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Mapping Spatial Distribution, Abundance, and Habitat Use of Endemic Sunbirds in Gishwati-Mukura National Park, Rwanda

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Abstract

Gishwati-Mukura National Park (GMNP) is an Important Bird and Biodiversity Area (IBA) that hosts several Albertine Rift Endemic (ARE) bird species such as sunbirds. This study aimed at mapping the spatial distribution, abundance, and habitat use of endemic sunbirds within GMNP. Point Count Method (PCM) and presence-absence were used to record the data on 16 transects varying from 1 to 4.4 km. The findings revealed an abundance of 69 and 138 endemic sunbirds in Gishwati and Mukura forests, respectively. The Regal Sunbird had the highest relative species abundance (75% of observations), followed by Rwenzori Double-collared Sunbird (11%), Purple-breasted Sunbird (10%), and Blue-headed Sunbird (5%). The study also revealed 37 plant species used by endemic sunbirds in GMNP for foraging and/or habitat. Plant species in Gishwati are significantly different from those in Mukura forest ($p \leq 0.01$). Moreover, altitude was positively correlated with the abundance of endemic sunbirds, while canopy and DBH (distance at breast height) were negatively correlated. Our findings revealed a positive impact of the LAFREC (Landscape Approach to Forest Restoration and Conservation) project on bird diversity and provide new insights for further strengthening efforts to conserve the park's biodiversity. Further research is required which might consider seasonality.

Keywords: Albertine Rift Endemic Sunbirds, Habitat use, Spatial Distribution. and Species abundance

1. Introduction

Gishwati-Mukura National Park (GMNP) is considered an Important Bird and Biodiversity Area (IBA) (Nsabagasani & Nsengimana, 2009). It is located on the western Palearctic migration route

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in Rwanda (Vande Weghe & Vande Weghe, 2011) and is home to a large number of endemic, migratory, and threatened bird species. Among the 27 confirmed Albertine Rift Endemic (ARE) bird species recorded in Rwanda, 21 have been found in Gishwati and 20 in Mukura forests (Vande Weghe & Vande Weghe, 2011). Among the 209 bird species reported in Gishwati, 20 of them are endemic to the Albertine Rift, from which 10 are threatened (ARCOS, 2012; Kisioh, 2015; REMA, 2015; Uwimana, 2007). Based on the richness in endemic species including sunbirds, GMNP constitutes a unique tourism destination that can attract many tourists, and contribute to its successful management (R. a. REMA, 2017). For instance, the following sunbirds are Albertine Rift Endemics previously recorded in GMNP: Blue-headed Sunbird (*Cyanomitra alinae*), Purple-breasted Sunbird (*Nectarinia purpureiventris),* Ruwenzori Double-collared Sunbird (*Cinnyris stuhlmanni*), and Regal Sunbird (*Cinnyris regius)* (REMA, 2018). Sunbirds are pollinators and occupy a wide range of habitats. Most of those species are found in primary rainforest, others in disturbed secondary forest, open woodland, and open scrub (Kubwimana & Fawcett, 2009). Despite the importance of Gishwati and Mukura natural forests as the habitat for a large number of endemic and threatened birds, this area has been severely reduced due to human activities in the last two decades. The forests have lost about 99.7% of their local fauna (Kisioh, 2018). Gishwati was reduced from 250,000 ha to 28,000 ha in the 1980s and later to small patches (700 ha) (GoR, 2014a). On the other hand, Mukura has been reduced from 30,000 to nearly 15,000 ha, due to deforestation since 1951. Before the 1980s , the two reserves were protected by the government and other partners (Musabyimana, 2014; REMA, 2018). The shrinking of both natural forests may have led to the disappearance of their main flora and fauna, particularly birds (GoR, 2014a), and a reduction in the abundance of nectar-feeding birds as observed in other regions (Mnisi, 2017) for South Africa.

To address the declining natural forests, Rwanda has gazetted Gishwati-Mukura National Park (GMNP) in 2016 as the fourth national park to horn biodiversity conservation which is in line with the Aichi Target number 11 of the Convention on Biological Diversity.

This aims at increasing the network of global protected areas and in this regard, the Gishwati Area Conservation Program (GACP) reforested 598 hectares from 2008 to 2011 and increased the size of the Core Forest from 610 to 1,484 hectares (Oliver Hughes, 2014). On the other hand, in Mukura, 187 ha of forest naturally regenerated. The Landscape Approach to Forest Restoration and Conservation (LAFREC) project contributed to restoring the highly degraded Gishwati-

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Mukura landscape, enhancing both productive and environmental values (GoR, 2014b) and some species, making a positive impact not only on biodiversity conservation but also on tourism. Although Some research has been conducted in GMNP, including biodiversity surveys (REMA, 2018), nevertheless, there is still insufficient data on the occurrence, abundance, and habitat use of the individual bird species, especially the endemic and threatened species. More research and surveys are needed in the GMNP, particularly on endemic and endangered bird species to inform decision-makers and achieve effective conservation of such species since this was one of the objectives of the 10 years GMNP Management Plan and 3 years Action Plan (R. a. REMA, 2017). In 2013, ARCOS estimated the total value of Mukura to be $1 million per year while the values of Gishwati were estimated at $3 million per year (The New Times, 2017).

However, the forest reduction in the GMNP affected some bird species, and some expected birds are hardly found in GMNP (REMA, 2018). On one hand, with mentioned interventions made to rehabilitate GMNP, its forest cover increased, subsequently increasing the biodiversity, including endemic sunbirds. Mnisi (2017) mentioned the return of birds in the restored area while Urbanska, Webb, and Edwards (1997) argue that there is no assurance that pollinators will return. The increase of biodiversity, especially endemic sunbirds, could play significant roles in the plant community dynamics of recovering forest landscapes, indicators for other terrestrial biodiversity and are good starting points for setting conservation priorities (Julian et al., 2015). Knowledge about the population size and trends of common bird species is crucial for planning conservation actions. Due to limited research conducted, the core problem for planning remains the lack of information about abundance, distribution (Balmford, Crane, Dobson, Green, & Mace, 2005; Collen, Ram, Zamin, & McRae, 2008). In 2009, Nsengimana and Nsabagasani conducted a survey on all endemic birds in Gishwati only, while in 2019, REMA carried out a general biodiversity survey in GMNP (REMA, 2018). In addition, Inman and Ntokiyimana (2020) conducted bird surveys in Gishwati, but, all those researches didn't provide specific information on distribution, habitats used by endemic sunbirds and factors influencing their distribution in GMNP. Therefore, this study aimed to provide information on the abundance, distribution, and habitat use of Albertine Rift Endemic (ARE) sunbirds in GMNP. The specific objectives of this study were: 1. to assess the abundance of four endemic sunbirds species (Blue-headed Sunbird, Purple-breasted Sunbird, Ruwenzori Double-collared Sunbird and Regal Sunbird) within GMNP; 2. to determine the spatial

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distribution of these four ARE sunbirds; 3. to assess habitat use by these four ARE sunbirds species, and 4. to identify factors that influence their distribution in GMNP. This study provided baseline information to refer to in long-term monitoring of ongoing restoration by the LAFREC project and help in the development of ecotourism and bird watching plans in GMNP.

2. Materials and Methods

2.1. Description of the Study area

Mukura and Gishwati forest reserves are in the Western part of Rwanda (Figure 1) and constitute the fourth national park in Rwanda. GMNP is situated in Rutsiro and Ngororero Districts. Both forests were linked by a corridor between Rutsiro and Ngororero (Rema et al., 2014). However, both areas are today disconnected as a consequence of progressive deforestation from eight decades of transformation into agricultural lands and pasture and settlements in the surrounding areas, particularly following the settlement of refugees in the area in 1994 (GoR, 2014b). The Gishwati-Mukura National Park is composed of Gishwati and Mukura forest patches with a total area of 3,558 ha comprising an area of 1,570 ha for Gishwati forest and 1988 ha for Mukura forest reserve (GoR, 2016). Gishwati natural forest is located within Kigeyo, Nyabirasi, and Ruhango Sectors of Rutsiro district, while Mukura forest is located within Mukura, Rusebeya, and Ndaro Sectors of Rutsiro and Ngororero Districts (Figure 1).

