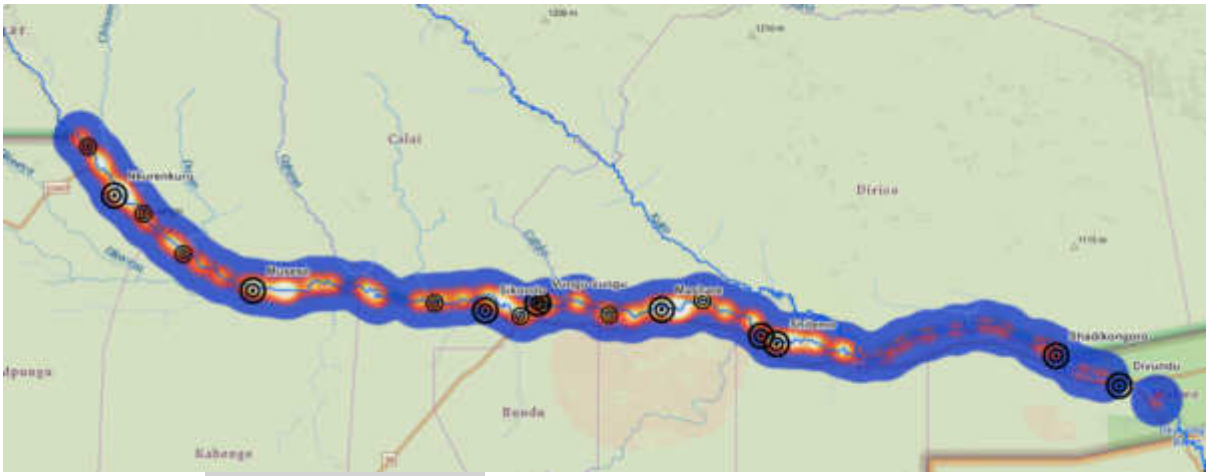
Appendix 1.42: Specific conductivity. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.



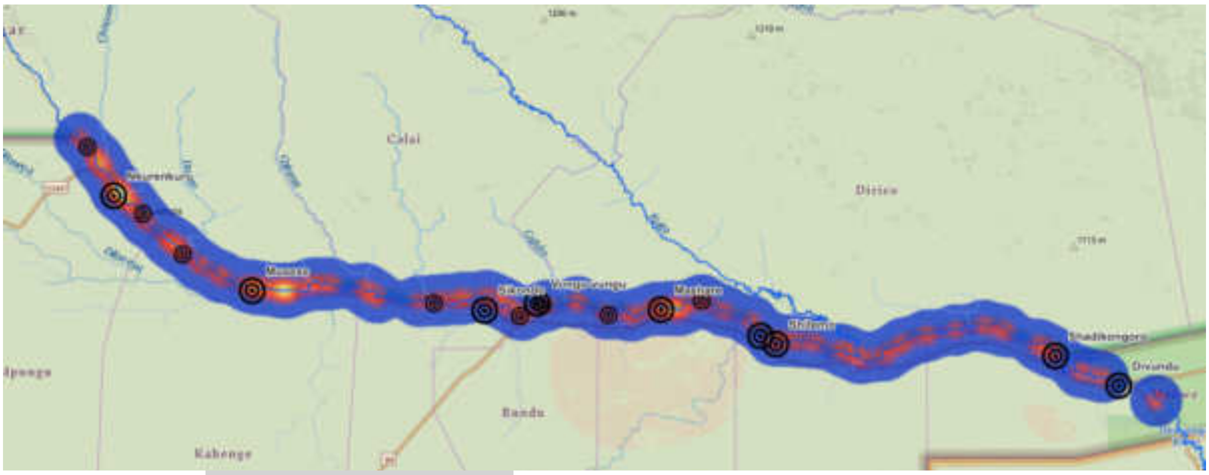
Appendix 1.43: Resistivity. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.



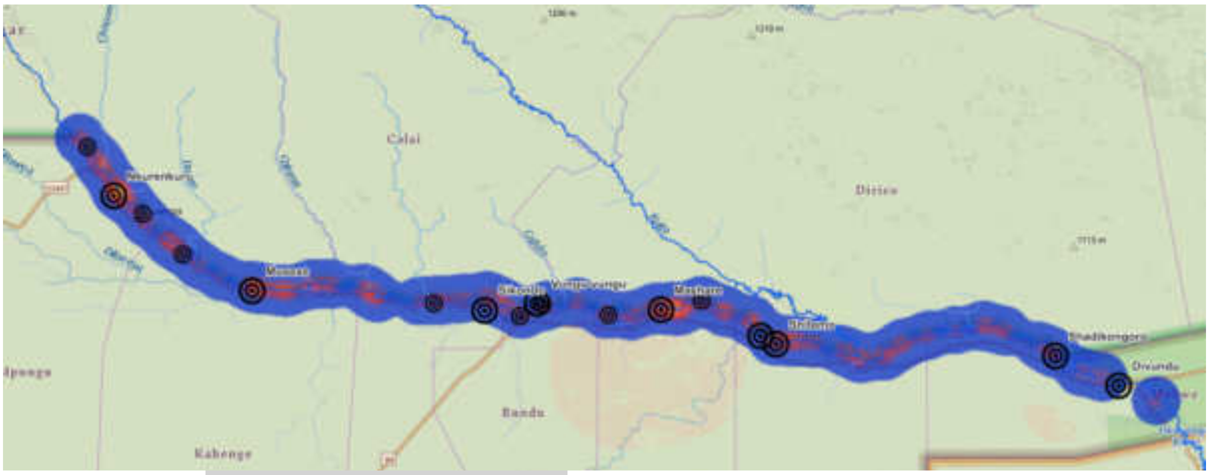
Appendix 1.44: Salinity. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.



