African Journal of Ecology

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African Journal of Ecology

RESEARCH ARTICLE OPEN ACCESS

Testing Camera Trapping to Survey the Ground-Dwelling Bird Assemblage of Two Afromontane Rainforest Fragments in Rwanda

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Received: 10 June 2025 | **Revised:** 4 December 2025 | **Accepted:** 9 December 2025

Keywords: Albertine Rift Valley | bird diversity | community structure | evenness | Gishwati-Mukura NP | species richness

ABSTRACT

Ground-dwelling birds play vital roles in forest ecosystems, such as seed dispersal and pest control, but are vulnerable to habitat fragmentation and hard to detect using traditional survey methods. Camera traps offer a non-invasive, effective alternative for monitoring these elusive species, especially in difficult terrain and over extended periods. Camera trapping can enhance data collection on species behaviour, distribution and diversity, especially on rare, elusive species. The Albertine Rift Valley, a biodiversity hotspot, is home to many endemic bird species, yet their ecology remains poorly understood. A study in Rwanda's Gishwati-Mukura National Park used camera traps to assess bird diversity and compare two forest fragments. The study used 64 camera traps arranged in 4×4 grids across Gishwati and Mukura Forests from May 2017 to May 2018. Images were analysed for ground-dwelling birds using defined photographic events. Species richness was assessed through rarefied species accumulation curves and Jacknife-2 estimators. Diversity was measured using Shannon, Simpson, and evenness indices, which were subsequently compared between forest fragments. Bird community composition was examined using Detrended Correspondence Analysis. Eighteen bird species were recorded, with similar richness and diversity in either forest, though Mukura showed greater species heterogeneity, that is, greater variation in species composition. Detection rates were limited due to insufficient sampling effort, suggesting true species richness may well exceed 20 species. Some rare and endemic species were documented, highlighting camera trapping to be a valuable supplement to traditional survey methods. Despite habitat disturbance, both forests maintain healthy bird communities. However, more extensive sampling is needed to improve precision and to better understand community structure and species turnover between forest fragments.

1 | Introduction

Ground-dwelling birds play important ecological roles in forest ecosystems, including the dispersal of seeds (e.g., ground-dwelling doves, finches; Caves et al. 2013; Estrada-Villegas et al. 2022), regulating small mammal populations (e.g., birds of prey; Korpimäki 1984; Norrdahl and Korpimäki 1995), or controlling insectivorous pest species (insectivorous birds; Sekercioglu et al. 2002; Monteagudo et al. 2023). Given these diverse functions, changes in their abundance or distribution can have cascading effects on forest structure and dynamics (Gumede, Ehlers Smith, Ehlers Smith, et al. 2022; Gumede, Ehlers Smith, Ngcobo, et al. 2022; Bitani et al. 2023). Forest birds are particularly vulnerable to forest fragmentation and degradation, especially those species that are rare forest specialists or unable to disperse across human-modified habitats such as secondary forest, woodlots or home gardens (Lampila et al. 2005; Korfanta et al. 2012; de Matos et al. 2018; Timmers et al. 2022; Weeks et al. 2023). They are often elusive and difficult to detect, putting an obstacle on traditional survey methods, such as visual or acoustic point counts (Jiménez et al. 2003; Colyn et al. 2020; Jean-Pierre et al. 2022). Such constraints make camera trapping a valuable alternative to survey ground-dwelling forest birds in tropical forest ecosystems (O'Brien and Kinnaird 2008; Burton et al. 2015; Moore et al. 2020; Vargas-Daza et al. 2023). Using camera traps allows non-invasive monitoring of bird species dwelling, foraging or nesting on the ground and facilitates—unlike traditional methods—the collection of continuous long-term data, increasing the likelihood of detecting species with crepuscular or nocturnal activity patterns (O'Brien and Kinnaird 2008; Ortmann and Johnson 2021; Joel et al. 2024). Moreover, camera traps can capture data in areas that are difficult to access, increasing the chance to detect rare or cryptic species, especially when paired with species-specific attractants like baits, replayed calls or nesting aids (O'Brien and Kinnaird 2008; Fontúrbel et al. 2020; Joel et al. 2024). Camera trapping data provide verifiable records on habitat utilisation (Winarni et al. 2009; Pérez-Irineo et al. 2021; Feldman et al. 2024), distribution (Jeganathan et al. 2002; Jean-Pierre et al. 2022; Nordin et al. 2025), abundance (Ramesh and Downs 2014; Jean-Pierre et al. 2022; Mo et al. 2021), and occupancy (Murphy et al. 2018; Jean-Pierre et al. 2022; Abrha et al. 2023), and they are increasingly applied in community studies to estimate richness, diversity, and evenness (Burton et al. 2015; Meng et al. 2021; Wearn et al. 2022; Nguyen et al. 2025). However, some studies analysing and interpreting camera trapping data of forest birds urged caution, since precision is a function of the number of trapping sites and days, the distance between bird and camera, and the size of the bird species (O'Brien and Kinnaird 2008; O'Brien 2010; Randler and Kalb 2018; Tanwar et al. 2021). Moreover, camera trapping