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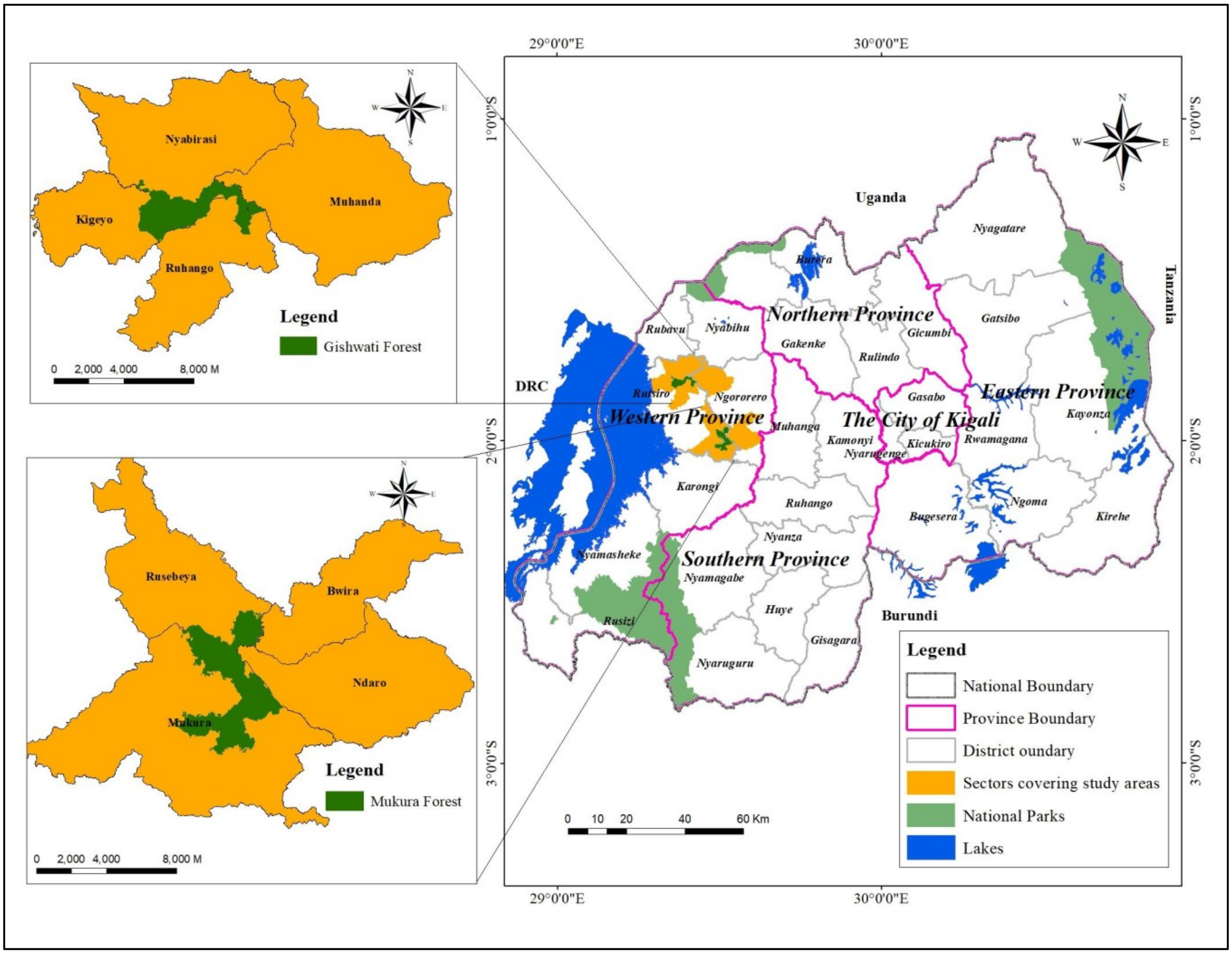

Figure 1: Location of Gishwati-Mukura National Park

The GMNP is a part of the Albertine Rift and Congo-Nile divide. It is composed of montane rainforest fragments that lie in the North-West of Rwanda (1° 49´S, 29° 22´ E). GMNP's climate is tropical with temperatures ranging from 20° to 24°C, the annual rainfall ranging from 1,500 to 1,600mm, and elevations from 2,000 to 3,000m (Blondel, 2006). The slope for Gishwati is 35% (Nyandwi & Mukashema, 2011).

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2.2. Study design

The current study was conducted from January 2019 to May 2020. Transect design and data collection was carried out in 60 days from May to August 2019. We designed a total of 16 line transects in GMNP (8 in Gishwati and 8 in Mukura, Figure 2). Transects varied from 1km to 4, 4 km in length, and two neighboring transects were separated by 400m. Each Transect has a different distance due to the irregular boundaries of the reserve, across different habitats (Ranner, 2021) and the location of the core area of forest was given priority than to the much more degraded habitat and zone of exotic plant (Inman & Ntoyinkama, 2020). No transect was designed in eastern part of Gishwati (zone of Kinyenkanda) as it was very disturbed due to mining (Muhire et al., 2021; Nyandwi & Mukashema, 2011) with low chance to observe endemic sunbirds (Paulo Catry et al., 2000). On each line transect, we designed systematic point counts; the distance between two neighboring points was 200 m. The radius of each point count was 30 m and was marked using a roller. GPS coordinates were taken for each point wherever possible to map the distribution of endemic sunbirds as well as other endemic birds.

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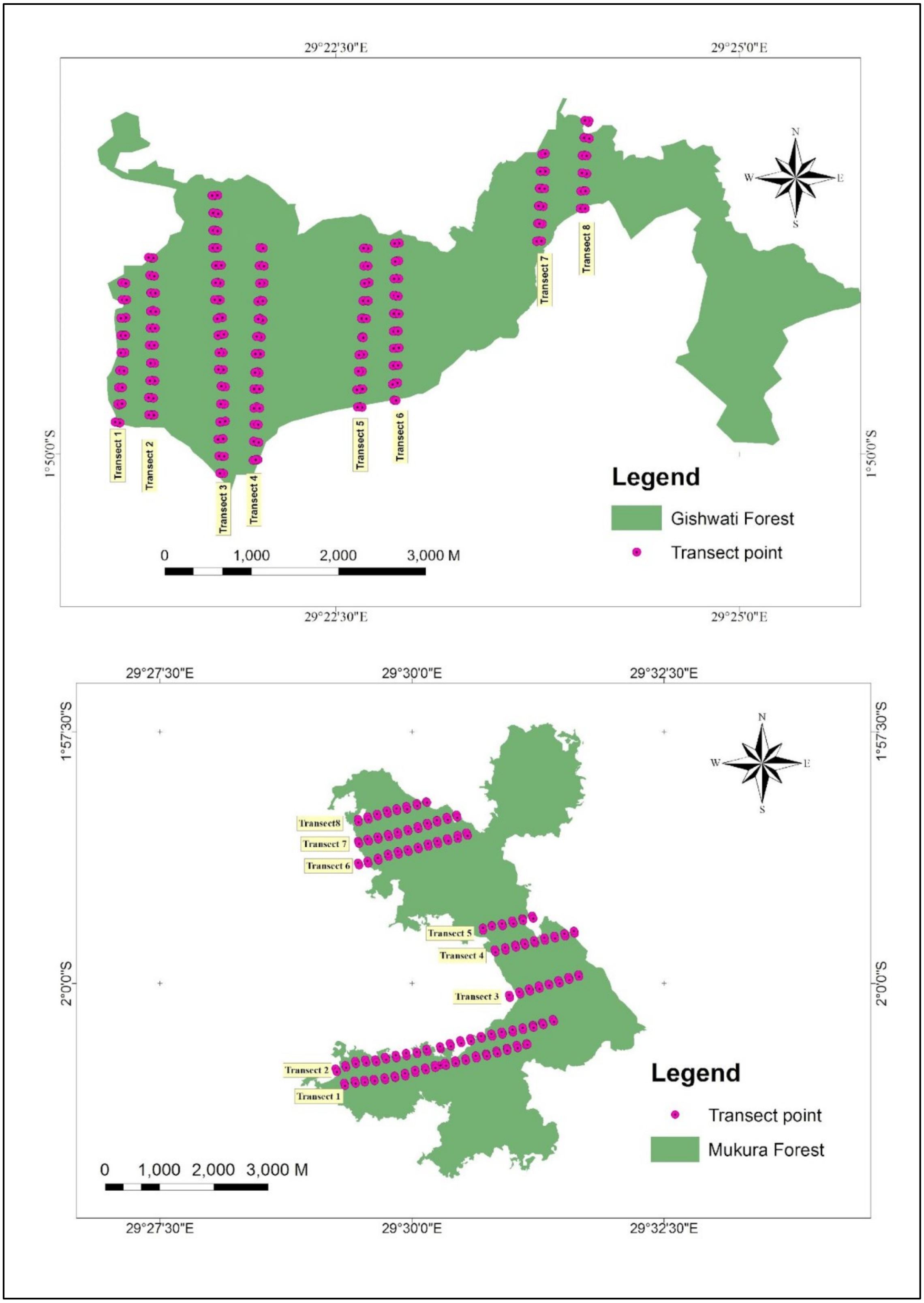

