A Technical Report for

PROJECT MAHAMPY: PHASE I

Improving and sustaining livelihoods for traditional female reed weavers through targeted capacity development and research

May 2022

Contents

1 Summary

Project Mahampy aims to improve the livelihoods of rural women in Madagascar whilst ensuring that the reedbeds upon which they rely are healthy, resilient, and productive.

This report forms part of one of four project objectives, which focuses on monitoring and managing the conservation of *mahampy* reedbeds by understanding and addressing drivers of decline in reedbed productivity. In order to achieve this, research began in June 2020, and continued through the end of Project Mahampy: Phase I, in March 2022. Researched aimed to create a baseline understanding of the wetlands, including documenting the biodiversity that they supported, their ecological qualities, and the *mahampy* reeds within them.

Survey methods included the longitudinal monitoring of quadrats; belt transects including water quality, vegetation, bird, and herpetofauna assessments; remote sensing data; participatory monitoring of regrowth after harvest; and qualitative consultations with resource users.

Research and preliminary analysis revealed species present, as well as variations across wetland sites. 29 bird species were recorded in total, with species richness having little variation across wetland sites. Floral species richness did vary between wetlands, with the composition of floral species varying by location. However, this variation was not able to be explained by any environmental variables measured. Herpetofauna communities had neither high species richness nor abundance, with the species present largely generalists.

Water quality assessments were not able to yield detailed insight into wetland characteristics, with water absent for much of the study period, and limited access to calibration materials.

Consultations with weavers identified fire as the main perceived threat to wetland sustainability, with fires set to clear land for agriculture a main driver of this threat. *Mahampy* harvesting technique was also identified as having a potential impact on the wetlands, however, participatory monitoring was not able to yield conclusive results, though overall mahampy condition appeared to be higher in those quadrats were wetlands were harvested by cutting rather than by pulling.

Overall, the research herein aided the team in gaining a more holistic understanding of the *mahampy* reedbeds, their importance, their composition, and potential threats. This research can help form the basis for the creation of conservation management plans, ensuring that they are context-appropriate, evidence-based, and supported by traditional ecological knowledge.

2 Introduction

This report summarises the findings from research collected between August 2020 and March 2022 as part of Project Mahampy. The context, research methods, results, and implications are outlined herein. This report will inform SEED's continued work during Mahampy: Phase II, and contributes to global literature on *mahampy* reedbeds and wetland management.

2.1 Background

Freshwater ecosystems support a disproportionately large amount of biodiversity. Despite occupying less than 1% of the Earth's surface, one in three vertebrate species depend on freshwater ecosystems for their survival (Dudgeon et al., 2006). These environments also provide valuable ecosystem services such as carbon sequestration and flood abatement (Zedler and Kercher, 2005) and in many parts of the world there is a high reliance on the income provided by wetland habitats (Darwall et al., 2011). Freshwater ecosystems, however, are amongst the world's most vulnerable, with the 2020 Living Planet Index (LPI) reporting an 84% decline in freshwater populations since 1970 (WWF, 2020). Humans are thought to be largely responsible for this trend, with disturbances such as habitat degradation restricting the global extent of freshwater habitat (Hu et al., 2017; Reid et al., 2019). Freshwater ecosystems remain relatively understudied compared to their terrestrial counterparts (Darwall et al., 2011), with the protection of freshwater biodiversity being labelled “the ultimate conservation challenge” (Dudgeon et al., 2006).

Within Madagascar, wetland habitats play a similarly important role. Madagascar has been recognised as being a global hotspot of freshwater biodiversity with high levels of endemism (Benstead et al., 2003). Additionally, wetlands provide the raw materials needed for making products such as mats and baskets, as well as being used for housing and cooking fuel (Andrianandrasana et al., 2005). Despite this importance, Madagascar’s wetlands have received little research attention and are declining faster than its forests, with some regions in Madagascar losing over 60% of wetland coverage since 1960 (Bamford et al., 2017). The clearing of land for rice farming is thought to be an important driver behind this decline, together with siltation following deforestation. This human disturbance has been associated with lower biodiversity and threatens the ecosystem services associated with wetlands (Bamford et al., 2017).

In Sainte Luce, a rural, coastal village in the Anosy region of southeast Madagascar, the wetland reed *Lepironia mucronata*, known locally as *mahampy*, is harvested by women and used as a weaving material. *Mahampy* is important both culturally and economically; selling products crafted from *mahampy* forms an important source of income, particularly for rural communities with little to no access to formal employment. However, unsustainable resource use may lead to declines in *mahampy* reedbeds, impacting the livelihoods of the people who depend on them. There is, therefore, an urgent need to obtain a detailed account of the state of Sainte Luce’s wetlands and the factors that influence the health and extent of these valuable ecosystems.

One area that has received little research attention is the impact of harvesting technique on *mahampy* reedbeds. In Sainte Luce, stems are harvested using one of two techniques: either individual stems are pulled away from the rhizome, or a bundle of stems are cut near the base using knives. In the KwaZulu-Natal province of South Africa, using the cutting technique has been criticised as wasting 75% of the harvested material because only the longest reeds are of use to weavers (Heinsohn, 1990). The cutting technique is also believed to impede new growth as the discarded reeds form a thick mat on the ground (Traynor, Kotze and Mckean, 2010). Similarly, in the Mekong Delta, Vietnam, cutting *Lepironia* with knives was banned by local authorities, as it was believed to be detrimental to the health of the reedbeds (Triet, 2010). However, neither example involved an explicit comparison between wetlands cut with each technique. Women from the community of Sainte Luce harvest reeds by pulling, with the advantage of selectively harvesting the longest stems, which are needed for weaving mats. However, it has been reported that women travelling to Sainte Luce from neighbouring communities prefer to harvest using a cutting technique. This enables them to rapidly collect multiple stems and maximise productivity during their time at the reedbeds, which results in including stems that are too short to weave and are subsequently discarded. Although the plant would be expected to continue to produce new stems as long as the rhizome is left intact, few studies have directly compared the effect of different harvesting techniques on reed growth, with existing knowledge suggesting cutting may be detrimental, but no comparable research conducted on *mahampy* in Madagascar.

Fire is another factor that likely impacts *mahampy* wetlands, but the effects of burning on wetland communities is relatively understudied (Kotze, 2013). Species with underground rhizomes, such as *Lepironia*, are expected to be able to resist fire by resprouting following disturbance, but it is not known how changes in fire frequency affect *Lepironia* growth. A study of *Lepironia* in Malaysia found that growth was lower in burned areas compared to unburned areas (Ikusima, 1978). However, in other wetland systems, the opposite is true, with burning promoting reed growth and leading to a higher density of stems within the reedbed (Gao et al., 2021). Because drier conditions have been shown to influence the severity of fires (Kotze, 2013), understanding the response of wetlands to fire is especially important in the context of severe and chronic droughts which are occurring with higher frequency in southern Madagascar (UNICEF, 2021). In Madagascar, fire is also commonly used as a management tool for agricultural purposes, using a technique known as *tavy*, which involves setting intentional fires to clear land for agriculture and can spread to adjacent areas including wetlands. Fires may therefore occur from both natural and human-caused sources in rural areas. In conjunction with drought and with *tavy* frequently used around Sainte Luce, it is more important than ever to understand the link between fire and the sustainability of *mahampy* weaving as a livelihood, fire's role In biodiversity, and whether any management mitigation needs to be taken.

Project Mahampy seeks to address these knowledge gaps by collecting data on the *mahampy* wetlands in Sainte-Luce using a combination of longitudinal quadrats, belt transects, drone imagery, participatory monitoring, and weaver consultations. In doing so, the project aims to answer the following guiding research questions:

- What is the ecological baseline of *mahampy* wetlands in Sainte-Luce?
- How does harvesting technique (cutting versus pulling) affect *mahampy* wetlands?
- How does fire affect *mahampy* wetlands?

These overarching research questions contribute to Objective Four of Project Mahampy, *to monitor and manage the conservation of mahampy reedbeds*, by shedding light on the reedbeds of Sainte Luce, and identifying what, if any, needs for conservation intervention exist. To answer these questions, data collection was designed and updated to encompass the following specific research aims:

1. To determine what differences, if any, exist among wetlands with historical rates of frequent and infrequent harvesting and to establish a previously unknown ecological baseline that includes vegetation, water, and biodiversity for *mahampy* reedbeds;
2. To monitor the effects of harvesting technique (cutting versus pulling) on *mahampy* regeneration through participatory monitoring;
3. Conduct consultations and surveys with weavers and other resource users to supplement knowledge on historical and contemporary reedbed use (including frequency and wetland selection), threats, and management challenges;
4. To observe and record landscape-scale changes of the *mahampy* reedbeds, particularly how they relate to the threat of fire to the wetlands;
5. To inform conservation recommendations and identify future research needed for the *mahampy* wetlands, and to disseminate this information with weavers and key stakeholders.

This report will outline findings related to research aims 1, 2, 3, and 4.

3 Methods

3.1 Study site and data collection

Project Mahampy conducted research across six wetlands in the Anosy region of southeast Madagascar (24° 46' S, 47° 10' E) (Figure 1). The project involved using longitudinal quadrats, belt transects, drone imagery, qualitative surveys, and participatory monitoring to collect data. The longitudinal quadrats, belt transects, and drone imagery were used to establish the ecological baseline of the *mahampy* wetlands, with the drone imagery also being used to monitor how the wetlands respond to fire events. These elements of data collection were led by SEED's Conservation Research Programme (SCRP). Participatory monitoring was used to measure the effect of harvesting technique (cutting vs pulling) on wetland health, led by weavers from the Mahampy Weavers' Cooperative and supported by SCRP. Additionally, qualitative surveys were administered in the community of Sainte Luce with members of the Mahampy Weavers' Cooperative to understand wetland use and perceived threats to the sustainability of reedbeds and weaving as a livelihood. These surveys were delivered by the Project Mahampy Coordinator. Data collection took place between August 2020 and March 2022.

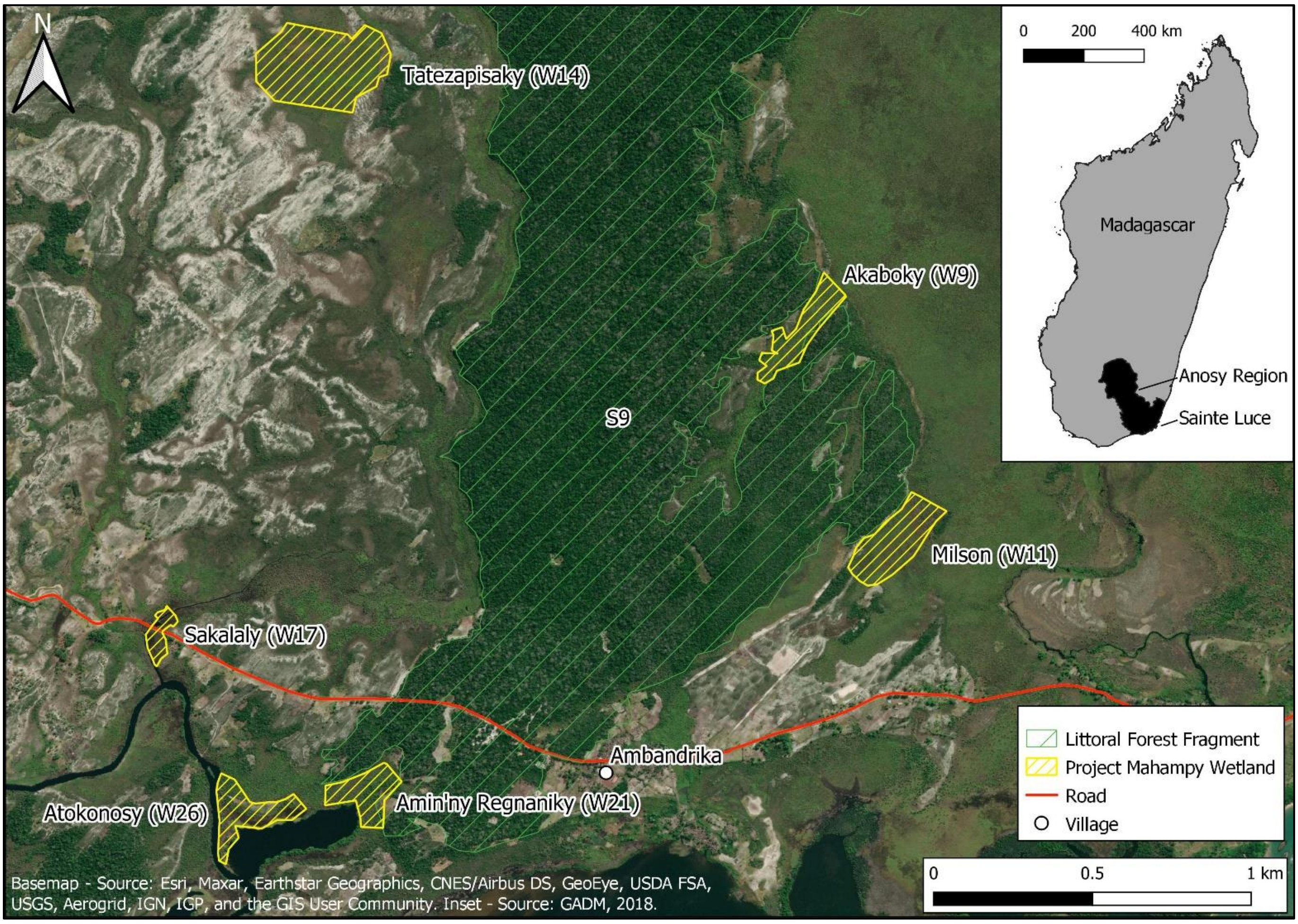

Figure 1 – Sainte Luce study site

3.2 Establishing ecological baseline

3.2.1 Longitudinal quadrats

To gather temporal data and contribute to ecological baseline knowledge within each of the six target mahampy wetlands, data were collected from three permanent quadrats measuring 1m x 1m within each wetland. Two quadrats were positioned near the wetland edge, and one quadrat was placed within the wetland interior for each target wetland, to account for differences in habitat structure within the wetland. Assessments of floral diversity and, where possible, water quality were made in each quadrat. Measurements were taken every two months from September 2020 until September 2021. At the start of the study period, GPS coordinates were noted for each quadrat. Before each survey, the number of researchers was noted, as well as the survey start time. Time at survey end was also noted.

3.2.1.1 Flora

In each quadrat, all floral species present were noted, and abundance counts were performed by estimating the percent coverage of each floral species, in increments of 10% based on how much of each quadrat a given floral species was perceived by data collectors to cover. If perceived to be less than 10%, increments of 1% were used. Additionally, the condition of each species was scored on a scale of 1-4, where a score of 1 meant that the plant was dead whilst a score of 4 indicated a plant with no signs of damage. Data collection was carried out using local Malagasy names for each species. An identification guide is currently being curated, whereby scientific names are being sought for each species requiring external assistance from botanical experts. However, Malagasy names are used herein in the absence of a completed identification guide. In addition to floral species in general, to better understand the characteristics of *mahampy* over time, measurements of *mahampy* were included in floral biodiversity assessments (both percent coverage and condition), and the average height of *mahampy* reeds in each quadrat was estimated by measuring a stem judged to be representative of the quadrat.

3.2.1.2 Water
To gain a better understanding of the water quality in each of the wetlands, measurements were taken of surface water presence, water depth, algal presence, water state (e.g., fast flowing, slow flowing, stagnant), pH, colour (hue, value, chroma), and sediment level. Colour was measured by filling a jar with water from the quadrat and comparing it to Munsell system standard soil colour charts after allowing sediment to settle.

