NATIONAL GEOGRAPHIC

OKAVANGO WILDERNESS PROJECT

REPORT 9

Okavango Delta Transects, 2022

EXECUTIVE SUMMARY

In August 2022, the National Geographic Okavango Wilderness Project (NGOWP) deployed two teams to traverse the length of the Okavango Delta on mekoro. For the 2022 iteration of the Annual Okavango Delta Crossing, an eastern and western transect of the Okavango Delta was completed by each team, respectively. The eastern transect began at Seronga, continued along the Maunachira and Santantadibe channels and ended near Maun, approximately 288 km later. The western transect began at Mopiri and continued along the Boro channel, reaching Maun approximately 244km later. In total, the two teams paddled approximately 532km over 21 days, with the main objective of this annual expedition to collect scientific data on biodiversity, human impacts, hydrology and ecological health through repeat surveys and new cutting-edge monitoring techniques. The data collected serves to detect change through time and to determine whether such changes are attributed to natural or anthropogenic causes. Upstream human impacts of particular concern include modified flows (dams and diversions), pollution (agriculture, industry, increased human settlements, etc), over utilisation of resources (overfishing, overgrazing, deforestation, etc), increased and unnatural burning, the introduction of alien invasive species, and climate change.

As the respective teams proceeded along the transect, all animals, birds and humans were counted, water quality was measured, eDNA samples extracted, river health assessments conducted, fires mapped, and permanent records of the wetland habitat recorded using 360-degree cameras, drones and several other scientific instruments.

As shown in previous surveys, the annual transect indicated very little change in the measured parameters. This is an excellent and unique result. *Biodiversity, habitat quality and water quality remained excellent as was the case in previous surveys.*

It is imperative that the NGOWP continues to monitor the Okavango Delta through the annual transects to detect changes to the environment. Such changes may require decisive and rapid remedial action that is guided by science and the data collected. Each year the team completes the transects adds to an already significant long-term database.

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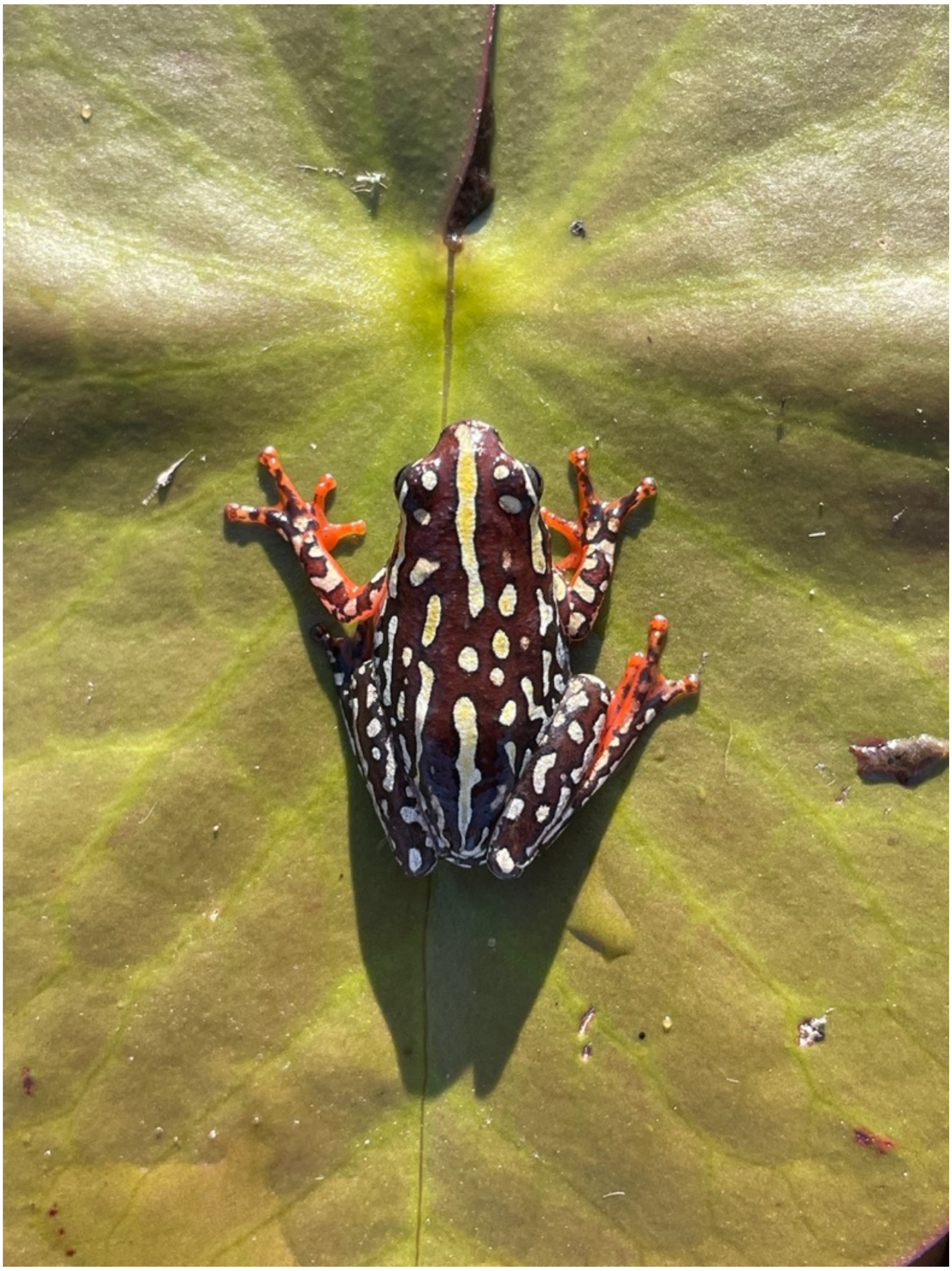

Figure 1: Angolan Reed Frog on a waterlily.

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Figure 2: An African Jacana perched on the head of a Hippo in the Okavango Delta.

TERMS AND ABBREVIATIONS

Abbreviation	Term
AIP	Alien Invasive Plants
ADCP	Acoustic Doppler Current Profiler
ASPT	Average Score Per Taxon
DO	Dissolved Oxygen
EC	Electrical Conductivity
eDNA	Environmental DNA
OKASS	Okavango Scoring System
NGO	Non-Governmental Organisation
NGOWP	National Geographic Okavango Wilderness Project
NGS	National Geographic Society
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
WBT	Wild Bird Trust

Figure 3: A Nomad dragonfly enjoys the last rays of sunlight.

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 in 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 but 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 2400 km downstream 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, a 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 4: Birds and game can be approached quietly on a Mekoro allowing for accurate counts.

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 fibreglass 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. The team member at the back of the mekoro is the captain who propels the mekoro forward with a nkashi (a long pole with a forked tip). The captain is responsible for speed, steering and safety, and the team member at the front helps with paddling.

Depending on river flow, obstructions and wind, the team can cover 10-30 km per day. In the mornings the team usually gets underway by 10:00, slowly moving down the river collecting scientific observations on digital tablets and phones. The captains, being more experienced, call out observations and the team members in the front of the mekoro record the data. At around 16:00, camp is set up on the riverbank, food is prepared, data is uploaded, and the team settles down to rest for the night. NGOWP has extensive experience with this manner of river exploration, using these techniques to traverse the length of the Okavango, Cuito, Cuanavale, Kavango, most of the Cubango and Cuando rivers and has completed a total of 14 crossings of the Okavango Delta (over 1,000 km in total).

All possible avenues for medical support and general safety have been put into place. 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.

Figure 5: An inquisitive elephant approaches camp.

1.3 Study Site Description

The Cubango and the Cuito rivers are the head waters of the Okavango in central Angola from where they flow in a south-easterly direction for about 1000 km before entering Namibia. Once the river enters Namibia it is called the Kavango, where it forms the boundary between Namibia and Angola. When the river enters Botswana it becomes the Okavango forming the 'panhandle' that culminates in an alluvial fan, the Okavango Delta (figure 6).

The world-renowned Okavango Delta is a UNESCO world heritage site and Ramsar wetland of international importance. It is protected as a Wildlife Management Area and Game Reserve, and it is an ecologically important conservation area supporting vast herds of game and home to numerous wetland bird breeding colonies. The rich game and bird-viewing provides exceptional tourism opportunities which is a major driver of the local and regional economy.

During the winter months, the Okavango Delta receives an annual flood pulse from summer rainfall in its Angolan catchment. At its peak the Okavango carries 400-600m3/s of water. This water disperses into many channels when it reaches the alluvial fan of the Okavango Delta - forming winding rivers, oxbow lakes and vast seasonally flooded floodplains.

Two transects were surveyed simultaneously in 2022. The western transect was surveyed for the 11th year and started at Mopiri near Etsha 6, moved across to the Boro and then followed the Boro down the western edge of Chief's Island, eventually reaching Maun. On this western transect, one section of the river was repeated over 7 consecutive days to better understand the variability between days.

The eastern transect was surveyed for the 3rd time. The eastern transect started in Seronga and the major channels surveyed included the Maunachira and the Santantadibe. The Maunachira channel is a larger channel flowing in an easterly direction from Vumbura into the Moremi Game Reserve. The Santantadibe channel splits off the Maunachira in a southerly direction forming the eastern boundary of Chief's Island before joining onto the Tamalakane River upstream of Maun.

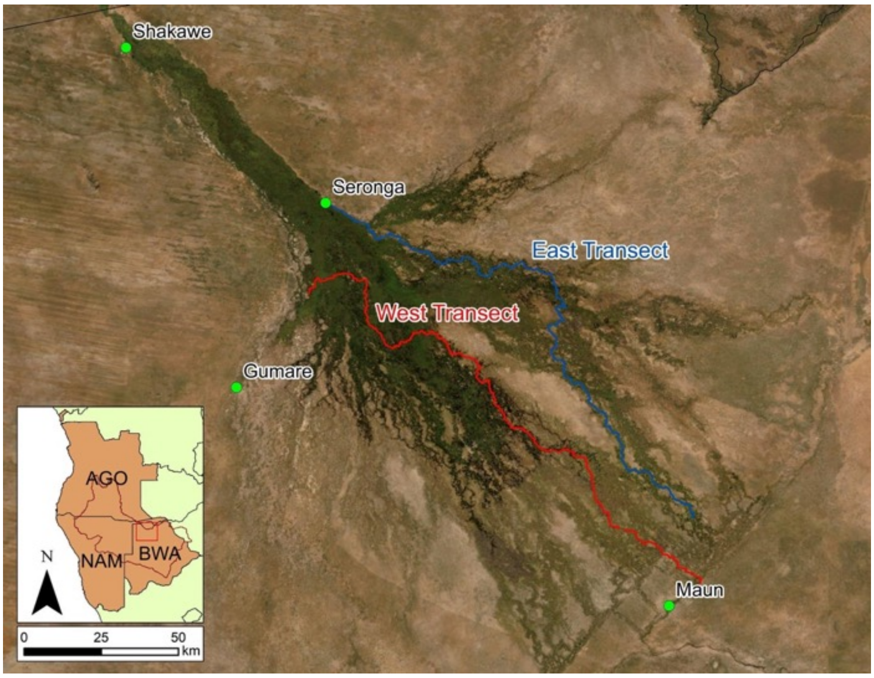
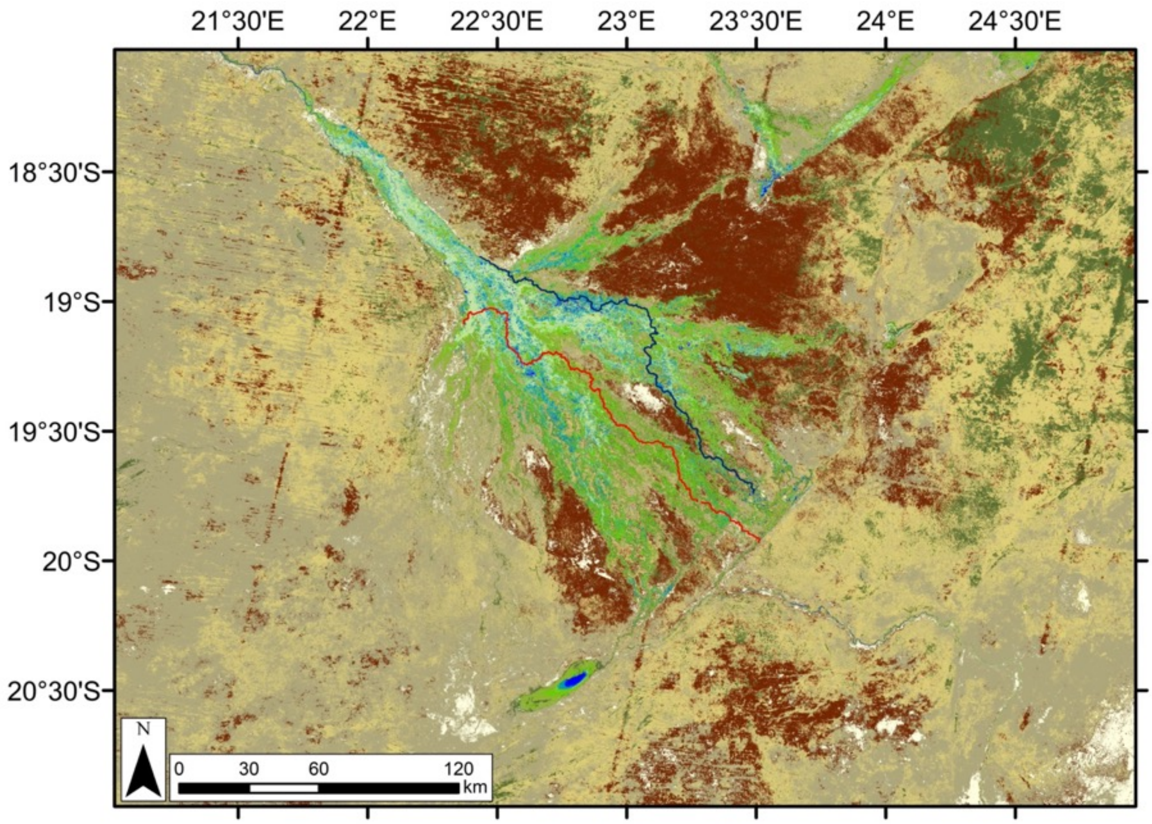


Figure 6: The Okavango Basin spans the countries of Angola, Namibia and Botswana. The Okavango Delta crossings take place across the alluvial fan in Botswana. In 2022, two transects were conducted simultaneously - the western transect (red) and the eastern transect (blue).



Legend	Okavango Delta broad vegetation level 1 classes (10 m)	Mapped Region		LULC per transect	
		Area (km^2)	Proportion (%)	West (%)	East (%)
	Open water	184	0.1	2.1	5.2
	Inundated wetlands	1416	1.0	13.6	30.3
	Seasonally saturated wetland	2670	1.8	32.0	42.0
	Seasonally wet wetlands	2241	1.5	23.2	8.9
	Temporary wet floodplains	2851	1.9	21.8	9.9
	Seasonally wet uplands	169	0.1	2.1	0.5
	Woodland	11845	8.0	4.5	2.9
	Dense sand veld	43018	28.9	0.5	0.2
	Open to moderately dense sand veld	57806	38.9	0.1	0.1
	Mopani veld	22232	14.9	0.1	0.04
	Grassland / saltpans / degraded woodland	4288	2.9	0.0	0.0
	Total	148719	100	100	100

Figure 7: Okavango Delta broad vegetation level 1 classes, proportion indicates percentage of land cover type for the entire mapped area shown in the figure as well as per transect.

1.4 Expedition Timing and Team Members

The western transect commenced on the 1st of August 2022 from Mopiri and ended 20 days later on the 20th of August at the Ngashi Knowledge Centre in Maun. The expedition team consisted of 13 core members on 6 mekoro. Additional guests and members of the WBT management team joined for parts of the expedition.

The eastern transect commenced on the 2nd of August 2022 from Seronga and ended 21 days later on the 23rd of August at Daonara Gate near Maun. The expedition team consisted of 10 people on 5 mekoro.