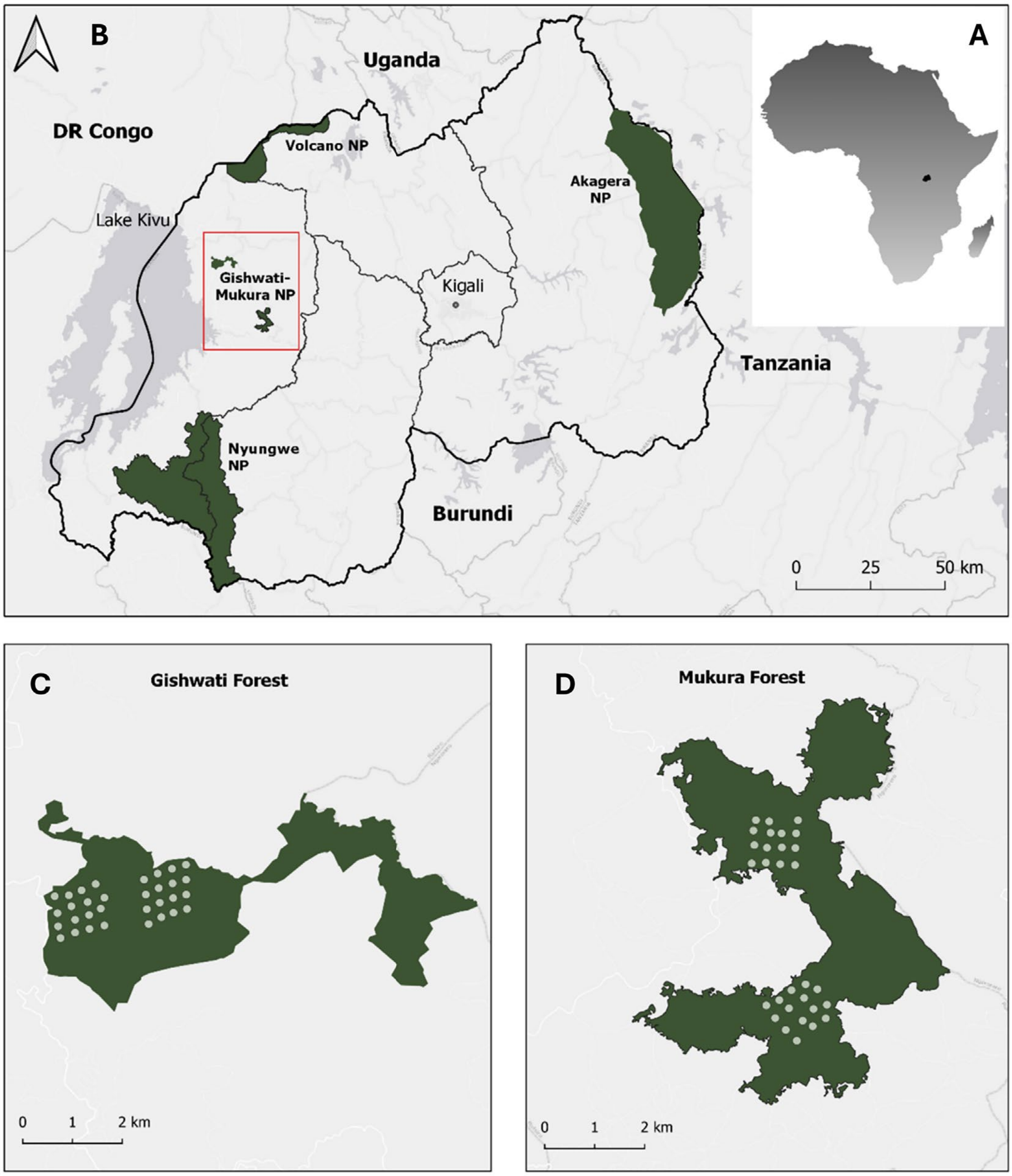

FIGURE 1 | Location of Rwanda in Africa (A), location of Gishwati-Mukura NP in western Rwanda (B) and locations of four camera-trapping grids in Gishwati (C) and Mukura Forest (D).

surveys can be limited by high equipment costs (Glover-Kapfer et al. 2019), risk of theft or vandalism (Meek et al. 2019), or by difficulties detecting small or fast-moving species due to trigger speed and sensor limitations or poor placement (Walton et al. 2022).

The forests of the Albertine Rift Valley are considered a major biodiversity hotspot, being home to a variety of endemic plant and animal species (Brooks et al. 2001; Plumptre et al. 2007, 2016), many of which are threatened due to ongoing deforestation and habitat fragmentation (Twongyirwe et al. 2015). The region hosts 40% of Africa's mammal and 50% of bird species, of which 4% (41 of 1061) are endemic (Stattersfield et al. 1998). Out of this, 310 bird species are Afromontane rain forest dwellers, most of which occur in the forests of western Rwanda (Vande Weghe and Vande Weghe 2011). Despite numerous threats faced by tropical forest birds—such as habitat loss and degradation (Moore et al. 2008; Betts et al. 2022; Mills et al. 2023; Socolar et al. 2025), international wildlife trade (Symes et al. 2018; Zanvo et al. 2024) and predation by invasive carnivores (Morgan et al. 2022; Wampole et al. 2024)—their ecology remains often unknown and poorly understood (Pollock et al. 2022). In our study, initially set up to survey mammals (primates, ungulates and carnivores; Sun et al. 2022), we looked at ground-dwelling forest birds across two forest fragments of pristine Afromontane rain forest within the Gishwati-Mukura National Park, Rwanda's youngest protected area (Kisioh 2015). In our study we made use of the frequent detection of non-target species from camera traps (i) to align our bird inventory to species lists published by Vande Weghe and Vande Weghe (2011) and Inman and Ntoyinkama (2020), (ii) to investigate whether species richness of ground-dwelling birds can be reasonably established using camera traps and (iii) to compare the diversity and community composition of ground-dwelling birds between Gishwati and Mukura Forest fragments.