3.2.2 Belt transects
To gain a more holistic and detailed understanding of the biodiversity found within each of the mahampy wetlands, longitudinal quadrat data collection was replaced by belt transect data collection in December 2021, and run until March 2022. The belt transect methodology was chosen as it is a stratified sampling technique that collects information from a greater area of the wetland than permanent quadrats (Hill et al., 2005). Data was collected on the birds, herpetofauna, and flora of each wetland, alongside water quality assessments.

Transects were started by selecting a random point on a wetland edge, and then run in a randomly chosen direction into the wetland. Quadrats measuring 2m x 2m were positioned every ten meters apart for larger wetlands, and every five metres apart for smaller wetlands, with the transects running until 10 quadrats were created. In theory, this method will have allowed the transect to intercept many heterogeneous micro-habitats within each wetland. Within each quadrat, floral and water assessments took place. Bird surveys took place prior to the start of each belt transect, whilst herpetofauna surveys took place continuously across the length of the transect.

3.2.2.1 Birds
Bird biodiversity assessments were conducted via point counts at 08:00 prior to the start of each belt transect. Three SCRP staff, equipped with binoculars, carried out the point count. All bird species that were heard or seen over a period of 25 minutes were recorded. A note was made of whether each observation was under or over fifty metres away. Each observation was given an index number depending on when during the survey each individual was observed. For example, a bird seen within the first five minutes of the survey was given an index number of 5, whereas a bird seen in the last five minutes was given an index number of 1. To reduce the chance of duplicated data, efforts were made to track the same individuals throughout the duration of the observation period.

3.2.2.2 Herpetofauna
Herpetofauna biodiversity surveys took place continuously along the length of each belt transect. This was done by searching the area two metres to each side of the transect line for reptiles and amphibians, with the total strip width being four metres. When an individual was sighted, the species name, time of observation, behaviour and location at time of observation, and life stage (adult, sub-adult, or juvenile) was recorded. Additionally, data was collected on the individual's height above ground or depth below water surface, and vegetation type that it was found on.

3.2.2.3 Flora
Floral biodiversity surveys were conducted within 10 equally-spaced quadrats along the length of the transect. The methodology was the same as that used in the longitudinal quadrats (Section 3.2.1.1), with the addition that the average height was measured for every floral species instead of just for *mahampy*, and average crown width was recorded for tree species within the quadrat.

3.2.2.4 Water
Water assessments were conducted within every other quadrat along the belt transect, for a total of five water assessments per belt transect. The same methodology was used as in the longitudinal quadrats (Section 3.2.1.2). From February 2022, salinity measurements were also taken with the arrival of appropriate equipment.

Using the floral, bird, and herpetofauna data collected, species richness and Shannon-Wiener diversity index were calculated. Total species richness and total Shannon-Wiener diversity index were also calculated for all taxa combined. Environmental variables were summarised, and a linear mixed-effects (LME) model was run to uncover whether any of the collected environmental variables could explain variation in species richness and Shannon-Wiener diversity index.

3.2.3 Drone imagery

To gain a landscape-level understanding of Sainte Luce's *mahampy* wetlands, Project Mahampy collected aerial imagery of the project's six target wetlands between August 2020 and November 2021 using a remotely-piloted aircraft (Mavic Air DJI drone).

Each of the project's six wetlands were sampled approximately every four to six months to account for changes in the wetlands due to seasonality and time of year. The drone was flown on days without high cloud cover, rain, or high wind to minimise atmospheric effects on the imagery collected and reduce noise in each of the collected images. During data acquisition, the drone was flown at an elevation of 100m, moving at a speed of 10m/s. High resolution true colour (RGB) photographs (4056 x 3040 pixel resolution) were taken every 10m. The drone's camera lens was angled perpendicular to the ground throughout the flight to minimise image distortion. To ensure full coverage of each wetland, digital flight paths were programmed and stored in Litchi (flylitchi.com). The collected photographs were stitched together in Structure from Motion (SfM) software using the GPS data embedded in each photograph. To achieve this, OpenDroneMap (opendronemap.org) was used to produce a single GeoTIFF file to be analysed in a Geographic Information System (GIS). Due to limited on-the-ground staff capacity, ground truth data were unable to be collected.

Quantum GIS (QGIS) was used to analyse aerial imagery and create maps of each wetland. The health of the wetland vegetation was calculated using indicators that used bands only in the visible spectrum (i.e. red, green, and blue). The index used to assess vegetation health in the wetlands was Green Chromaticity Coordinates (GCC). All analyses of the imagery took place in QGIS, with each true colour image being separated by red (620-750 nm), green (495-570 nm), and blue (450-495 nm) wavelength first, and indices then calculated.

GCC is an index that is not as affected by varying sampling conditions such as sunlight brightness and angle, and camera properties (Larrinaga and Brotons, 2019). This is important as the drone flights took place at different times of the year/day. Differences between wetlands were confirmed statistically using an Analysis of Variance (ANOVA) test conducted in R (R Core Team, 2021).

3.3 Participatory monitoring of harvest techniques

To investigate the effect of harvesting technique on the *mahampy* wetlands, Project Mahampy compared the health of reedbed areas that were harvested using different techniques; either cutting or pulling. A participatory monitoring programme was set up and led by reed harvesters from the Weavers' Cooperative of Sainte Luce, who were particularly interested in determining whether either harvesting technique was detrimental to reedbed regrowth. Such participatory monitoring programmes not only respond directly to the research areas identified as most pressing by resource users, but they are especially appropriate in wetlands as the health of the environment directly relates to the participants' livelihood (Andrianandrasana et al., 2005).

Three 2m x 2m quadrats were established in three of the project's target wetlands (W17, W21, and W26), for a total of nine quadrats. Within each quadrat, *mahampy* was treated in one of three different ways: harvested by pulling individual reeds consistent with traditional local methods, harvested by cutting reeds near the base of the stem, or left unharvested. Each treatment (pulling, cutting, unharvested) was applied to three quadrats in each wetland. All members of the Weavers' Cooperative were aware of the research, and avoided harvesting by any technique within the quadrats. Poles with flagging tape were erected around each quadrat to reduce entry by other weavers or resource users. Data was then collected bi-monthly from June 2021 until November 2021, when a fire in Wetland 17 and Wetland 26 destroyed six of the quadrats.

To determine the health of the reedbeds, the coverage, condition, thickness, height, and density of *mahampy* was recorded. Coverage was measured by determining whether "all", "most", "some", or "none" of the quadrat was covered by *mahampy*. Condition was scored on a scale of 1-4, using the same criteria as for the longitudinal quadrat floral surveys (Section 3.2.1.1). Reed thickness and height were measured on ten randomly selected individual reeds before taking an average for the quadrat. Reed density was measured by counting the number of live mahampy stems within four 50cm x 50cm interquadrats affixed to each corner of the 2m x 2m main quadrat. An average measurement per interquadrat was then calculated.

3.4 Weaver consultations

To contextualise research and supplement knowledge on wetland use and threats, surveys were conducted with members of the Weavers' Cooperative in Sainte Luce from November 9 to 18, 2021. Prior to all surveys, an explanation was given to participants about the purpose of the survey, the contents, and what would be done with the information gathered. Participants were only surveyed with their informed verbal consent. Weavers were then asked a series of questions using Open Data Kit (ODK) mobile surveys.

4 Results

4.1 Establishing ecological baseline

4.1.1 Longitudinal quadrats

It should be noted that, due to the small sample size in each wetland for the longitudinal quadrats, these results should not be taken as representative of the given wetlands' characteristics as a whole, but rather help inform how quadrats changed over time.

Each of the six target wetlands were surveyed eight times between September 2020 and November 2021, with the exception of Wetland 14 in February due to scheduling, and Wetlands 21 and 26 in November due to fire. With each wetland containing three quadrats, 135 total quadrat assessments were completed over the study period.

4.1.1.1 Flora

Floral data was collected during each of the 135 quadrat assessments. The initial values of the height and coverage of *mahampy* in each wetland are summarised in Table 1. There was no apparent trend in mean height across the study period (Figure 2) whilst mean percentage cover of mahampy appeared to decrease over time (Figure 3).

Table 1 – Mean and median height and coverage of mahampy *stems in the longitudinal quadrats.*

Wetland	Mean height (m)	Median height (m)	Mean coverage (%)	Median coverage (%)
Wetland 9	1.19	1.15	62.6	70.0
Wetland 11	0.89	0.90	61.7	67.5
Wetland 14	0.73	0.80	46.5	50.0
Wetland 17	1.15	1.11	79.2	80.0
Wetland 21	1.07	1.10	62.8	60.0
Wetland 26	0.99	1.00	54.7	50.0

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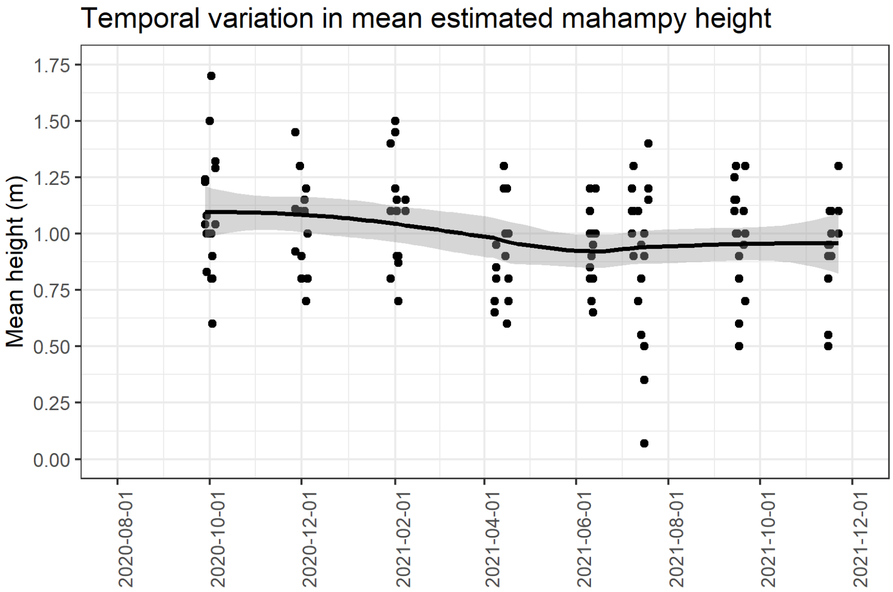

Figure 2 – Temporal variation of mean estimated mahampy *height for all wetlands between September 2020 and November 2021. Line fitted by locally estimated scatterplot smoothing (LOESS).*

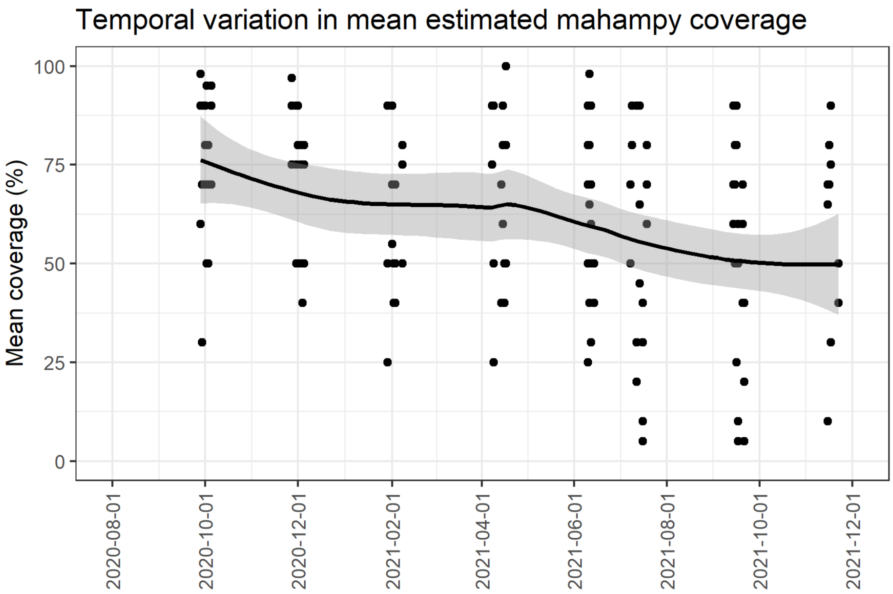

Figure 3 – Temporal variation of mean estimated mahampy *coverage for all wetlands between September 2020 and November 2021. Line fitted by locally estimated scatterplot smoothing (LOESS).*

Floral condition was generally high across the sample sites, with quadrats in each wetland having a mean condition score between 3 (Fair) and 4 (Excellent) (Table 2). Floral condition appeared to peak between July and September 2021 (Figure 4).

Table 2 – Mean and median floral condition scores of quadrats in each wetland, on a scale of 1 to 4. Values are calculated after first calculating the mean condition score in each quadrat.

Wetland	Mean	Median
Wetland 9	3.56	3.67
Wetland 11	3.45	3.50
Wetland 14	3.35	3.18

Wetland 17	3.71	3.78
Wetland 21	3.77	4.00
Wetland 26	3.60	4.00

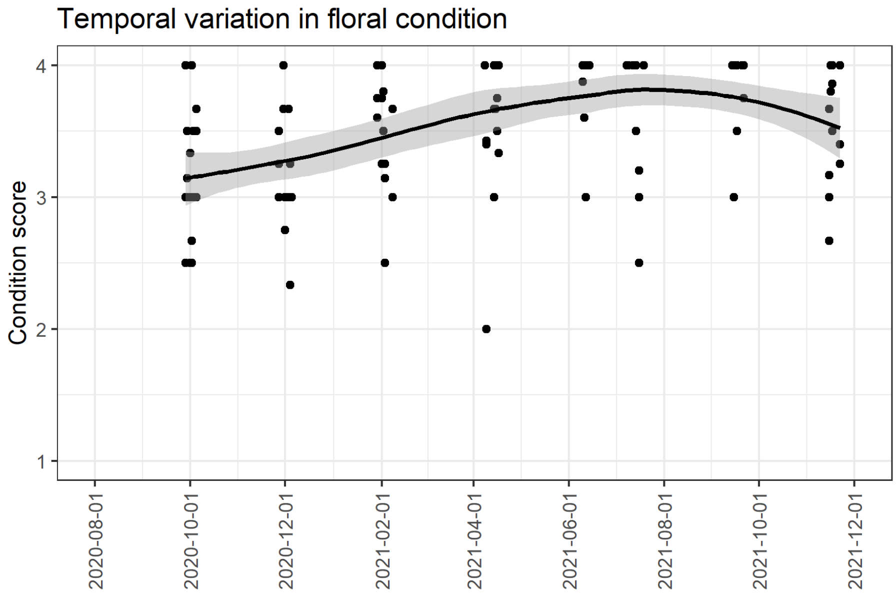

Figure 4 – Temporal variation in the mean condition score per quadrat between September 2020 and November 2021. Data is shown from all six wetlands. Line fitted by locally estimated scatterplot smoothing (LOESS).

4.1.1.2 Water

Water data collection was attempted during all 135 samples between September 2020 and November 2021. In 120 of these attempts, there was no surface water present to measure. At least one water survey was possible in each wetland. There was no algae cover observed in any of the wetlands. Water properties (sediment level, pH, colour hue/value/chroma) are summarised in Table 3.