Logistical support and resupply efforts was provided by the Wild Bird Trust and Botswana Wild Bird Trust teams.

Table 1: Okavango 2022 expedition team members

Eastern Team

Western Team

Expedition Team	Role	Expedition Team	Role
Rainer von Brandis	Expedition leader/research	Steve Boyes	Expedition leader
Gobonamang 'GB' Kgetho	Lead poler	Götz Neef	Research
Rob Taylor	Research	Water Setlabosha	Lead poler
Goabaone Ramatlapeng	Research	Nkeletsang 'Ralph' Moshupa	Poler
Mphetsolang 'Bokspits' Kesenolotswe	Poler	Thalefang Charles	Story telling
Kgalalelo 'KG' Mpitsang	Poler	George Butler	Artist
Balebogeng Mbwe	Poler	Ian Miller	NGS Chief Scientist
Itshepiseng Samoela 'Abigail'	Poler	David Garrett	CEO WBFoA
Tjadza Tapologo 'Pretty'	Poler	Kai Collins	Research
Karabo Moilwa	Story telling	Bernard 'BT' Tumeletso	Camp logistics
		Keabetswe Xhao 'MmaRalph'	Camp logistics
		Oarabile Xhao 'Yamaha'	Poler
		Moshupa Saereko 'Comet'	Poler

1.5 Expedition Objectives

The objective of the expedition was to traverse the Okavango Delta from Mopiri via the Boro cannel in the west and from Seronga via the Maunachira and Santantadibe channels in the east and ending some 244km (west) and 288km (east) later at Maun. The surveys that were completed are a repeat of the sampling techniques and methods completed during previous Okavango Delta crossings. The data collected adds to the extensive environmental monitoring data archive.

1.6 Survey Design

From 2009-2018, NGOWP traversed the western transect on an annual basis. In 2019 the NGOWP expedition team conducted the first eastern transect across the Okavango Delta via the Maunachira and Santantadibe channels, this was repeated in 2021. The objective for all previous transects was to collect baseline data along a continuous transect to assess general ecosystem health. As the team poled downstream, all animals, birds and anthropogenic impacts were documented, water quality was measured using a multiparameter sonde and a permanent record of the wetland habitat was photographed using a 360-degree camera at 1-minute intervals.

In 2022, the team's research objectives were to repeat both the western and eastern surveys, using identical methods and procedures. There are a total of 51 fixed monitoring sites in the east, including 10 intensive sites, and 25 fixed monitoring sites in the west, including 6 intensive sites. The sites are roughly equidistant from each other along the length of the river. At all sites the team stopped to measure water quality and deploy a drone to capture fixed-point photos of the river and its surrounds. At the intensive monitoring sites the team also conducted a rapid bio-assessment of the ecological river condition using the Okavango Scoring System (OKASS) and collected eDNA samples to detect fish diversity and invasive species. Lastly, we collected termites, deployed an acoustic recorder and a fyke-net at overnight camps to record bat and fish diversity respectively.

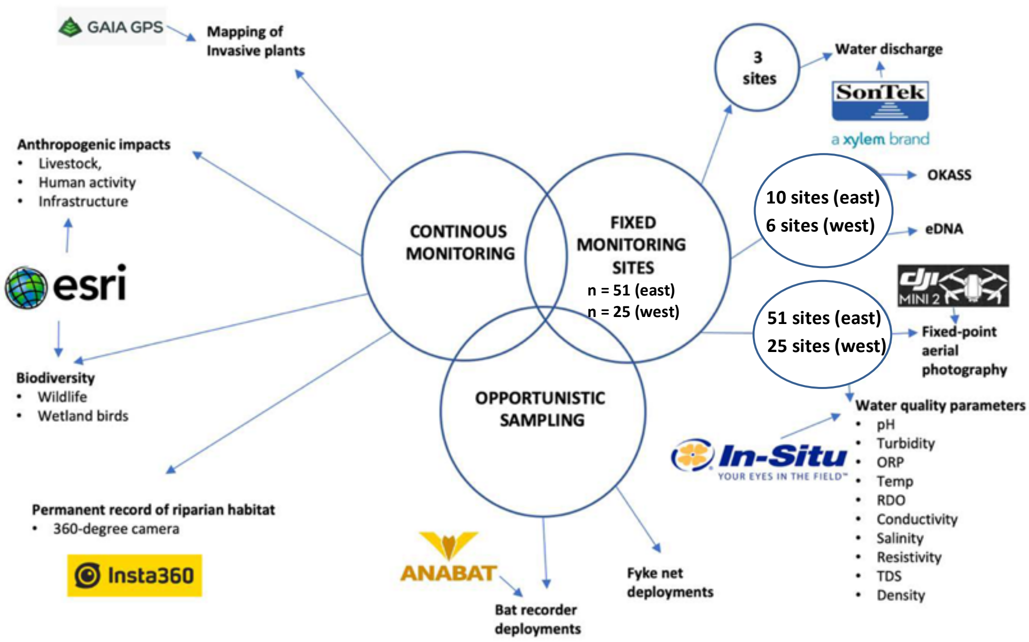


Figure 8: The various types of data that were collected continuously along the transect, including data collected at the fixed monitoring sites and at opportunistic monitoring sites.

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. Where necessary, our findings elicit detailed investigations by relevant scientists, academics and recognised local authorities.

Survey Limitations and potential data bias include:

• Ideally, surveys should be repeated several times a year to reflect different river flow states and climatic conditions. For consistency, expeditions start at the beginning of August. However, start dates have varied in the past owing to the timing of flood waters entering into the delta each year.

• Channel morphology changes over time and occasionally it is necessary for the survey team to digress from the original tracks by using different channels between islands.

• The expedition follows a single track through the vast expanse of the Okavango. Animals or impacts out of sight from this track cannot reported on in this report.

• The team only counts what is visible within 100m or so of the channel edge. This measurement is an estimation and is affected by vegetation density.

• Survey time is restricted to daytime hours only, between 09:00 and 16:00. Time spent on the water each day is varied due to multiple factors.

• Prevailing weather, dense vegetation, difficult terrain and the presence of hippos can introduce observer bias.

Figure 9: The flood arrives in the Okavango Delta in mid-winter breathing life into a vast dry landscape.

2. CONTINUOUS MONITORING ALONG THE OKAVANGO TRANSECT

The team travelled downstream between 10 and 30km per day between the hours of 09:00 and 16:00, continuously collecting data on biodiversity, vegetation and anthropogenic impacts, while recording 360-degree images at one-minute intervals. Those standing at the back of the mekoro, referred to as observers, constantly scanned the channel and surrounding wetlands (<100m from the water's edge) and vocalised their sightings to the team. The team confirmed observations and relayed these to the recorder seated at the front of a mokoro. The recorders used a smartphone to ingest the data into Survey123 (ESRI), after which the data is uploaded to a cloud database for safekeeping. Survey123 forms were created beforehand and set to automatically assign geolocation, date and time for each entry.

2.1 Mammal and Avian Biodiversity

Methods: Biodiversity

Long term monitoring of bird, mammal and larger reptile abundance and distribution can provide important insight into ecosystem health. We recorded all sightings of wildlife (medium to large mammals and large reptiles) as well as all wetland birds. Over a period of 7 days we repeated a section of the western transect to compare changes observations between consecutive days.

Figure 10: A large flock of White-faced Whistling Ducks lifts off.

Results and Discussion: Biodiversity

During the 2022 iteration, a total of 1022 observations, including 7467 mammals and larger reptiles belonging to 21 species were made on the western transect, and a total of 386 observations, including 1894 mammals and larger reptiles belonging to 19 species were made on the eastern transect. A total of 4942 observations, including 26912 birds belonging to 46 species were made on the western transect, and A total of 1960 observations, including 3750 birds belonging to 43 species were made on the eastern transect.

The major difference between the number of mammals and larger reptiles and birds observed on the two transects is likely due to the difference in vegetation, specifically the amount of temporarily wet floodplain which is both highly productive and affords great visibility. On the western transect, 21.8% of the transect passes through temporarily wet floodplain compared to only 9.9% on the eastern transect (figure 7). The animals are generally well distributed over their respective transects, however the reedbuck became more abundant in the south where the floodplains are dryer for longer periods during the year (figure 11). Many large herds of red lechwe (figure 11) and large flocks of ducks, geese and teal were observed on the western transect, west of Chiefs Island (figure 12), this is a highly productive area of the Okavango Delta.

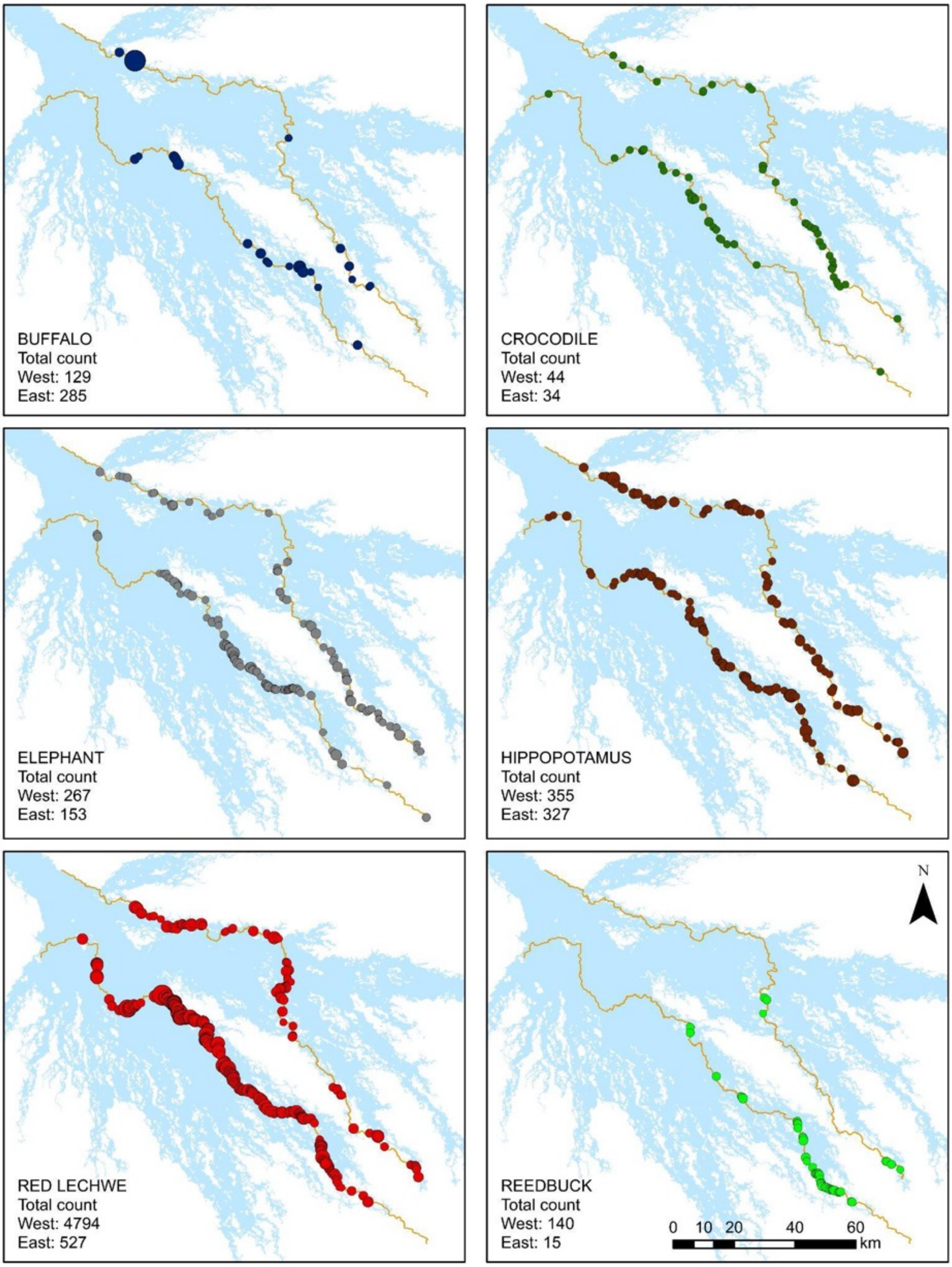


Figure 11: The location of selected mammals and larger reptiles frequently observed on the eastern and western transects. The size of the circle indicates the number of individuals per observation.

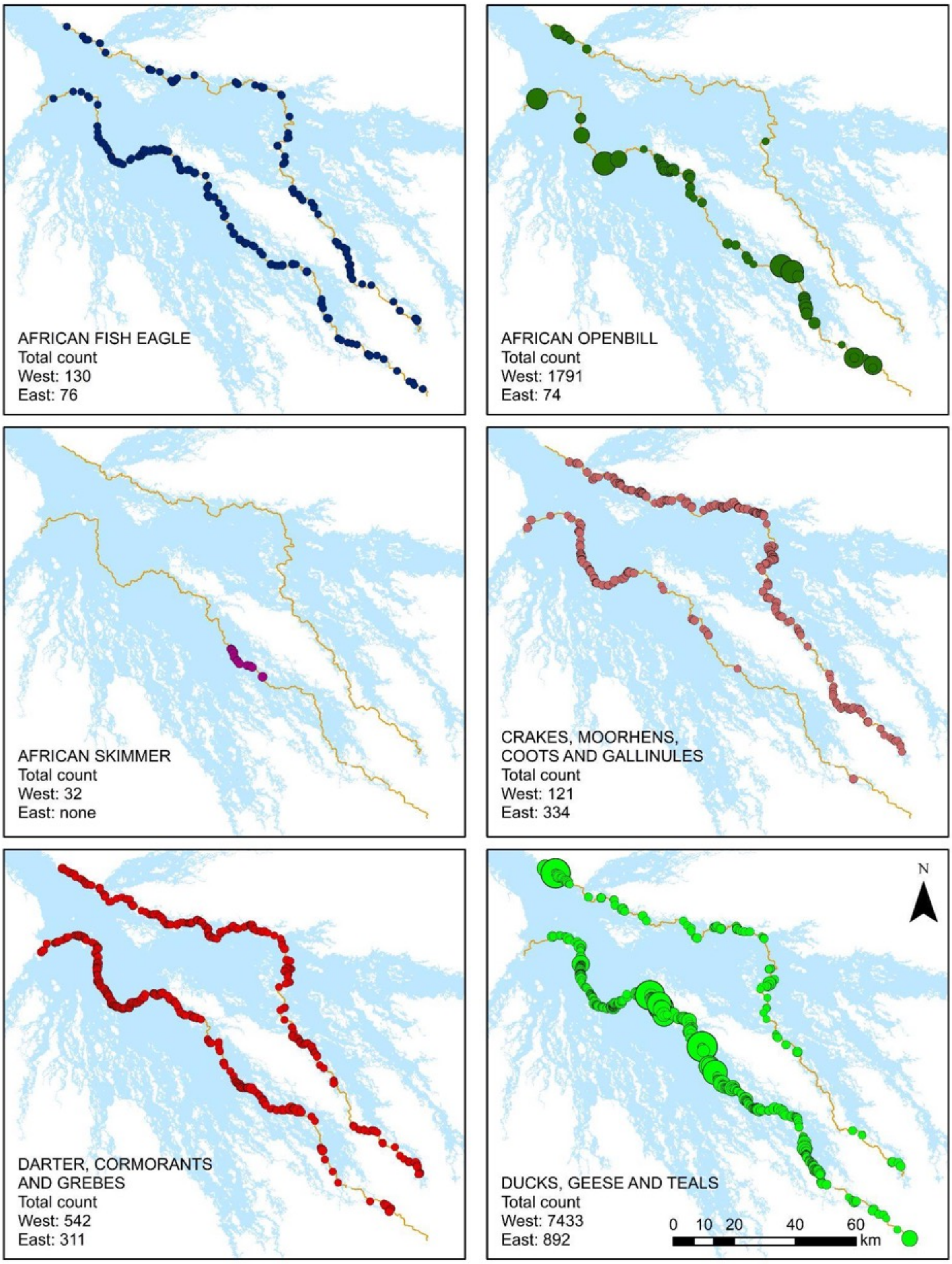


Figure 12: The location of birds observed on the eastern and western transects. Some of the birds have been lumped into feeding guilds. The size of the circle indicates the number of individuals per observation.