Figure 2: Designed transects in Mukura (Down) and Gishwati forest (Up)

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2.3. Data collection on endemic sunbirds and their habitat use

We conducted systematic point counts and presence-absence to gather data on species and abundance (Dornelas et al., 2012; Gatali & Wallin, 2015; Gibbons, Hill, & Sutherland, 1996; Volpato et al., 2009). A total of 176 points (95 in Mukura and 81 in Gishwati) were established (Figure 2). During recording, the observer went in 30-meter perpendicular to the transect on both right and left side of the transect in the place where sunbirds were not being disturbed. To avoid the edge effect from the transect, the central point count was taken at least 30 m away from the transect (Girma, Mamo, Mengesha, Verma, & Asfaw, 2017). We waited for 3 minutes at each point before counting to allow birds to settle down and resume normal behavior. We recorded all the birds seen or heard for a period of 10 minutes (Sutherland, 2000). Binoculars were used for bird identification as well as the Field Guide of Birds of East Africa by Steven and Fanshawe (2009). We also recorded habitat type, altitude, and GPS coordinates. Additional 3 minutes were used for collection of species feeding ecology observations.

Each point was surveyed two times. Surveys were conducted in the early morning between 6-10 am when birds are more active, and 2-5 hours before sunset (around 6:00 pm). Because the transect was long (~4000 m), on the following day, the morning count was started on the opposite side of the transect to maximize the sighting of endemic sunbirds which were most active in the morning time. Ornithologists and botanists for both birds and plant species identification and one local guide in data collection were part of the data collection team. Opportunistic recordings were conducted to maximize the number of sunbird species encountered in each point of the surveyed transect (Nsabagasani & Nsengimana, 2009). During recordings, the researcher used the field data sheets referring to those developed by O'Donnell and Dilks (1988) for quantifying the habitat used by forest birds. Collected data included names of bird species, observer's name, plant species, vegetation type, time, DBH, forest cover, activity, altitude, GPS coordinates, and tape meter to measure DBH of trees. Canopy cover estimations were made visually (Ochanda, 2012). After data collection, the data were entered into an excel sheet and arranged for analysis.

2.4. Data analysis

The abundance was calculated by the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), the relative abundance (%) =

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Isi/∑Nsi X 100 where, Isi = total number of individual species; ∑ Nsi = total number of species population (Nur, Jones, & Geupel, 1999). Data for habitat use was analyzed by computer to determine the frequency of histograms of habitat use for each sunbird species. Cross-tabulation of variables was also produced. Bird's preference for plants was provided by comparing the abundance of each plant species with its use by endemic sunbirds (O'Donnell & Dilks, 1988). All data were also summarized per plot per habitat type during both the morning count and the evening count in a table.

Both R-studio and Microsoft Excel were used for the charts and tables production, Bird species and habitat use distribution were mapped using ArcGIS software. The spatial distribution of endemic sunbirds was performed using ordinary kriging (Carroll & Pearson, 2000; Rauf, 2012). Plant community (habitat) similarity was calculated using the Sorensen index:

Sorensen's index $= CCs = \frac{2.C}{S1+S2}$ where S1 is the number of species in a given plot 1, S2: number of species in given plot 2, C: number of common species as used by REMA (2018). ANOVA was used in an Excel sheet to compare and check the difference in the abundance of endemic sunbird species per habitat (Singh, 2018). The relationship of the abundance of endemic sunbirds with factors that may influence the distribution of endemic sunbirds including elevation, habitat used, site, time of the count, DBH, food availability, and vegetation cover, were analyzed using linear and multiple regression in R-studio and Microsoft Excel.

3. Results

This section presents the results on abundance, spatial distribution, plants used by endemic sunbirds in GMNP and factors such as elevation, time of data collection, canopy cover, food types that influence the distribution of endemic sunbirds in GMNP.

3.1. Abundance of endemic sunbird species in GMNP

A total of 207 individual endemic sunbirds were recorded in GMNP. The higher Shannon–Weiner diversity index (H'=0.839742) was recorded in Mukura forest while the lower diversity index was recorded in Gishwati forest (H'= 0.78032)**.** This indicates that Mukura has higher endemic sunbirds abundance than the Gishwati forest. All four endemic Sunbirds species namely "Rwenzori Double-collared Sunbird, Purple-breasted Sunbird, Blue-headed Sunbird, and Regal Sunbird were recorded

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in both Mukura and Gishwati sites. The Regal Sunbird had the highest number of individuals identified (75%), followed by Rwenzori Double-collared Sunbird, (10.5%), Purple- breasted Sunbird (9.5%), while Blue-headed Sunbird had the lowest relative abundance (5%). Mukura forest hosts a higher number of endemic sunbird species compared to Gishwati forest ($p \leq 0.04$, Figure 3).

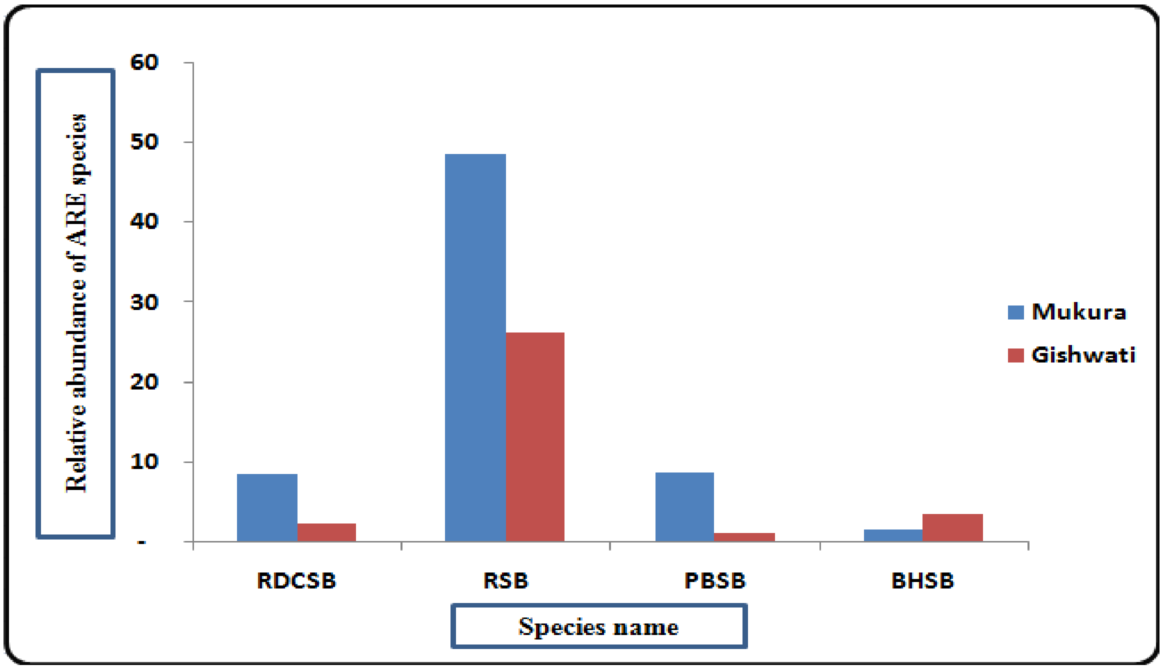

Figure 3: Relative abundance of endemic sunbirds compared between Gishwati and Mukura

BHSB: Blue-headed Sunbird, RDCSB: Ruwenzori-Double-collared Sunbird, RSB: Regal Sunbird, and PBSB: Purple-breasted Sunbird.