2 | Material and Methods

2.1 | Study Area

As part of the Congo-Nile Divide Forest complex, Gishwati-Mukura National Park (NP) represents two isolated forest fragments located on the eastern escarpment of the Albertine Rift Valley in western Rwanda (Gishwati Forest: 1°49′S, 29°22′E; Mukura Forest: 1°59′S, 29°31′E; Figure 1B). The core areas have a total size of 34.3 km^2 (Gishwati Forest: 14.4 km^2, Mukura Forest: 19.9 km^2), comprising an indigenous Afromontane high-altitude rainforest. Both fragments are surrounded by a matrix of farmland, pastures and forest plantations (woodlots of *Pinus*, *Eucalyptus*, and *Alnus*) partly included in the national park (Rwanda Environment Management Authority [REMA] 2015; Rwanda Development Board [RDB] 2015; United Nations Environment Program-World Conservation Monitoring Centre [UNEP-WCMC] 2020). The region is mountainous, characterised by steep slopes (mean 35%) with an altitudinal range from 2300 to 2700 m asl. The mean annual temperature is 15°C–17°C, while mean annual rainfall reaches between 1200 and 1500 mm (Safari 2012). Despite severe deforestation (i.e., decreasing size and increasing fragmentationin the past), both forest fragments still have substantial biodiversity, including three primate species, 250 plant species (Kisioh 2015) and about 200 bird species (including 20 Albertine Rift endemics; Vande Weghe and Vande Weghe 2011; Inman and Ntoyinkama 2020). Locations of camera-trapping grids were selected to reflect natural habitat

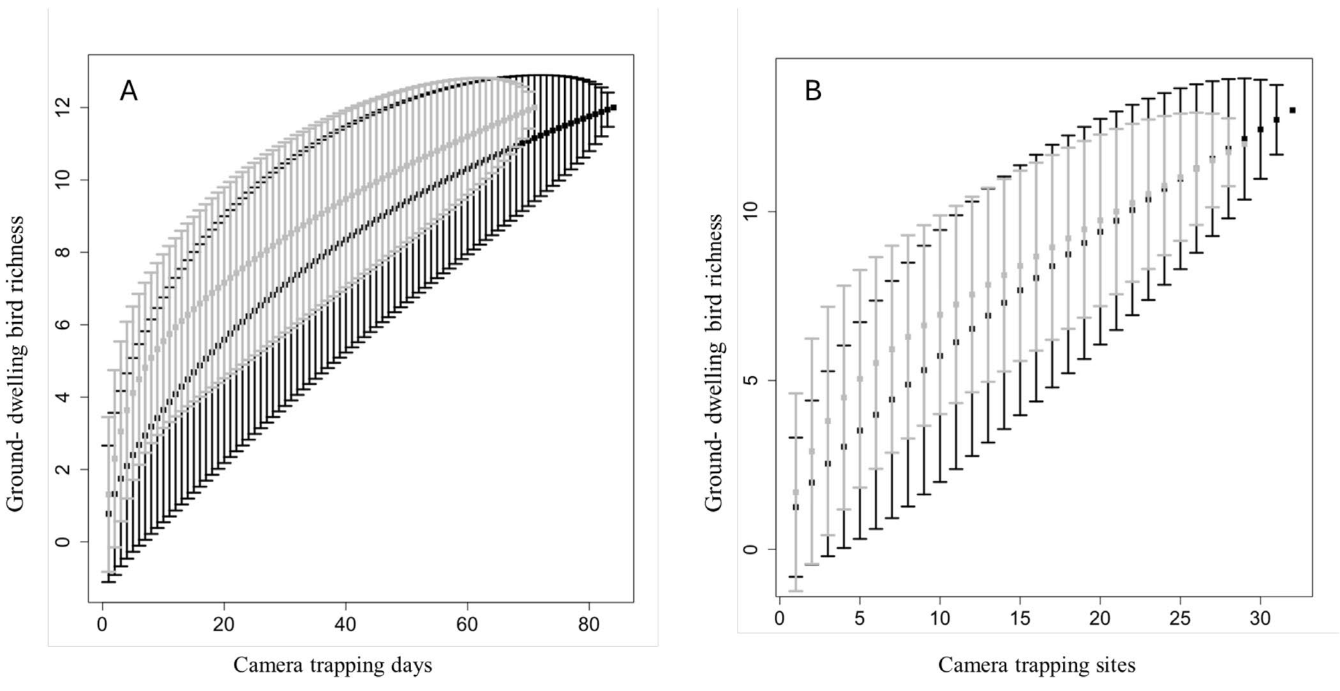

FIGURE 2 | Species accumulation curves plotting cumulative species richness against number of camera trapping days (A) and camera trapping sites (B) in Gishwati Forest (black) and in Mukura Forest (grey). The dotted line indicates the expected mean species richness; error bars indicate the 95% conference intervals.