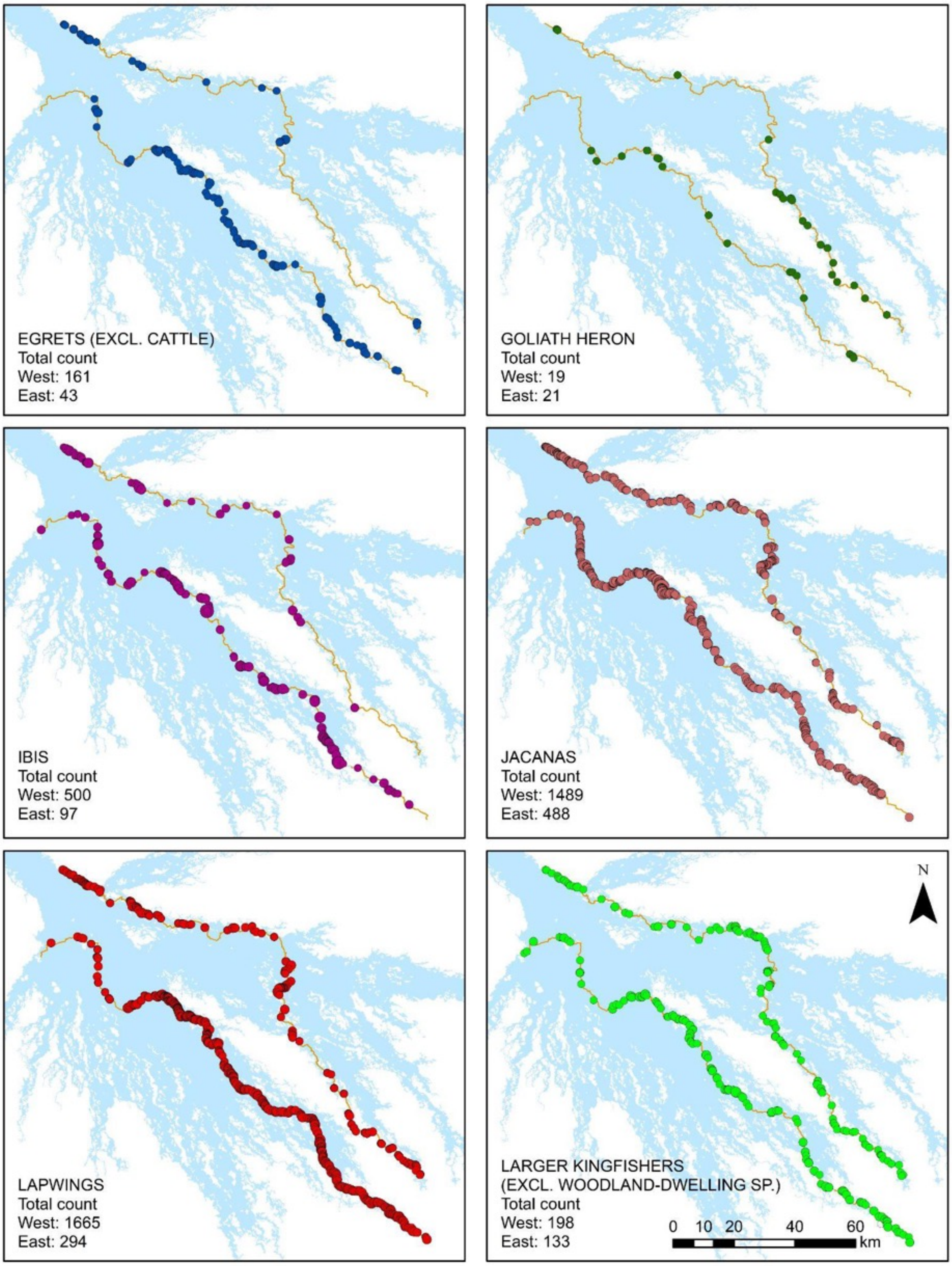


Figure 12 cont.: The location of birds observed on the eastern and western transects. Some of the birds have been lumped into feeding guilds. The size of the circle indicates the number of individuals per observation.

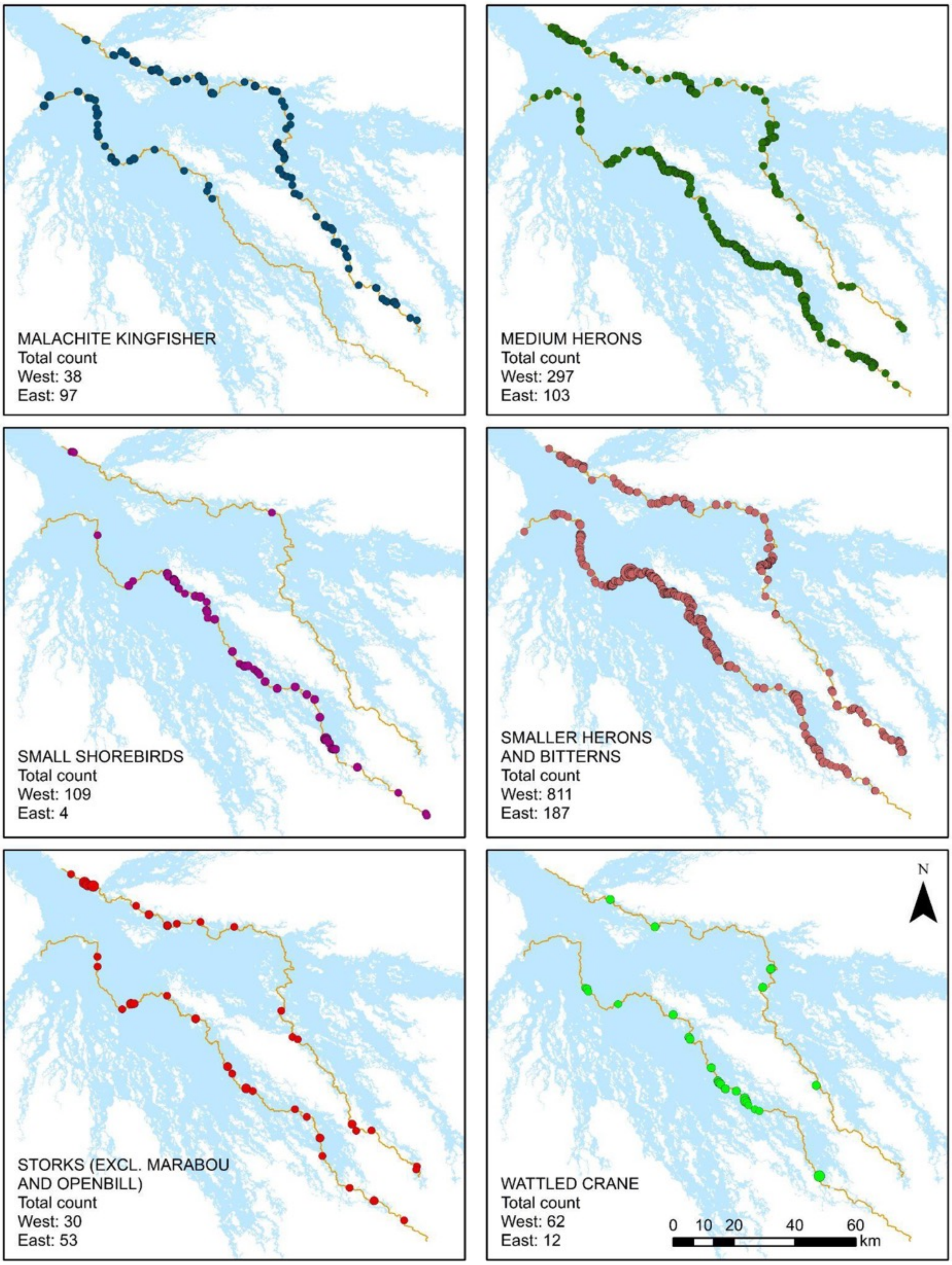


Figure 12 cont.: The location of birds observed on the eastern and western transects. Some of the birds have been lumped into feeding guilds. The size of the circle indicates the number of individuals per observation.

Variability between repeated survey days (7-13 August 2022) on western transect

Overall there was a general decline in total numbers of both birds and large mammals as the days progressed (tables 2 and 3). This is most likely a result of strong winds which picked up over the latter few days which would have kept animals low making them harder to count. To a lesser extent some of the animals could have moved off due to the repeat disturbance.

The hippo stayed in approximately the same locations over the days (appendix 4). African Fish Eagle, Goliath Heron and Wattled Crane counts were fairly consistent over the days – these birds have home ranges or territories which they prefer stay close to (table 3, appendix 4).

Table 2: Variability between repeated transect days - Large mammals and crocodiles

Date	07 Aug	08 Aug	09 Aug	10 Aug	11 Aug	12 Aug	13 Aug
Buffalo	19	15	354	27	7	12	26
Crocodile	1	1	6	3	1	1	1
Elephant	12	31	33	30	35	24	0
Hippopotamus	29	5	4	28	13	3	3
Red lechwe	858	944	680	583	953	708	589
Reedbuck	0	0	0	0	0	0	36
Grand Total	919	996	1077	671	1009	748	655

Table 3: Variability between repeated transect days – Birds and bird feeding guilds

Date	07 Aug	08 Aug	09 Aug	10 Aug	11 Aug	12 Aug	13 Aug
African Fish Eagle	6	6	8	2	1	4	1
African openbill	118	77	94	73	70	61	11
Crakes, moorhens, coots and gallinules	0	1	0	1	0	3	0
Darter, cormorants and grebes	15	13	7	12	6	14	1
Ducks, geese and teals	1898	1571	1438	1225	738	694	693
Egrets (excl. cattle)	16	16	8	14	15	6	6
Goliath Heron	2	2	2	3	2	3	0
Ibis	32	17	10	17	5	4	12
Jacanas	382	333	484	314	283	256	149
Lapwings	229	218	125	121	173	187	91
Larger Kingfishers	3	11	8	5	2	4	4
Medium herons	19	32	20	24	7	18	7
Small shorebirds	11	5	11	9	8	11	13
Smaller herons and bitterns	58	62	50	55	27	46	11
Storks (excl. Marabou and openbill)	0	0	0	0	0	1	0
Wattled Crane	2	2	0	2	0	2	0
Grand Total	2791	2366	2265	1877	1338	1314	999

2.2 Anthropogenic impacts

Methods: Anthropogenic Impacts

Anthropogenic impacts are very limited within the Okavango Delta which is protected as Wildlife Management Areas and Game Reserves and incorporated in the Okavango UNESCO World Heritage Site and Ramsar Wetland of International Importance. Where there were human impacts (human activity, domestic animals, fires and invasive plants) these were recorded using Survey123.

Results and Discussion: Anthropogenic Impacts

Human impacts were mostly confined to the vicinity of Seronga in the north, several tourism camps in the core delta area, and the area south of the buffalo fence approaching Maun (figure 13). The invasive plants differed from this trend as the alien invasive water fern Salvinia molesta has been able to penetrate deep into the Okavango wilderness. However, the Salvinia molesta was found with the biocontrol weevil that has been introduced to control the spread of the species.

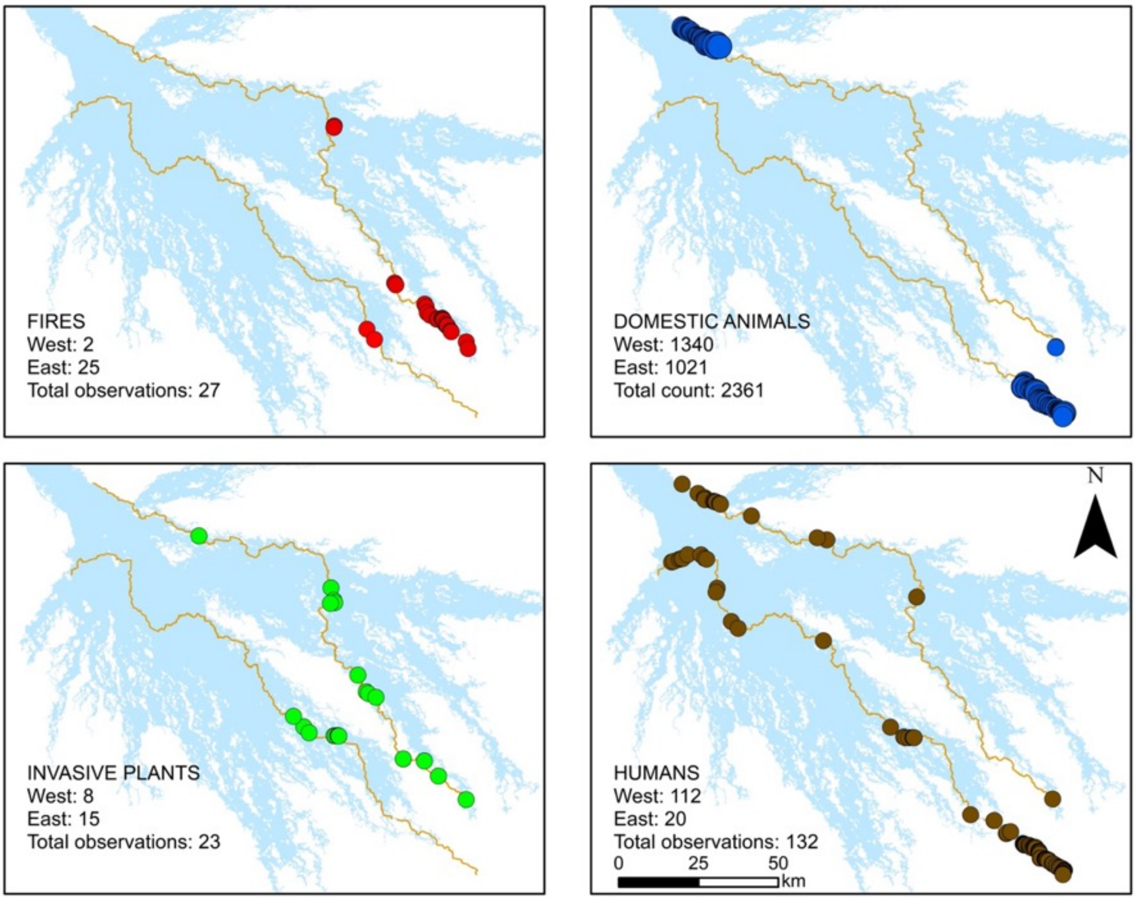


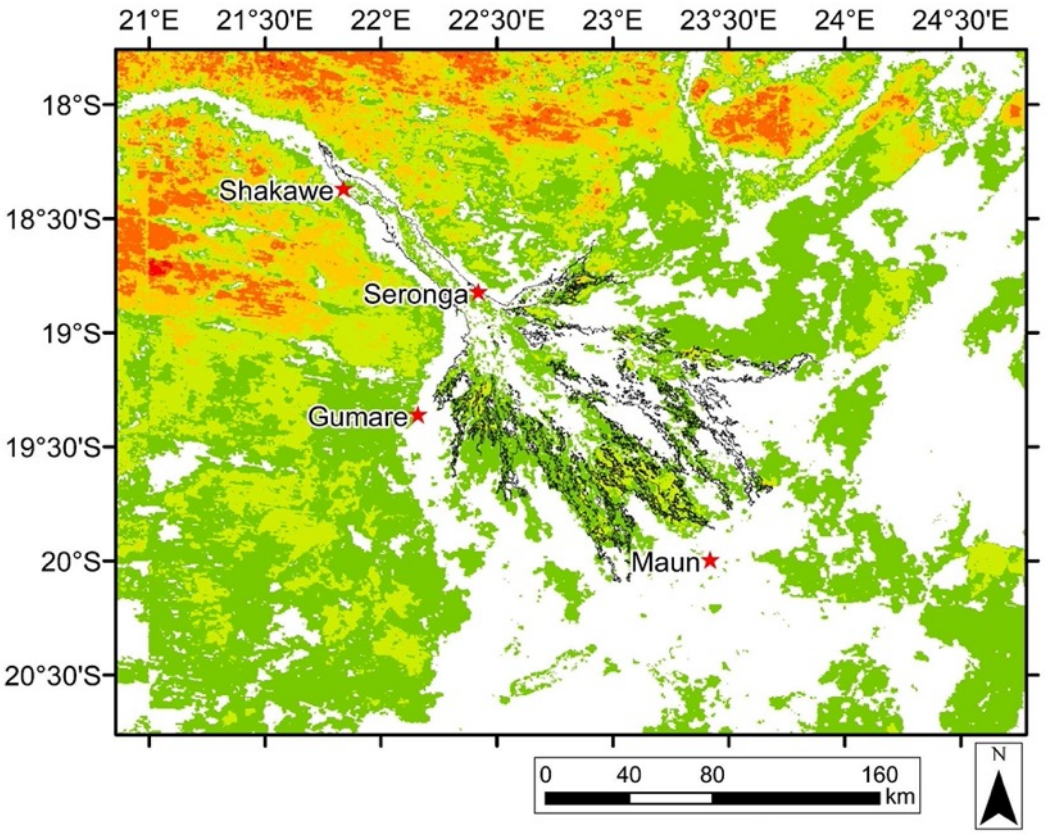
Figure 13: Anthropogenic impacts (fire, domestic animals, invasive plants and humans) recorded on the transects across the Okavango Delta in 2022.