3.2. Spatial distribution of endemic sunbirds in GMNP

Figures 4a and 4b show the spatial distribution of endemic sunbirds in Mukura and Gishwati forests. Regal Sunbird and Rwenzori Double-collared Sunbird were more evenly distributed in Mukura forest than Blue-headed Sunbird and Purple-breasted Sunbird were found in some parts of Mukura forest (Figure 4a). This may be linked to the forest type which was a secondary forest. The exotic tree species were dominated by *Pinus Patula* and Eucalyptus *sp* which may not favor the endemic bird species (Goded et al., 2019). While in Gishwati forest, Regal Sunbird is distributed in the entire area (Figure 4b), Purple-breasted Sunbird was found only in one transect in the center of Gishwati forest and Blue-headed Sunbird was simply recorded in the western part of Gishwati. As shown in Figures 4 a&b, most of the endemic sunbirds were distributed in the core

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remaining forest. Figure 4c, shows a map of the vegetation cover of both Gishwati and Mukura forests, where 5 vegetation cover types named dense vegetation, sparse vegetation, bare soil, cultivated area, and water were classified. Core remaining forest (where ARE sunbirds were concentrated) is represented by dense forest, while bare soil (illegal mining) and sparse forest was degraded, especially in eastern zone of Gishwati under regeneration.

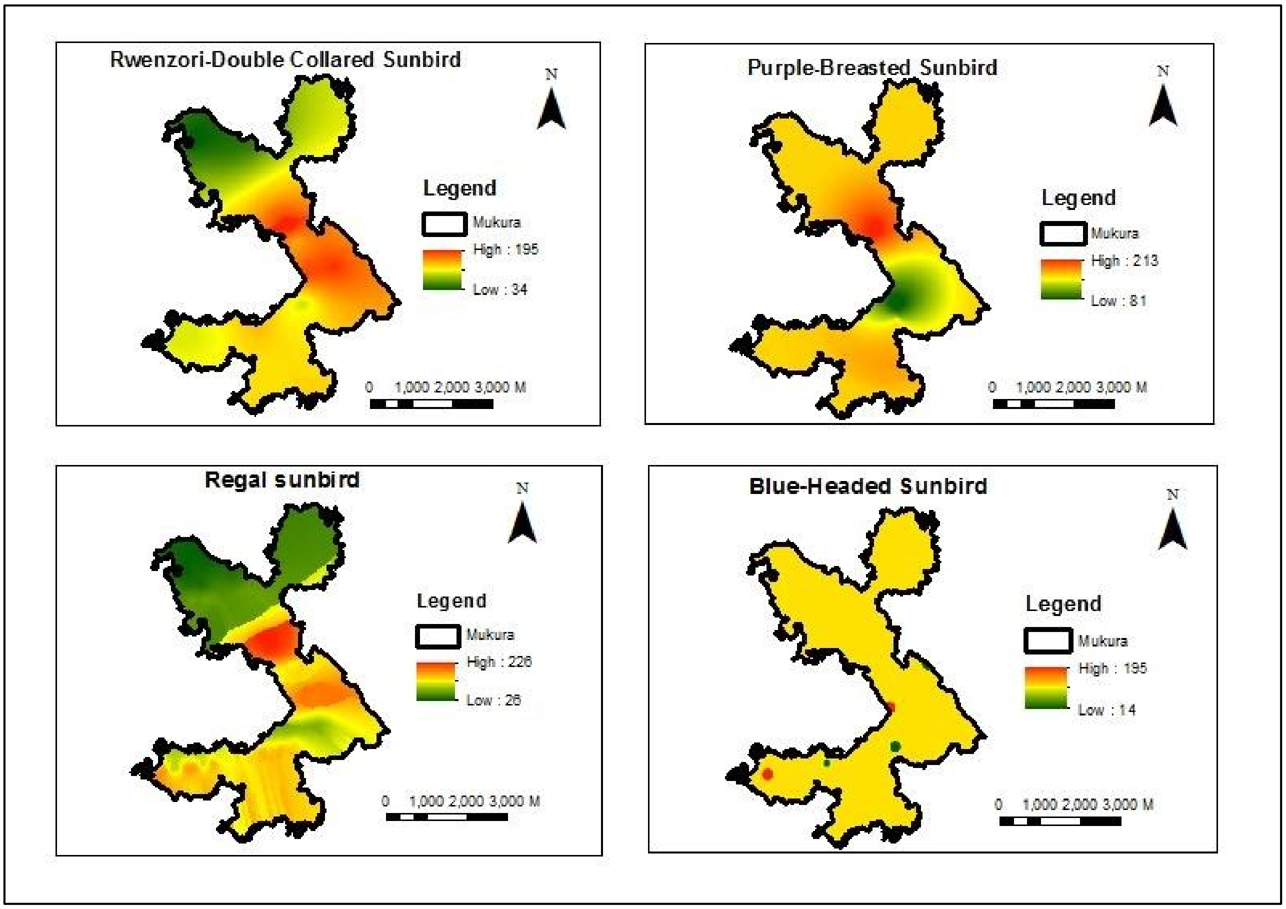

Figure 4a: Probability map of four endemic sunbirds' distribution in Mukura forest

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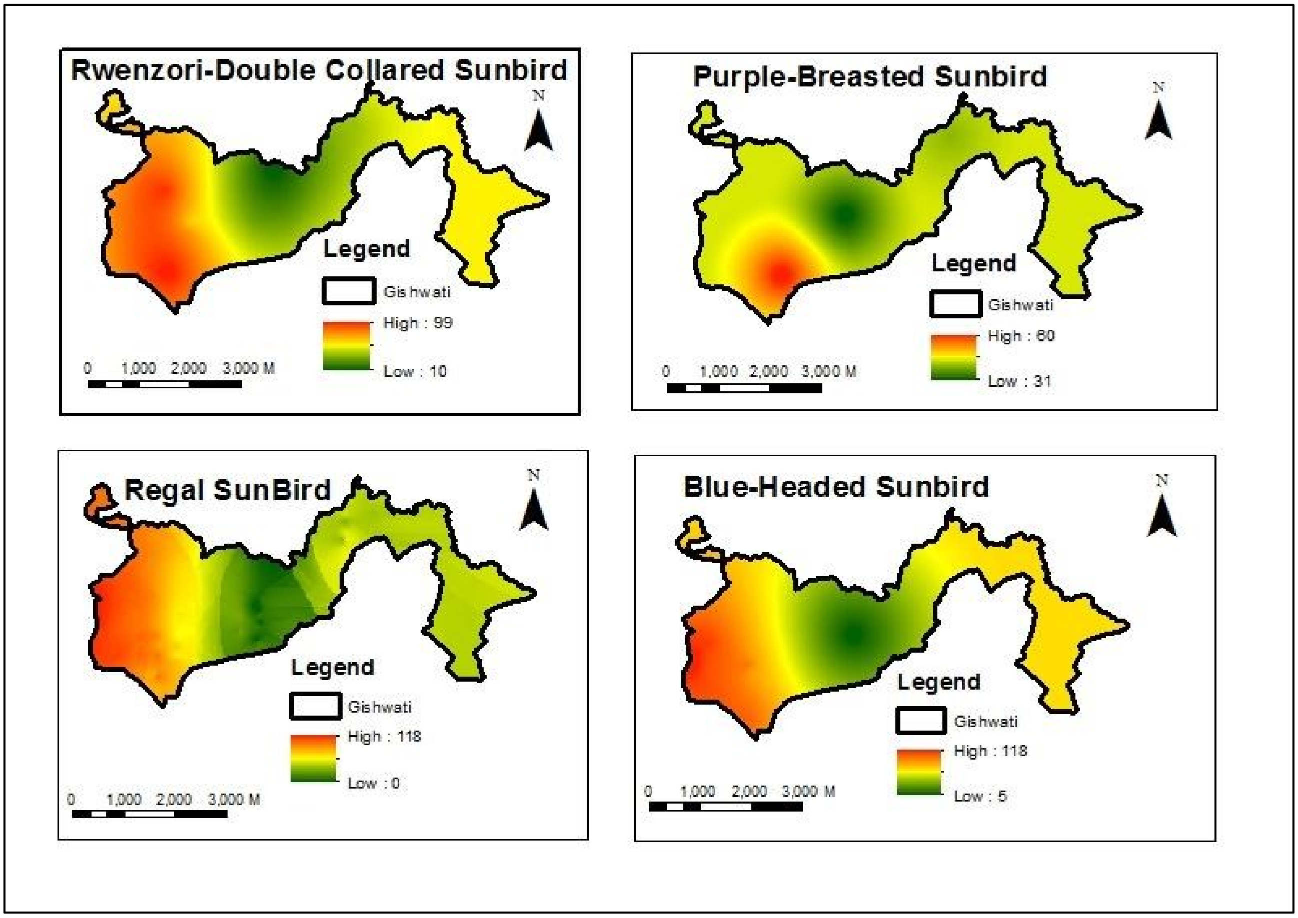

Figure 4b: Probability Map of 4 endemic sunbirds distribution in Gishwati forest

The probability map in Figure 4b indicates the likelihood that the number of individuals of species will exceed the observed median. Regal Sunbird is strongly associated with both Mukura and Gishwati forests. While Blue-headed Sunbird was weakly linked to Mukura forest. In Gishwati forest, the high distribution probability was found in the western part of the forest for the four endemic sunbirds (Figure 4b). This may be associated with core forest types with many indigenous tree species (Figure 4c), and many ARE sunbirds were recorded in this region.