TABLE 1 | List of ground-dwelling bird species recorded by camera traps in Gishwati and Mukura Forest (values represent numbers of independent photographs per species), their functional guilds, conservation status, whether they are ground-dwellers (g) or ground visitors (v), and their naïve occupancy.

Vernacular name	Scientific name	Functional guild	Conservation status	Ground-dweller or visitor	Naïve occupancy (this study)		No of images (his study)		Vande Weghe and Vande Weghe (2011)		Inman and Ntoyinkama (2020)
					Gishwati	Mukura	Gishwati	Mukura	Gishwati	Mukura	Gishwati
Handsome Francolin*	*Pternistis nobilis*	Graminivore	LC	g	0.719	0.483	80	28	x	x	x
Scaly Francolin	*Pternistis squamatus*	Omnivore	LC	g	0.031	0.000	1		x	x	x
Common Quail	*Coturnix coturnix*	Omnivore	LC	g	0.031	0.000	1		x	x	
African Goshawk	*Aerospiza tachiro*	Carnivore	LC	v	0.031	0.000	1		x	x	x
Buff-spotted Flufftail	*Sarothrura elegans*	Insectivore	LC	g	0.031	0.034	2	1	x	x	
Tambourine Dove	*Turtur tympanistria*	Graminivore, Omnivore	LC	v	0.063	0.241	3	34	x	x	x
Blue-spotted Wood Dove	*Turtur afer*	Graminivore	LC	g	0.000	0.345		24	x	x	x
Red-eyed Dove	*Streptopelia semitorquata*	Graminivore, Frugivore	LC	v	0.031	0.034	1	1	x	x	x
Nightjar spec.	Caprimulgiformes	Insectivore	LC	g	0.031	0.000	1				
Mountain Illadopsis*	*Illadopsis pyrrhoptera*	Insectivore	LC	g	0.000	0.069		3	x	x	x
White-starred Robin*	*Pogonocichla stellata*	Insectivore, Frugivore	LC	g	0.000	0.034		1	x	x	x
Red-throated Alethe*	*Chamaetylas poliophrys*	Insectivore	LC	g	0.031	0.000	1		x	x	x
Equatorial Akalat*	*Sheppardia aequatorialis*	Insectivore	LC	g	0.094	0.034	4	2	x	x	x
Archer's Robin-Chat*	*Dessonornis archeri*	Insectivore	LC	g	0.031	0.034	2	1	x	x	x
Red-capped Robin-Chat	*Cossypha natalensis*	Insectivore, Frugivore	LC	g	0.031	0.000	1				x

(Continues)

TABLE 1 | (Continued)

Vernacular name	Scientific name	Functional guild	Conservation status	Ground-dweller or visitor	Naïve occupancy (this study)		No of images (his study)		Vande Weghe and Vande Weghe (2011)		Inman and Ntoyinkama (2020)
					Gishwati	Mukura	Gishwati	Mukura	Gishwati	Mukura	Gishwati
African Thrush	*Turdus pelios*	Omnivore	LC	g	0.094	0.310	10	16			
Familiar Chat	*Cercomela familiaris*	Insectivore	LC	v	0.000	0.034		1			
Dusky Crimsonwing*	*Cryptospiza jacksoni*	Graminivore	LC	g	0.000	0.034		1	1	x	x

Note: Observations are aligned with presence/absence data reported by Vande Weghe and Vande Weghe (2011) and Inman and Ntoyinkama (2020). Asterisks indicate Albertine Rift endemics.

conditions, while also ensuring accessibility and practicality for camera installation and maintenance.