Figure 14: Most of the human impact is on the periphery of the Okavango Delta where local people can utilise the landscape as is seen here with grass harvesting (left) and cattle foraging (right).

2.3 Fire from remotely sensed satellite products

The fire frequency between 2000 and 2022 of the Okavango delta and surrounds was extracted from the MCD64A1.061 MODIS Burned Area Monthly Global 500m product. A total of six burn frequency categories was included in the analysis (Figure 15). The fire history reveals that large sections (35990 km^2/ 25%) of the Okavango Delta and its surrounds have not burned since 2000 according to this satellite product. These are areas within the panhandle and main distributaries of the delta as well as large sections to the southeast of the mapped region. The largest burn area occurred within the frequency of 1-5 burns (71192 km^2/ 49%) between 2000 and 2022. The majority of the Okavango delta (shown in a simple black border) burned at this frequency (1-5 burns) between 2000 and 2022. The highest burn frequencies occurred in the northwest of the mapped area. It must be noted that although this product does produce burn area estimates with accuracy, the size of burn areas must be greater than 500m, and so smaller fires may not be identified by this product.

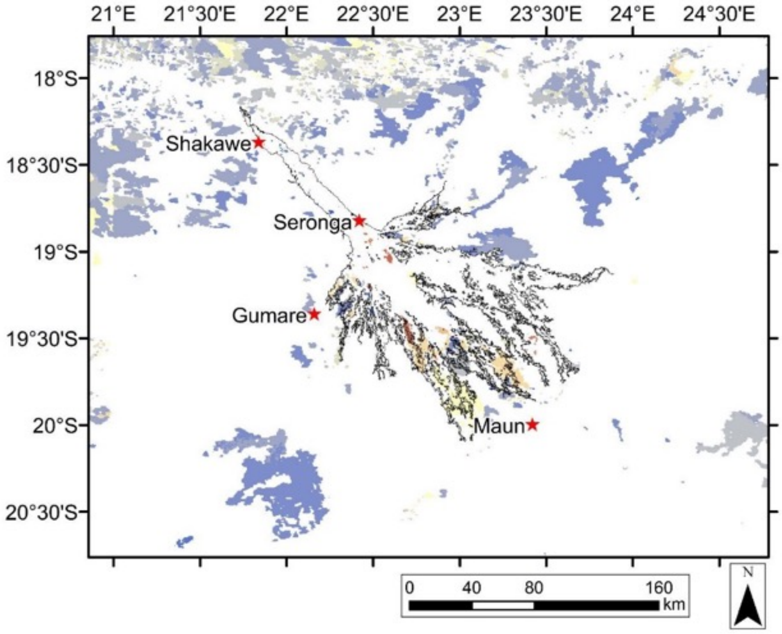
According to Cassidy et al. (2022), much of southern Africa's savanna wildernesses experience wildfires and burn unchecked. This is particularly true for the woodland savannas of northern Botswana, where wildfires originate outside of management areas and are left uncontrolled (Cassidy et al., 2022). Our analysis reveals similar patterns in that the northern sections of the mapped area have experienced near year on year burning due to limited resources for fire management and remoteness. There is concern that these severe annual wildfires that occur around wilderness areas may disturb woodland tracts within reserves and protected areas. Cassidy et al. (2022) conclude that annual fire frequencies are far higher than would be expected without anthropogenic ignition. The role of human activity and increasing fire frequency remains a concern for this region. This is not limited to the mapped area, the trend of increasing fire frequency and human activity has also been identified within the Angolan headwater catchments of Okavango Delta (Van Wilgen et al., 2022; Lourenco et al., 2022).



Legend	Burn Frequency (2000-2022)	Area (km^2)	Proportion (%)
	No Burn	35990	25%
	1-5	71192	49%
	6-10	21814	15%
	11-15	11554	8%
	16-20	4805	3%
	21-22	103	0,1%
	Total Area	**145457**	**100%**

Figure 15: Fire Frequency from 2000 to 2022 from MCD64A1.061 MODIS Burned Area Monthly Global 500m product

Fires were extracted from the MCD64A1.061 MODIS Burned Area Monthly Global 500m product for 2022 (Figure 16). Within the mapped region, a total of 20203 km^2 burned in 2022. The highest proportion of burning occurred in August (18,8%), September (36%) and October (29%). Majority of the burning occurred within the northern sections of the mapped area, with some burning in the western and southern sections of the Delta, near Gumare and Maun, respectively. The results are similar to those of Cassidy et al. (2022), fires peaked in September, several weeks before the onset of the rainfall season. These fires are associated with lightning strikes and dry fuel loads. Adaptive fire management strategies are needed within this region and the upper catchments of the Okavango Delta (Van Wilgen et al., 2022; Lourenco et al., 2022).



Legend	Month (2022)	Burn Area (km²)	Proportion (%)
	No Burn	125254	-
	January	27	0,1%
	February	100	0,5%
	March	10	0,05%
	April	37	0,2%
	May	679	3,4%
	June	1156	5,7%
	July	1143	5,7%
	August	3808	18,8%
	September	7265	36,0%
	October	5853	29,0%
	November	95	0,5%
	December	31	0,2%
	Total Burn Area (2022)	**20203**	**100%**

Figure 16: Burn area per month during 2022 from MCD64A1.061 MODIS Burned Area Monthly Global 500m product

2.4 Permanent Record of Riparian Habitat

Methods: Permanent Record Of Wetland Habitat

Permanent records were created of the wetland 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 and Discussion: Permanent Record of Wetland Habitat

Pictures were taken along the transect 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.

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. Direct comparisons can be made to previous crossings of the Okavango Delta.

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 provides an indication of change through 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 have established 51 fixed monitoring sites in the east transect, including 10 intensive sites, and 25 fixed monitoring sites in the west, including 6 intensive sites (Figure 17). At all fixed monitoring sites, we dispatched a drone to collect habitat photos and used a multiparameter sonde to collect water quality readings. At the 'intensive sites' we collected eDNA samples and conducted a rapid bio-assessment of the ecological river condition using the Okavango Scoring System (OKASS).

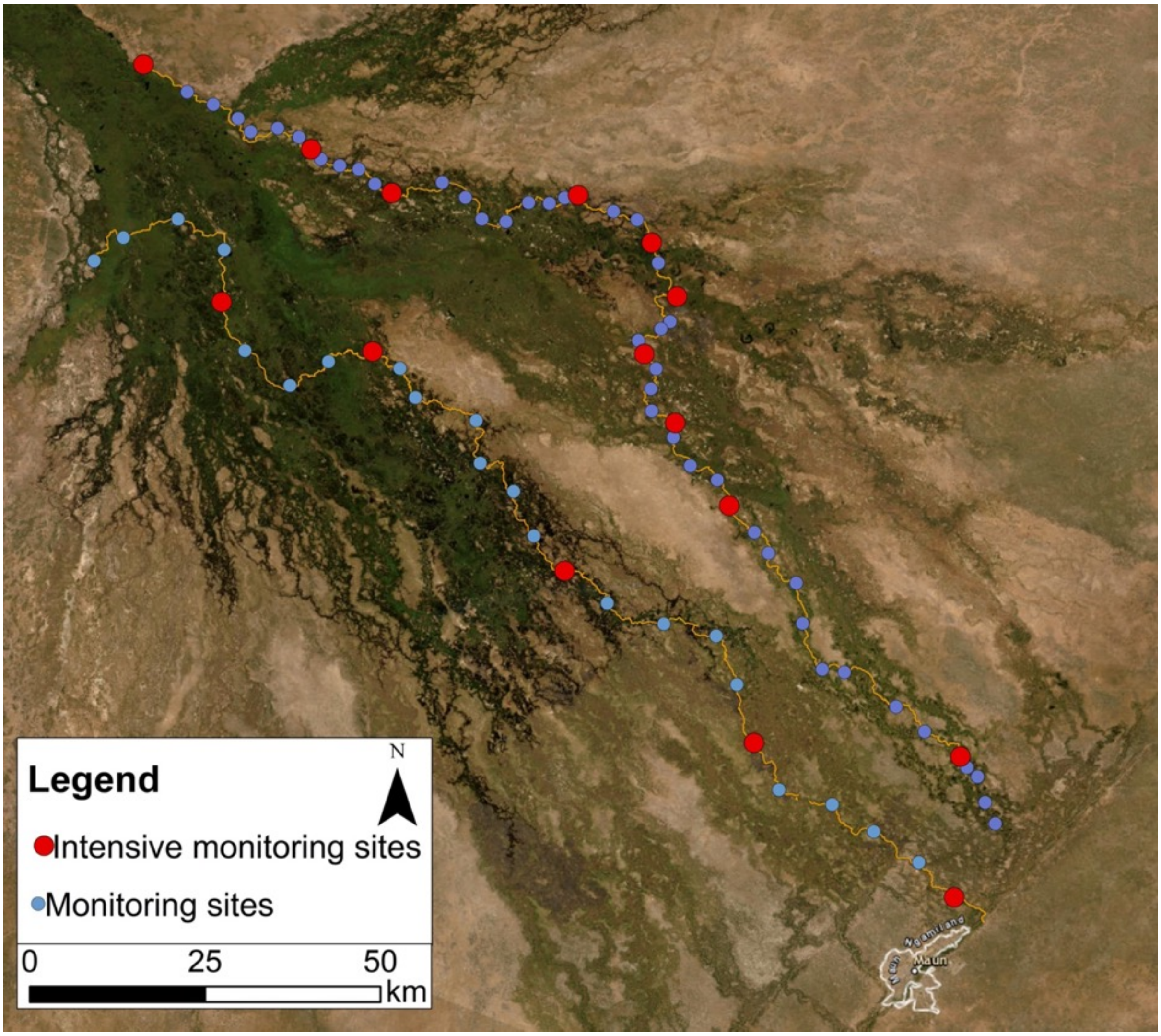


Figure 17: Fixed monitoring sites across the Okavango in 2022

3.1 Fixed Point Aerial Photography

Methods: Fixed Point Aerial Photography

At each fixed monitoring site, a DJI Mini2 drone was deployed 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 with the drone camera pointing straight down. Following this, four separate images (North, East, South, West) were taken at an angle of -20 degrees to the horizon and four images at -45 degrees.

Results and Discussion: Fixed Point Aerial Photography

Fixed point photos were collected at all 76 sample sites. 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 18: Drones are used to conduct fixed point aerial photography.

Figure 19: An example of fixed-point aerial photography taken from 300m. Left images were taken in 2021 and right in 2022. Note the Salvinia molesta infestation that appeared in 2022, significantly clogging up the channel (top image pair). Also note the burned aquatic grassland in 2022 (bottom image pair).

3.2 Water Quality

Methods: Water quality

Water quality parameters were measured at each fixed monitoring site along the eastern and western transects of the Okavango Delta using an InSitu Aquatroll 600 multi-parameter sonde (pH; Oxidation Reduction Potential; Total Suspended Solids; Turbidity; Dissolved oxygen; Conductivity; Salinity; Resistivity; Temperature and water density). Additional experiments were conducted along the eastern transect which involved river water sampling using the grab technique and sampling for Dissolved Inorganic Carbon (DIC) to gain further understanding on the controls of the river water quality. The samples were protected from sunlight and kept in a cool storage. These samples were transported to the University of California, Davis (USA), where they were filtered through 0.45 µm nylon syringe filters and refrigerated until analyses. Aliquots of the river water samples (n=48) were analyzed for stable hydrogen (δD) and oxygen ($\delta^{18}O$) isotopes using the Picarro Water Isotope Analyzer (Cavity Ringdown Spectrometer, L2140-i) and for major ions (anions: Fluoride, Chloride, Sulfate, Nitrate and Phosphate and cations: Calcium, Potassium, Magnesium and Sodium) using the Dionex Ion Chromatography System (ICS-6000 EG). Analysis for DIC is yet to be performed and results will be available by the second quarter of 2023.

Figure 20: The collection of water samples for laboratory analysis.

Results and discussion: Water quality

Electrical conductivity is a measure of conductive ions in water and is controlled by the presence of inorganic dissolved anions (e.g., chloride, nitrate, sulfate and phosphate) and cations (magnesium, calcium, sodium and potassium) which are often associated with pollution if they exceed their maximum contaminant levels.

In both the eastern and western transects, conductivity shows corresponding spatial behaviour with the total dissolved ions (TDI). This spatial behaviour manifests as progressive downriver enrichment in both conductivity and TDI (Figure 21a and b; Figure 22a and b). Although conductivity and TDI gradually increased downriver along the two transects, they are both still well below their maximum contaminant levels (conductivity=1500 µS/cm; TDI=500 mg/L) provided by the United States Environmental Protection Agency (EPA), (2012). The lower conductivity values and TDI concentrations in the river water is a good indicator of pristine water conditions along the eastern and western transects of the Delta.

Major ions (anions and cations) also increase downriver along the eastern transect with chloride dominating anions and cations being dominated by sodium with the highest concentrations (Figure 21c and d). There are 2 sites with higher nitrate concentrations (Figure 21c: ~2.5 mg/L and ~1.3 mg/L) which may either be from point source pollution or microbial driven nitrification.

The observed downriver enrichment in solutes along both transects can be attributed to progressive evapotranspiration effects (i.e., in river evaporation and transpiration by vegetation). Evaporation and transpiration involve loss of water to the atmosphere which results in the concentration of solutes in the river. Evidence for evaporative effects on the river chemistry was assessed from the stable water isotopes (δD and $\delta^{18}O$) and the d-excess parameter from the eastern transect. As evaporation concentrates solutes (e.g., figure 21a and b), it also causes isotopic fractionation which enriches the stable hydrogen (δD) isotope (e.g., Figure 21e) in the river water (Atekwana et al., 2016). Evaporation is also reflected by the gradual decrease in the d-excess parameter as lower d-excess values indicate greater extent of evaporation (Figure 21f). In addition, the δD and $\delta^{18}O$ composition of the water samples co-vary, fall below the Maun Local Meteoric Water Line (LMWL) and cluster along the Okavango Delta Evaporation Line (ODEL) (Figure 23), consistent with the dominance of evaporation in this system (Dincer et al., 1979; Atekwana et al., 2016; Akondi et al., 2019).

River water temperatures from the eastern transect range between 14 and 23 ℃ (Figure 21g), and show fluctuations controlled by the weather conditions on the day of sampling. Although the water temperatures fluctuated with no apparent downriver increase in the eastern transect, the study still captured the progressive evaporative effects that water is subjected to as it transits downstream. In the western transect, water temperatures increased downriver coinciding with evapo-concentration of solutes in the river (Figure 22c).