*Table 3 – Summary table of water properties in each wetland. *Mean pH should be read with caution, as calibration was not able to be performed to the suggested frequency due to lack of access to appropriate equipment during this study period.*

Wetland	Quadrats with Water	Date(s) water present	Mean Sediment Level (mm)	Mean pH*	Colour Hues	Colour Values	Mean Chroma	Colour Names
Wetland 9	6	14/6/2021 15/9/2021	2.83	4.18	10GY, 7.5GY, 5G, 2.5GY	7, 8	0.83	Gray, Grayish White, Light Gray
Wetland 11	2	10/6/2021	3.50	3.75	7.5Y, 10YR	7	5.50	Pale Yellow, Yellow Orange
Wetland 14	8	5/12/2020 8/4/2021 12/6/2021	0.00	3.90	0Y, 10Y, 10YR	8/1, 2/1, 8/3, 1/7	1.40	Light Gray, Light Gray Yellow, Gray
Wetland 17	3	1/2/2021	0.17	6.07	10YR	1/7	1.00	Black

Wetland 21	3	11/6/2021	1.67	3.87	10BG, 5B, 2.5Y	7, 8	1.00	Light Bluish Gray, Light Gray
Wetland 26	1	11/6/2021	1.00	4.20	5YR	8/2	2.00	Yellow

4.1.2 Belt transects

Between December 2021 and March 2022, four surveys were carried out in each of the six target wetlands, with the exception of Wetland 17 and 26, which could not be surveyed in December due to fire. In total, 22 belt transect surveys were conducted, encompassing 220 quadrats. During each survey, a floral biodiversity survey, water assessment, bird biodiversity survey, and herpetofauna biodiversity survey were conducted. From these surveys, a total of 29 bird, 11 herpetofauna, and 54 floral species were observed across all of the wetlands (Annex I).

4.1.2.1 Mahampy

Mahampy height, coverage, and condition varied across the target wetlands (Table 4), with Wetland 9 demonstrating the highest mean height (Figure 5), Wetland 21 demonstrating the highest mean coverage (Figure 6), and Wetland 26 demonstrating the highest mean condition score (Figure 7). Wetland 14 exhibited the lowest coverage score, in addition to one of the lowest condition scores of all the target wetlands.

Table 4 – Mean and median height, coverage, and condition of mahampy *stems in the belt transects.*

Wetland	Mean height (m)	Median height (m)	Mean coverage (%)	Median coverage (%)	Mean condition score	Median condition score
Wetland 9	1.04	1.00	39.9	30.0	2.29	2
Wetland 11	0.81	0.80	33.3	30.0	2.31	2
Wetland 14	0.76	0.80	10.2	5.0	2.07	2
Wetland 17	0.59	0.50	42.2	40.0	2.77	2.5
Wetland 21	0.93	1.00	42.4	50.0	2.50	2.5
Wetland 26	0.53	0.60	34.5	30.0	3.07	3

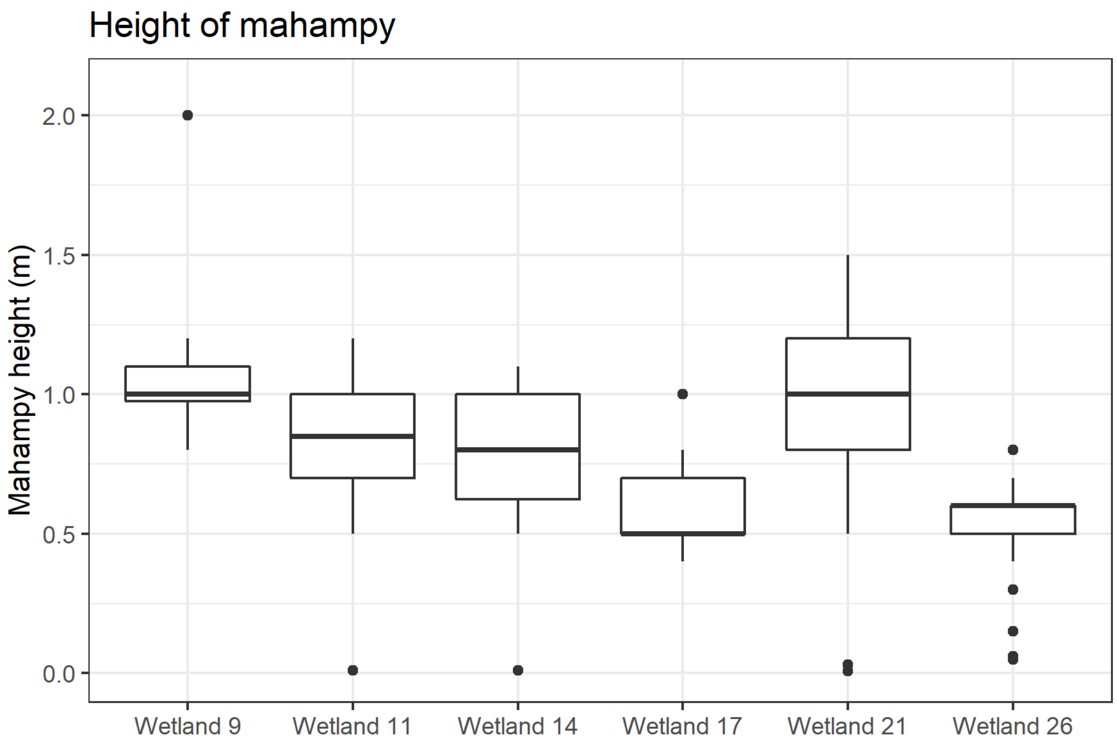

Figure 5 – Boxplot showing height of mahampy *stems in the belt transects.*

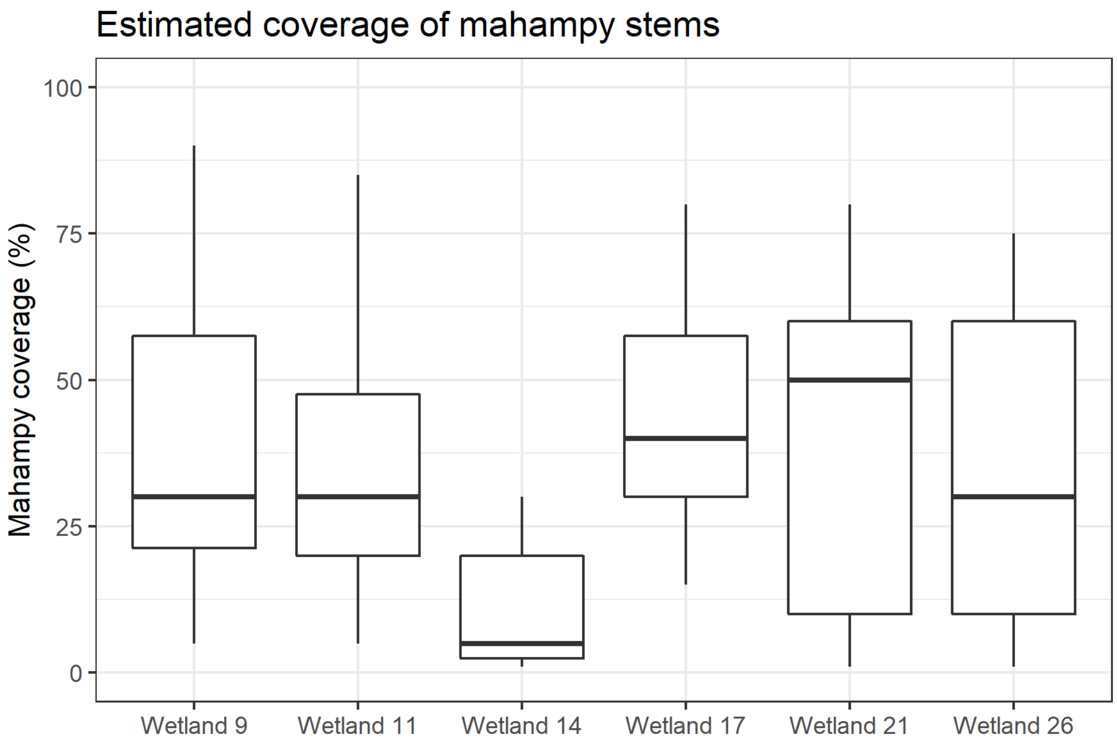

Figure 6 – Boxplot showing estimated coverage of mahampy *stems in the belt transects.*

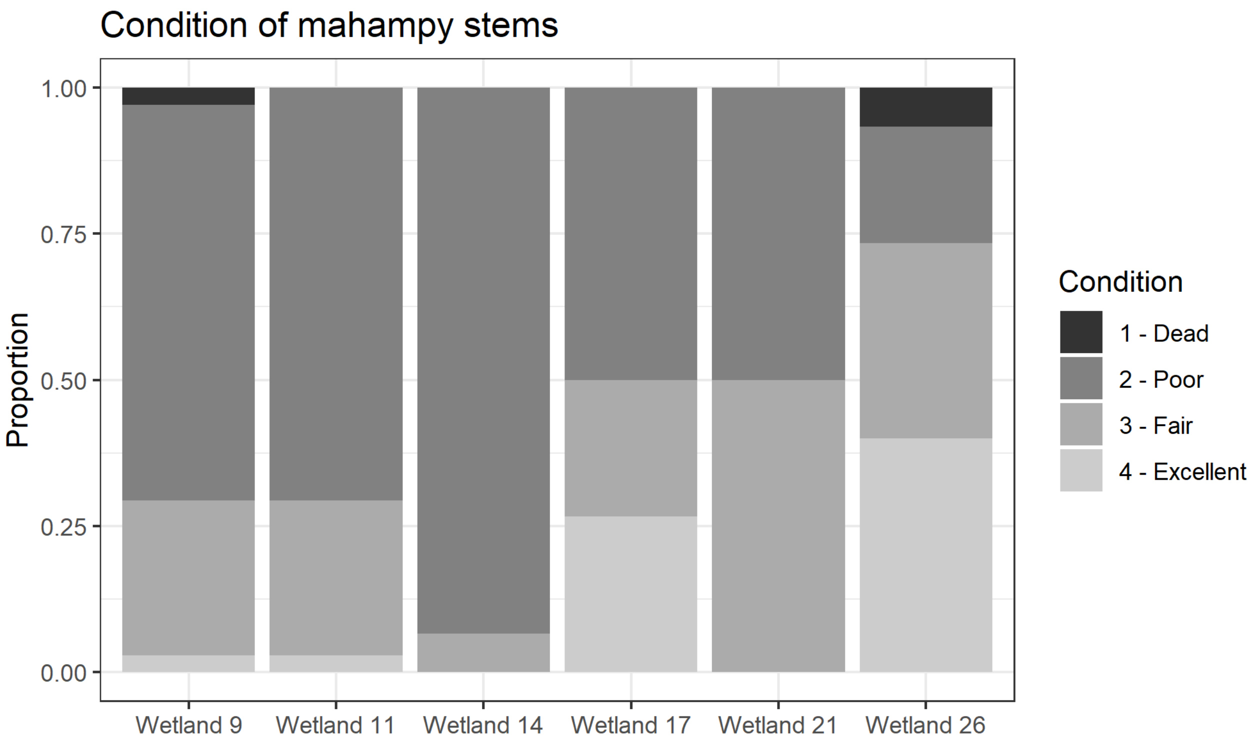

Figure 7 – Proportion of mahampy *stems for each condition score*

There was some temporal variation in *mahampy* height, but with no apparent trend across the study period (Figure 8). *Mahampy* coverage exhibited a general negative trend from the start to the end of the data collection period (Figure 9), and condition exhibited no clear trend (Figure 10).

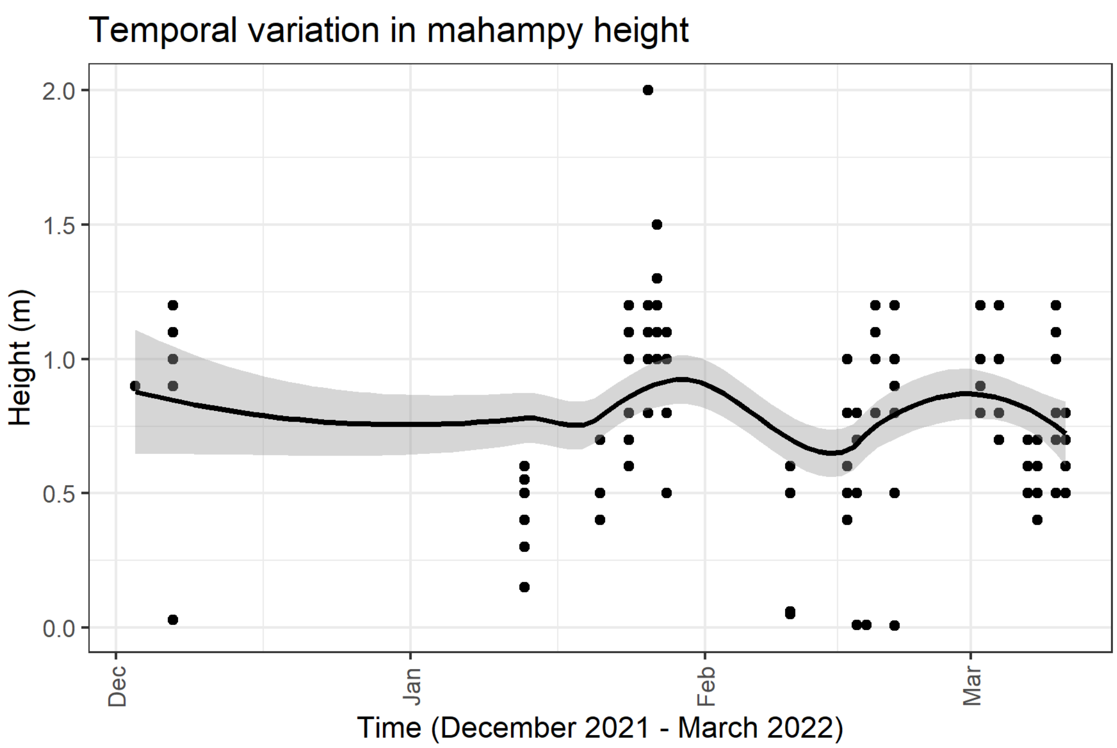

Figure 8 – Temporal variation of mahampy *height for all wetlands between December 2021 and March 2022. Line fitted by locally estimated scatterplot smoothing (LOESS).*