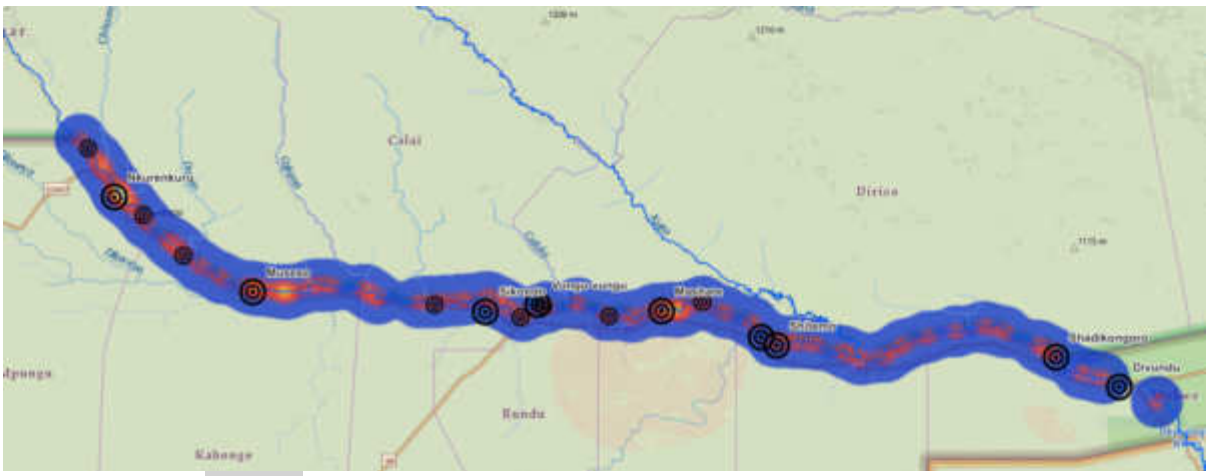
Appendix 1.45: Total Dissolved Solids. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.



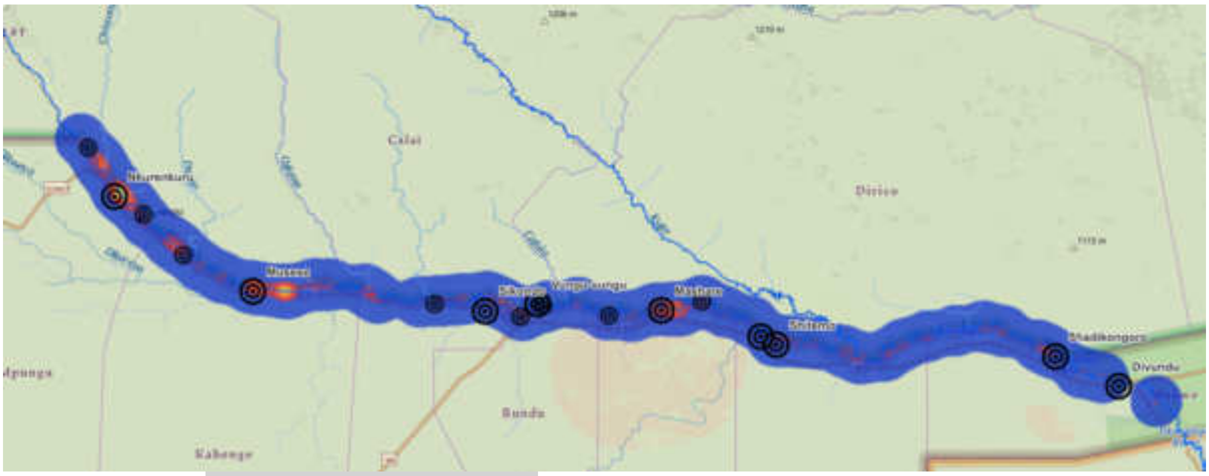
Appendix 1.46: Oxygen Partial Pressure. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.



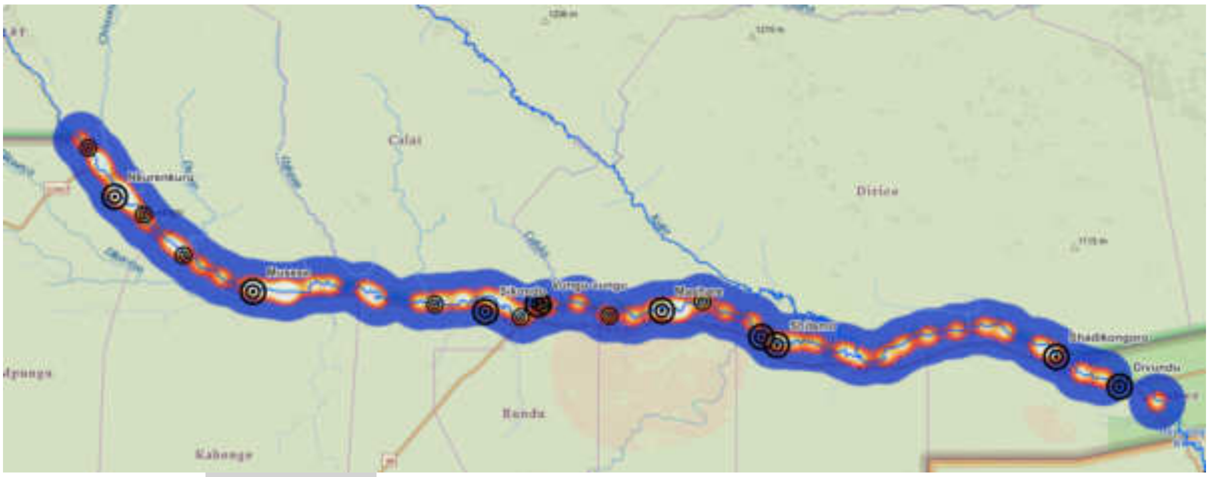
Appendix 1.47: Oxygen Reduction Potential. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.



Appendix 1.48: Density. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.



Appendix 1.49: Rugged Dissolved Oxygen. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.



Appendix 1.50: Temperature. Large circles represent Green schemes (labelled), small circles represent other large agricultural schemes.