The observed dominance of sodium in the cations from the eastern transect is reflective of dissolution of sodium carbonate minerals; trona ($Na_3(CO_3)(HCO_3)\cdot 2H_2O$) or thermonatrite ($Na_2CO_3\cdot H_2O$) in the Okavango Delta during flooding (e.g., McCarthy et al., 1991; McCarthy and Ellery, 1995). The river interacts with salts (trona or thermonatrite) stored in the local watershed during flooding which facilitates the transfer of the dissolved salts into the river.

Other river water quality parameters such as pH slightly increased along the eastern and western transects, transitioning from acidic to neutral status (Figure 24a). The spatial behaviour of pH along the two transects is indicative of neutralisation as we move away from human settlements around Seronga, towards the pristine parts of the Delta with little to no anthropogenic pressures. Dissolved oxygen (DO) levels started off higher along the two transects, followed by a drop and subsequent gradual increase (Figure 24b). The lower DO levels at some sites could be due to location specific factors such as higher aerobic respiration, and stagnant flow that limits atmospheric input of oxygen into the river at the sites. Additionally, the varying extents of influence from photosynthesis by aquatic vegetation can also modify the pH and DO in the river. Aquatic vegetation utilizes solar radiation to photosynthesize during the day and the process of photosynthesis uses up carbon dioxide, thus resulting in lower water acidity concentrations. Photosynthesis also releases DO, thereby, contributing to increased DO levels. Turbidity was relatively low across the two transects (Figure 24c) except for a few perturbed sites with turbidity of ~10, 15 and 30.

Our findings reveal that the Delta is still pristine and that evapotranspiration, river interaction with salts in the local watershed and photosynthesis by aquatic vegetation during the day are important processes that drive the spatial changes in the river chemistry across the Okavango Delta. Our findings are not only useful in characterizing the major drivers of changes in the river chemistry, but they also form the basis for solute cycling models in rivers that interact extensively with their vegetated floodplains and wetlands. The spatial enrichment of solutes across the Delta is a good indication of the need for continuous monitoring of the Okavango Delta system to capture the shifts in the extent of solute enrichment under the ongoing climate change. The monitoring will open new frontiers to investigate controls of the water chemistry of rivers in other endorheic (closed) basins.

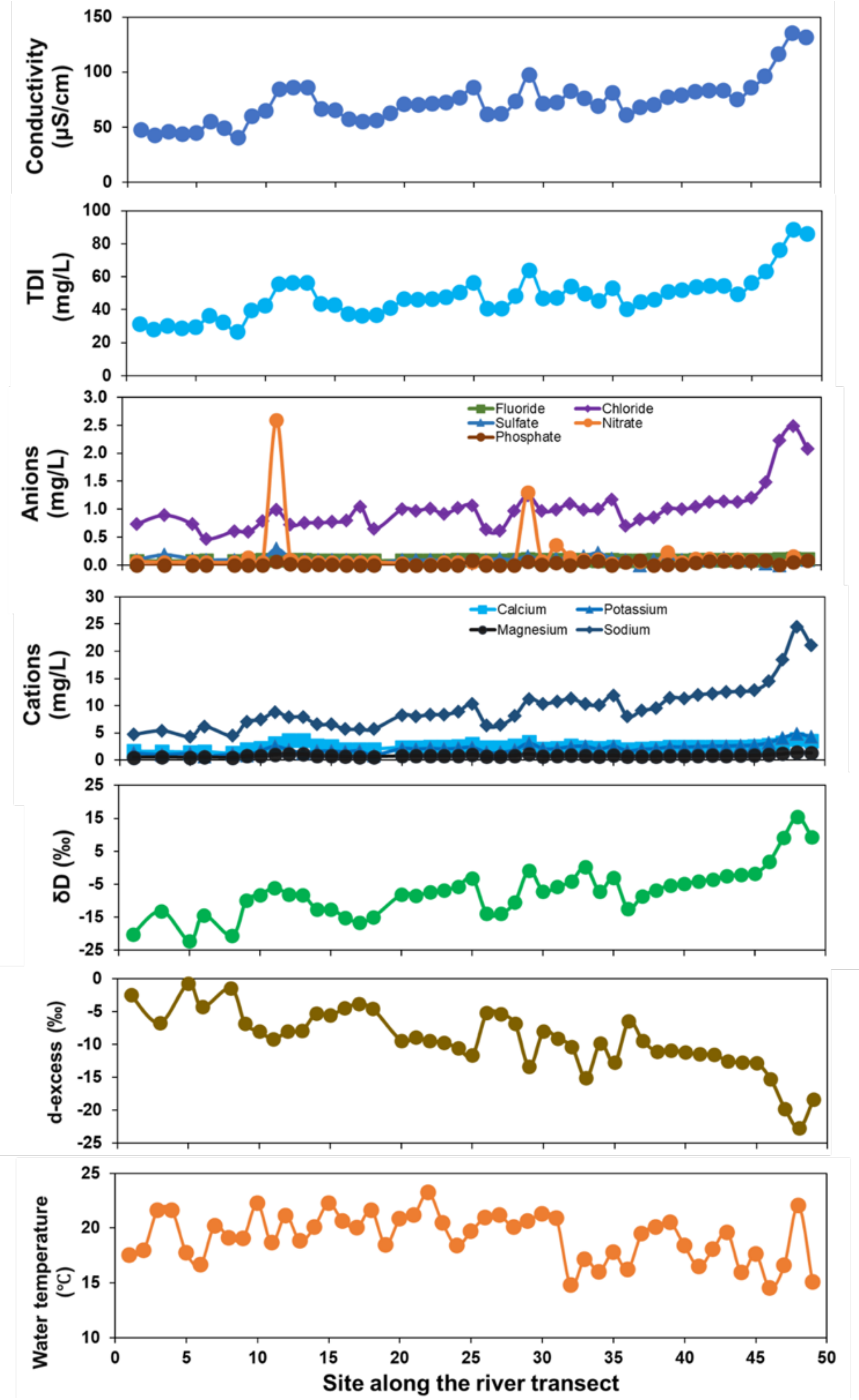


Figure 21: Spatial plots of (a) Conductivity, (b) total dissolved ions (TDI), (c) anions, (d) cations, (e) stable hydrogen isotope (δD), (f) d-excess and (g) river water temperature measured along the eastern transect of the Okavango Delta, Botswana.

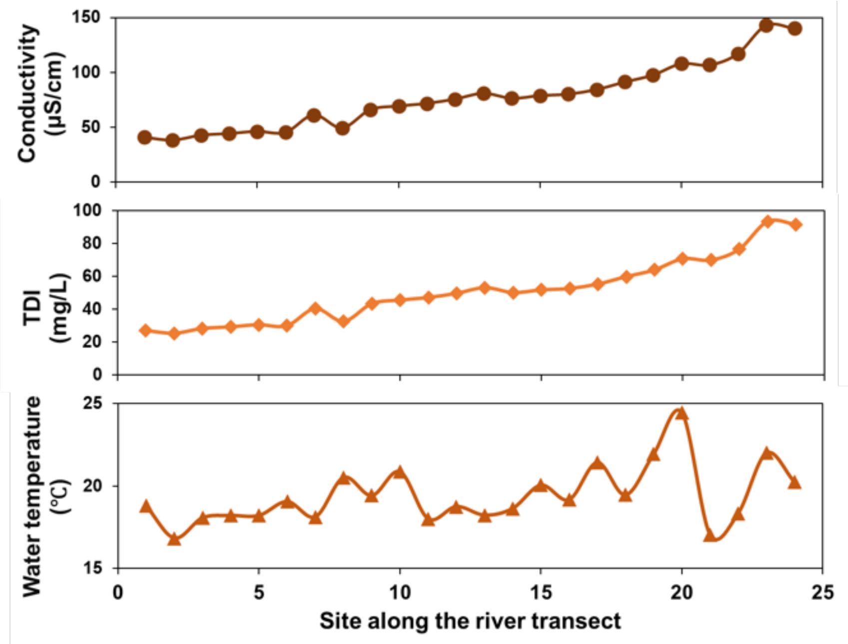


Figure 22: Spatial plots of (a) Conductivity, (b) total dissolved ions (TDI), (c) river water temperature measured along the western transect of the Okavango Delta, Botswana.

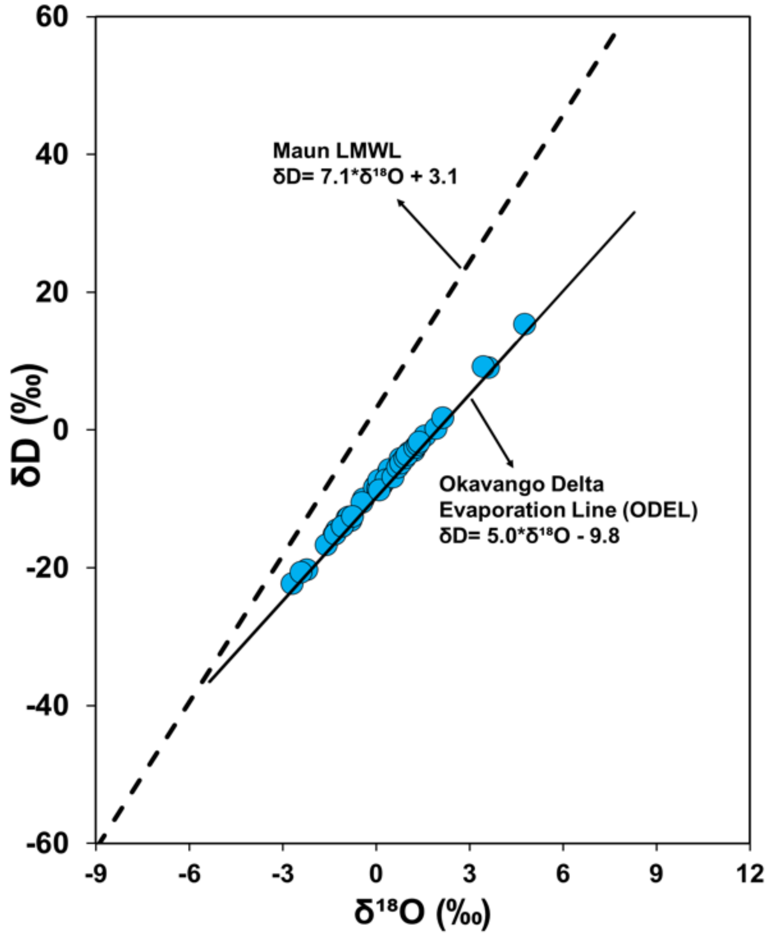


Figure 23: Plot of the stable oxygen isotopic composition ($\delta^{18}O$) vs. the stable hydrogen isotope (δD) for river samples collected along the eastern transect of the Okavango Delta, Botswana. The local meteoric water line from Maun rain (LMWL) from Akondi et al. (2019) and the Okavango Delta evaporation line (ODEL) of Atekwana et al. (2016) are also included.

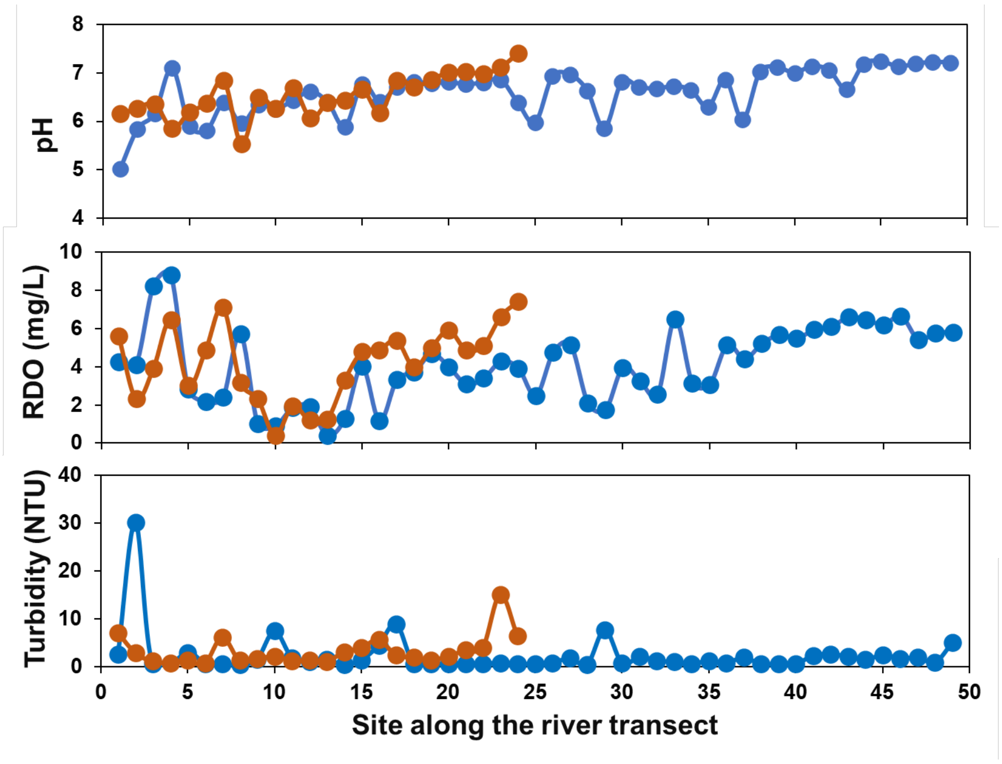


Figure 24: Spatial plots of pH, dissolved oxygen (RDO) and turbidity measured along the eastern (blue filled circles) and western (brown filled circles) transects of the Okavango Delta, Botswana.

3.3 Environmental DNA

Methods: Environmental DNA

In 2020 and 2021 eDNA samples were collected at 10 sites along the eastern transect in order to look at fish communities in the system. In 2022 these were repeated with an addition of 6 sites on the western transect. 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 of 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 assessed 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 known to devastate river ecosystems.

Results and Discussion: Environmental DNA

Analysis currently underway at Stellenbosch and Rhodes University.

Figure 25: The collection of eDNA samples.

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. The Okavango Scoring System (OKASS) is used as a standardized field-based method for assessing the aquatic macroinvertebrate fauna at a family level. Many aquatic macroinvertebrate taxa are sensitive to changes in their habitat and are useful indicators of system health. Healthy and diverse aquatic habitats will host a high diversity or aquatic taxa. Any impact on the habitat will result in the loss of sensitive taxa. 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.

A long-term database will allow for comparisons to be made over the years and if necessary provide quantifiable data on and the early detection of potential impacts to the system. OKASS data was collected in 2020 and 2021 at all the intensive sampling sites on the eastern transect, this was repeated in 2022.

The OKASS assessment scores each site based on the number of sensitive species found at that site. Additional metrics for comparison includes the total number of taxa, and the Average Score Per Taxon (ASPT). To complement the OKASS data, water quality was recorded using a handheld water quality logger. Parameters recorded included dissolved Oxygen, electrical conductivity, temperature, turbidity, and pH.

Figure 26: Sorting and identifying aquatic macroinvertebrates as part of the OKASS assessment.

Results and Discussion: Aquatic Macroinvertebrates

In 2022, sites sampled along the Okavango transect achieved OKASS scores ranging from 99 to 152 in lagoons and 81 to 134 in channels (appendix 1). The numbers of taxa ranged from 17 to 28 in lagoons and 14 to 31 on channels. The Average Score Per Taxon (ASPT) – considered the most consistent and reliable indices – ranged from 5.1 to 5.8 in lagoons and 4.7 to 6.3 in channels.

Table 2: The OKASS score, Number of taxa recorded, and the Average Score Per Taxon (ASPT) for each for each of the sites.