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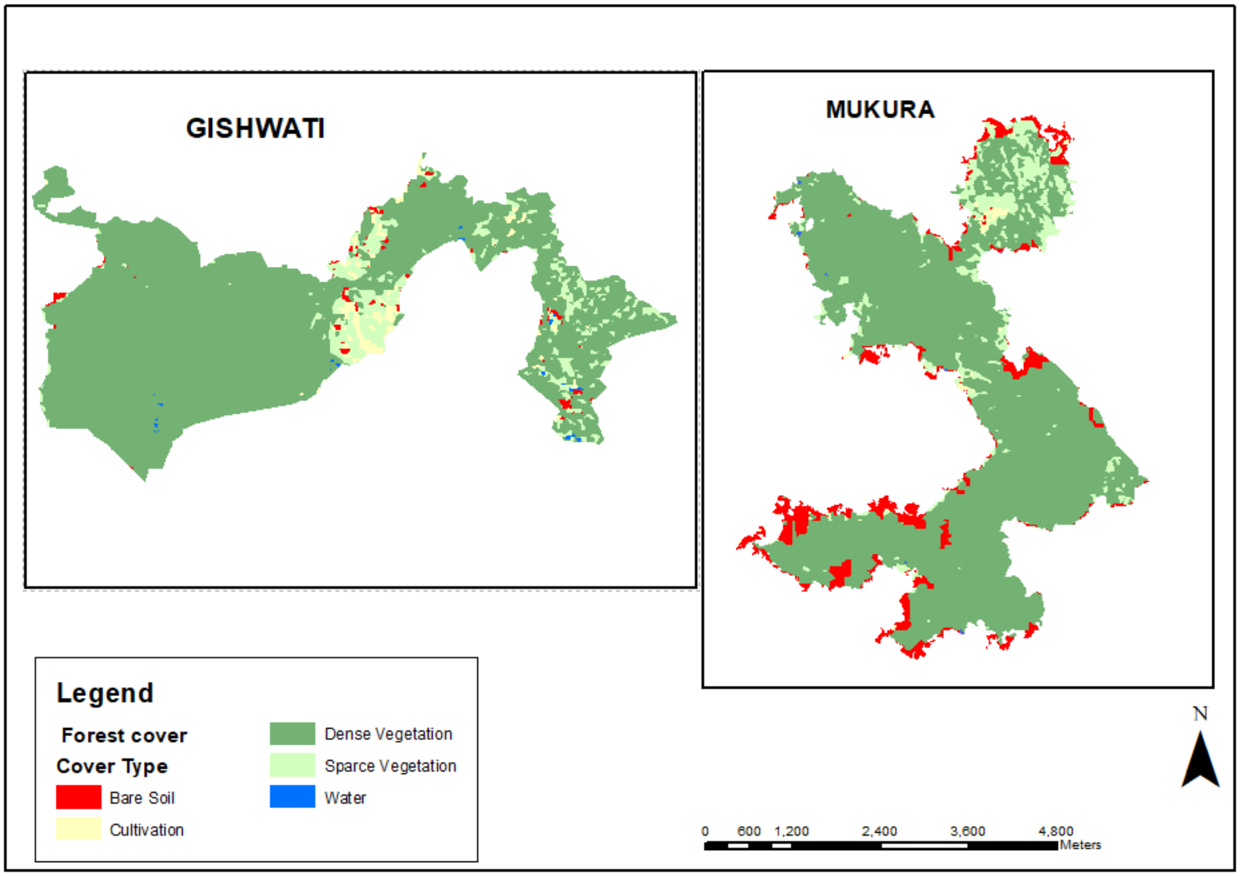

Figure 4c: Vegetation cover of Gishwati and Mukura forest

3.3. Plants/Habitat use by endemic sunbird species in GMNP

A total of 37 plant species were recorded as plants used by endemic sunbirds in GMNP, of which 27 in Mukura and 18 in Gishwati, 9 of them, were commonly used by these endemic sunbirds in both Mukura and Gishwati forests. In addition, 18 and 10 were exclusively only recorded as plants used by endemic sunbirds in Mukura and Gishwati, respectively (Table 1). Plant community similarity was calculated using Sorensen index= 2*9/27+19 = 0.4. This suggests that plants used by endemic sunbirds in Gishwati were different from those used in Mukura forest with similarity index approaching to zero and significant difference ($p \leq 0.01$, df=163), and among the plants used, *Macaranga kilimandscharica, Maesa lanceolata, Syzygium guineensee,* and P*sychotria mahonia* were most used by Regal Sunbird *(*n=*20,* 128 & 7, respectively), *Maesa lanceolata, Macaranga kilimandscharica,* and *Myrianthus holstii* were used by Blue-headed Sunbird (n=4 &3

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respectively), while *Maesa lanceolata* and *Syzygium guineense* were frequently used by Rwenzori Double-collared Sunbird (n=8 & 5 respectively) and S*ymphonia globulifera* was most used by Purple-Breasted Sunbird (n=9). *Macaranga kilimandscharica* was commonly used by all four endemic sunbirds in both sites (Table 1).

Table 1: Occurrence, location, of plant species used by endemic sunbirds in GMNP

	Gishwati				Mukura			
Plant / Bird species	**RSB**	**RDCSB**	**BHSB**	**PBSB**	**RSB**	**RDCSB**	**BHSB**	**PBSB**
Acacia meinsii	x	_	_	_	_	_	_	_
Acacia melanoxylon	x	x	_	x	_	_	_	_
Achyrospermum micranthum	x	x	_	_	x	_	_	_
Alangium chinense	x	x	_	_	_	_	_	_
Albizia gummifera	x	_	_	_		_	_	_
Balthasarea schliebenii	_	_	_	_	x	_	_	x
Bersama abyssinica	_	_	_	_	x	_	_	_
Bothriocline glomerata	_	_	_	_	x	_	_	_
Clutia abyssinica	_	_	_	_	x	_	_	_
Dombeya goetzenii	x	_	x	_	_	_	_	_
Erythrina abyssinica	x	_	_	_	_	_	_	_
Ficalhoa laurifolia	_	_	_	_	_	_	_	x
Galiniera coffeoides	_	_	_	_	x	x	_	_
Ipomoea involucrata	_	_	_	_	x	_	_	_
Loberia Giberroa	x	_	_	_	x	x	_	_
Macaranga kilimandscharica	x	_	x	_	x	x	_	x
Maesa lanceolata	x	x	x	_	x	x	x	_
Mikaniopsis usambarensis	_	_	_	_	_	x	_	_
Mimelodica phoentida	_	_	x	_	_	_	_	_
Mimulopsis solmsii	_	_	x	_	_	_	_	_
Myrianthus holstii	x	_	_	_	_	_	_	_
Neoboutonia macrocalyx	_	_	_	_	x	_	_	_
Ocotea usambarensis	_	_	_	_	x	_	_	_
Olinia rochitiania	_	_	_	_	x	_	_	_
Polyscias fulva	x	_	_	x	_	_	_	_
Psychotria mahonii	_	_	_	_	x	x	_	_
Rapanea melanophloeios	_	_	_	_	x	x	_	_
Schefflera goetzenii	_	_	_	_	x	_	_	_
Senecio maranguensis	_	_	_	_	x	_	_	_
Strombosia scheffleri	x	_	_	_	_	_	_	_
Symphonia globulifera	x	x	_	x	x	x	_	x
Syzygium guineense	_	_	_	_	x	x	_	x
Triumfetta cordifolia	_	_	_	_	x	_	_	_
Triumfetta rhomboidea	_	_	_	_	x	_	_	_
Vernonia auriculifera	x	_	_	_	_	x	_	_
Virectaria major	x	_	_	_	_	x	_	_
Xymalos monospora	_	_	x	_	x	_	_	_

X: presence of Sunbirds. -: Absence of Sunbirds.

Table 1 shows that many plant species were visited by endemic sunbirds in Mukura

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3.4. Plants used by endemic sunbirds and the LAFREC project rehabilitation

Among the plants used by endemic sunbirds, ARE, four plant species *Symphonia globulifera, Maesa lanceolata***,** *Myrianthus holstii*, and *Polyscias fulva* were planted by the LAFREC project.