APPENDIX 2: WATER ABSTRACTIONS RECORDED ALONG THE KAVANGO RIVER IN 2021

Country	long	lat	Water abstraction purpose	Currently pumping?	Tot-Diameter	Size
Namibia	19.6229159	-17.863758	Green scheme	Yes	357	x-large
Namibia	20.1667731	-17.885233	Green scheme	Yes	357	x-large
Namibia	18.95621	-17.825036	Green scheme	No	245	x-large
Namibia	19.8400632	-17.878285	Green scheme	Yes	172	x-large
Namibia	20.5028802	-17.954338	Green scheme	No	130	x-large
Namibia	19.8989872	-17.877608	Green scheme	?	118	x-large
Namibia	20.4766891	-17.952385	Green scheme	No	102	x-large
Namibia	20.1682349	-17.881997	Green scheme	No	89	large
Namibia	18.5361814	-17.54213	Green scheme	Yes	83	large
Namibia	18.931487	-17.821849	Green scheme	No	83	large
Namibia	19.7618156	-17.909256	Municipal_water_supply	Yes	82	large
Namibia	20.5407107	-17.983249	Green scheme	No	82	large
Namibia	20.5278045	-17.976763	Green scheme	Yes	72	large
Namibia	19.8534448	-17.882734	Green scheme	Yes	59	large
Namibia	18.6158427	-17.613027	Fish farm	Yes	57	large
Namibia	18.7381947	-17.729623	Hospital	Yes	55	large
Namibia	21.4007298	-18.01204	Green scheme	No	51	large
Namibia	18.4484534	-17.420163	Agriculture	Yes	50	large
Namibia	21.3873714	-18.013166	Green scheme	No	48	large
Namibia	21.3764754	-18.011404	Green scheme	No	47	large
Namibia	21.4010997	-18.012303	Green scheme	Yes	46	large
Namibia	20.1682532	-17.881957	Green scheme	No	45	large
Namibia	19.5013049	-17.87124	Agriculture	No	44	large
Namibia	20.0301132	-17.905628	Agriculture	Yes	38	large
Namibia	20.2101496	-17.884583	Green scheme	No	38	large
Namibia	20.5576265	-17.985587	Green scheme	Yes	36	large
Namibia	20.3138499	-17.86282	Agriculture	No	35	large
Namibia	19.8309673	-17.873315	Agriculture	No	33	large
Angola	19.2724362	-17.821716	Green scheme	No	32	large
Namibia	18.7901248	-17.766924	Green scheme	No	31	large
Namibia	21.6900665	-18.152306	KIFI	No	24	medium
Namibia	19.7456969	-17.909421	Agriculture	Yes	19	medium
Namibia	21.5555331	-18.098706	Municipal_water_supply	Yes	19	medium
Namibia	18.5428328	-17.553147	Agriculture	Yes	17	medium
Namibia	20.9334821	-17.977215	Private_residence	Yes	17	medium
Namibia	19.7494616	-17.910811	Agriculture	Yes	17	medium
Namibia	19.0101864	-17.831402	Chicken farm	No	16	medium
Namibia	19.8160566	-17.868345	Lodge	No	15	medium
Namibia	19.6797911	-17.854068	Building site	No	14	medium
Namibia	20.0330096	-17.904741	Agriculture	No	14	medium
Namibia	18.9745683	-17.828834	Agriculture	Yes	14	medium
Namibia	18.5365037	-17.54219	Agriculture	Yes	11	medium
Namibia	19.5440756	-17.875526	Unknown	Yes	11	medium

Namibia	19.7912736	-17.876707	Agriculture	No	11	medium
Namibia	20.1019375	-17.907717	Agriculture	No	11	medium
Namibia	21.6361682	-18.104491	Lodge	Yes	11	medium
Namibia	18.6222751	-17.635168	Agriculture	No	11	medium
Namibia	18.6239173	-17.636626	Unknown	No	11	medium
Namibia	18.795633	-17.768445	Agriculture	Yes	11	medium
Namibia	19.0539933	-17.835918	Private_residence	No	11	medium
Namibia	19.355976	-17.857876	Agriculture	No	11	medium
Namibia	20.7019778	-18.010298	Agriculture	No	11	medium
Namibia	20.7067726	-18.008962	Water truck abstraction site	No	11	medium
Namibia	21.4215998	-18.025084	Agriculture	Yes	11	medium
Namibia	19.4663424	-17.866611	Agriculture	Yes	11	medium
Namibia	20.2588629	-17.871937	Agriculture	Yes	11	medium
Namibia	20.8406633	-18.036985	Lodge	?	11	medium
Namibia	19.8308273	-17.873328	Lodge	No	10	medium
Namibia	20.5560744	-17.98526	Private_residence	No	10	medium
Namibia	21.098121	-17.950286	Private_residence	No	10	medium
Namibia	21.5553936	-18.105227	Unknown	No	10	medium
Namibia	19.8819837	-17.880255	Agriculture	No	10	medium
Namibia	20.701986	-18.010293	Agriculture	No	10	medium
Namibia	21.3441533	-17.988231	Chicken farm	?	10	medium
Namibia	21.3441547	-17.988193	Agriculture	No	10	medium
Namibia	21.5563106	-18.094245	Green scheme	?	10	medium
Namibia	21.5559221	-18.097088	Green scheme	?	10	medium
Namibia	21.5558556	-18.106417	Water truck abstraction site	Yes	10	medium
Namibia	18.9146209	-17.820642	Agriculture	No	9	medium
Namibia	19.4837454	-17.870048	Agriculture	Yes	8	medium
Namibia	20.1764936	-17.878159	Agriculture	No	8	medium
Namibia	21.4863982	-18.080128	Agriculture	Yes	8	medium
Namibia	21.555247	-18.104358	Agriculture	No	8	medium
Namibia	20.5027854	-17.954158	Private_residence	Yes	8	medium
Namibia	19.3559729	-17.857882	Church	No	7	medium
Angola	18.4976727	-17.485755	Agriculture	No	6	medium
Namibia	18.643641	-17.647279	Agriculture	No	6	medium
Namibia	18.7143521	-17.704229	Agriculture	No	6	medium
Namibia	18.743462	-17.73828	Agriculture	No	6	medium
Namibia	18.9315004	-17.821871	Farm headquarters	No	6	medium
Namibia	19.3614568	-17.848365	Agriculture	No	6	medium
Namibia	19.5056444	-17.870946	Agriculture	No	6	medium
Namibia	19.6233579	-17.863199	Private_residence	No	6	medium
Namibia	20.7860867	-18.024894	Chicken farm	No	6	medium
Namibia	21.251479	-17.961566	Private_residence	No	6	medium
Namibia	19.0332887	-17.835613	Agriculture	Yes	6	medium
Namibia	19.064428	-17.835102	Private_residence	Yes	6	medium
Angola	20.440176	-17.907381	Agriculture	No	6	medium
Namibia	18.6151148	-17.618337	Private_residence	No	6	medium