	Site	OKASS Score			No. of Taxa			ASPT			Comments
	No.	2020	2021	2022	2020	2021	2022	2020	2021	2022	
Marginal Veg out of Current (Lagoon)	1	94	95	116	19	18	22	4.9	5.3	5.3	Small lagoon/ impacted by cattle trampling
	3	130	120	152	22	23	28	5.9	5.2	5.4	Large lagoon
	4	131	128	133	25	23	26	5.2	5.6	5.1	Large lagoon
	10	97	137	99	19	24	17	5.1	5.7	5.8	Small lagoon, was impacted by Salvinia in 2020
Marginal Veg in Current (Channel)	2	90	132	107	22	25	23	4.1	5.3	4.7	Slow flowing
	5	96	119	145	20	21	23	4.8	5.7	6.3	Slow flowing
	6	61	72	81	9	11	14	6.8	6.5	5.8	Fast flowing large channel
	7	123	120	154	23	23	28	5.3	5.2	5.5	Small channel
	8	108	134	160	20	24	31	5.4	5.6	5.2	Small channel
	9	90	132	105	18	22	18	5.0	6.0	5.8	Fast flowing

The faster flowing more oxygenated channels (sites 6 and 9) recorded low diversities due to the strong current but high ASPT scores as the available oxygen enabled the more sensitive taxa to persist.

There were no obvious differences between the scores from sites in lagoons versus those in channels.

ASPT remained fairly consistent with scores from 2021. Higher ASPT in both 2021 and 2022 were recorded at many of the sites compared when compared to 2020. One notable change was recorded at site 10 which had been infested with Giant Salvinia in 2020. Since the initial observation, the biocontrol weevil had been introduced to the area and it had successfully controlled the Salvinia. With the decline in Salvinia was a decrease in turbidity and electrical conductivity and an increase in both the diversity of aquatic macroinvertebrates and their OKASS and ASPT scores.

The 10 sites sampled were representative of habitats found on the Okavango Delta. Unfortunately, limited work has been done on the Okavango to determine ecological health scores for OKASS assessments, however, sites 2 to 10 are all in a natural to near-natural states. No other southern African indices have been designed to work in lentic systems so comparisons to other ecoregions cannot be made. The sample sites selected will continue to support our ongoing monitoring objectives.

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) on the Khiandiandhavu channel in front of Little Vumbura camp and on both the Maunachira and the Santantadibe channels immediately downstream of the bifurcation of these two channels.

We pulled the ADCP across the channels using ropes, while remaining within acceptable limits in terms of sampling speed and trajectory. At each site, we conducted 4 transects across the river so that variance could be calculated. In cases where variance was too high (COV > 0,5), resampling is required.

Figure 27: ADCP in use to measure and record water discharge down one of the major channels in the Okavango Delta.

Results: Acoustic Doppler Current Profiler

Coefficient of variation between 4 transects at each site were below 0,05, an excellent result with very high accuracy and precision. Little change occurred in water discharge between the 2021 and 2022 flood seasons, both measured in the second week of August.

Table 5: Water discharge measurements taken at three locations during the second week of August in 2021 and 2022

Channel	2021	2022
Khiandiandhavu at Little Vumbra	7,9 m3/s (COV = 0,04)	9,9 m3/s (COV = 0,02)
Maunachira at Santantadibe split	18.8 m3/s (COV = 0,02)	18,9 m3/s (COV = 0,01)
Santantadibe at Maunichira split	3,8 m3/s (COV = 0,05)	2,8 m3/s (COV = 0,05)

4. OPPORTUNISTIC SAMPLING

4.1 Termite collections

Termites were collected from around the overnight camps on the eastern and western transects These were sent to Dr Barbara van Asch of Stellenbosch University for analysis.

Genus *Macrotermes* (fungus-growing, mound builder, the largest Macrotermitidae)

A total of 46 specimens were sequenced. The majority (n = 41) were *Macrotermes michaelseni*, which is common throughout Botswana and Southern Africa. *M. falciger* (n = 4) and *M. natalensis* (n = 2) were also found. These two species seem to be very rare in Botswana (they had not been recorded elsewhere in Botswana) but they are common in South Africa and in Namibia.

Other groups / genera:

Only eight specimens from other groups were sequenced because the priority at the time was *Macrotermes*.

Six genetic species were found including *Hodotermes mossambicus,* one species of *Microtermes*, three species of *Odontotermes* and one species of *Trinervitermes* (morphological analyses is yet to be done – however informative characters are rare at the species level). It is remarkable that eight specimens selected for sequencing randomly yielded six genetic species. No matches on the DNA databases (BOLD and GenBank) were found because so little work has been done on African termites and the morphology and genetic diversity overlap poorly.

4.2 Bat recorder deployments

Bat echolocation recordings were obtained each night during the river expedition using a *Wildlife Acoustics Song Meter SM4BAT-FS* detector. 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.

5. LAND USE CHANGE ANALYSIS 1992-2020

The European Space Agency (ESA) Climate Change Initiative (CCI) land cover classification (Copernicus Climate Change Service, Climate data store 2019) 300 m resolution maps for 1992 and 2020 were extracted (Figure 28) to provide an estimate of the land cover change for the Okavango Delta. According to this global land cover product, the Okavango Delta is described as *shrub or herbaceous cover, flooded, freshwater*.

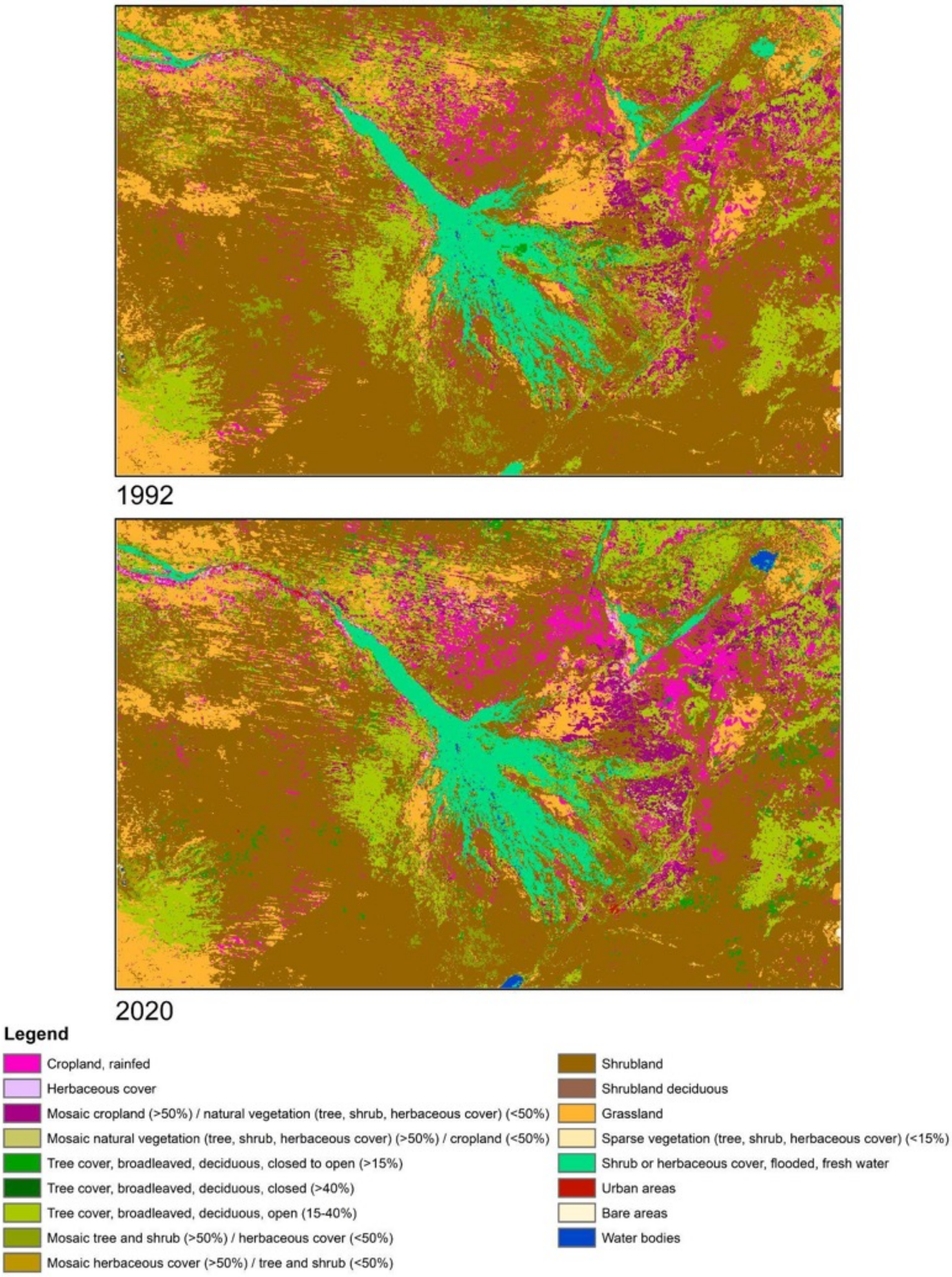


Figure 28: The 1992 and 2020 300m resolution ESA CCI land cover area for the Okavango Delta and surrounds.

Table 6: The % increase/ decrease of land cover types between 1992 and 2020.

		1992	2020	
Legend	**European Space Agency Climate Change Initiative LULC Classes**	**Area (km²)**	**Area (km²)**	**Increase/ decrease (%)**
	Cropland, rainfed	7461	8604	15,32%
	Herbaceous cover	196	566	189,10%
	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	5480	6640	21,16%
	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	593	837	41,17%
	Tree cover, broadleaved, deciduous, closed to open (>15%)	1082	3092	185,82%
	Tree cover, broadleaved, deciduous, closed (>40%)	0,18	0,18	-
	Tree cover, broadleaved, deciduous, open (15-40%)	20762	21269	2,44%
	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	4910	2247	-54,24%
	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	3734	1164	-68,82%
	Shrubland	81371	81528	0,19%
	Shrubland deciduous	381	361	-5,25%
	Grassland	15447	14802	-4,17%
	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	2,43	2,34	-3,70%
	Shrub or herbaceous cover, flooded, fresh water	8502	8484	-0,21%
	Urban areas	68	164	140,93%
	Bare areas	37	38	3,16%
	Water bodies	159	387	143,24%
	Total Area	150185	150185	-

Since 1992, there has been a net percentage increase in *Croplands* (15,32%), *Herbaceous cover* (189,10%), *mosaic croplands* (21,60%) *and urban areas* (140,93%) within the surrounding areas of the Okavango Delta. These specific land cover types negatively influence river discharge and water quality. Land cover estimates for 2020 reveal the mapped region contains 8604 km², 566 km², 6640 km² and 164 km² of area classified as *Croplands, Herbaceous cover, Mosaic croplands and urban areas* respectively. While net gains have been calculated for these specific land cover types, losses in both *mosaic tree and shrub/ herbaceous cover* (-54.24%) and *mosaic herbaceous cover/ tree and shrub* (-68.82%) have occurred since 1992. This suggested that these two land cover types are being converted to either cropland or urban areas. The Okavango Delta is described as *shrub or herbaceous cover, flooded, freshwater*, this land cover type has seen minimal change between 2020 and 1992 (net loss of 0.21%). However, the gain in land cover types which negatively influence both discharge and water quality is concerning for the Okavango Delta and its catchment area.

6. CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH DIRECTIONS

As with previous surveys, the annual transect showed very little change in water quality, biodiversity, and anthropogenic disturbance. This is an excellent result that is not shared with many other river systems in Africa.

The data collected on these annual transects across the Okavango Delta aids understanding the complexity and natural variability of the system. These surveys serve as a long-term baseline study, which is important in determining what changes are within the thresholds of natural variability of the system and what can be explained by upstream changes in water quality and quantity.

It remains imperative that NGOWP continues with the annual transects across the delta so that if (or when) the ecosystem begins to degrade, remedial action can be decisive, fast and guided by scientific data. Every year the team adds to the data already collected, the baseline becomes more scientifically robust. The combination of repeatable continuous monitoring and fixed point monitoring methods together with opportunistic sampling helps to build a better and bigger picture of the ecology of the system and provide valuable knowledge and advice to policy makers and land managers.

Recommendations:

Incorporating water sampling for both transects: Our results from the eastern transect reveal that combining water source partitioning techniques such as solutes and stable water isotopes elucidates the dominance of evaporation in this system and river connectivity to salts during flooding. These vital processes that can modify water quality cannot be confidently constrained and quantified without collecting water samples for further chemical analyses.

The role of groundwater in changing the surface water chemistry in the Okavango Delta remains enigmatic. Perhaps future work can explore the surface water-groundwater interaction and its impact on the river water quality. This can be done via monitoring the water and solutes in the river and nearby wells using automated dataloggers.

Very limited termite collections have taken place in Botswana (Botswana was not covered in the southern African surveys by Coaton and Sheasby in the 1970s). As there is little known regarding the diversity of termites in the country, it would be favourable to increase termite collections in the Okavango Delta which can supplement records for Botswana.

Understanding the anthropogenic influence on fire and fire ignitions within the Okavango Delta and greater Okavango catchment is an important future research direction. Satellite products are also limited to large fires and so smaller (more common) fires are not identified. Fire is a natural phenomenon within this region of southern Africa, however, with increased human activity and presence, fire frequencies often increase, resulting in the ‘savannisation’ of large tracts of wooded land across forest reserves, protected areas, and surrounding wilderness areas.

Figure 29: The expedition team poling through the Okavango Delta on Mekoro.

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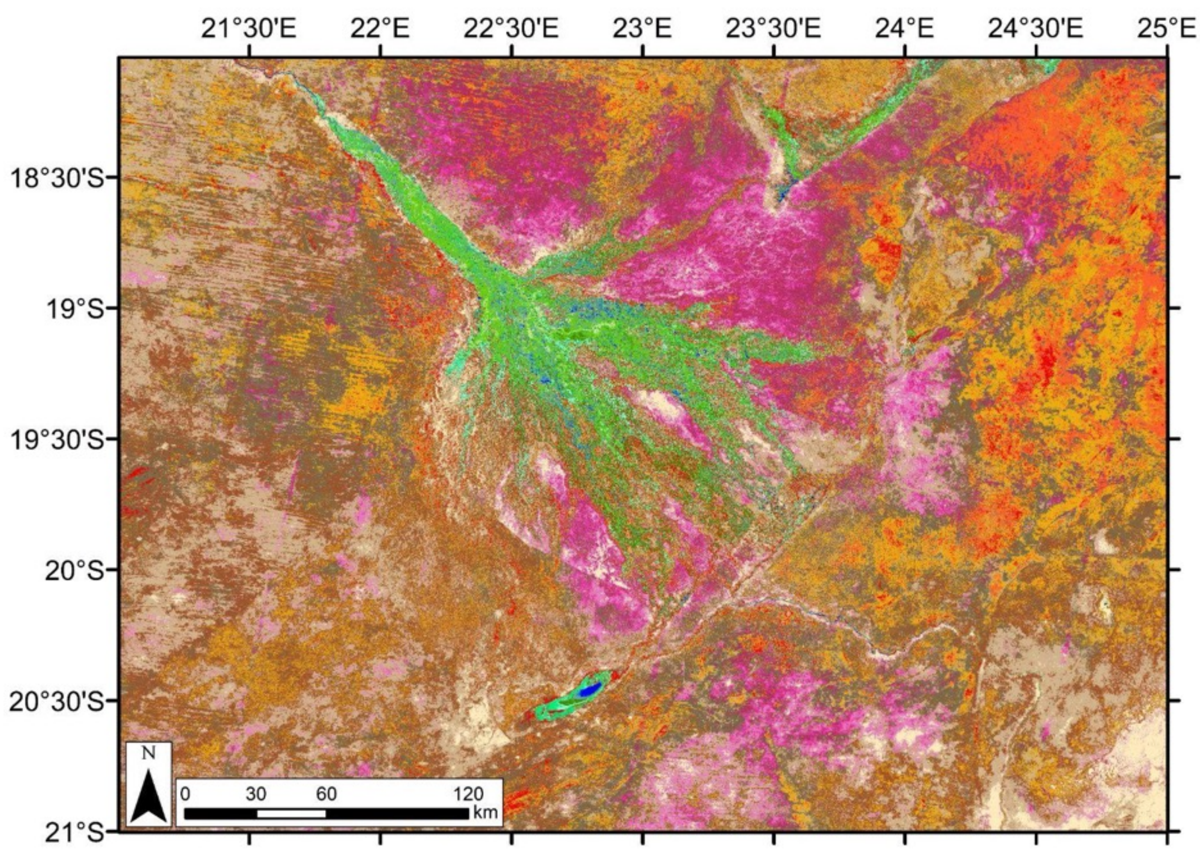
APPENDIX 1: Feeding Guilds