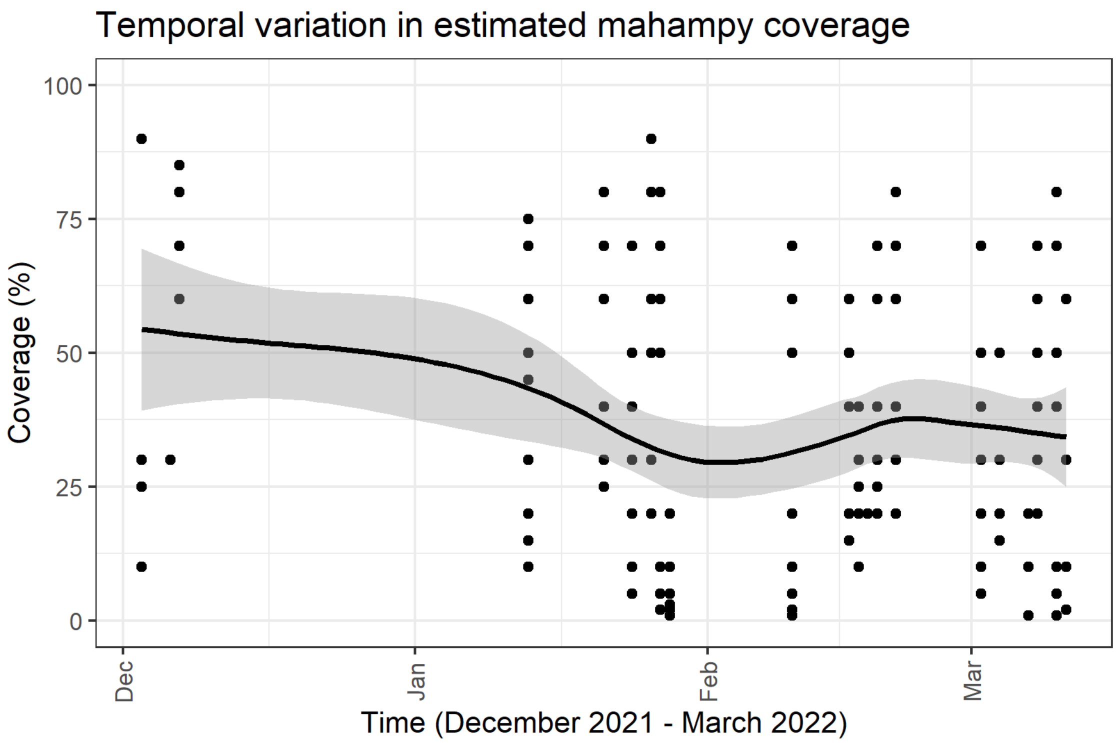

Figure 9 – Temporal variation of mahampy *coverage for all wetlands between December 2021 and March 2022. Line fitted by locally estimated scatterplot smoothing (LOESS).*

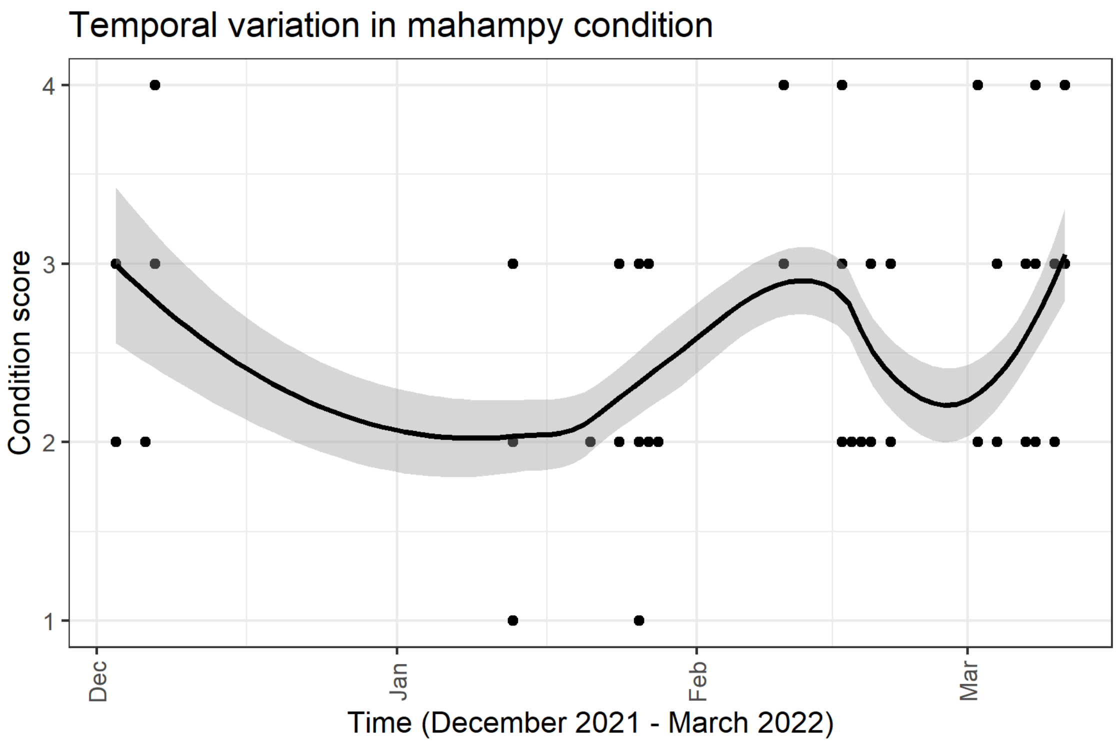

Figure 10 – Temporal variation of mahampy *condition for all wetlands between December 2021 and March 2022. Line fitted by locally estimated scatterplot smoothing (LOESS).*

4.1.2.2 Flora

The floral community composition was similar in each wetland (Figure 11). Wetland 17 appeared to have a slightly different community composition, clustering separately on the non-metric multidimensional scaling (NMDS) plot. This was brought about by the abundance of certain species which were either absent from other wetlands or present in small quantities, such as the grass species *sofimbolavo* and the shrub species *sonjokoaky.* Grasses, including *mahampy,* and mosses were the dominant vegetation types in the wetlands, with trees, shrubs, ferns, and vines constituting a much smaller proportion of the ecosystem (Figure 12). Wetland 14 is notable in its high coverage of non-*mahampy* grasses and relatively low *mahampy* coverage, whilst Wetland 11 had a relatively high proportion of tree species, and Wetland 17 much more bare ground and lower overall vegetation coverage than the other wetlands.

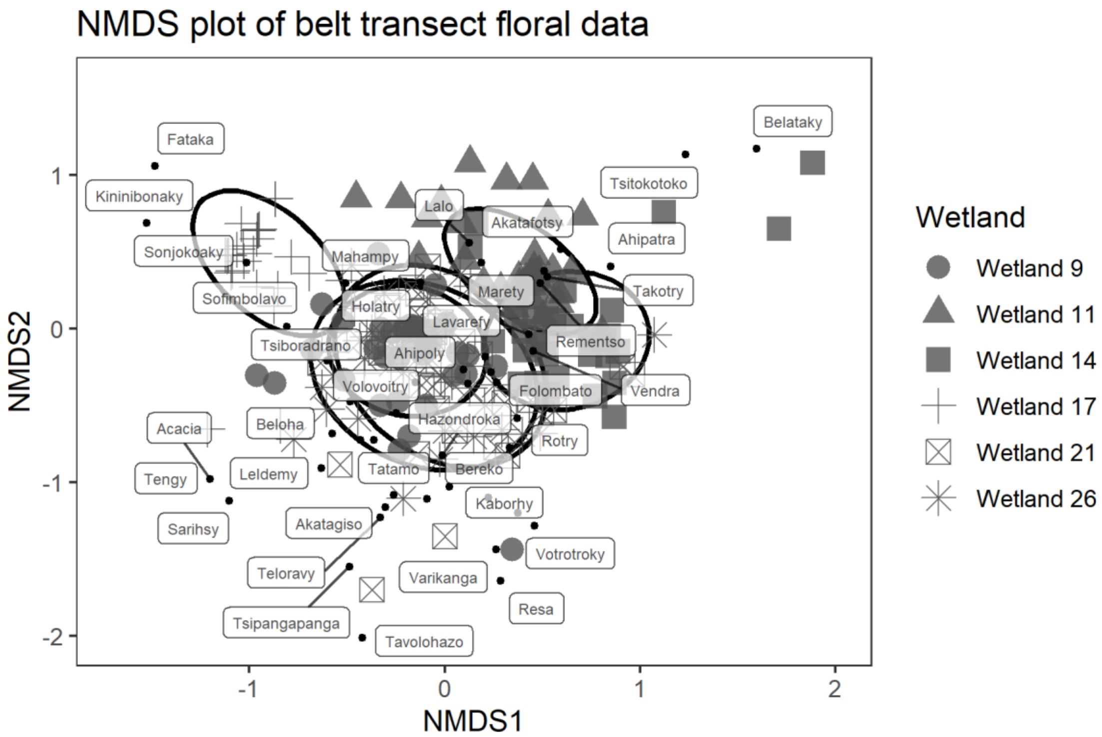

Figure 11 – NMDS plot showing differences in floral community composition between the wetlands in the belt transects. Ellipses drawn to 80% confidence level.

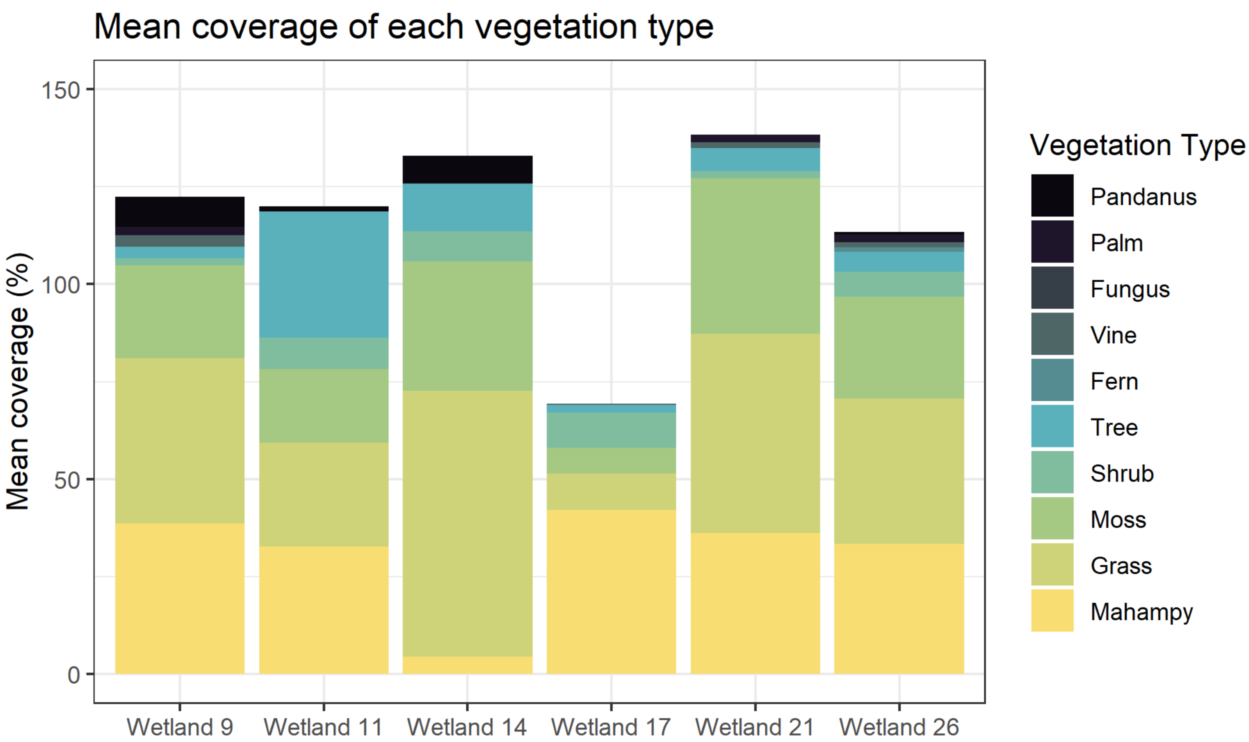

Figure 12 – Mean coverage of each vegetation type in the belt transects. Because coverage is estimated independently for each species in a quadrat, the total coverage can exceed 100%. Bare ground and/or water were considered as having no floral species present.

Floral condition was relatively consistent across the wetlands, with most floral species in all wetlands receiving a score of 2 (Poor) or 3 (Fair) (Table 5; Figure 13). Wetlands 9, 17, and 26 contained the highest proportions of floral species rated as 4 (Excellent) with over a quarter of all species receiving this score. Variation was observed in floral species condition over time (Figure 14), with lower scores present overall in the period of January – February 2022.

Table 5 – Mean and median condition scores of quadrats in each wetland in the belt transects. Values are calculated after first calculating the mean condition score in each quadrat.

Wetland	Mean condition score	Median condition score
Wetland 9	2.91	2.86
Wetland 11	2.86	2.71
Wetland 14	2.68	2.75
Wetland 17	2.86	3.00
Wetland 21	2.85	2.83
Wetland 26	3.02	3.11

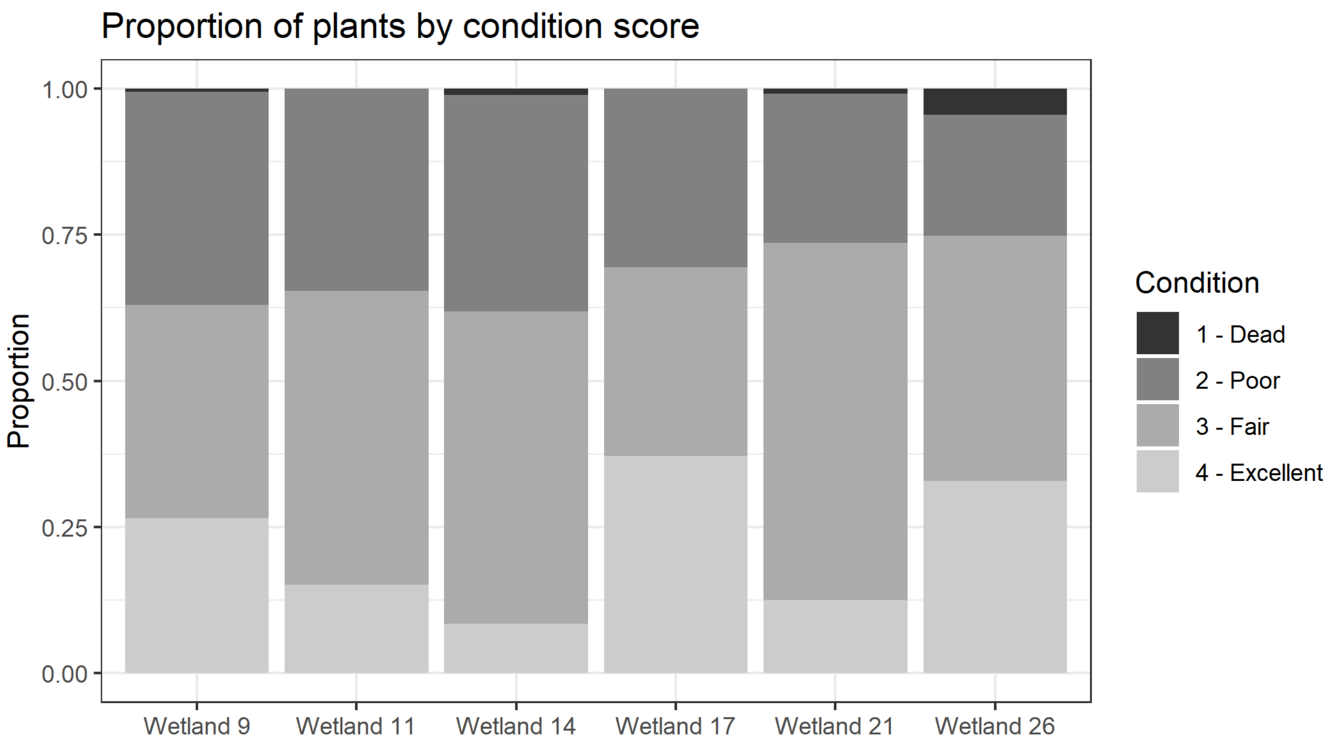

Figure 13 – Proportion of floral species in each wetland shaded according to condition.