Namibia	18.6168779	-17.62705	Private_residence	No	6	medium
Namibia	18.6186961	-17.630333	Agriculture	Yes	6	medium
Namibia	19.0868255	-17.836092	Agriculture	Yes	6	medium
Namibia	19.4142258	-17.867799	Agriculture	No	6	medium
Namibia	19.6863482	-17.858674	Private_residence	No	6	medium
Namibia	19.6870205	-17.859839	Private_residence	No	6	medium
Namibia	19.687026	-17.859837	Private_residence	No	6	medium
Namibia	19.74205	-17.907264	Agriculture	Yes	6	medium
Namibia	19.7927313	-17.876253	Agriculture	No	6	medium
Namibia	19.7403831	-17.901807	Agriculture	Yes	6	medium
Namibia	19.8615857	-17.884045	Agriculture	No	6	medium
Namibia	20.0326149	-17.904808	Agriculture	No	6	medium
Namibia	20.0571274	-17.885932	Lodge	Yes	6	medium
Namibia	20.1009807	-17.907488	Agriculture	No	6	medium
Namibia	20.1059952	-17.910679	Agriculture	No	6	medium
Namibia	20.1167494	-17.909245	Agriculture	No	6	medium
Namibia	20.1167493	-17.909244	Agriculture	No	6	medium
Namibia	20.1755799	-17.877803	Agriculture	No	6	medium
Namibia	20.2431815	-17.892158	Agriculture	No	6	medium
Namibia	20.283308	-17.871759	Lodge	No	6	medium
Namibia	20.3648458	-17.894927	Agriculture	No	6	medium
Namibia	20.4173143	-17.908824	Agriculture	No	6	medium
Namibia	20.5096038	-17.96463	Lodge	?	6	medium
Namibia	21.1096601	-17.946254	Lodge	No	6	medium
Namibia	21.1452186	-17.936776	Agriculture	?	6	medium
Namibia	21.1505474	-17.935964	Agriculture	?	6	medium
Namibia	21.1662245	-17.935968	Private_residence	Yes	6	medium
Namibia	21.1662245	-17.935968	Private_residence	Yes	6	medium
Namibia	21.1662336	-17.935969	Private_residence	No	6	medium
Namibia	21.1725887	-17.936934	Agriculture	No	6	medium
Namibia	21.1754119	-17.937908	Agriculture	No	6	medium
Namibia	21.2007402	-17.933569	Private_residence	No	6	medium
Namibia	21.2007965	-17.933529	Private_residence	No	6	medium
Namibia	21.303727	-17.977002	Agriculture	No	6	medium
Namibia	21.3231302	-17.989735	Agriculture	No	6	medium
Namibia	21.3305544	-17.990566	Lodge	No	6	medium
Namibia	21.3626755	-17.987159	Agriculture	No	6	medium
Namibia	21.3626811	-17.987128	Agriculture	No	6	medium
Namibia	21.3703774	-18.005686	Water truck abstraction site	No	6	medium
Namibia	21.3728898	-18.010375	Private_residence	No	6	medium
Namibia	21.3792316	-18.01239	Agriculture	No	6	medium
Namibia	21.3851953	-18.013704	Agriculture	No	6	medium
Namibia	21.3853639	-18.013691	Agriculture	No	6	medium
Namibia	21.4154327	-18.017092	Agriculture	Yes	6	medium
Namibia	21.5184267	-18.08693	Private_residence	No	6	medium
Namibia	21.4872168	-18.080502	Agriculture	No	6	medium

Namibia	21.4902558	-18.082067	Agriculture	No	6	medium
Namibia	21.4902897	-18.082085	Agriculture	No	6	medium
Namibia	21.5216191	-18.087662	Agriculture	Yes	6	medium
Namibia	21.5559465	-18.092718	Private_residence	No	6	medium
Namibia	21.5555747	-18.099096	Green scheme	?	6	medium
Namibia	21.5555483	-18.099478	Unknown	No	6	medium
Namibia	21.5582205	-18.108953	Private_residence	No	6	medium
Namibia	21.5623496	-18.114393	Agriculture	Yes	6	medium
Namibia	21.5694869	-18.123493	Private_residence	No	6	medium
Namibia	21.5930108	-18.108397	Unknown	No	6	medium
Namibia	21.6030646	-18.103222	Agriculture	No	6	medium
Namibia	21.6240102	-18.101721	Private_residence	?	6	medium
Namibia	21.6690025	-18.113726	Lodge	?	6	medium
Namibia	21.6721936	-18.118243	Lodge	?	6	medium
Namibia	21.6818799	-18.140307	Lodge	?	6	medium
Angola	19.74121	-17.901307	Agriculture	Yes	5	small
Angola	20.4401579	-17.907388	Agriculture	No	5	small
Namibia	18.4326095	-17.406164	Agriculture	No	5	small
Namibia	18.4739437	-17.453661	Agriculture	Yes	5	small
Namibia	18.4763221	-17.471158	Agriculture	No	5	small
Namibia	18.4776116	-17.481507	Agriculture	No	5	small
Namibia	18.7385658	-17.732084	Agriculture	No	5	small
Namibia	19.0840232	-17.836017	Chicken farm	Yes	5	small
Namibia	19.1186499	-17.836839	Resturant	Yes	5	small
Namibia	19.1207087	-17.835107	Private_residence	No	5	small
Namibia	19.1208006	-17.835013	Private_residence	No	5	small
Namibia	19.4803565	-17.869962	Agriculture	Yes	5	small
Namibia	19.544067	-17.875502	Agriculture	No	5	small
Namibia	19.5440569	-17.875509	Private_residence	No	5	small
Namibia	19.5453726	-17.875597	Private_residence	No	5	small
Namibia	19.5465002	-17.875766	Private_residence	No	5	small
Namibia	19.6233816	-17.863206	Private_residence	No	5	small
Namibia	19.6473142	-17.851206	Agriculture	No	5	small
Namibia	19.666046	-17.849784	Private_residence	No	5	small
Namibia	19.6660534	-17.849794	Private_residence	No	5	small
Namibia	19.6660524	-17.849769	Private_residence	No	5	small
Namibia	19.6667651	-17.849772	Private_residence	No	5	small
Namibia	19.6707965	-17.849676	Lodge	Yes	5	small
Namibia	19.6724798	-17.849595	Lodge	No	5	small
Namibia	19.6832412	-17.855907	Private_residence	No	5	small
Namibia	19.7420479	-17.907254	Agriculture	Yes	5	small
Namibia	19.7420517	-17.90727	Agriculture	Yes	5	small
Namibia	19.7767371	-17.891502	Agriculture	No	5	small
Namibia	19.783392	-17.884769	Agriculture	Yes	5	small
Namibia	19.7289953	-17.887523	Private_residence	No	5	small
Namibia	19.7297237	-17.888436	Lodge	No	5	small