Ducks, geese and teals	White-faced Whistling Duck	**Small shorebirds**	Black-winged Stilt	**Darter, cororants and grebes**	Little Grebe
	Fulvous Whistling Duck		Pied Avocet		Black-necked Grebe
	White-backed Duck		Common Ringed Plover		African Darter
	Spur-winged Goose		Kittlitz's Plover		Reed Cormorant
	Knob-billed Duck		Three-banded Plover		White-breasted Cormorant
	Egyptian Goose		Whit-fronted Plover	**Ibis**	African Sacred Ibis
	African Pygmy Goose		Caspian Plover		Glossy Ibis
	Blue-billed Teal		Greater Painted Snipe		Hadeda Ibis
	Cape Shoveler		Black-tailed Godwit	**Smaller herons and bitterns**	Eurasian Bittern
	Yellow-billed Duck		Ruff		Dwarf Bittern
	Cape Teal		Curlew Sandpiper		Little Bittern
	Red-billed Teal		Little Stint		White-backed Night Heron
	Southern Pochard		African Snipe		Black-crowned Night Heron
Crakes, moorhens, coots and gallinules	African Rail		Common Sandpiper		Striated Heron
	African Crake		Green Sandpiper		Squacco Heron
	Spotted Crake		Marsh Sandpiper		Rufous-bellied Heron
	Lesser Moorhen		Wood Sandpiper	**Medium herons**	Grey Heron
	Common Moorhen		Common Greenshank		Black-headed Heron
	Red-knobbed Coot		Cape Wagtail		Purple Heron
	Allen's Gallinule		African Pied Wagtail		Great Egret
	African Swamphen	**Jacanas**	Lesser Jacana		Intermediate Egret
	Black Crake		African Jacana		African spoonbill
	Baillon's Crake		Yellow-billed stork	**Egrets (excl. cattle)**	Black Heron
	Striped Crake	**Storks (excl. Marabou and openbill)**	Black Stork		Slaty Egret
Lapwings	Long-toed Lapwing		Abdim's Stork		Little Egret
	Blacksmith Lapwing		Woolly-necked Stork	**Larger Kingfishers**	Giant Kingfisher
	Crowned Lapwing		White Stork		Pied Kingfisher
	African Wattled Lapwing		Saddle-billed Stork		

APPENDIX 2: Okavango Delta broad vegetation level 2 classes, proportion indicates percentage of land cover type for the entire mapped area shown in the figure.



Legend	Okavango Delta broad vegetation level 2 classes (10 m)	Area (km^2)	Proportion (%)
	Open water	184	0.1%
	Permanently inundated	320	0.2%
	Seasonally inundated	1096	0.7%
	Saturated channel margins	486	0.3%
	Saturated back channels	2184	1.5%
	Seasonally wet upper floodplains	2241	1.5%
	Temporary wet upper floodplains	508	0.3%
	Temporary wet lower floodplains	2343	1.6%
	Seasonally wet uplands	169	0.1%
	Woody pan edges	6	0.004%
	Dense woodland / riparian forest	4393	3.0%
	Miombo / Bakeia woodland	7449	5.0%
	Mopani / Terminalia woodland / Sandveld	20795	14.0%
	Sand veld 1	30369	20.4%
	Sand veld 2	23027	15.5%
	Mountain woodland / Swarthaak / Combretum	26632	17.9%
	Mopani / Terminalia channels	10208	6.9%
	Mopani / Terminalia open to moderately dense uplands	5485	3.7%
	Mopani / Terminalia open channels	6538	4.4%
	Grassland / saltpans / degraded woodlands	4286	2.9%
	Total Area	148719	100%

APPENDIX 3: Birds and game distribution in relation to vegetation type

Buffalo	West	East
Open water	1	4
Permanently inundated	0	1
Saturated back channels	55	184
Saturated channel margins	23	61
Seasonally inundated	1	31
Seasonally wet uplands	6	0
Seasonally wet upper floodplains	20	4
Temporary wet lower floodplains	20	0
Temporary wet upper floodplains	3	0
Grand Total	**129**	**285**

Crocodile	West	East
Open water	0	2
Permanently inundated	0	5
Dense woodland/riparian forest	1	0
Saturated back channels	9	15
Saturated channel margins	1	1
Seasonally inundated	2	4
Seasonally wet upper floodplains	8	4
Temporary wet lower floodplains	23	1
Temporary wet upper floodplains	0	2
Grand Total	**44**	**34**

Elephant	West	East
Dense woodland/riparian forest	0	1
Miombo/Bakeia woodland	0	2
Open water	0	13
Mopani /Terminalia woodland/Sandveld	1	0
Permanently inundated	29	13
Sand veld 2	1	0
Saturated back channels	63	58
Saturated channel margins	12	7
Seasonally inundated	37	31
Seasonally wet uplands	3	0
Seasonally wet upper floodplains	46	20
Temporary wet lower floodplains	69	1
Temporary wet upper floodplains	6	7
Grand Total	**267**	**153**

Hippopotamus	West	East
Dense woodland/riparian forest	3	3
Miombo/Bakeia woodland	1	0
Open water	10	33
Permanently inundated	4	38
Saturated back channels	104	52
Saturated channel margins	2	13
Seasonally inundated	23	116
Seasonally wet uplands	23	0
Seasonally wet upper floodplains	115	30
Temporary wet lower floodplains	49	4
Temporary wet upper floodplains	21	38
Grand Total	**355**	**327**

Red lechwe	West	East
Dense woodland/riparian forest	93	0
Miombo/Bakeia woodland	8	12
Mopani /Terminalia woodland/Sandveld	5	0
Mountain woodland/Swarthaak/Combretum	23	0
Open water	1	25
Permanently inundated	87	151
Sand veld 2	2	0
Saturated back channels	939	182
Saturated channel margins	275	7
Seasonally inundated	273	94
Seasonally wet uplands	133	0
Seasonally wet upper floodplains	1451	44
Temporary wet lower floodplains	1274	11
Temporary wet upper floodplains	230	1
Grand Total	**4794**	**527**

Reedbuck	West	East
Permanently inundated	0	3
Dense woodland/riparian forest	3	0
Saturated back channels	73	9
Saturated channel margins	2	0
Seasonally inundated	9	0
Seasonally wet upper floodplains	24	3
Temporary wet lower floodplains	15	0
Temporary wet upper floodplains	14	0
Grand Total	**140**	**15**

African Fish Eagle	West	East
Dense woodland/riparian forest	2	0
Miombo/Bakeia woodland	2	0
Open water	7	10
Permanently inundated	3	12
Saturated back channels	32	17
Saturated channel margins	13	2
Seasonally inundated	24	20
Seasonally wet uplands	7	1
Seasonally wet upper floodplains	22	6
Temporary wet lower floodplains	15	6
Temporary wet upper floodplains	3	2
Grand total	**130**	**76**

African openbill	West	East
Open water	1	0
Permanently inundated	170	0
Saturated back channels	779	10
Saturated channel margins	71	0
Seasonally inundated	305	5
Seasonally wet uplands	28	0
Seasonally wet upper floodplains	198	51
Temporary wet lower floodplains	15	8
Temporary wet upper floodplains	224	0
Grand Total	**1791**	**74**

African skimmer	West
Saturated back channels	9
Seasonally wet upper floodplains	12
Temporary wet lower floodplains	7
Temporary wet upper floodplains	4
Grand Total	32

Crakes, moorhens, coots and gallinules	West	East
Dense woodland/riparian forest	0	1
Open water	8	11
Permanently inundated	9	41
Saturated back channels	32	109
Saturated channel margins	21	38
Seasonally inundated	44	77
Seasonally wet upper floodplains	7	29
Temporary wet lower floodplains	0	7
Temporary wet upper floodplains	0	21
Grand Total	**121**	**334**

Darter, cormorants and grebes	West	East
Dense woodland/riparian forest	0	1
Open water	21	35
Permanently inundated	47	61
Saturated back channels	126	66
Saturated channel margins	29	19
Seasonally inundated	159	99
Seasonally wet uplands	5	0
Seasonally wet upper floodplains	84	10
Temporary wet lower floodplains	53	12
Temporary wet upper floodplains	18	8
Grand Total	**542**	**311**

Ducks, geese and teals	West	East
Dense woodland/riparian forest	5	3
Miombo/Bakeia woodland	2	0
Mopani /Terminalia woodland/Sandveld	32	0
Mountain woodland/Swarthaak/Combretum	4	0
Open water	81	23
Permanently inundated	243	50
Saturated back channels	1322	147
Saturated channel margins	1069	15
Seasonally inundated	848	109
Seasonally wet uplands	179	0
Seasonally wet upper floodplains	1633	49
Temporary wet lower floodplains	1361	49
Temporary wet upper floodplains	654	447
Grand Total	**7433**	**892**

Egrets (excl. cattle)	West	East
Dense woodland/riparian forest	0	1
Mopani /Terminalia woodland/Sandveld	3	0
Open water	2	1
Permanently inundated	5	0
Saturated back channels	43	11
Saturated channel margins	5	1
Seasonally inundated	11	2
Seasonally wet uplands	3	0
Seasonally wet upper floodplains	54	14
Temporary wet lower floodplains	28	10
Temporary wet upper floodplains	7	3
Grand Total	**161**	**43**

Goliath Heron	**West**	**East**
Open water	1	0
Permanently inundated	0	1
Saturated back channels	4	3
Saturated channel margins	1	1
Seasonally inundated	3	11
Seasonally wet uplands	1	0
Seasonally wet upper floodplains	4	3
Temporary wet lower floodplains	3	1
Temporary wet upper floodplains	2	1
Grand Total	**19**	**21**

Ibis	**West**	**East**
Dense woodland/riparian forest	0	2
Mopani /Terminalia woodland/Sandveld	1	0
Open water	5	0
Permanently inundated	16	5
Saturated back channels	136	14
Saturated channel margins	36	1
Seasonally inundated	40	34
Seasonally wet uplands	13	0
Seasonally wet upper floodplains	91	13
Temporary wet lower floodplains	97	19
Temporary wet upper floodplains	65	9
Grand Total	**500**	**97**

Jacanas	**West**	**East**
Dense woodland/riparian forest	2	4
Miombo/Bakeia woodland	0	2
Mopani /Terminalia woodland/Sandveld	1	0
Open water	12	19
Permanently inundated	53	60
Saturated back channels	295	136
Saturated channel margins	463	13
Seasonally inundated	145	181
Seasonally wet uplands	8	2
Seasonally wet upper floodplains	308	35
Temporary wet lower floodplains	107	24
Temporary wet upper floodplains	95	12
Grand Total	**1489**	**488**

Lapwings	West	East
Dense woodland/riparian forest	6	3
Miombo/Bakeia woodland	6	2
Mopani /Terminalia woodland/Sandveld	4	0
Mountain woodland/Swarthaak/Combretum	1	0
Permanently inundated	21	21
Sand veld 2	5	0
Saturated back channels	488	90
Saturated channel margins	191	22
Seasonally inundated	95	63
Seasonally wet uplands	25	0
Seasonally wet upper floodplains	458	38
Temporary wet lower floodplains	282	41
Temporary wet upper floodplains	83	5
Grand Total	**1665**	**294**

Larger Kingfishers (excl. woodland-dwelling sp.)	West	East
Dense woodland/riparian forest	4	0
Miombo/Bakeia woodland	1	0
Mopani /Terminalia woodland/Sandveld	1	0
Mountain woodland/Swarthaak/Combretum	1	0
Open water	1	12
Permanently inundated	1	24
Sand veld 1	0	1
Saturated back channels	50	39
Saturated channel margins	5	5
Seasonally inundated	43	30
Seasonally wet uplands	1	0
Seasonally wet upper floodplains	44	14
Temporary wet lower floodplains	35	5
Temporary wet upper floodplains	11	3
Grand Total	**198**	**133**

Malachite Kingfisher	West	East
Open water	3	1
Permanently inundated	2	3
Saturated back channels	8	39
Saturated channel margins	7	10
Seasonally inundated	10	18
Seasonally wet upper floodplains	4	17
Temporary wet lower floodplains	2	4
Temporary wet upper floodplains	2	5
Grand Total	**38**	**97**

Medium herons	West	East
Miombo/Bakeia woodland	2	0
Mopani /Terminalia woodland/Sandveld	1	0
Mountain woodland/Swarthaak/Combretum	1	0
Open water	1	5
Permanently inundated	3	12
Saturated back channels	94	21
Saturated channel margins	15	4
Seasonally inundated	40	26
Seasonally wet uplands	3	0
Seasonally wet upper floodplains	94	22
Temporary wet lower floodplains	34	10
Temporary wet upper floodplains	9	3
Grand Total	**297**	**103**

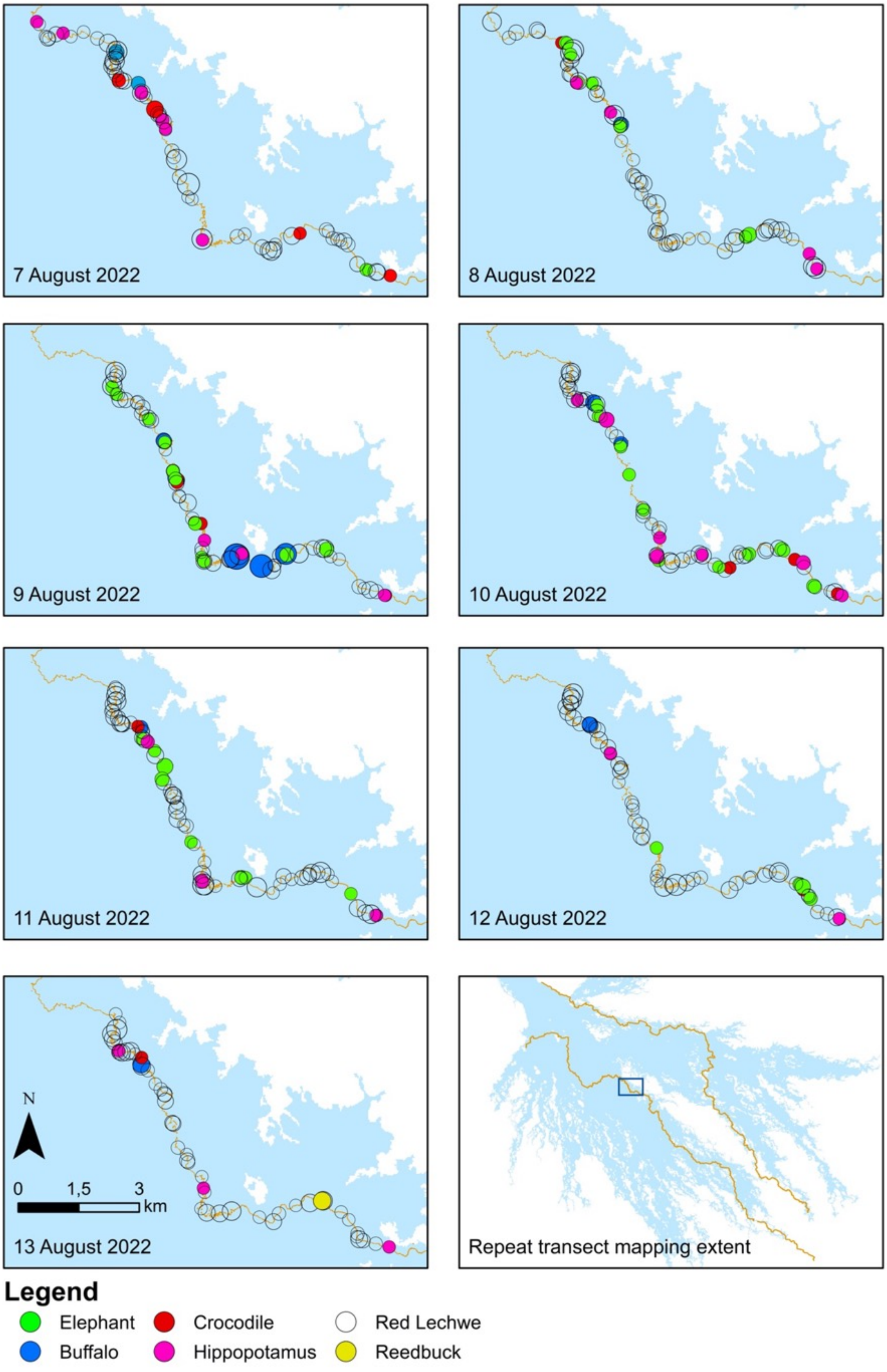
Small shorebirds	West	East
Saturated back channels	8	1
Saturated channel margins	27	0
Seasonally inundated	6	1
Seasonally wet uplands	3	0
Seasonally wet upper floodplains	32	0
Temporary wet lower floodplains	21	2
Temporary wet upper floodplains	12	0
Grand Total	**109**	**4**