3.5. Factors that influence the distribution of endemic sunbirds in GMNP

3.5.1. The relationship between the distribution of endemic sunbirds and elevation

The linear regression in Figure 5 illustrates the relationship of the abundance of endemic sunbirds in function to altitude in GMNP. Altitude was ranging from 2000 m to 2700m and grouped in 7 classes and represented by 1,2,3,3,4,5,6,7. Where 1= 2000-2100m, 2=2100-2200m, 3=2200-2300m, 4=2300-2400m, 5=2400-2500m, 6=2500m-2600m, 7=2600-2700m. Regarding the direction of lines on graph and equation, there is a positive relationship of altitude and total numbers of Regal Sunbird, Rwenzori Double-collared Sunbird and Purple-breasted Sunbird, and a slight negative relationship of altitude and Blue-headed Sunbird. Generally, when the elevation gradient increases, the number of endemic sunbirds increases. The high number of endemic sunbirds was recorded in altitude ranging between 2400-2500 m (Figure 5). Contrary, when the elevation gradient increases, the number of Blue-headed Sunbird significantly decreases ($p \leq 0.003$, df= 23).

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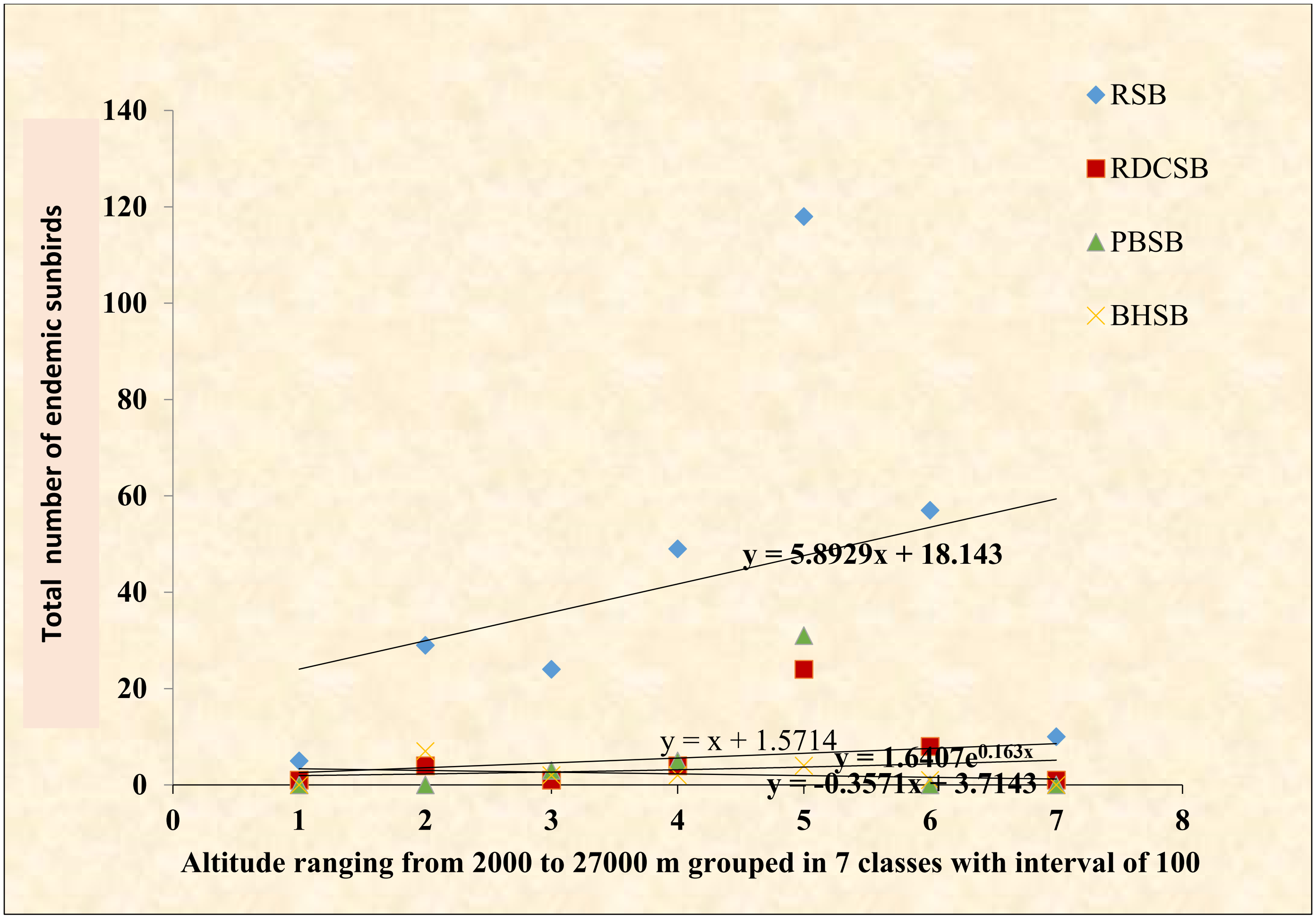

Figure 5: Relationship between the distribution of endemic sunbirds and altitude in GMNP

3.5.2. The relationship between the distribution of endemic sunbirds and time of data collection.

A high number of All 4 endemic sunbirds were found in the morning time. A total of 170 individuals of Regal Sunbird were recorded in the morning and 130 individuals in the afternoon. There was a significant difference between the times of collection ($p \leq 0.001$).

3.5.3. The relationship between the distribution of endemic sunbirds and canopy cover

Canopy cover had a negative correlation to endemic sunbirds as the canopy cover increases, the number of endemic sunbirds decreases (Figure 6).

The highest numbers of endemic sunbirds were recorded in canopy cover ranging between 30-40%. The difference between canopy covers was significant ($p \leq 1.44E\text{-}07$, df= 123).

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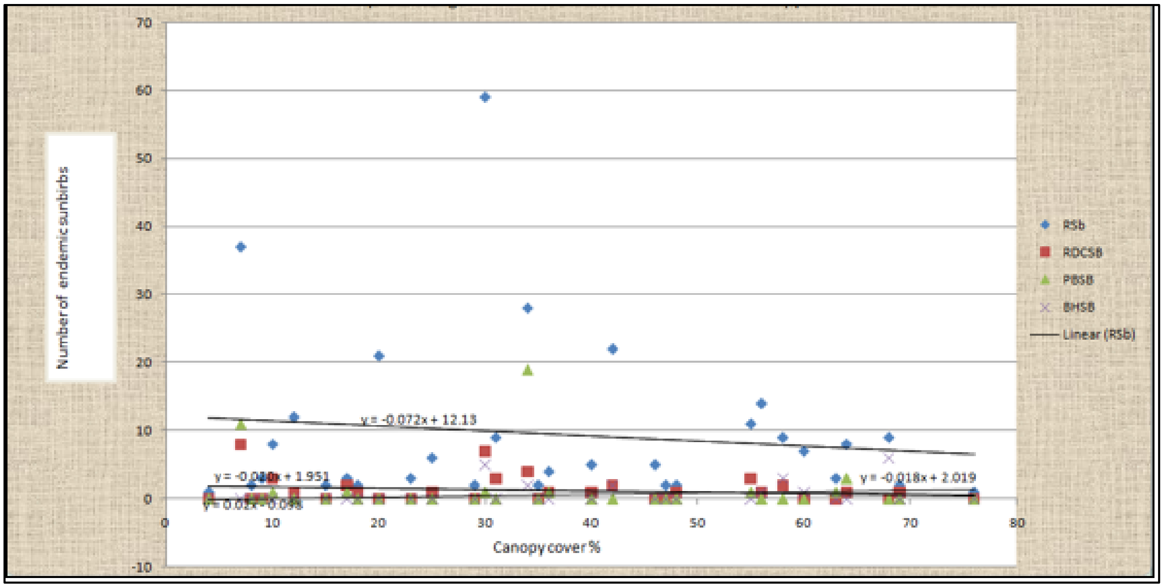

Figure 6: Relationship between the distribution of endemic sunbirds and canopy cover in GMNP

3.5.4. The relationship between the distribution of endemic sunbirds and food types

Both endemic sunbirds were grouped into two groups according to their types of food. Those were Insectivorous and Nectariniidae. Even if there was no significant difference in food used by the four endemic sunbirds ($p \leq 0.48$, df= 8), except Purple-breasted Sunbird, other endemic sunbirds used both nectars and insects. Both types of food were most used by the Regal Sunbird: 30 (42%) and 21(30%) individuals of Regal Sunbird used nectars and insects, respectively. Purple-breasted Sunbird used only one type of food (nectars) where 11(7%) individuals used nectars. Rwenzori Double-collared Sunbird and Blue-headed Sunbird used insects and nectars. In general, 61 % and 39 % of Sunbirds used nectars and insects respectively. The nectars were found on 13 plant species of which, the nectar of *Mimelodica phoentida* was used by Blue-headed Sunbird and *Symphonia globulifera* by Purple- breasted Sunbird.