Namibia	19.8607122	-17.883992	Private_residence	No	5	small
Namibia	19.8630958	-17.884056	Factory	No	5	small
Namibia	19.8630947	-17.88406	Lodge	No	5	small
Namibia	19.8650914	-17.883668	Private_residence	No	5	small
Namibia	19.9051794	-17.873232	Building site	Yes	5	small
Namibia	19.9062723	-17.866715	Lodge	Yes	5	small
Namibia	19.9301203	-17.864588	Lodge	Yes	5	small
Namibia	19.9653841	-17.886036	Agriculture	No	5	small
Namibia	19.9693456	-17.888063	Building site	?	5	small
Namibia	20.1254851	-17.904763	Agriculture	Yes	5	small
Namibia	20.1273801	-17.903699	Building site	No	5	small
Namibia	20.1374816	-17.899469	Agriculture	No	5	small
Namibia	20.1590412	-17.891896	Agriculture	No	5	small
Namibia	20.159043	-17.891891	Agriculture	No	5	small
Namibia	20.1648382	-17.888849	Agriculture	No	5	small
Namibia	20.2307216	-17.884928	Private_residence	Yes	5	small
Namibia	20.2526166	-17.884076	Building site	No	5	small
Namibia	20.2307216	-17.884928	Private_residence	Yes	5	small
Namibia	20.230723	-17.884929	Factory	No	5	small
Namibia	20.3699501	-17.898368	Private_residence	No	5	small
Namibia	20.3723145	-17.897941	Private_residence	No	5	small
Namibia	20.3724504	-17.897869	Agriculture	No	5	small
Namibia	20.3723768	-17.897825	Agriculture	No	5	small
Namibia	20.3848517	-17.894443	Agriculture	No	5	small
Namibia	20.4025812	-17.899828	Agriculture	No	5	small
Namibia	20.4040156	-17.900426	Agriculture	No	5	small
Namibia	20.427046	-17.908401	Agriculture	No	5	small
Namibia	20.4622032	-17.921014	Private_residence	No	5	small
Namibia	20.472277	-17.949586	Lodge	No	5	small
Namibia	20.4935561	-17.953832	Private_residence	?	5	small
Namibia	20.5364213	-17.981211	Private_residence	No	5	small
Namibia	20.5488948	-17.985279	Private_residence	Yes	5	small
Namibia	20.5527619	-17.985473	Private_residence	No	5	small
Namibia	20.684852	-18.002813	Building site	No	5	small
Namibia	20.6947864	-18.009256	School	No	5	small
Namibia	20.6955887	-18.009935	Private_residence	No	5	small
Namibia	20.7204594	-18.012039	Agriculture	No	5	small
Namibia	20.7525633	-18.020099	Lodge	Yes	5	small
Namibia	20.7525633	-18.020099	Lodge	Yes	5	small
Namibia	20.7702404	-18.020522	Private_residence	No	5	small
Namibia	20.803568	-18.037709	Agriculture	No	5	small
Namibia	20.8216918	-18.039541	Private_residence	Yes	5	small
Namibia	21.0054031	-17.960714	Private_residence	No	5	small
Namibia	21.0416193	-17.954326	Agriculture	No	5	small
Namibia	21.082442	-17.949656	Agriculture	No	5	small
Namibia	21.0932333	-17.951104	Water truck abstraction site	No	5	small

Namibia	21.0951149	-17.950905	Agriculture	No	5	small
Namibia	21.1561964	-17.934878	Private_residence	No	5	small
Namibia	21.1807914	-17.93781	Private_residence	No	5	small
Namibia	21.1897607	-17.936593	Private_residence	No	5	small
Namibia	21.1903514	-17.936451	Private_residence	No	5	small
Namibia	21.1964417	-17.935037	Private_residence	No	5	small
Namibia	21.2327451	-17.950892	Private_residence	No	5	small
Namibia	21.2990995	-17.975991	Agriculture	No	5	small
Namibia	21.3086256	-17.978266	Private_residence	No	5	small
Namibia	21.3246084	-17.989264	Agriculture	No	5	small
Namibia	21.330106	-17.990573	Lodge	No	5	small
Namibia	21.3305573	-17.990563	Lodge	Yes	5	small
Namibia	21.3718767	-17.994205	Private_residence	No	5	small
Namibia	21.3813799	-18.012822	Private_residence	No	5	small
Namibia	21.3821993	-18.013	Agriculture	No	5	small
Namibia	21.3947533	-18.010774	Private_residence	No	5	small
Namibia	21.3973944	-18.010798	Private_residence	No	5	small
Namibia	21.3984952	-18.011119	Private_residence	No	5	small
Namibia	21.3986654	-18.011154	Private_residence	Yes	5	small
Namibia	21.3992797	-18.011296	Private_residence	Yes	5	small
Namibia	21.4004001	-18.011794	Agriculture	No	5	small
Namibia	21.4005493	-18.011904	Agriculture	No	5	small
Namibia	21.401351	-18.012466	Private_residence	No	5	small
Namibia	21.4027691	-18.01322	Private_residence	No	5	small
Namibia	21.4028928	-18.013342	Agriculture	No	5	small
Namibia	21.4030358	-18.013425	Agriculture	No	5	small
Namibia	21.4037196	-18.014058	Agriculture	No	5	small
Namibia	21.4054583	-18.01472	Private_residence	No	5	small
Namibia	21.4054828	-18.014758	Private_residence	Yes	5	small
Namibia	21.4079606	-18.015194	Private_residence	No	5	small
Namibia	21.4105501	-18.015259	Agriculture	No	5	small
Namibia	21.4122712	-18.015616	Agriculture	No	5	small
Namibia	21.4142636	-18.016334	Agriculture	No	5	small
Namibia	21.4167814	-18.018181	Agriculture	No	5	small
Namibia	21.4176634	-18.018877	Private_residence	No	5	small
Namibia	21.4186945	-18.020149	Agriculture	No	5	small
Namibia	21.419453	-18.021241	Private_residence	No	5	small
Namibia	21.5186202	-18.086954	Agriculture	No	5	small
Namibia	21.5188665	-18.086964	Unknown	No	5	small
Namibia	21.4659139	-18.07689	Private_residence	No	5	small
Namibia	21.46599	-18.077104	Agriculture	No	5	small
Namibia	21.4661857	-18.077831	Private_residence	No	5	small
Namibia	21.4661858	-18.077831	Private_residence	No	5	small
Namibia	21.4781372	-18.078399	Agriculture	No	5	small
Namibia	21.5188665	-18.086964	Unknown	No	5	small
Namibia	21.5193424	-18.086843	Private_residence	No	5	small