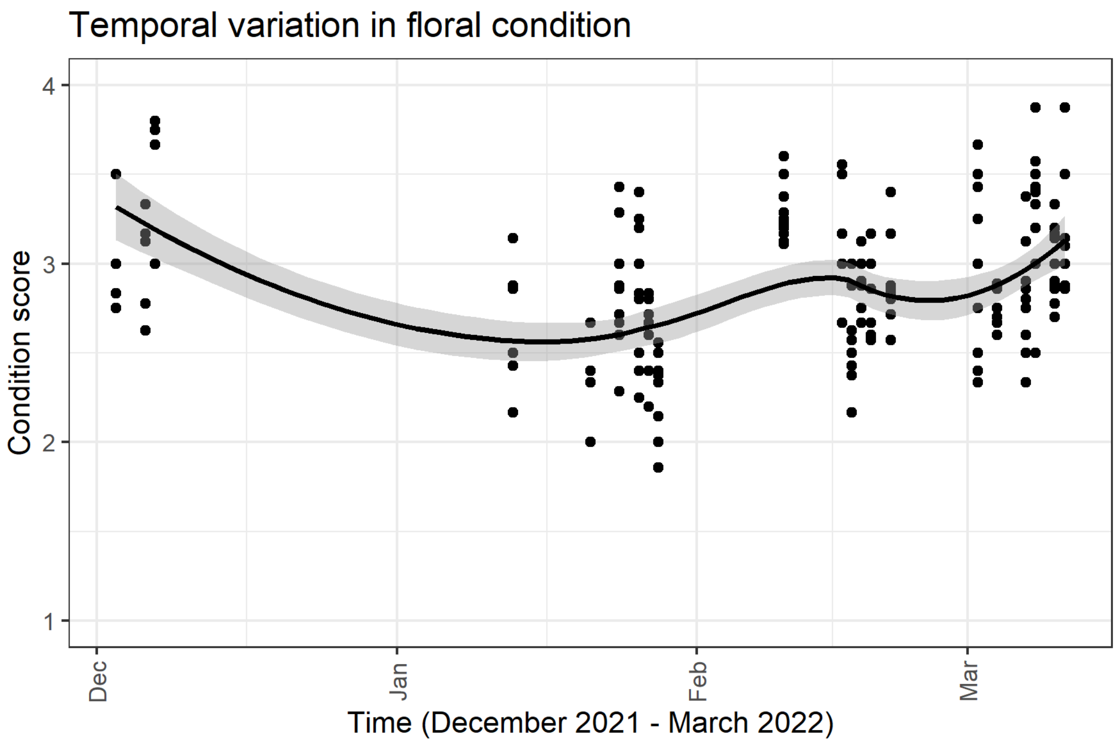

Figure 14 – Temporal variation in the mean condition score per quadrat between December 2021 and March 2022. Data is shown from all six wetlands. Line fitted by locally estimated scatterplot smoothing (LOESS).

4.1.2.3 Birds

Most of the 29 bird species sighted or heard in the wetlands were recorded multiple times, with the number of individuals recorded varying per wetland. Wetland 14 had the highest number of individual records, and Wetland 9 the least (Figure 15). The bird community composition in each wetland was similar, though some species occurred in higher numbers in certain wetlands. Wetland 17 appeared to have a different bird community composition, clustering separately on the NMDS plot (Figure 16). This difference was driven by the high occurrence of species such as Madagascar bush lark, Madagascar malachite kingfisher, and Madagascar red fody.

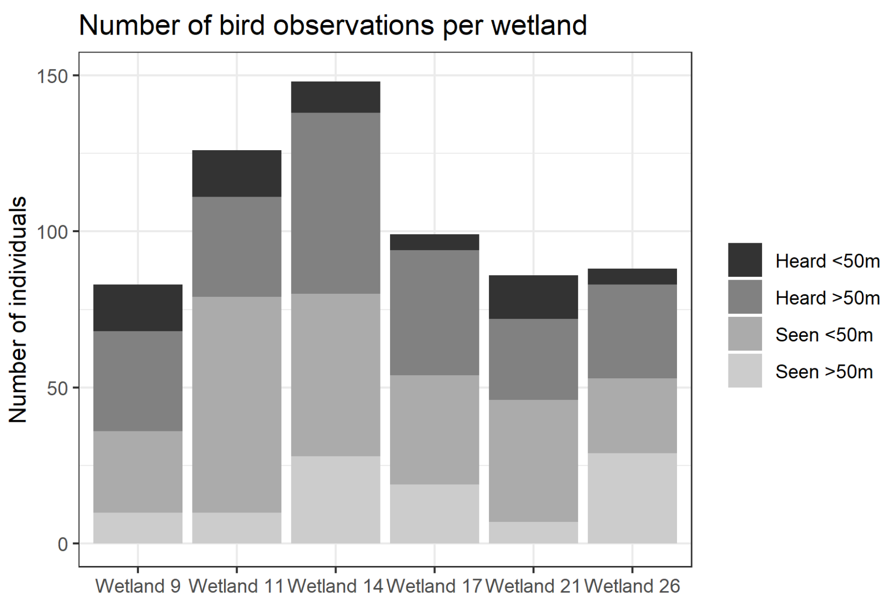

Figure 15 - Number of bird observations per wetland

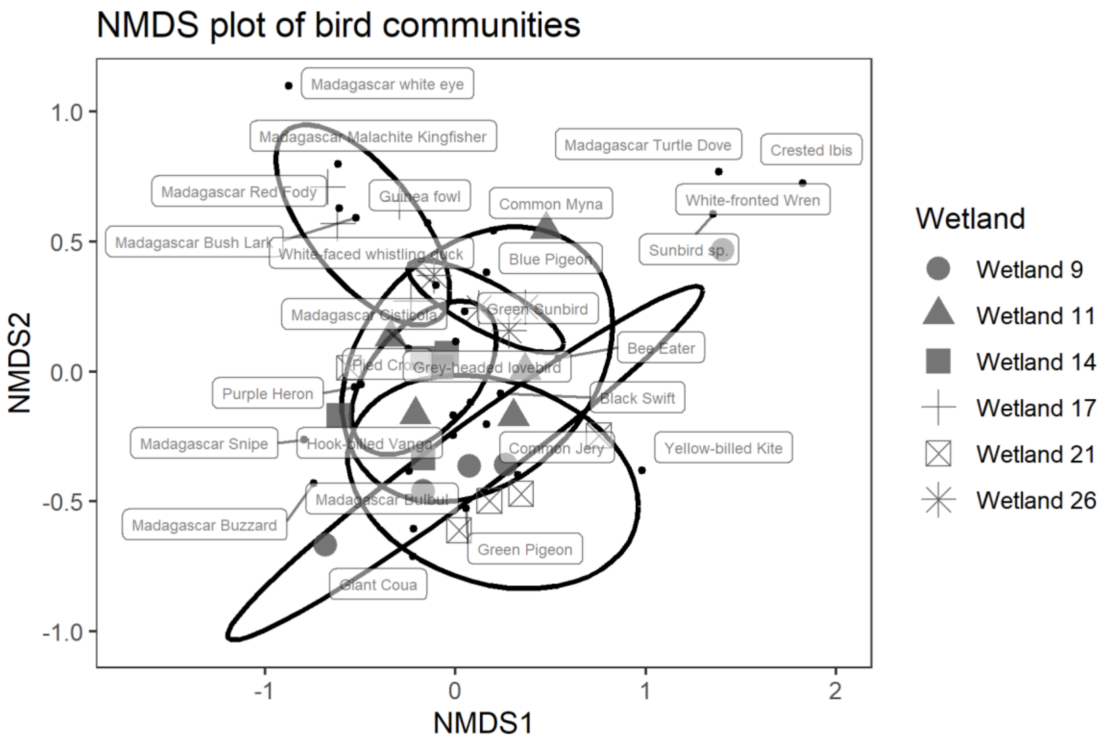

Figure 16 - NMDS plot showing differences in bird community composition between the wetlands. Ellipses drawn to 80% confidence level.

4.1.2.4 Herpetofauna

The greatest species richness and abundance of herpetofauna species was found within Wetland 26 (S=7). Conversely, Wetlands 14 and 17 were found to be least rich and abundant (S=3). The herpetofauna community of the wetlands is comprised of a relatively small number of generalist species. In terms of herpetofauna, the *mahampy* wetlands were not found to be particularly rich or abundant. A total of 11 different species were observed within all of the wetlands, including two species of snake (*Dromicodryas bernieri* and *Mimophis mahfalensis*), three species of frog (*Blommersia blommersae, Heterixalus boettgeri*, *and Ptychadena mascariensis*), three species of day gecko (*Phelsuma lineata, P. modesta,* and *P. parva*), one species of chameleon (*Furcifer lateralis*), and two species of skink (*Trachylepis elegans* and *T. gravenhorstii*).

4.1.2.5 Species richness and diversity

Wetland 26 was found to have the highest levels of species richness (n = 55) and the greatest overall Shannon-Wiener diversity index (H’ = 3.409885). Conversely, Wetland 9 was found to be the least species-rich (n = 32). Wetland 17 was found to have the lowest overall Shannon-Wiener diversity index (H’ = 2.980134), for more details see Table 6.

Table 6 – Summary of bird, floral, and herpetofauna species richness (S) and Shannon-Wiener Diversity (H’) calculated from belt transect survey.

Wetland	Bird - S	Bird - H’	Flora - S	Flora - H’	Herp - S	Herp - H’	Overall - S	Overall - H’
9	12	2.008198	21	2.448622	6	1.465807	39	3.056996
11	13	2.247047	14	2.349976	5	1.574097	32	3.031732
14	16	2.177921	20	2.722133	3	0.86474	39	3.248108
17	14	2.115565	18	2.295214	3	0.501047	35	2.980134
21	15	2.116854	18	2.797501	6	1.345503	49	3.313957
26	16	1.924537	32	2.924904	7	1.612933	55	3.409885

4.1.2.6 Environmental variables

In addition to biodiversity data, environmental variables were collected. Wetland 17 was observed having the greatest mean water salinity (0.155 ppt), water pH (4.82), and water depth (11.57cm) values. Wetland 17 was also observed having the lowest mean sediment level (0.71mm). Wetland 14 was the least saline (0.036 ppt), Wetland 11 was the most acidic (3.85) and on average had the least deep water (4.11cm). Finally, Wetland 9 had the greatest sediment load in the water, with 2.18mm of sediment settling in each sample. For further information, see Table 7.

Table 7 – Summary of environmental variables (water pH, water salinity, water depth, and sediment level) collected during the belt transect data collection.

Wetland	Mean water salinity (ppt)	Mean water pH	Mean water depth (cm)	Mean sediment level (mm)
W9	0.054	4.035714286	6.736842105	2.18
W11	0.047777778	3.85	4.105263158	1.577
W14	0.036	4.02	4.8	0.85
W17	0.155	4.828571429	11.57142857	0.714286
W21	0.06	3.573333333	4.363636364	1.716667
W26	0.057777778	4.264285714	7.571428571	1.571429

A Linear Mixed Effect Regression (LMER) model was used to assess the degree to which the collected environmental variables could explain the variation seen in two response variables; total species richness and overall Shannon-Wiener diversity index. The "lme4" package in R was used to achieve this (Bates et al., 2011; R Core Team, 2021). The wetland location variable was added to the model as a random effect. Due to a relatively small and unequal sample size amongst the environmental variables, 52 observations were removed from the LMER, leaving 21 observations to be analysed in the model. No significant relationships between any of the explanatory variables (water salinity, pH, depth, sediment load and GCC) and total species richness and diversity were observed.

4.1.3 Drone imagery

Between August 2020 and December 2021, a total of 23 aerial surveys took place. Due to adverse weather conditions and technical difficulties, an aerial survey of Wetland 21 in August 2020 was not possible. High resolution true colour images of each of the project's study wetlands are shown in Figure 17, whilst Figure 18 shows variation in the mean Green Chromatic Coordinate (GCC) across each wetland[a]. In most of the wetlands, mean GCC values showed little variation through time (Table 8; Figure 19). Wetland 21 presents the highest mean annual GCC value across the time period (0.39024), whereas Wetland 17 presents the lowest mean annual GCC value (0.339993).

Mean GCC values were normally distributed (Shapiro-Wilk Test: $W = 0.974$, $p = 0.792$) and so a parametric statistical test could be used to compare differences between the wetlands. A one-way ANOVA revealed a significant difference in mean GCC values between wetlands ($df = 5$, $F = 7.636$, $p = 0.0006$). Post-hoc comparisons using the Tukey test revealed that Wetland 21 had a higher mean GCC than all other wetlands ($p < 0.05$, Table 9).

[a] A higher GCC is indicative of a healthier wetland, with a higher index indicating a greener wetland, and a greener wetland being more healthy (Schneider et al. 2008).

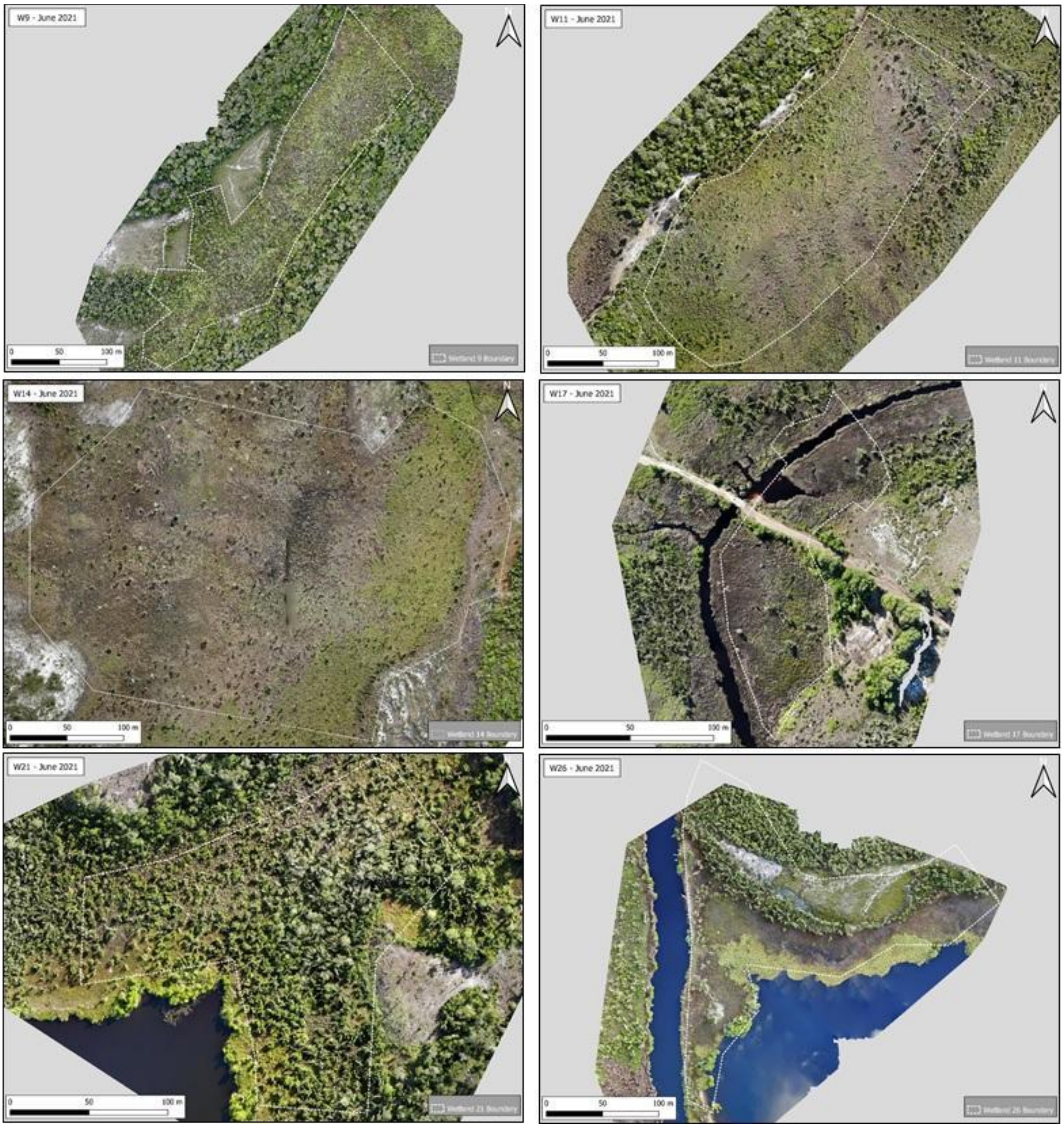

Figure 17 - Aerial images of all of Project Mahampy's study wetlands collected in June 2021. The edge of each wetland is highlighted using a white dotted boundary