3.5.5. The relationship between the distribution of endemic sunbirds and forest/habitat types

Forest types were grouped into mixed forest, primary forest, secondary, and wetland. The endemic sunbirds have used both forest/habitat types. Although there was no significant difference among endemic sunbirds that used those forest types ($p \leq 0.09$, df= 15), slightly higher abundance of Regal Sunbird with a total of 152 individuals were found in the primary forest followed by secondary

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forest with a total of 146 individuals. Regal Sunbird and Rwenzori Double-collared Sunbird were recorded in all habitat types, while Blue-headed Sunbird and Purple-breasted Sunbird were found only in primary and secondary forest.

3.5.6. The relationship between the distribution of endemic sunbirds and DBH

Figure7 represents the relationship between distribution of endemic sunbirds and DBH of trees, Group of DBH represented by **1**=0.1-0.4, **2**=0.5-0.8,**3**=0.9-1.2,**4**=1.3-1.6, **5**=1.7-2.0,**6**=2.0-2.3,**7**=2.4-2.7,**8**=2.8-3.1, **9**=3.2-3.5, **10**=3.6-3.9.

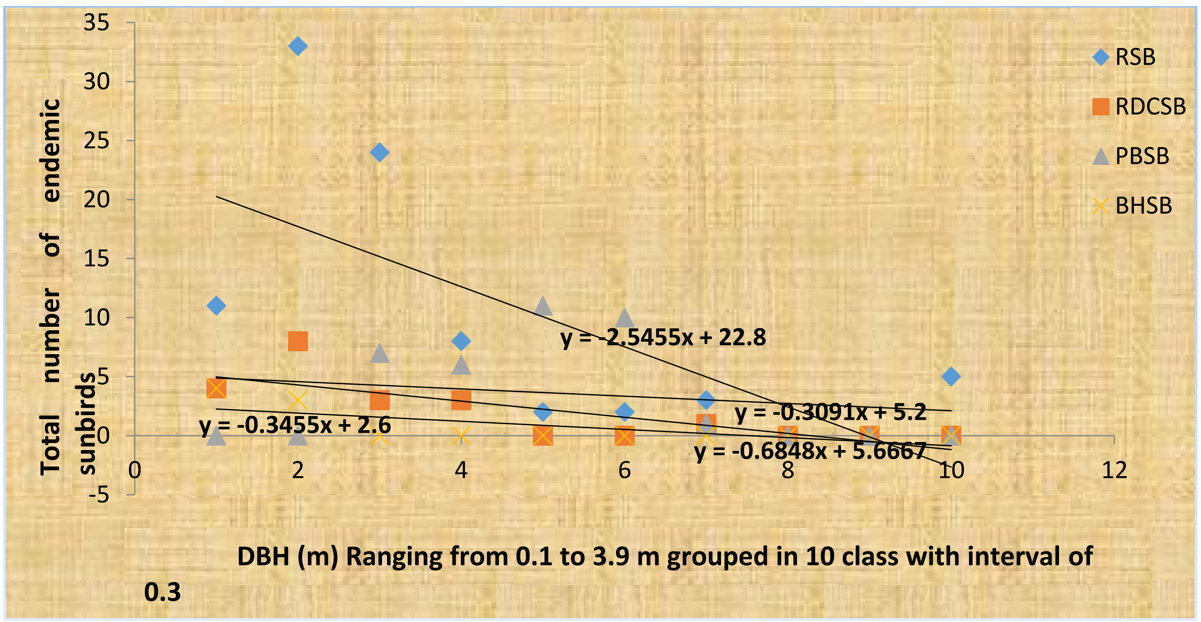

Figure 7: Relationship between the distribution of endemic sunbirds and DBH (m) in GMNP

The relationship of endemic sunbirds in function to DBH in GMNP, all endemic sunbirds in GMNP had a negative correlation with DBH, the higher DBH increased, the numbers of endemics sunbirds decreased (Figure 7). All four species used trees of significant difference of DBH ($p \leq 0.03$, df=39). The highest number of RSB and RDCSB with 33 and 8, respectively, were recorded in trees of DBH ranging from 0.4 to 0.8m, while the higher individual numbers of PBSB were found in trees of DBH ranging from 1.7 to 2.0 m. The highest DBH (3.82m) was recorded in *Symphonia globulifera,* followed by DBH of 3.62, 2.08m, and 2.03m for *Rapanea melanophloeios,*

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Macaranga kilimandscharica and *Olinia rochitiania* respectively*,* both used by Regal Sunbird while the lowest DBH is 0.3 m recorded in *Myrianthus holstii.*

4. Discussion

Compared to the Mukura forest, Gishwati had fewer endemic sunbirds. This could be linked to the timeframe of the survey with unfavorable phenology to sunbirds (Nsabagasani & Nsengimana, 2009) . In Gishwati, our survey was conducted at the end of the flowering period (end of July and early August) which normally diminishes the availability of nectars-food (Kalinganire, Harwood, Slee, & Simons, 2001) and yet, many species of endemic sunbirds feed on the nectars from flowers (Kubwimana & Fawcet, 2009). Also, the habitat types could have influenced the occurrence of sunbirds in both forests (Kubwimana & Fawcet, 2009). Compared to Gishwati, Mukura has a larger area of a core dense forest, which is the most favorite habitat for the sunbirds (Paulo Catry et al., 2000). Gishwati forest, on the other hand, has a higher domination by exotic plant species which not only are less attractive to the sunbirds but also disturb the natural regeneration processes (REMA, 2018; Uwimana, 2007). For instance, the Alnus glutinosa largely present in Gishwati was recognized as an invasive plant (Herron et.al., 2007) due to its competition ability which hinders the development of other tree species (REMA, 2018).

In contrast to the results of this study, Blue-headed Sunbird and Ruwenzori Double-collared Sunbird were not recorded in Mukura and Gishwati sites in earlier studies (Inman & Ntoyinkama, 2020; REMA, 2018). In comparison to this research, instead of regal sunbird, the individuals of Purple-breasted Sunbird were highest in Gishwati forest and in Volcanoes National park (Nsabagasani & Nsengimana, 2009) as well as higher occurrence in whole GMNP (RDB, 2017).

The distribution of endemic sunbirds in the West of Gishwati is probably linked to core forests with an abundance of native trees (Nsabagasani & Nsengimana, 2009). The higher probability value on regal sunbirds is probably associated with its highest abundance and many sampled points used in the model. This is similar to work done by (Garrison & Lupo, 2002) who found that model-based distribution maps are most accurate for species that are relatively abundant and have relatively large breeding ranges. The difference of plants/habitat used in Mukura and those of Gishwati is perhaps associated with a big part of Gishwati which was severely degraded and impacted slightly more plant species recorded (REMA, 2018). The high use of *Macaranga*

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capensis subsp. kilimandscharica, Symphonia globulifera, and *Syzygium guineense* trees by ARE Sunbirds may be related to the high abundance of those plants in both sites (REMA, 2018) and the abundance of these secondary trees species is evidently indicative of secondary forests in the progress of regeneration (REMA, 2018). This study confirms the use of plant trees including *Maesa lanceolata*, *Symphonia globulifera* by ARE sunbirds in Gishwati (Nsabagasani & Nsengimana, 2009). Every individual of Purple-breasted Sunbirds was found on *Symphonia* trees (RDB, 2017; Nsabagasani & Nsengimana, 2009). Unlike this study, *Croton macrostachis* was not recorded as a plant used by endemic sunbirds (Nsabagasani & Nsengimana, 2009).