Namibia	21.522134	-18.087622	Agriculture	No	5	small
Namibia	21.5224753	-18.087505	Agriculture	No	5	small
Namibia	21.5402343	-18.091065	Private_residence	No	5	small
Namibia	21.5468494	-18.093763	Private_residence	?	5	small
Namibia	21.547007	-18.093671	Private_residence	?	5	small
Namibia	21.5534974	-18.091372	Unknown	No	5	small
Namibia	21.5561071	-18.093351	Private_residence	No	5	small
Namibia	21.55591	-18.09678	Lodge	Yes	5	small
Namibia	21.5553566	-18.10145	Private_residence	No	5	small
Namibia	21.5552716	-18.103945	Agriculture	Yes	5	small
Namibia	21.556779	-18.107406	Agriculture	No	5	small
Namibia	21.4646458	-18.072917	Private_residence	No	5	small
Namibia	21.56275	-18.115348	Private_residence	No	5	small
Namibia	21.5635398	-18.11686	Unknown	No	5	small
Namibia	21.5653866	-18.120087	Factory	No	5	small
Namibia	21.5746995	-18.123579	Agriculture	No	5	small
Namibia	21.5776694	-18.123911	Unknown	No	5	small
Namibia	21.5851324	-18.119042	Lodge	?	5	small
Namibia	21.5866178	-18.116251	Unknown	No	5	small
Namibia	21.5867045	-18.116099	Lodge	?	5	small
Namibia	21.5902109	-18.111634	Lodge	?	5	small
Namibia	21.5918433	-18.110263	Unknown	No	5	small
Namibia	21.5921639	-18.109984	Unknown	No	5	small
Namibia	21.6144692	-18.105964	Agriculture	No	5	small
Namibia	21.6181659	-18.102931	Private_residence	No	5	small
Namibia	21.625149	-18.101819	Private_residence	No	5	small
Namibia	21.6301909	-18.102994	Agriculture	No	5	small
Namibia	21.6406345	-18.104879	Unknown	No	5	small
Namibia	21.6724178	-18.118511	Nature conservation office	?	5	small
Namibia	18.6144998	-17.615585	Agriculture	No	4	small
Namibia	19.0292345	-17.834983	Private_residence	No	4	small
Namibia	19.0333	-17.835661	Agriculture	No	4	small
Namibia	19.0643551	-17.835097	Agriculture	No	4	small
Namibia	19.4859021	-17.869891	Factory	No	4	small
Namibia	19.7803308	-17.889207	Private_residence	Yes	4	small
Namibia	19.8685179	-17.883017	Agriculture	No	4	small
Namibia	19.9019701	-17.875875	Agriculture	No	4	small
Namibia	20.1059952	-17.910679	Agriculture	Yes	4	small
Namibia	20.1134647	-17.910622	Private_residence	Yes	4	small
Namibia	20.1658665	-17.887038	Agriculture	No	4	small
Namibia	20.2403581	-17.892	Agriculture	No	4	small
Namibia	20.248133	-17.892666	Private_residence	Yes	4	small
Namibia	20.4628259	-17.926264	Lodge	No	4	small
Namibia	20.4752545	-17.95157	Agriculture	No	4	small
Namibia	18.4741293	-17.455169	Agriculture	No	4	small
Namibia	18.5695072	-17.585132	Agriculture	No	4	small

Namibia	18.6250689	-17.637343	Building site	No	4	small
Namibia	19.4697089	-17.867629	Agriculture	No	4	small
Namibia	19.5440847	-17.875534	Private_residence	No	4	small
Namibia	19.5691884	-17.873318	Private_residence	No	4	small
Namibia	19.6233579	-17.863199	Private_residence	No	4	small
Namibia	19.6689227	-17.849775	Private_residence	No	4	small
Namibia	19.6689225	-17.849774	Lodge	Yes	4	small
Namibia	19.6848641	-17.856964	Private_residence	No	4	small
Namibia	19.7420495	-17.907251	Agriculture	Yes	4	small
Namibia	19.7437809	-17.908576	Agriculture	No	4	small
Namibia	19.7114527	-17.885554	Private_residence	No	4	small
Namibia	19.9453831	-17.871281	Building site	No	4	small
Namibia	20.2543749	-17.879014	Private_residence	No	4	small
Namibia	20.2545905	-17.877517	Cemetary	No	4	small
Namibia	20.472432	-17.949801	Lodge	No	4	small
Namibia	20.4777379	-17.952415	Agriculture	Yes	4	small
Namibia	20.5028963	-17.954316	Agriculture	Yes	4	small
Namibia	20.5096041	-17.964624	Agriculture	No	4	small
Namibia	20.528506	-17.976928	Private_residence	No	4	small
Namibia	21.0138306	-17.954548	Lodge	No	4	small
Namibia	21.0564798	-17.952678	Private_residence	Yes	4	small
Namibia	21.3316798	-17.990551	Lodge	No	4	small
Namibia	21.380561	-18.012608	Private_residence	No	4	small
Namibia	21.5393079	-18.089874	Clinic	Yes	4	small
Namibia	21.5778825	-18.123874	Private_residence	No	4	small
Namibia	21.5782636	-18.123777	Private_residence	No	4	small
Namibia	18.5528286	-17.564685	Private_residence	No	4	small
Namibia	18.5533113	-17.565348	Private_residence	Yes	4	small
Namibia	18.5542972	-17.566736	Private_residence	No	4	small
Namibia	19.8276077	-17.871687	Private_residence	No	4	small
Namibia	19.8607358	-17.883989	Private_residence	Yes	4	small
Namibia	19.8644464	-17.883878	Private_residence	No	4	small
Namibia	20.16617	-17.886441	Agriculture	No	4	small
Namibia	20.2406692	-17.892041	Private_residence	?	4	small
Namibia	20.3636452	-17.893289	Agriculture	No	4	small
Namibia	20.5413235	-17.983401	Private_residence	No	4	small
Namibia	20.5418047	-17.983542	Private_residence	No	4	small
Namibia	20.5429193	-17.983779	Private_residence	No	4	small
Namibia	20.6839814	-18.002689	Private_residence	No	4	small
Namibia	20.7019778	-18.010298	Private_residence	No	4	small
Namibia	20.7953372	-18.031739	Agriculture	No	4	small
Namibia	20.8433581	-18.035871	Lodge	No	4	small
Namibia	21.0826024	-17.94982	Agriculture	No	4	small
Namibia	21.0827123	-17.949953	Agriculture	No	4	small
Namibia	21.0862375	-17.95025	Agriculture	No	4	small
Namibia	21.1452107	-17.936779	Agriculture	?	4	small

Namibia	18.6144579	-17.616718	Private_residence	No	3	small
Namibia	18.89604	-17.817665	Factory	No	3	small
Namibia	19.901977	-17.87587	Private_residence	No	3	small
Namibia	19.9633294	-17.885672	Agriculture	No	3	small
Namibia	19.9818216	-17.889149	Agriculture	No	3	small
Namibia	21.3057173	-17.976687	Agriculture	No	3	small
Namibia	21.5774714	-18.123934	Unknown	No	3	small
Namibia	18.9726983	-17.828427	Agriculture	No	3	small
Namibia	19.6760311	-17.851673	Private_residence	No	3	small
Namibia	19.8548491	-17.883137	Private_residence	No	3	small
Namibia	21.2312302	-17.94832	Agriculture	No	2	small
Namibia	21.5639762	-18.11816	Factory	No	2	small

APPENDIX 3: Information cards summarizing the habitats, conditions and data collected at each of the 9 intensive monitoring sites along the Kavango River in August 2021

Intensive monitoring site 1

Lat: -17.393682°	**Lon:** 18.421942°
Date: 2021/08/30	**Time:** 09:30




Habitat assessment: All biotopes were present and well represented. Stones were found in current, in riffels and runs, as well as out of current. There was no bedrock present. Gravel, sand and mud were present. Vegetation was the most limited biotope but suitable Persicaria and overhanging bushes were present. Biotope score was 4.5 out of 5.