2.2 | Camera Trapping

The survey design consisted of 16 camera trapping points, placed at 300-m intervals on a regular 4×4 square grid. Equal numbers of cameras were used in both sites to standardise effort, despite lower coverage in Gishwati Forest. The grid was located to align with the remaining patches of natural habitat in Gishwati and Mukura Forest, which represent the core area of the current National Park (Kisioh 2015; Figure 1C,D). Each study site included two camera trapping grids (Figure 1C,D), covering an area of 1.2×1.2 km (2.88 km^2 per forest fragment), corresponding to a total of 64 camera trapping locations and a trapping density of one trapping location per 0.05 km^2. Camera traps (Ltl Acorn 6310, Shenzhen, China) were installed within 50 m from each grid centroid, about 30–50 cm above ground. Passive infrared sensors were set to capture only one image per event, with a trigger time of 0.1 s and a detection range of 25 m. Due to logistical and financial limitations, camera trap grids were sampled one after the other rather than at the same time. Camera trapping was carried out between May 2017 and May 2018, encompassing dry and wet seasons in each forest (for temporal patterns of wet and dry seasons in western Rwanda see Sebaziga et al. 2024). Recording was continuous, in Gishwati Forest from 10 May to 18 August 2017 (wet and dry season; 100 trapping days), and from 16 August to 17 November 2017 (wet season, 93 trapping days). Sampling in Mukura spanned from 4 December 2017 to 4 February 2018 (dry season; 62 trapping days) and from 5 February to 11 May 2018 (dry and wet season; 95 trapping days).

2.3 | Data Collation and Processing

We employed the Exiv2 software tool (Huggel 2012) to extract images and metadata, including the camera trap ID, date and time of capture. Ground-dwelling and ground-visiting birds were identified to species level and organised into independent photographic events. An event was defined as a sequence of images of the same species, separated by at least 60 min from the last image of that species (Tobler et al. 2008; Amin et al. 2015). To calculate the time intervals between images, we used the 'lubridate' package (Spinu et al. 2020) in R. Species identification was grounded on Stevenson and Fanshawe (2002) and reinforced using bird species lists of Gishwati and Mukura Forest (Vande Weghe and Vande Weghe 2011; Inman and Ntoyinkama 2020; Table S1).

2.4 | Camera Trapping Effort and Naïve Occupancy

Camera trapping efforts—measured by both the number of camera trapping sites and days and—were evaluated to verify whether they were sufficient to detect most species in the study area. We applied sample-based rarefied species accumulation curves (SACs) on species-by-sampling-unit incidence matrices and plotted the cumulative species richness against the number of camera trapping days or sites. SACs help to identify the