Early succession species like *Triumphetta cordifolia* used by Regal Sunbird, and this plant species was previously dominant in the eastern part of Gishwati and over time, the diversity of plants species will increase because the present situation is part of natural vegetation dynamic following disturbance (REMA, 2018). Similar to this study, the presence and abundance of secondary forest tree species such as *Macaranga capensis* var. *kilimandscharica* and *Maesa lanceolata* highlighted the recovery and regeneration of the forest (REMA, 2018), which suggests the increase for endemic sunbirds due to intervention made by LAFREC to rehabilitate degraded areas by planting plants in GMNP. It was reported that birds and mammals including primates, help in seed dispersal in forest management (Gross-Camp, Masozera, & Kaplin, 2009), recommended having a priority to improve and accelerate natural regeneration of the forest (REMA, 2018).
Due to time and budget constraints, this study didn't cover the whole restored area that was highly degraded in Gishwati. Intensive survey of endemic Sunbirds and habitat use in this zone known as Kinyenkanda in Gishwati forest which is under passive regeneration (REMA, 2014), is required to provide baseline information for monitoring the effectiveness of LAFREC project.

Compared to Albertine Rift endemics of Virunga, no AREs were found in altitude higher than 3600 m while similar to other birds ,they are abundant in altitude between 2100 -2700m and start decreasing with an increase of altitude in Virunga massif (Owiunji et al., 2005). The results of this study are similar to those reported by Kubwimana and Fawcet (2009) on the positive correlation of altitude and number of Rwenzori Double-collared Sunbird in Volcano National Park, contrary to the numbers of Regal Sunbird decrease as the altitude increase (Kubwimana & Fawcett, 2009). Normally, this species occurs between 1,500-3,100 m (Birdlife-International, 2012), Rwenzori

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Double-collared Sunbird at 2000m, and Blue-headed Sunbird occupy a wide range to 4900m (Cheke, 2008). In this study, more individuals of Regal Sunbird were recorded between the altitude of 2400 to 2600 m which may be linked to the presence of many flowering trees including *Syzygium guineense* and *Macaranga kilimandscharica* which were recorded at that altitude. This study is in confirmation of the survey conducted by REMA (2018) which reported the frequent presence of Regal Sunbird at an altitude higher than 2200m. The observation of Rwenzori Double–collared Sunbird was also recorded in high altitude (>4,300 m) in Virunga massif (van der Hoek, Faida, Musemakweli, & Tuyisingize, 2020). The lower abundance of endemic Sunbirds in the Gishwati forest is probably related to the huge decrease in natural vegetation at a lower elevation of Volcanoes National Park as well as the total disconnection of Gishwati forest. This change in habitat availability might have pushed species ranges in higher elevation (Kanyamibwa, 1998). Similar experiences were recorded from other montane regions that practice intense deforestation at lower elevations (Grueter et al., 2013; Neate-Clegg, Jones, Burdekin, Jocque, & Şekercioğlu, 2018). Contrary, Gima, et al. (2017) reported higher relative abundance in the lower elevation of Wondo Genet Forest, Ethiopia, which was associated to varied characteristics of habitats in lower altitude, close to human settlements that provide a better chance of foraging and different nesting and roosting sites (Girma et al., 2017).

The results of this study confirms the findings from the study of Kubwimana and Fawcet (2009) who found the higher number of RSB and RDCSB in morning counts in Volcano National Park. Similarly, the bigger number of ARE Sunbirds present in the morning, coupled with the higher activity of Sunbirds in the morning. The difference is also influenced by the varying weather conditions (Sun, Huang, Chen, & Huang, 2017). This may be linked to some flowering plants which have more nectar in the morning and are reduced in the late morning due to evaporation and harvesting by birds, ants, and insects (Kalinganire et al., 2001). Sunbirds are specialized nectar feeders and depend on nectar for their energy requirements (Nsengimana & Nsabagasani, 2009). The ARE Sunbirds in GMNP may be attracted by the presence of flowering plants (Kubwimana & Fawcet, 2009). A study by Wolf (1986) suggested that nectar volumes may be important in relation to the variation in the visitation rates and foraging times of sunbirds (Kalinganire et al., 2001), and it is necessary to explore and quantify the nectar volume used by ARE Sunbirds in GMNP.

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The results of this study are also similar to those provided by (McWethy, Hansen, & Verschuyl, 2010) who mentioned that bird abundance decreases with canopy cover closure in the developed forest (McWethy et al., 2010) and contrary, the high number of birds found in closed-canopy at the higher upper forest (Chettri, Deb, Sharma, & Jackson, 2005). The higher abundance of ARE Sunbirds in the moderate canopy of 30-40%, slight open conditions which may give the enhanced position of food-gathering for a variety of species, making this a better habitat for a wide range of species (Raman, Rawat, & Johnsingh, 1998; Sawidis, Chettri, Papaioannou, Zachariadis, & Stratis, 2001).

GMNP has been disturbed and shows indications of recovery as it has secondary trees (REMA, 2018). The results of this study on the higher number of endemic Sunbirds used nectars in GMNP are slightly in confirmation that nectarivores are probably linked to disturbed habitat, which may possibly be due to the higher number of flowering plants under open conditions (Chettri et al., 2005; Laiolo & Rolando, 2003). A further deep study should confirm this information on more nectar availability and ARE Sunbird presence in a disturbed area of GMNP. Girma et al. (2017) reported insectivores to be abundant in agroforestry while most GMNP is occupied by native plant species. On the other hand, insectivores showed a significant relation with undisturbed habitat (Chettri et al., 2005) in closed-canopy with dense vegetation influenced by moist conditions and intense plants (Erwin, 1982). This may be the case for the Mukura site. The presence of more individuals of Regal Sunbird, Rwenzori Double-collared Sunbird, and Blue-headed Sunbird in the primary forest is in the same direction as the research conducted by (Nsabagasani & Nsengimana, 2009) where all endemic birds found in the core remaining forest of Gishwati. Purple-breasted Sunbird used more frequently the Symphonia trees in high dense forest. Even though tall trees are not common in the GMNP (REMA, 2018), the primary forest used by ARE Sunbirds included the tall trees and plants found in undisturbed areas of GMNP. Also, more individuals of ARE Sunbirds in secondary forest is possibly caused by the large area of GMNP which is in secondary trees forest including *Macaranga kilimandscharica* because of previous disturbance (REMA, 2018).

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5. Conclusion and recommendations

More endemic Sunbirds were observed in Mukura than in the Gishwati forest. Regal Sunbird is more widely distributed and have higher abundance than other endemic sunbirds in GMNP, although Rwenzori Double-collared Sunbird was reported to be abundant in the past. About 37 plant species were used by endemic Sunbirds in GMNP, nine of which were commonly used by endemic Sunbirds in both Mukura and Gishwati forest. Plants used by endemic Sunbirds in Gishwati were significantly different from those used in Mukura forest. This study suggests that S*ymphonia globulifera* is frequently used by Purple-breasted sunbirds**.** This research highlighted the important natural trees in GMNP especially *Macaranga kilimandscharica* which was used by all four species in both sites. The presence, use, and abundance of secondary forest tree species including *Macaranga spp.* highlighted the recovery and regeneration of forest in GMNP. Four plant species planted under the LAFREC project including *Symphonia globulifera and Maesa lanceolate* were frequently used by Purple-Breasted Sunbirds and Regal Sunbirds. This implies the role of those trees on endemic sunbirds which is promising the increase of habitat and abundance of sunbirds, ARE in GMNP. There was no significant difference among forest types (e.g., primary, secondary forest) used by endemic sunbirds.

The altitude showed a positive relation with sunbird distribution while the canopy and DBH were negatively correlated to the abundance of endemic sunbirds in GMNP. This result concluded that the season or period of survey (dry and wet) and a counting time of day (morning or afternoon) has a big influence on the abundance of endemic sunbirds in GMNP. In contrast, Purple Breasted Sunbird used only nectars. Although, there was no significant difference in food used by the four endemic sunbirds, this research provided baseline information necessary for monitoring and planning conservation of endemic sunbirds and promoting avitourism in GMNP.

Though, further research to provide more understanding and comprehensive information to guide conservation planning and actions are recommended.

This research recommends the following actions: (1). To conduct similar research in two different seasons in order to maximize seasonality data of ARE Sunbirds and regular monitoring of endemic sunbirds in GMNP for more understanding and better planning; (2) Comparative study on Regal Sunbirds and purple-breasted sunbirds is needed to confirm the findings of this study; (3) Further

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study to analyze the effect of environment on the spatial distribution of endemic sunbird and apply remote sensing to monitor the spatial-temporal dynamic of endemic sunbird in GMNP is recommended to provide comprehensive information for better conservation planning and decision making; and (4) Endemic sunbirds are more distributed and use the natural plant species/or habitat including those planted under LAFREC project, further strengthening conservation and rehabilitation efforts such as removing exotic plant species which might not favoring the endemic sunbird is required to increase natural habitat and the park's biodiversity.

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