Water Flow: Moderate to low flow.

Water Quality:

Temperature (°C)	19.52	**pH**	8.32
Turbidity (NTU)		**Phosphate**	
Specific Conductivity (µS/cm)	43.68	**Nitrate**	0.43
Dissolved oxygen (mg/L)	7.79		

Habitat integrity: A lot of disturbance by cattle grazing on the banks, invasive Mimosa pigra was growing along the banks

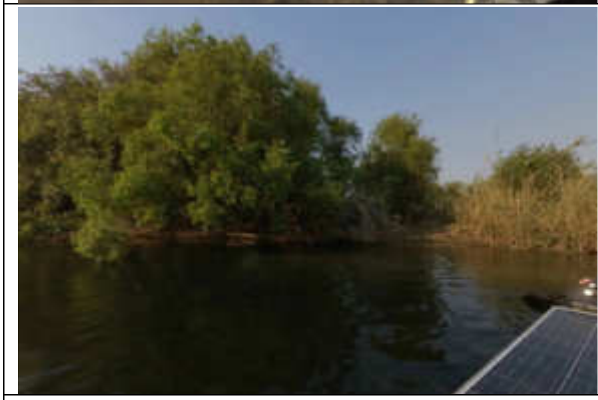
Macroinvertebrates: A very high diversity, including some very high scoring sensitive taxa. Ephemeroptera and Tricoptera families were well represented. High scoring taxa included mayflies: Oligoneuridae, Prosopistomatidae and Ephemeridae. Dominant taxa included Heptageniidae and more than 2 species of Baetidae – a result of the high abundance and diversity of stones in current. Porifera (sponges) and Viviparidae (snails) were also abundant on the stones in current.

NASS score	220	**No. of Taxa**	31
ASPT	7.10		

A high scoring site in near natural condition.

Intensive monitoring site 2

Lat: -17.71506973°	**Lon:** 18.731031°
Date: 2021/09/01	**Time:** 15:35



Habitat assessment: The stone biotope was absent from this site. Vegetation was represented by some overhanging branches and submerged vegetation. Sand and mud were well represented. Biotope score was 2 out of 5.

Water Flow: Moderate to low flow.

Water Quality:

Temperature (^{0}C)	22.40	**pH**	8.75
Turbidity (NTU)	0.99	**Phosphate**	10
Specific Conductivity (µS/cm)	45.52	**Nitrate**	40.02
Dissolved oxygen (mg/L)	8.43		

Habitat integrity: Some disturbance by grazing cattle grazing on the banks, invasive Mimosa pigra was growing along the banks

Macroinvertebrates: A moderate diversity, comprising mostly low scoring taxa. High scoring taxa were Ephemeridae and Machadorythidae. Dominant taxa included Gomphids and Ephemeridae – a result of the high abundance of GSM.

NASS score	121	**No. of Taxa**	23
ASPT	5.26		

A low score but not unexpected considering the limited biotopes available

Intensive monitoring site 3

Lat: -17.8353442°	**Lon:** 19.06059482°
Date: 2021/09/03	**Time:** 15:43

Habitat assessment: All biotopes were present however stones were represented by bedrock. Sand and mud were present. Vegetation was limited to phragmities. Biotope score was 2.5 out of 5.

Water Flow: Moderate to low flow.

Water Quality:

Temperature (^{0}C)	22.80	**pH**	8.95
Turbidity (NTU)	1.09	**Phosphate**	3
Specific Conductivity (µS/cm)	45.11	**Nitrate**	60.24
Dissolved oxygen (mg/L)	8.45		

Habitat integrity: A lot of disturbance by grazing cattle grazing on the banks, invasive Mimosa pigra was growing along the banks

Macroinvertebrates: A low diversity, comprising mostly low scoring taxa. Ephemeridae and >2 sp. of Baetidae were the only high scoring taxa found. Dominant taxa included Gomphids, Ephemeridae – a result of the high abundance of GSM – and Chironomid midges.

NASS score	100	**No. of Taxa**	19
ASPT	5.26		

A low score from an impacted site

Intensive monitoring site 4

Lat: -17.8644322°	**Lon:** 19.449491081°
Date: 2021/09/06	**Time:** 07:01
	
	

Habitat assessment: The stone biotope was absent from this site. Vegetation was represented by phragmites reeds and submerged vegetation. Sand and mud were well represented. Biotope score was 2 out of 5.

Water Flow: Moderate to low flow.

Water Quality:

Temperature (^{0}C)	23.28	**pH**	8.19
Turbidity (NTU)	2.42	**Phosphate**	3
Specific Conductivity (µS/cm)	47.47	**Nitrate**	94.45
Dissolved oxygen (mg/L)	6.65		

Habitat integrity: A lot of disturbance by grazing cattle grazing on the banks, invasive Mimosa pigra was growing along the banks

Macroinvertebrates: A low diversity, comprising mostly low scoring taxa. Ephemeridae was the only high scoring taxa found. Dominant taxa included Gomphids, Ephemeridae – a result of the high abundance of GSM – and Caenid mayflies and Chironomid midges.

NASS score	101	**No. of Taxa**	18
ASPT	5.61		

A low score from an impacted site

Intensive monitoring site 5	
Lat: -17.879108°	**Lon:** 19.841145°
Date: 2021/09/09	**Time:** 09:10
	
	

Habitat assessment: All biotopes were present. Stones were found in current, in riffels and runs, as well as out of current. There was no bedrock present. Gravel, sand and mud were present. Vegetation was Persicaria and Phragmites. Biotope score was 4 out of 5.

Water Flow: Moderate to low flow.