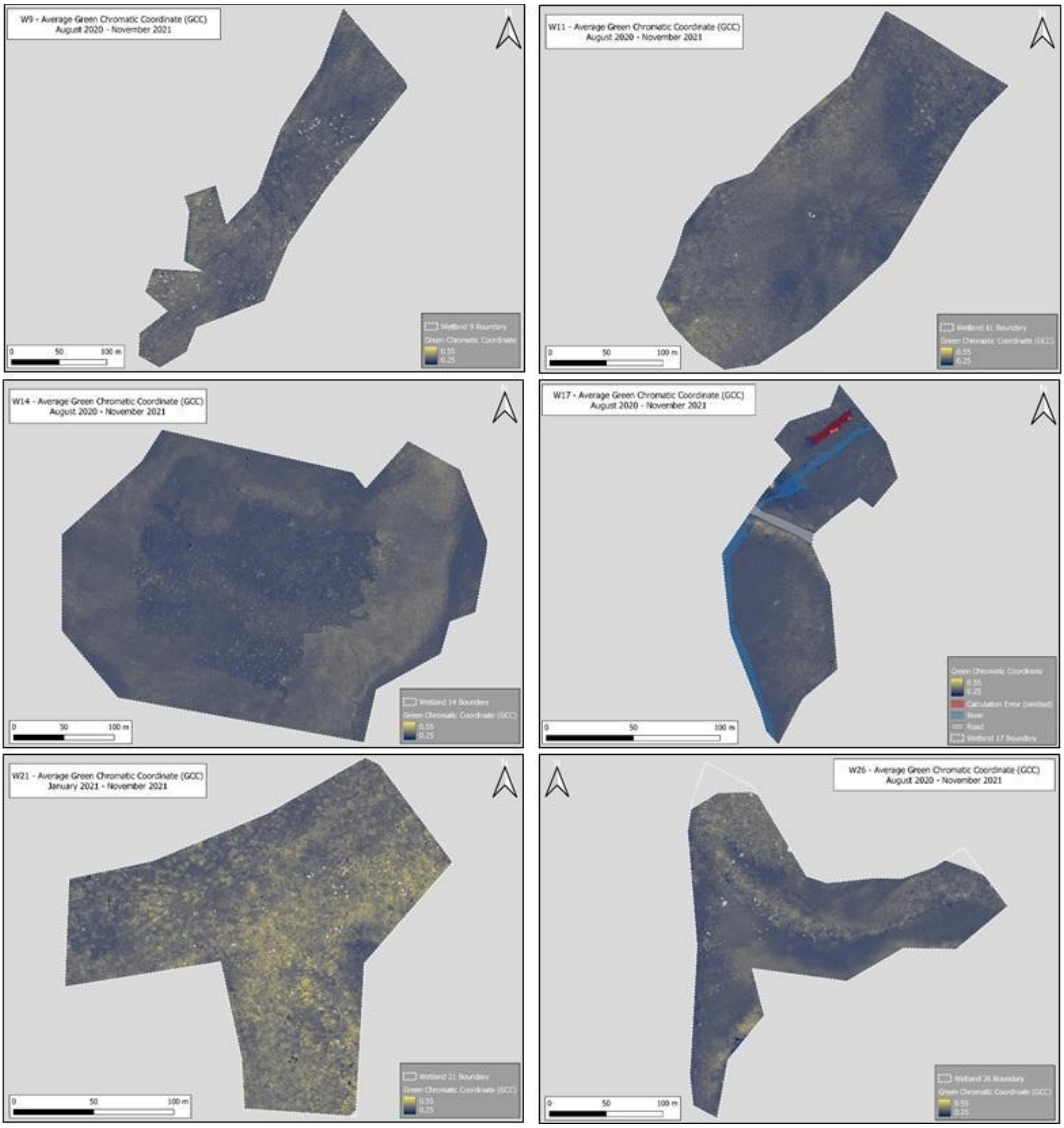

Figure 18 - Average Green Chromatic Coordinate for each of Project Mahampy's study wetlands.

Table 8 - Summary of green chromatic coordinate (GCC) results derived from wetland aerial imagery. No aerial imagery was collected for Wetland 21 in August 2020 due to technical and weather-related difficulties.

Wetland	Mean Green Chromatic Coordinate (GCC) Value				
	August 2020	January 2021	June 2021	November 2021	Mean Annual
W9	0.33162	0.37158	0.37561	0.37433	0.363285
W11	0.34983	0.36362	0.36149	0.36048	0.358855
W14	0.35247	0.35476	0.34999	0.37022	0.35686
W17	0.33537	0.34479	0.34020	0.33961	0.339993
W21	-	0.38160	0.38720	0.40190	0.359125
W26	0.35889	0.35868	0.36009	0.35884	0.39024

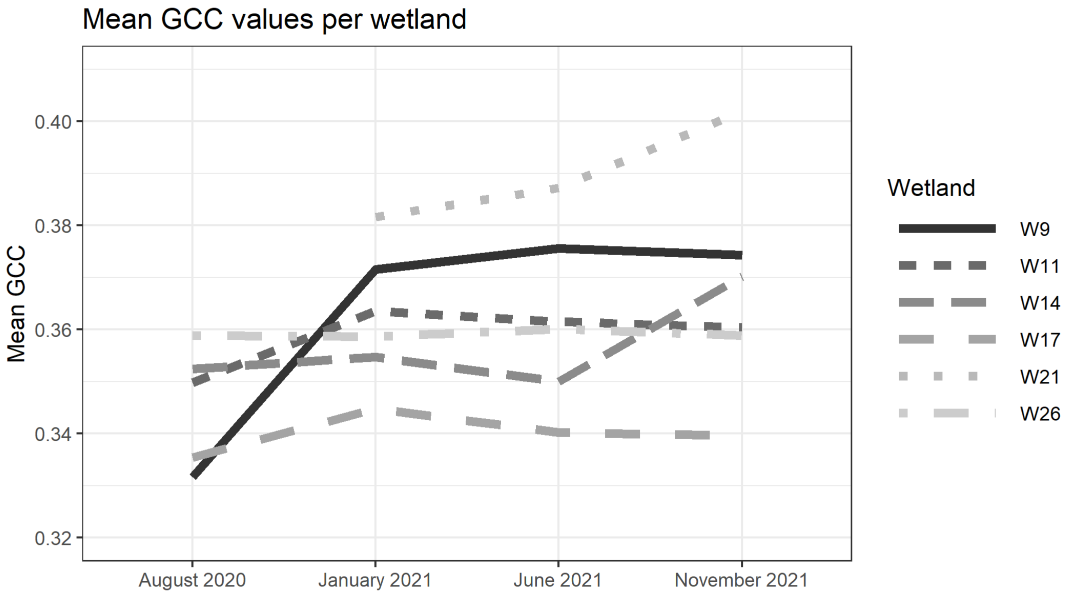

Figure 19 - Mean GCC values per mahampy *wetland*

Table 9 - Summary of statistically significant differences in wetland GCC values derived from one-way ANOVA and Tukey test analyses.

Wetlands	Difference	p-value
W21 – W11	0.0313850	0.0146672
W21 – W14	0.0333800	0.0089375
W21 – W17	0.0502475	0.0001447
W26 – W21	-0.0311150	0.0156792
W9 – W21	-0.0269550	0.0430702

4.2 Effect of harvesting techniques

4.2.1 Participatory monitoring

A total of 33 observations were made across three of the study wetlands between June 2021 and November 2021 to determine how harvesting technique (cut/pull/none) affects *mahampy* growth. Mean values of *mahampy* height, width, density, and condition are summarised in Table 10 and in Figures 20 - 22. Height, density, and condition were analysed by two-way ANOVA and post-hoc Tukey tests, summarised in Tables 11 and 12. Because the residuals of mean *mahampy* width were not normally distributed (Shapiro-Wilk test: $W = 0.8504$, $p < 0.001$), it was analysed with a Mann-Whitney U Test (Table 12).

Table 10 – Mean values for reed height, width, density, and condition for each harvesting technique.

Technique	Mean height (m)	Mean width (mm)	Density (stems per interquadrat)	Condition Score
None	0.883	2.905	114.6	2.40
Cut	0.643	3.119	77.3	3.23
Pull	0.694	3.449	81.5	2.30

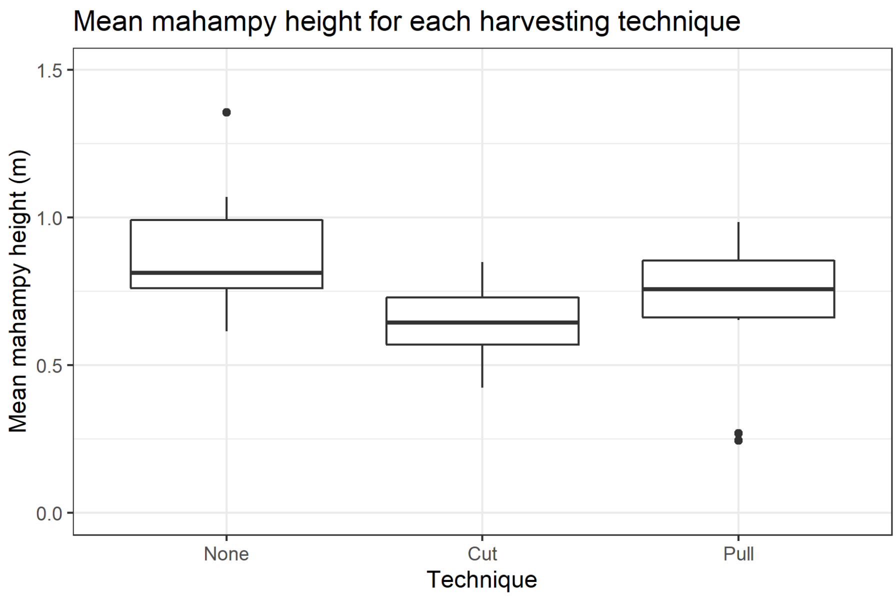

Figure 20 – Mean mahampy *height by harvesting technique.*

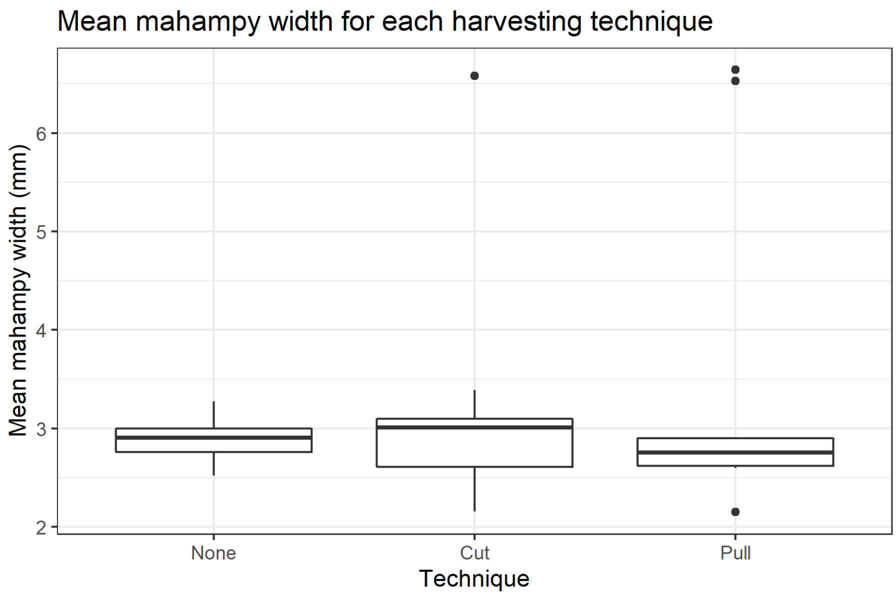

Figure 21 – Mean mahampy *width by harvesting technique.*

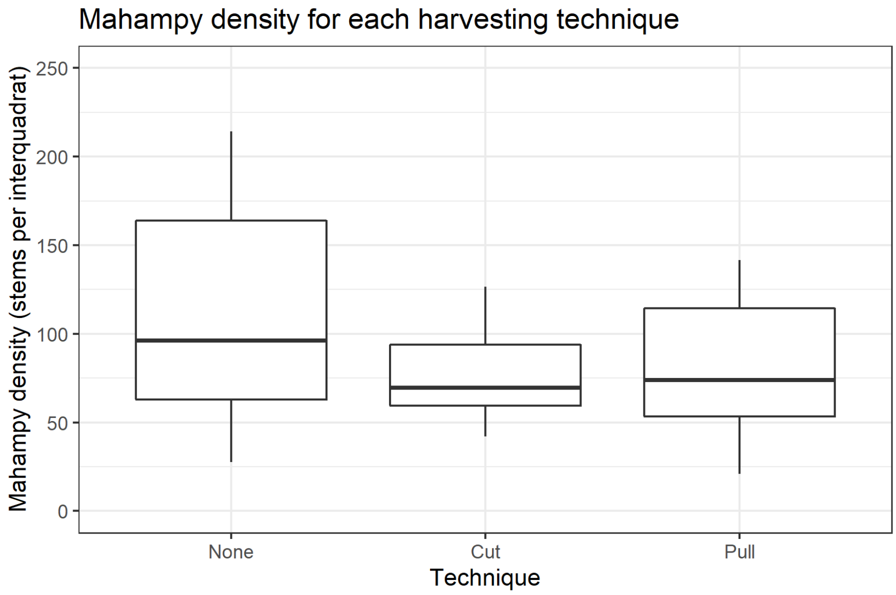

Figure 22 – Mahampy *density by harvesting technique.*

Mean *mahampy* height was highest in the unharvested quadrats. There was only a marginally significant difference between mean *mahampy* height in the cut versus pulled quadrats (p = 0.057), with quadrats harvested by pulling having a notable but not statistically significant shorter mean height. The Tukey test showed that *mahampy* in quadrats harvested by cutting was significantly shorter than in the unharvested quadrats (p = 0.008), but with a significantly higher condition score (p= 0.012) (Table 11). *Mahampy* condition was higher in the cut quadrats compared to both pulled (p = 0.005) and unharvested (p = 0.012, Table 11). Stem density and width did not significantly differ between the treatments.

There were also differences between the wetlands. Wetland 21 had shorter *mahampy* stems than the other two wetlands, but had the highest stem density (Table 12). There was no evidence for a difference in *mahampy* condition between the wetlands. The Mann-Whitney U tests revealed differences in mean reed width, with Wetland 21 having the thickest reeds (mean = 3.90mm) and Wetland 17 having the least thick reeds (mean = 2.55mm).