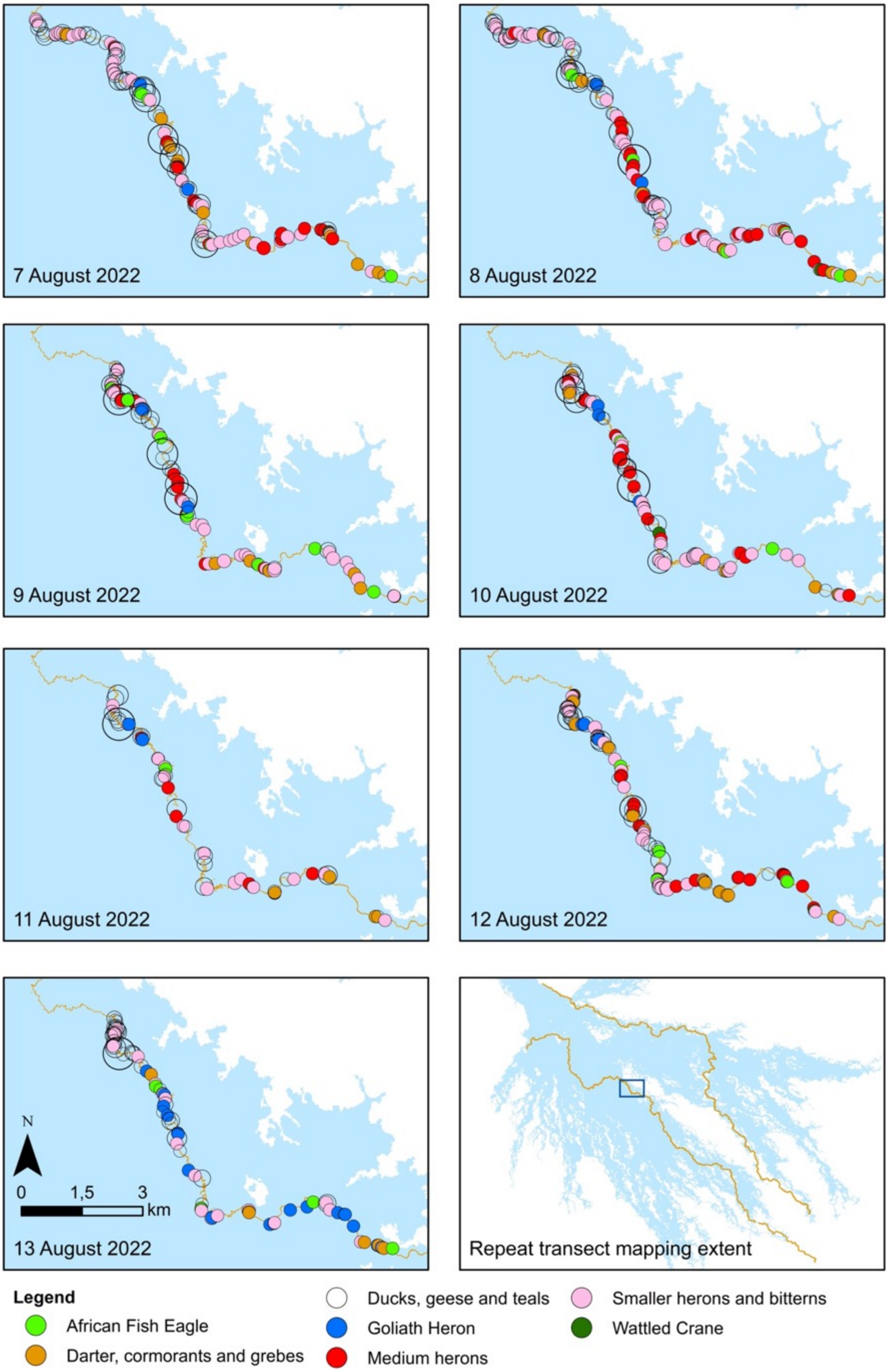
Smaller herons and bitterns	West	East
Dense woodland/riparian forest	2	2
Miombo/Bakeia woodland	4	0
Mountain woodland/Swarthaak/Combretum	1	0
Open water	1	13
Permanently inundated	19	25
Saturated back channels	221	49
Saturated channel margins	134	9
Seasonally inundated	42	52
Seasonally wet uplands	6	0
Seasonally wet upper floodplains	185	11
Temporary wet lower floodplains	128	13
Temporary wet upper floodplains	68	13
Grand Total	**811**	**187**

Storks (excl. Marabou and openbill)	West	East
Dense woodland/riparian forest	0	1
Open water	0	1
Permanently inundated	2	5
Saturated back channels	9	12
Saturated channel margins	0	4
Seasonally inundated	4	15
Seasonally wet upper floodplains	10	9
Temporary wet lower floodplains	4	3
Temporary wet upper floodplains	1	3
Grand Total	**30**	**53**

Wattled Crane	West	East
Miombo/Bakeia woodland	0	2
Permanently inundated	10	0
Saturated back channels	20	4
Seasonally inundated	6	4
Seasonally wet upper floodplains	8	2
Temporary wet lower floodplains	8	0
Temporary wet upper floodplains	10	0
Grand Total	**62**	**12**

APPENDIX 4: Animals and birds recorded on the section of transect repeated over 7 consecutive days. Size of the circle indicates the size of each herd/flock.




7 August 2022
8 August 2022
9 August 2022
10 August 2022
11 August 2022
12 August 2022
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km
13 August 2022
Repeat transect mapping extent
Legend
African Fish Eagle
Darter, cormorants and grebes
Ducks, geese and teals
Goliath Heron
Medium herons
Smaller herons and bitterns
Wattled Crane

APPENDIX 5: Information cards summarizing the habitats, conditions and data collected at each of the intensive monitoring sites along the eastern transect in August 2022

Intensive site 1 - Marginal Veg out of Current (Lagoon)			
Lat: -18.8286493°, **Lon:** 22.43318177°			
	Date: 2020/10/03 **Time:** 14:00	**Date:** 2021/07/27 **Time:** 15:30	**Date:** 2022/08/01 **Time:** 09:36
Temperature (°C)	33.98	14.71	17.52
Turbidity (NTU)	5.24	3.59	2.72
Specific Conductivity (µS/cm)	133.86	33.74	47.33
Dissolved oxygen (mg/L)	6.25	3.33	4.28
pH	7.39	6.93	5.03
OKASS score	94	95	116
No. of Taxa	19	18	22
ASPT	4.9	5.3	5.3
Comments: Very little flow all years. Site disturbed by cattle trampling and heavy grazing, harvesting of tswii (water lilies) and human foot traffic. A low diversity of plants and aquatic habitats resulting in a relatively low diversity of macroinvertebrates. OKASS scores were very consistent between years.			

Intensive site 2 - Marginal Veg in Current (Channel)			
Lat: -18.9361556°, **Lon:** 22.650094°			
	Date: 2020/10/03 **Time:** 16:20	**Date:** 2021/08/06 **Time:** 15:00	**Date:** 2022/08/05 **Time:** 15:04
Temperature (°C)	28.81	19.33	22.24
Turbidity (NTU)		0.03	7.50
Specific Conductivity (µS/cm)	89.74	46.54	64.47
Dissolved oxygen (mg/L)	1.01	2.12	0.89
pH	6.45	6.78	6.26
OKASS score	90	132	107
No. of Taxa	22	25	23
ASPT	4.1	5.3	4.7
Comments: Moderate flows. All years the water was shallow. The water was more turbid in 2022 but could have been from animals moving upstream. Dissolved oxygen and electrical conductivity were relativly low. Tall clumps of Miscanthus junceus forming islands in the channel. Waterlilies and emergent grasses were on the margins. A moderate diversity, mostly consisting of low and average scoring taxa. This site was in a natural condition.			

Intensive site 3 - Marginal Veg out of Current (Lagoon)			
Lat: -18.991862°, **Lon:** 22.753031°			
	Date: 2020/10/03 **Time:** 17:39	**Date:** 2021/08/08 **Time:** 13:30	**Date:** 2022/08/07 **Time:** 14:10
Temperature (^{o}C)	28.09	19.46	22.24
Turbidity (NTU)		0.05	1.49
Specific Conductivity (µS/cm)	103.30	46.96	65.00
Dissolved oxygen (mg/L)	2.87	4.17	4.03
pH	6.89	7.05	6.77
OKASS score	130	120	152
No. of Taxa	22	23	28
ASPT	5.9	5.2	5.4
Comments: A large lagoon with hippo. A high diversity of vegetation from tall emergent grass, to water lilies and water shields. In natural condition.			

Intensive site 4 - Marginal Veg out of Current (Lagoon)			
Lat: -18.995173°, **Lon:** 22.992412°			
	Date: 2020/10/17 **Time:** 09:00	**Date:** 2021/08/11 **Time:** 14:15	**Date:** 2022/08/10 **Time:** 13:40
Temperature (^{o}C)	24.99	20.44	23.24
Turbidity (NTU)	1.73		0.74
Specific Conductivity (µS/cm)	121.33	62.45	70.84
Dissolved oxygen (mg/L)	2.77	4.47	3.41
pH	6.72	7.18	6.80
OKASS score	131	128	133
No. of Taxa	25	23	26
ASPT	5.2	5.6	5.1
Comments: A large lagoon with hippo. A high diversity of vegetation from tall emergent grass, to water lilies and water shields. In natural condition.			

Intensive site 5 - **Marginal Veg in Current (Channel)**			
Lat: -19.056062°, **Lon:** 23.086391°			
	Date: 2020/10/14 **Time:** 12:00	**Date:** 2021/08/13 **Time:** 10:10	**Date:** 2022/08/12 **Time:** 10:30
Temperature (°C)	26.27	17.31	19.68
Turbidity (NTU)	3.18		0.71
Specific Conductivity (µS/cm)	205.66	88.96	85.87
Dissolved oxygen (mg/L)	1.77	1.48	2.49
pH	6.83	7.15	5.98
OKASS score	96	119	145
No. of Taxa	20	21	23
ASPT	4.8	5.7	6.3
Comments: Low flows. Very low diversity of macroinvertebrates in 2020 increasing to moderate and high diversity in 2021 and 2022. This site was in a natural condition. Emergent grass and sedges, Utricularia and water shield provided good macroinvertebrate habitat however the DO was low all years, as is expected from water drained out of a wetland.			

Intensive site 6 - **Marginal Veg in Current (Channel)**			
Lat: -19.124884°, **Lon:** 23.119101°			
	Date: 2020/10/13 **Time:** 16:00	**Date:** 2021/08/13 **Time:** 14:30	**Date:** 2022/08/12 **Time:** 14:05
Temperature (°C)	27.77	19.88	21.15
Turbidity (NTU)		0.96	1.84
Specific Conductivity (µS/cm)	105.53	47.42	61.80
Dissolved oxygen (mg/L)	4.79	6.14	5.14
pH	6.67	7.36	6.96
OKASS score	61	72	81
No. of Taxa	9	11	14
ASPT	6.8	6.5	5.8
Comments: Very strong flows with high DO level. Very low diversity of macroinvertebrates due to the stronger currents. Some of the species that were found were high scoring resulting in higher OKASS scores on some years. This site was in a natural condition.			

Intensive site 7 - Marginal Veg in Current (Channel)			
Lat: -19.19908725 °, **Lon:** 23.07698912 °			
	Date: 2020/10/03 **Time:** 12:05	**Date:** 2021/08/15 **Time:** 13:10	**Date:** 2022/08/14 **Time:** 12:30
Temperature (^{0}C)	27.11	19.60	20.87
Turbidity (NTU)			2.17
Specific Conductivity (µS/cm)	129.20	60.02	71.87
Dissolved oxygen (mg/L)	1.94	2.71	3.25
pH	6.74	7.12	6.71
OKASS score	123	120	154
No. of Taxa	23	23	28
ASPT	5.3	5.2	5.5
Comments: Low flows. All years the water slightly murky with a low DO level. Great habitat for macroinvertebrates provided by emergent sedges and grasses, and waterlilies. This site was in a natural condition. The macroinvertebrate diversity and score was consistent between years			

Intensive site 8 - Marginal Veg in Current (Channel)			
Lat: -19.28723163°, **Lon:** 23.1165984 °			
	Date: 2020/10/03 **Time:** 10:45	**Date:** 2021/08/17 **Time:** 11:30	**Date:** 2022/08/16 **Time:** 12:18
Temperature (^{0}C)	25.33	18.43	17.77
Turbidity (NTU)			1.32
Specific Conductivity (µS/cm)	121.80	68.21	80.80
Dissolved oxygen (mg/L)	1.41	2.73	3.08
pH	6.62	7.25	6.30
OKASS score	108	134	160
No. of Taxa	20	24	31
ASPT	5.4	5.6	5.2
Comments: Low flows. Water was fairly clear with a low DO level. Great habitat for macroinvertebrates provided by emergent sedges and grasses, and waterlilies. This site was in a natural condition. The macroinvertebrate diversity and score was fairly consistent between years			

Intensive site 9 - **Marginal Veg in Current (Channel)**			
Lat: -19.39382388°, **Lon:** 23.185518207°			
	Date: 2020/10/02 **Time:** 15:37	**Date:** 2021/08/18 **Time:** 13:00	**Date:** 2022/08/17 **Time:** 14:50
Temperature (ºC)	27.43	19.57	20.49
Turbidity (NTU)		0.59	0.74
Specific Conductivity (µS/cm)	124.39	64.75	77.14
Dissolved oxygen (mg/L)	4.57	5.15	5.68
pH	6.81	7.43	7.11
OKASS score	90	132	105
No. of Taxa	18	22	18
ASPT	5.0	6.0	5.8
Comments: Moderate to strong flows. Water was very clear with fairly high dissolved oxygen levels, due to the faster flowing water. The tall marginal grass does not provide great habitat for macroinvertebrates and scored low in 2020 improving substantially in 2021 and 2022. This site was in a natural condition.			

Intensive site 10 - **Marginal Veg out of Current (Lagoon)**			
Lat: -19.715601°, **Lon:** 23.481936°			
	Date: 2020/10/23 **Time:** 16:00	**Date:** 2021/08/21 **Time:** 16:00	**Date:** 2022/08/21 **Time:** 16:50
Temperature (ºC)	29.76	22.73	22.05
Turbidity (NTU)	12.17	4.32	0.98
Specific Conductivity (µS/cm)	282.89	127.64	135.04
Dissolved oxygen (mg/L)	4.11	3.34	5.79
pH	7.05	7.57	7.22
OKASS score	97	137	99
No. of Taxa	19	24	17
ASPT	5.1	5.7	5.8
Comments: Flow was limited. The Salvinia infestation observed in 2020 had been mostly eradicated by 2021 through the use of the Salvinia Weevil biocontrol. In 2020 a lot of fine sediments had been caught in the Salvinia roots, the water was clearer in 2021 and clear in 2022 with more open water and a lower turbidity. OKASS score was low in 2020 this increased in 2021 and 2022.			