Water Quality:

Temperature (^oC)	22.11	**pH**	8.34
Turbidity (NTU)	1.81	**Phosphate**	3
Specific Conductivity (µS/cm)	55.96	**Nitrate**	74.94
Dissolved oxygen (mg/L)	6.98		

Habitat integrity: Rocks were covered in a lot of algae. There was an upstream extraction point for a large irrigation scheme and earthworks had disturbed the bank. Some of the 'stones' samples were bricks and concreate. Invasive Mimosa pigra was growing along the banks

Macroinvertebrates: A very high diversity, including both low and high scoring taxa. High scoring taxa included mayflies families: Oligoneuridae, Prosopistomatidae and Ephemeridae although all in very low densities. The biting midge Ceratopogonidae was dominant as were snails in the family Viviparidae and Coenagrionid damselfies.

NASS score	180	**No. of Taxa**	30
ASPT	6.0		

A relatively high NASS and a very high No. of Taxa however a lower than expected ASPT as several low scoring species were found. A site with good availability and diversity of biotopes is expected to have a higher ASPT this suggests that the site is has been impacted and deviated from its natural state.

Intensive monitoring site 6

Lat: -17.894667°	**Lon:** 20.381807°
Date: 2021/09/11	**Time:** 16:00




Habitat assessment: All biotopes were present and well represented. Stones were found in current, in riffels and runs, as well as out of current. There was no bedrock present. Gravel, sand and mud were present. Vegetation was the most limited biotope but suitable Phragmites and overhanging bushes were present. Biotope score was 4.5 out of 5.

Water Flow: Moderate to low flow.

Water Quality:

Temperature (°C)	21.19	**pH**	8.37
Turbidity (NTU)	2.99	**Phosphate**	7
Specific Conductivity (µS/cm)	56.97	**Nitrate**	25.89
Dissolved oxygen (mg/L)	7.28		

Habitat integrity: Some disturbance by grazing cattle and small subsistence farms on the banks, some invasive Mimosa pigra was growing along the banks

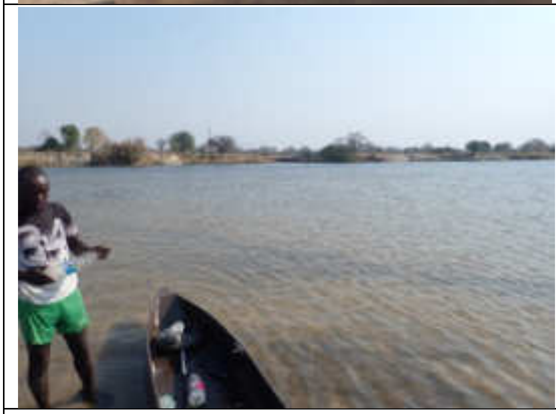
Macroinvertebrates: A very high diversity, including some very high scoring sensitive taxa. Ephemeroptera and Tricoptera families were well represented. High scoring taxa included Perlidae, Prosopistomatidae and Ephemeridae and Machadorythidae. Dominanted by mayflies and snails – a result of the high abundance and diversity of stones in current.

NASS score	211	**No. of Taxa**	29
ASPT	7.28		

High scoring in all 3 indices with the highest scoring ASPT - in near natural condition.

Intensive monitoring site 7			
Lat: -18.028057°		**Lon:** 20.790718°	
Date: 2021/09/13		**Time:** 15:30	
			
Habitat assessment: The stone biotope was absent from this site. Vegetation was limited to overhanging branches in very strong current. Sand and mud were well represented. Biotope score was 1 out of 5. Downstream of the confluence with the Cuito River.			
Water Flow: Moderate to fast flow.			
Water Quality:			
Temperature (^{0}C)	23.42	**pH**	8.15
Turbidity (NTU)	2.99	**Phosphate**	7
Specific Conductivity (µS/cm)	20.01	**Nitrate**	0.30
Dissolved oxygen (mg/L)	7.65		
Habitat integrity: Some cattle grazing on the banks, invasive Mimosa pigra was growing along the banks			
Macroinvertebrates: A very low diversity, with few high scoring sensitive taxa. No one group dominated although Gomphid dragonflies were common in the sand. The highest scoring taxa was philopotamidae in the sand.			
NASS score	74	**No. of Taxa**	12
ASPT	6.17		
A low score but not unexpected considering the limited biotopes available			

Intensive monitoring site 8			
Lat: -18.068892°		**Lon:** 21.460740°	
Date: 2021/09/16		**Time:** 15:30	
			
Habitat assessment: Stones were very limiting. Bedrock was found in and out of current. Sand and mud were present. Vegetation was abundant and diverse. Biotope score was 3 out of 5.			
Water Flow: Moderate to fast flow.			
Water Quality:			
Temperature (^{0}C)	24.51	**pH**	8.43
Turbidity (NTU)		**Phosphate**	7
Specific Conductivity (µS/cm)	27.18	**Nitrate**	181.01
Dissolved oxygen (mg/L)	7.48		
Habitat integrity: Natural			
Macroinvertebrates: Not dominated by any one particular group although Ephemeridae mayflies were abundant in the GSM and Gyrinidae beetles were abundant on the water surface near the vegetation. High scoring taxa included more than 2 species of Baetidae and Ephemeridae. This site was the only site in which the Chlorocyphid damselflies and Atyid shrimps were present – likely do the availability of suitable habitat.			
NASS score	148	**No. of Taxa**	22
ASPT	6.73		
A moderate score but not unexpected considering the limited biotopes available			

Intensive monitoring site 9			
Lat: -18.150815°		**Lon:** 21.691382°	
Date: 2021/09/17		**Time:** 15:45	
			
			
Habitat assessment: A packed gabion structure out of current was the only stones available to sample. Vegetation was limited to a few overhanging branches in the water. Sand and mud were present. Biotope score was 2 out of 5.			
Water Flow: Moderate flow.			
Water Quality:			
Temperature (^{0}C)	24.27	**pH**	8.55
Turbidity (NTU)		**Phosphate**	3
Specific Conductivity (µS/cm)	27.42	**Nitrate**	4.26
Dissolved oxygen (mg/L)	7.77		
Habitat integrity: Some disturbance by livestock grazing on the banks.			
Macroinvertebrates: A low diversity, with few high scoring sensitive taxa. Diptera were well represented. No one group dominated although Gomphid dragonflies were common in the sand. The highest scoring taxa was the more than 2 species of Baetidae - recoded between the vegetation and the stone gabions			
NASS score	115	**No. of Taxa**	20
ASPT	5.75		
A low score but not unexpected considering the limited biotopes available			

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