Table 11 – Pairwise comparison of reed height, density, condition, and width between harvesting techniques. Columns for height, density, and condition show differences between treatments and p-values from post-hoc Tukey tests. Column for reed width shows output of Mann-Whitney U Test. Significant differences (p < 0.05) are shown in bold.

Comparison	Difference in mean height (m)	Difference in density (stems per interquadrat)	Difference in condition score	Mann-Whitney U Test output for mean width (mm)
Cut – None	**-0.240 (p = 0.008)**	-37.3 (p = 0.084)	**0.831 (p = 0.012)**	U = 70, p = 0.780
Pull – None	-0.189 (p = 0.057)	-33.1 (p = 0.169)	-0.100 (p = 0.935)	U = 37, p = 0.344
Pull – Cut	0.050 (p = 0.777)	4.2 (p = 0.966)	**-0.931 (p = 0.005)**	U = 55, p = 0.556

Table 12 - Pairwise comparison of reed height, density, condition, and width between wetlands. Columns for height, density, and condition show differences between treatments and p-values from post-hoc Tukey tests. Column for reed width shows output of Mann-Whitney U Test. Significant differences (p < 0.05) are shown in bold.

Comparison	Difference in mean height (m)	Difference in density (stems per interquadrat)	Difference in condition score	Mann-Whitney U Test output for mean width (mm)
W21 – W17	**-0.202 (p = 0.037)**	**50.5 (p = 0.020)**	0.520 (p = 0.173)	**U = 101, p < 0.001**
W26 – W17	-0.011 (p = 0.989)	0.25 (p > 0.999)	0.333 (p = 0.471)	**U = 91, p = 0.009**

W26 – W21	**0.191 (p = 0.033)**	**-50.3 (p = 0.012**)	-0.187 (p = 0.756)	**U = 35.5, p = 0.037**

There was little difference between cutting and pulling on *mahampy* coverage with "Most" and "Half" being tied as the most common coverage categories. Unharvested plots appeared to have the lowest *mahampy* coverage, with only one quadrat having a coverage of "Most" compared to six quadrats covered by only "some" *mahampy*. Weaver consultations

4.2.2 Wetland usage

48 members of the Weavers' Cooperative were surveyed, again from the hamlets of Ambandrika, Ampanasatomboky, and Manafiafy. Of the weavers interviewed, 46 were active mahampy harvesters at the time of the study (Table 13).

Table 13: Survey participants and their harvest status, by Weavers' Sub-Cooperative

Mahampy Weavers' Sub-Cooperative	Women Interviewed	Active Harvesters
Fanatenana	10	10
Mahefa	11	10
Soa Gny Rary SL	10	10
Soamandroso	9	8
Taratsy Mahavotsy Mpandrary	8	8
Total	48	46

When provided with statements about wetland health, 90% of women agreed that wetlands that had better *mahampy* reeds also had more flora and fauna present. Further, 92% agreed that wetlands that had better *mahampy* reeds also had clean water. When asked which factors influenced where weavers harvested, the leading factor, identified by 76% of active harvesters, was the quality of the reeds. High-quality reeds were described as those that were long enough to weave mats from, with the wetland characteristics including those that contained strong and plentiful reeds. Unfavourable reedbeds where described as those that were dry, had brittle or easily-broken reeds, and/or had short reeds.

With regards to sustainability of the reedbeds, 59% of weavers reported the need arising to change where they harvested reeds because of factors including 'reeds running out' or 'reeds being finished' in a wetland, 'remaining reeds [being] too short' in a wetland, and wetlands drying up or burning.

4.2.3 Wetland threats

All survey participants, including those that were not active harvesters, were asked about threats to the wetlands. When asked about threats to the wetlands, 96% of survey participants identified fire as the greatest threat to the *mahampy* reedbeds. Threats other than fire identified included both environmental factors (e.g., pests and a lack of water) and the anthropogenic factor of harvesting via cutting (Table 14).

Table 14: Percentage of survey participants identifying a given threat (other than fire)

Threat	% of women identifying the threat
Locusts	46%
Cutting the reeds	50%
Lack of water	6%

Heat of the sun	6%
No other threats identified	6%

With regards to fire frequency, 50% of women identified fires as happening once every few years, with the next most common answers being 1-2 per year (23%) and 3-4 per year (17%). The majority of women (69%) identified fires as decreasing in frequency over the last five years, with 23% reporting fires have increased in frequency over the last five years, and 8% perceiving no change. The majority (71%) of women claimed that fires typically last multiple days as opposed to less than a day or a week or more. Additionally, the majority of women (90%) claimed that the typical fire duration is longer than in the past, over a recall period of five years.

The most common answers regarding how much of a given wetland typically burned during a fire event were: most (56%); half (21%); and all (15%).

83% of women said that one year after a fire event, it was possible to resume harvesting reeds. 13% said that this is not possible, and that the reeds are still too small one year after a fire event.

Women were also asked to identify the causes of the fires in the wetlands, with the majority identifying intentional fires set for the purpose of ground clearance as the leading cause (Table 15). Only 4% of respondents reported fires being the result of natural causes.

Table 15: Percentage of participants identifying a given cause of fires in the wetlands

Cause	% respondents identifying cause
Ground clearance	83%
Smoking fish	10%
Natural	4%
Other	0
Unsure	8%

Additionally, the majority of women (73%) said that certain wetlands were more at risk from fires than others. These wetlands tend to be the ones that were adjacent to agricultural fields. 94% of women said more should be done to protect against fires, with multiple mitigation strategies suggested (Table x).

Table 13: Percentage of participants identifying a given fire mitigation strategy

Strategy	% of women identifying strategy
Firebreaks	92%
No fires allowed on windy days	17%
Restricting when people can light fires	4%
Restricting where people can light fires	15%

94% of women said they would be personally interested in helping create firebreaks around some *mahampy* reedbeds to help protect the wetlands from fires.

5 Discussion

Overall, data collected were able to provide a fuller picture of the *mahampy* wetlands, enabling the research team to describe the wetlands in the area, and begin to examine their differences. Floral, bird, and (to a lesser extent) herpetofauna communities were described for each wetland, and an understanding of species richness gained. Environmental variables proved challenging, with variables lacking clear relationships with other data collected. Though data were not able to uncover the drivers behind differences in the wetlands, the descriptions of the *mahampy* wetlands, in conjunction with weaver knowledge, aid in understanding what healthy wetlands look like from both a livelihoods and biodiversity perspective. These findings are discussed in further detail below.

5.1 Establishing ecological baseline

5.1.1 Longitudinal trends

Both longitudinal quadrats and belt transects were able to track wetland variables over time; with longitudinal quadrats spanning a longer period but with much lower overall coverage of the wetlands as a whole. Mean height was not found to vary throughout either study period, though mean coverage did decline in the longitudinal-specific quadrats (sections 4.1.1.1 and 4.1.2.1). Comparatively, trends were not clearly present in the temporal examination of belt transects. Though this may point to low variation in *mahampy* characteristics including height, coverage, and condition, it should also be noted that prior to December 2021, severe drought gripped the Sainte Luce area, whereas from December 2021 through the end of the study period, regular rainfall has been present and may have obscured trends that would otherwise be seen in a 'regular' wet-season / dry-season cycle. Such variation in normally expected weather patterns will likely continue as climate change intensifies in the region (Amnesty International, 2021). For this reason, continued data collection may reveal long-term trends that may not have been captured within this shorter and finer-scale study.

5.1.2 *Mahampy* characteristics

Belt transects enabled the team to gain an accurate picture of *mahampy* characteristics across a variety of wetlands. In terms of characteristics that were labelled as 'high-quality' by weavers (see Section 4.3.1), Wetlands 9, 21, and 26 contained the best *mahampy*, with high values for mean height, mean coverage, and mean condition. Conversely, Wetlands 14 and 17 would be the least favourable, with low mean coverage, low mean condition, and short mean height. Interestingly, none of the target wetlands in the study would reach the 'ideal' threshold for mat-weaving reeds, with women favouring reeds of 1.5m or taller to make mats, the most commonly-sold *mahampy* product in Sainte Luce. As examined below, there were not any environmental variables in particular, nor shared characteristics of wetlands with 'high-quality' *mahampy*, that were significant predictors of *mahampy* quality.

5.1.3 Wetland biodiversity

Belt transects were able to shed light on species richness and diversity in the wetlands, with a focus on bird, herpetofauna, and floral diversity. Supplemental information on the surrounding habitat has also been added for context, collected through researcher observations.

5.1.3.1 Birds

With regards to bird species in particular, species observed during belt transects were largely generalist (e.g. Black swift, Pied crow, and Common myna) and forest-dwelling (e.g. Hook-billed vanga and Madagascar coucal) or grassland-dwelling (e.g. Common jerry and Madagascar cisticola) species. While a few waterbird species were observed, such as the Madagascar malachite kingfisher, Purple heron, and White-faced whistling duck, they were observed far less frequently. Many of these species observations, with the exception of the waterbirds, are thought to be largely a result of each wetland's proximity to a large littoral forest fragment, rather than because the wetland provided primary habitat for foraging, nesting, or other purposes. To better understand how biodiverse the *mahampy* wetlands are relative to other ecosystems in Sainte Luce (e.g. littoral forest, degraded littoral forest, grassland, agricultural land) further research into the spatial distribution of Sainte Luce's avian community is needed.

5.1.3.2 Herpetofauna

Similar to the bird species recorded, the herpetofauna species found during the belt transects were largely generalists, and not specific to wetland environments. Some species observed, such as *Trachylepis sp.*, *D. bernieri*, and *M. mahfalensis*, are particularly well adapted to drier habitats such as grass and scrubland. The *mahampy* wetlands do, however, provide important habitat for amphibian species, particularly *B. blommersae*. The limited herpetofauna diversity in the wetlands could be a consequence of limited habitat heterogeneity, high levels of exposure (e.g. few/no large tree canopies present), or relative dryness, however it is not possible to say with certainty whether these anecdotal descriptions cause these observations. Additionally, all surveys throughout the project were carried out during the day, with nocturnal herpetofauna species unable to be assessed.

5.1.3.3 Flora and environmental characteristics

Floral species were generally uniform across the wetlands (section 4.1.2.2) though characteristics such as condition and coverage did vary. For both *mahampy* and for floral species, Wetland 26 had not only the highest condition, but also the most variation in condition. This Wetland also supported the highest species richness and highest diversity index (section 4.1.2.4). Within Wetland 26, there exists habitat heterogeneity likely a result of the nearby river, some lightly forested areas in the eastern part of the wetland, and sections of the wetland that are recovering from being burned by a large fire in November 2021. These different microhabitats are characterised by different floral communities. For example, areas of the wetland that had been recently burned contained fast-growing species such as grasses (e.g. *mahampy*, *tsiboradrano*, and *tsitokotoko*) in greater abundance, whereas the more forested areas contained tree species such as *lalo* and *ravenala*. It is possible that high habitat heterogeneity may have supported more diverse communities, though again no significant predictor variables were found.

Wetlands 14 and 17 also had several unique characteristics across the data collected. Wetland 14 had low values for multiple *mahampy* characteristics (section 4.1.2.1) and further stood out with regards to its unique floral community including a high proportion of non-*mahampy* grasses (section 4.1.2.2), highest number of individual bird records (section 4.1.2.3), and least saline water (section 4.1.2.6). With regards to observed characteristics, Wetland 14 is covered in small pools, where rainwater collects, and a collection of small freshwater streams pass through the wetland. During transects, most of the water sampling took place within the small rainwater pools, which are inherently less saline. Again, the LMER model was not able to relate species richness and diversity with environmental characteristics, though it is worth exploring further what factors may influence the relatively low presence and lower quality of *mahampy.*

Wetland 17 was particularly anomalous, with a different floral and bird community composition than the other wetlands (section 4.1.2.2 and 4.1.2.3). Interestingly, despite having the most 'bare ground' of all wetlands, it contained the highest relative percentage of *mahampy,* with overall high condition of floral species present. Conversely, it produced the lowest biodiversity index (section 4.1.2.5) as well as the lowest mean GCC and therefore, in theory, would be considered the least healthy wetland. It is possible that *mahampy* is particularly competitive and in some circumstances limits the growth of other wetland species, however additional research and analysis would be required to confirm the degree to which this relationship exists. Wetland 17 was also nearly entirely burned in November 2021 and is infrequently grazed by cattle due to the wetland's proximity the main local road. Therefore, it is possible that the lower average annual GCC value for this wetland is a result of the loss of green vegetation during the fire event and from grazing pressure, preventing diverse floral communities from establishing. Additionally, it was the most saline wetland, with the deepest average water depth of all wetlands and lowest sediment load (section 4.1.2.6). Water salinity, depth and sediment load are factors that influence wetland floral assemblages. Saline water can be damaging to some plants, particularly those that are adapted to fresh water, and impact biogeochemical processes (Herbert et al., 2015). Water depth is known to influence the cover and structure of wetland plant communities (Song et al., 2019), with shallower waters associated with highly productive emergent floral species (Lou et al., 2016). Whether carried in suspension or deposited, sediment can inhibit a plants ability to photosynthesize by limiting a plant's exposure to sunlight. In this context, one possible explanation of the unique characteristics of Wetland 17 is the location of the wetland as compared to the other target wetlands. Wetland 17 is located alongside a freshwater river that is influenced by the tide, and it is regularly inundated by river water during periods of high tide and/or recent rainfall within the catchment. The other five target wetlands are each fed by water sources including smaller streams, pools of rainwater, and (in the case of Wetlands 21 and 26) rivers themselves. However, these five wetlands are not inundated to the same extent and frequency as Wetland 17. It is possible, therefore, that the frequency and duration of water cover over the wetland controls which species can establish. Species observed in Wetland 17 such as *mahampy*, *sofimbolavo*, and *sonjokoaky* are found frequently in particularly wet environments, so their higher abundance in Wetland 17 compared with other wetlands potentially indicates this. However, as this study did not focus on the local fluvial regime and the specific effects it may have on wetland biodiversity, this is merely a hypothesis, and requires targeted research to better understand. Furthermore, due to the total number of water samples made in each wetland being unequal and low in number, accurate conclusions cannot be made regarding overall water quality in each wetland, and the relationship between water quality and species richness or abundance.

Wetlands 9, 11, and 21 also exhibited characteristics that set them apart from the other wetlands, further contributing to the understanding that *mahampy* wetlands can be extremely varied. Wetlands 9 and 21 had relatively favourable *mahampy* for weaving (section 5.1.2), though Wetland 21 had the highest mean GCC and therefore would be considered the healthiest wetland by this metric. This wetland also had very high coverage, with floral species present having a high amount of overlap and very little, if any, bare ground, which is likely a contributing factor to this high GCC value. Though Wetland 9 did not have as high of a GCC as Wetland 21, it did exhibit the largest change in GCC during the study period and had the second-highest GCC value at the most recent drone flight. Meanwhile, Wetland 11 was fairly central with regards to most of the metrics measured, standing out on neither end of the ranges seen. However, it did have the highest proportion of tree species present, as well as the shallowest average water depth, factors which may be related.

5.1.4 Synthesis

It is likely that these factors – water presence and quality, sediment load, bird species, herpetofauna species, and floral community composition and coverage – influence each other and the *mahampy* present, though these ties were not able to be explained statistically with the data available. Natural variation across wetlands supported different communities as well as variations in *mahampy* characteristics, with wetlands overall supporting generalist species and providing additional habitat for a number of forest-dwelling species. Taken together, there was no clear relationship between wetlands that supported favourable *mahampy* characteristics and their environmental variables, including GCC, species richness, diversity, and community composition. As such, within the scope of this research, the data were not able to identify what characteristics denote a healthy wetland, but rather, data showed that there exists a variety of wetland types in the study area which are all influenced by a complex suite of interacting variables.

5.2 Participatory monitoring of harvest techniques

Data revealed relatively little regarding the differences in characteristics between the cut, pulled, and unharvested quadrats. When directly comparing cut to pulled quadrats, the only significantly different result was that mean *mahampy* condition was found to be higher within quadrats that had been cut. No significant differences were found regarding width, density, or height. However, multiple factors may have influenced this finding. When verifying data collection methods during the study, it was revealed that condition was a difficult metric to apply subjectively for those who had not had previous exposure to data collection. Rather than recording an average condition for all *mahampy* in the quadrats, which would include dead stems and those that were cut or pulled as part of the assessment, only the condition of alive reeds was judged. There were also other findings that pointed to a need for additional training and verification of data collection methods. For example, one would expect to see differences in mean density of quadrats harvested by any method versus those left unharvested, as there would be physically less *mahampy* in the harvested quadrats.

The lack of significant relationships between other metrics either suggests that reed thickness and density is not related to harvesting technique, or that not enough data have been collected to make statistically significant conclusions. From these initial findings, though it can be tentatively inferred that cutting *mahampy* lends to higher *mahampy* condition after regrowth, the lack of differences in any other metrics, and uncertainty surrounding condition mean that definite conservation recommendations cannot be made at this time.

5.3 Weaver consultations

Surveys with members of the Weavers' Cooperative revealed perceptions regarding wetland health, threats, and harvest selection. In general, there was widespread agreement that factors that would render a wetland ecologically healthy and diverse were also favourable for harvestable wetlands. For the weavers of Sainte Luce, reedbeds that contained long, strong, and numerous reeds were most useful to them (section xx); reedbeds that contained reeds conducive to weaving large mats. Many weavers also reported needing to change the wetland in which they harvested reeds, with the reasons given touching upon various forms of resource decline – reeds running out; remaining reeds being too short; and fire or drought rendering the reeds unusable. This is consistent with anecdotal reports of weavers periodically rotating the wetlands in which they harvested, moving on when reedbeds were no longer suitable. An interesting continuation of these surveys would be to determine how long wetlands take to 'recover' before they are rotated back to and harvested from anew.

Fire was identified as the leading threat to the wetlands, and therefore to weaving as a livelihood, followed by the threats of harvesting by cutting and damage from locusts. Furthermore, these fires were reported as largely anthropogenic in origin, with the leading cause reported as clearing land for agriculture. This is further supported by reports that the wetlands most at risk from fire were those located closest to agricultural fields. Additionally, despite the majority of women reporting that the frequency of fires seemed to be decreasing over a five-year period, the majority opinion was that when fires did happen, they burned for longer, and affected most of the area of a given wetland. This may point to more intense and potentially damaging fires occurring than in the past.

With chronic drought becoming a persistent factor in rural Anosy, these fires may be fed by an increased fuel load and comparatively little moisture. More research is needed into the historical fire regime, including whether there may be a shift from low-intensity, high frequency fires to infrequent and intense fires. Similarly, more information is needed on the role of fires in the *mahampy* wetlands, including whether fire can act as a restoring and natural part of the ecosystem, or a destructive force. Many women were strongly in favour of taking fire mitigation action, including the creation of firebreaks around wetlands particularly susceptible to fire. Before fire mitigation tactics are taken, including fire suppression, it is important to gain a greater understanding of fire's impact on the wetlands and whether it is damaging to both biodiversity and livelihoods. As fire suppression and mitigation can have far-reaching impacts on ecological communities and species composition (Alvarado et al., 2018; Moura et al., 2019), it is important to understand the fire regime in the area and what affects fire mitigation could have. This study has begun to uncover such relationships, including through drone imagery and community consultations, and will continue to do so in the next project phase to inform management decisions.

5.4 Additional context – fire

Between August 2020 and November 2021, fire events took place within three of the project's wetlands: Wetland 14, 17, and 26. Though not part of the original study, information is included herein to provide context.

In January 2021, a large fire took place within Wetland 14. Using the imagery collected by the Project Mahampy's drone flights at the time of the fire in January, and again in June 2021, burned areas were identified and measured using GIS (QGIS). Approximately 61,284m^2 of the wetland burned (63.58%) during this fire event, with a much greater area of the surrounding environment also burned.

In November 2021, a large fire event took place which burned two of the project's wetlands: Wetland 17 and 26. Approximately 9,502m^2 of Wetland 17 (96.58%) and 6,703m^2 of Wetland 26 (20.46%) burned during the fire event, with a much greater area of the surrounding landscape also burned.

These fires are potentially damaging to wetland biodiversity, in addition to immediately reducing *mahampy* availability for weavers in the surrounding communities, impacting their livelihoods. SEED is continuing with the participatory monitoring of the wetlands to better understand how *mahampy* regrows after a fire event.

6 Next Steps and Limitations

6.1 Limitations

During the implementation of this research, the SCRP team identified a variety of limitations affecting the study. Many of the issues were rectified, however, some were unable to be addressed during the study period or otherwise need to be considered as confounding factors that negate the ability to draw clear conclusions from the research.

Throughout the project, the wetlands that form the focus of this study have been found to be lacking in water. As such, SEED was not able to complete regular and even water assessments within each of the wetlands. Due to this limited opportunity for data collection, more sampling of the water is needed to strengthen the ability to make statistically significant conclusions about the hydrological environment within *mahampy* wetlands. Furthermore, it was hoped that dragonfly larvae assessments would have been completed within each of the wetlands to further inform wetland biodiversity and ecosystem services. However, due to a lack of deep, standing water within the study wetlands, optimum conditions for dragonfly larvae growth were rarely reached. Pilot dragonfly larvae assessments were completed in Wetland 9, 11, and 17, however, no larvae were discovered.

Technical limitations also presented themselves during the study, with one of the primary limitations being an inability to acquire sufficient calibration salts and deionised water, without which regular calibration of the pH meter was not possible. As a result, the measurements taken from the wetland are likely not accurate reflections of the wetland water pH.

A further area of SCRP's research approach that contained limitations included the drone imagery and analysis. Although much was done to standardise the drone flights and minimise the effect of light level and image noise on the output images, issues still arose. A lack of ground-truth points (e.g. white disks/distinct landscape features such as palm trees or bare soil) within each of the wetlands meant that inconsistencies arose when the final output images were combined using Structure from Motion (SfM) software. SfM software can struggle to accurately stitch images together by georeferencing when there are fewer points of reference on the landscape, as was the case with Wetland 14. Due to the large size of Wetland 14 and the drone's battery capacity limitations, multiple flights were needed to acquire imagery for the entire wetland. Due to the relatively homogenous appearance of the wetland's floral community from the drone's elevation, it was difficult for the software to create complete images of the wetland, leaving a hole in the middle of the resulting image. This was the case for three of the four aerial images collected for Wetland 14. In future, it is important that points of reference on the ground are added to each wetland to help the software create singular images without irregularities more easily.

Due to limited time, only one index was calculated for each wetland across the time period. SCRP will continue to analyse the collected aerial imagery, using additional indices to assess the health of the vegetation within the wetlands. Further vegetation indices could be used to infer wetland health. While GCC is a good estimator of wetland health, there are other indices that are superior in other aspects of remote sensing. For example, Excess Greenness Index (ExGI) is known to have a high capacity for differentiating between bare soil and vegetation (Sonnentag et al. 2012), while Visible Atmospherically Resistant Index (VARI) is also an index that is minimally affected by atmospheric conditions, and can identify vegetation with relatively low error (Mokarram et al. 2016).. Furthermore, with regard to interpretation of the results, GCC values of wetlands within the wider literature for comparison purposes are limited as very few studies have taken place that use RGB imagery to quantify wetland vegetation health. Most studies that have taken place within wetlands use indices that require other wavelengths of the electromagnetic spectrum, namely Near Infrared (NIR), however, data for this particular index is not possible to collect with the equipment currently available to SEED.

Though study taxa were chosen to describe the communities and biodiversity of the wetland habitat, these groups are not necessarily representative of taxa that rely most heavily on the wetlands, or species that might be wetland specialists. Aquatic species, including freshwater fish and shrimp, have been reported to inhabit the wetlands, but surveying these groups was not a part of project research. Future projects may wish to examine these groups to gain a fuller understanding of species within the wetlands, including those important for local consumption and/or sale.

Further, it should be noted that the wetlands studied in each of the surveys were open to the surrounding communities, and as such weavers, passers-by, and any other resource uses had access to all wetlands at all times. So, it is possible that people walking through and/or around the transects may have influenced study results, particularly if any form of harvest occurred during the study period.

6.2 Next steps

With fire identified as a management priority amongst weavers, and fires potentially increasing in intensity, Mahampy: Phase II will seek to better understand fire's effects on the wetlands, including regrowth and harvesting ability, and to understand ecological succession following a fire event. With multiple fire events occurring during the 2021-2022 fire season, there is an important window of opportunity to collect these data and use it to inform management discussions with the weavers and wider community. This data collection will be further supported by regular drone flights, which can provide both insight into recovery after a fire and to long-term, landscape-scale changes.

Participatory monitoring will also continue, with renewed focus on uncovering any differences between cut and pulled wetlands in the absence of significant conclusions able to be drawn. With harvesting technique being a high priority for many *mahampy* weavers, this research will continue, led by weavers but supported by SCRP, especially with regards to training on methodology and survey techniques. Data collection protocol will adjust to ensure that variable collected provide an accurate picture of *mahampy* regrowth after harvest, including tracking the height of individual stems or clumps over time to assess growth from zero. Weavers' Cooperative members will also aid in monitoring regrowth after fire events, following similar protocols and aiding in uncovering fire's effects on the wetlands.

Moving forward, SCRP will continue to analyse data collected from each wetland, particularly belt transect observations and drone imagery. Analytical techniques will be refined and additional statistical methods employed, such as generalised linear mixed-effect regression (GLMER) modelling, to quantify and understand relationships between *mahampy,* environmental variables, and biodiversity in greater detail. SCRP will also continue to develop a floral identification guide of the observed species observed. Once complete, SCRP will share findings with botanical specialists to increase understanding of the taxonomy and natural history of each species observed throughout the project.

Holes in the data collection will also be filled in future data collection, such as the lack of reliable water quality data. Further details can be found in the **Project Mahampy: Phase II Proposal.**

7 Conclusion

Research carried out on the *mahampy* reedbeds during Project Mahampy: Phase I provided a holistic understanding of the various wetlands in Sainte Luce, the *mahampy* they contain, and the levels of biodiversity they support.

The six target wetlands studied varied in their bird, floral, and herpetofaunal community composition; however, no causal relationships can be established with the data collected. *Mahampy* condition, height, and coverage were also examined, and varied across wetlands but with no variables identified that were able to predict where 'high quality' *mahampy* may occur. A significant start was made on uncovering the impacts of differential harvest techniques, with further research positioned to draw stronger conclusions about whether one technique may be more sustainable than the other. Furthermore, insight was also gained regarding weavers' perceptions of threats to the wetlands and how they had changed over time, with fire identified as both a potential major threat to livelihoods and an area needing further study.

With little literature existing on *mahampy* wetlands in general, the results of the research carried out from 2020 – 2022 has provided key descriptive accounts of wetlands in the region. Gaps in knowledge were identified, with areas where further data collection or more detailed analysis can be performed defined. Findings will inform future research and areas of conservation intervention in Project Mahampy: Phase II.

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Annex I – Species Observed Per Wetland

	Wetland 9	Wetland 11	Wetland 14	Wetland 17	Wetland 21	Wetland 26
Bird Species						
Madagascar bee eater				1	2	1
Black swift	5	7	1	1		
Blue coua						
Blue pigeon		2		2		2
Common jerry	15	13	7	1	7	1
Common myna		17		18	1	14
Giant coua	1					
Green pigeon	1	5	2		1	
Green sunbird	1	8	7	4	1	5
Helmeted guinea fowl						1
Hook-billed vanga	5	3	7	1	1	2
Lesser vasa parrot	3		8	5	5	5
Madagascar bulbul	1		1			
Madagascar bush lark			5	10		1
Madagascar buzzard	2			1	1	
Madagascar cisticola	1	10	24	9		2
Madagascar coucal	8	5	7	5	9	4
Madagascar grey-headed lovebird		2	2		2	
Madagascar malachite kingfisher				4		1
Madagascar red fody				3	1	
Madagascar snipe			1			
Madagascar turtle dove		1				
Pied crow			6	1	2	1
Purple heron			8			2
Souimanga sunbird	29	32	28	14	18	24
White-faced whistling duck						1
White-throated rail	1	1	1	1		1
Yellow-billed kite					1	
Herpetofauna Species						
Blommersia blommersae	4	2	5		1	18
Dromicodryas bernieri	1					
Furcifer verrocosus	2					
Heterixalus boettgeri		1		2	1	
Mimophis mahfalensis						2

Phelsuma lineata	10	1	5		13	5
Phelsuma modesta		2				
Ptychadena mascareniensis				14	3	6
Trachylepis elegans	1					2
Trachylepis gravenhorstii	2				3	3

Annex II – Weaver Consultation Survey

Project Mahampy – Reedbed Harvest and Fire Survey [Delivered via Open Data Kit software]
Do you harvest mahampy reeds?
Contextual Mahampy Wetland and Harvesting Information
Which wetlands have you harvested from in the past three-months? Please check all that apply.
Why do you harvest in these wetlands? (Please check all that apply)
Which wetlands do you think have the best reeds?
Why do you think those wetlands are the best? (Please check all that apply)
Which wetlands do you think have the worst reeds?
Why do you think those wetlands have the worst reeds?
Do you agree or disagree with the following statement: "Wetlands that have better mahampy reeds also have more plants and animals"?
Do you disagree or agree with the following statement: "Wetlands that have better mahampy reeds also have clean water"?
Have you ever had to change where you harvest mahampy because the reeds were no longer good?
If "Yes", what was wrong with the reeds?
Mahampy Wetland Fire Regime Information
What is the biggest threat to the mahampy wetlands?
Other than fire, what do you think is the next biggest threat to mahampy reedbeds?
Which wetlands have you seen fires in or near during the time Barina has been the Chef Quartier of Sainte Luce?
How often have you seen or heard of fires happening in or near the mahampy wetlands?
Please fill in the blank: During the time Barina has been the Chef Quartier, I think fires in the wetlands are [].
What do you think is causing the fires in and around the mahampy wetlands?
How long do fires in and around the mahampy wetlands usually burn for?
Please fill in the blank: When a fire starts in or around a wetland, does it burn for [amount of time] it did before Barina became the Chef Quartier of Sainte Luce?
When you have seen a fire in or near the mahampy wetlands, how much of the wetland is usually burned?
One year after a fire event, is the wetland ok to harvest in again?
If "No", why can't you harvest there?
Fire Management Strategy Information
Do you think some wetlands are more at risk from fire than others?
If "Yes", which wetlands are more at risk from fire?
If "Yes", why are some wetlands more at risk to fire than others?
Should more be done to protect the wetlands from fire?
What strategies do you think could help protect the wetlands from fire?
Which wetlands would you want to see firebreaks around?
Would you yourself be interested in helping create firebreaks around some mahampy reedbeds to help prevent fires?