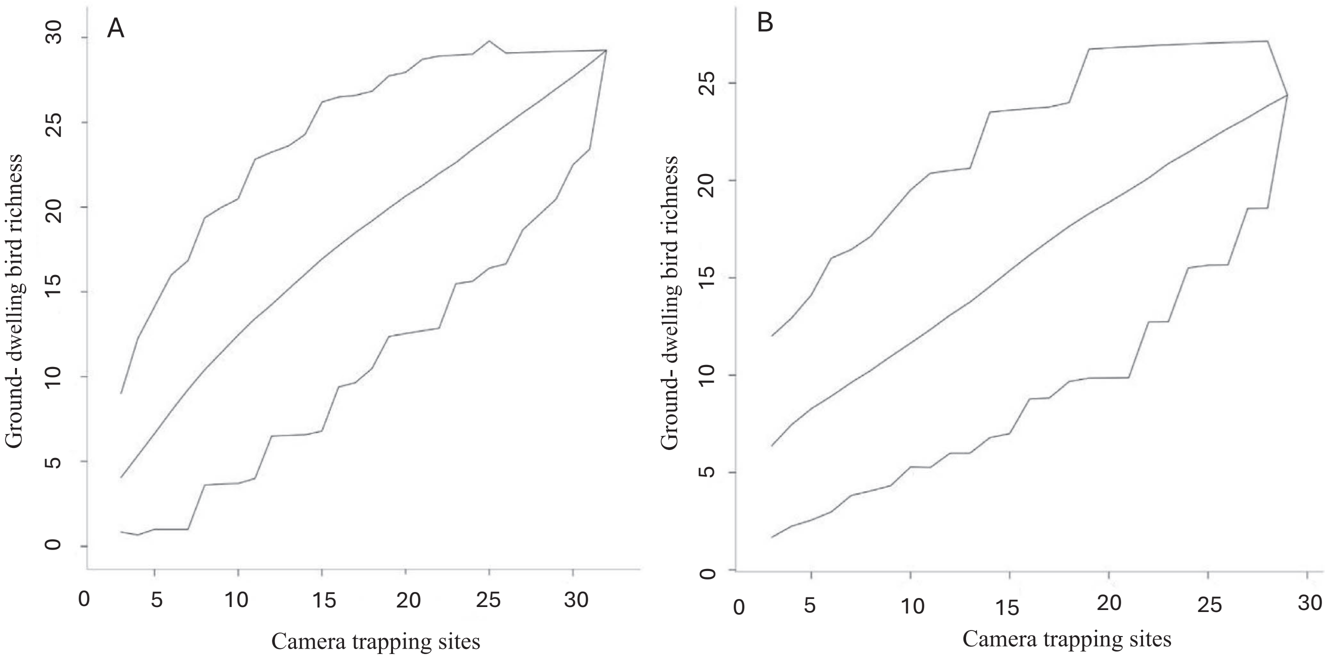

FIGURE 3 | Estimated true species richness of ground-dwelling birds from camera traps in Gishwati Forest (A) and Mukura Forest (B), calculated using the Jackknife-2 method. The solid line represents the mean species accumulation curve, while the upper and lower lines represent the 95% confidence intervals.

optimal sampling efforts by indicating the threshold at which additional sampling would result in no—or minimal—further increase in species richness (Thompson and Withers 2003). SACs were generated using the 'exact' method based on the observed number of sites or days. A 95% confidence interval was added for visual assessment of species richness accumulation. We calculated naïve occupancy by dividing the number of camera trapping sites where the target species was detected at least once by the total number of operational sites.

2.5 | Species Richness, Diversity and Composition

To obtain a more realistic view on species richness in Gishwati and Mukura Forest, we applied a rarefaction process using non-parametric Jacknife-2 estimators to evaluate the true species richness. Given the high number of rare species detected during our study (i.e., species that were detected < 3 times), the Jacknife-2 estimator was considered best suited to provide robust estimates of true species richness (Béguinot 2016).

Analyses were performed in R using the 'vegan' package and the 'specpool' function (Oksanen et al. 2019). To assess the diversity of ground-dwelling birds in Gishwati-Mukura NP, we calculated three diversity metrics, namely Shannon diversity index, Simpson diversity index and Shannon evenness index. Subsequently, we applied a Mann–Whitney *U* test to unravel differences in diversity metrics between Gishwati and Mukura Forest. Finally, the structure of bird assemblages was explored using Detrended Correspondence Analysis (DCA)—an ordination method that reduces dimensionality with minimal loss of ecological information. DCA enhanced the correspondence between sampling sites and bird species, enabling sites with similar bird composition to cluster together. The analysis was also performed using the 'vegan' package in R (Oksanen et al. 2019).

3 | Results

3.1 | Camera Trapping Efforts

In Gishwati Forest, 32 camera traps were installed, operating for about 84 days throughout the study period. In Mukura Forest, 32 camera traps were installed, but only 29 recorded for about 71 days since three cameras were stolen. The SAC showed that species richness steeply increased in both forests with increasing number of camera trapping days, but did not reach the asymptote, that is, the level-off point at which further sampling would result in no further increase in species richness (Figure 2A). A similar pattern was observed, that is, an initially increasing SAC with no signs to level off (Figure 2B). These results strongly suggest that neither the number of camera trapping days nor the number of camera trapping sites was sufficient to capture most ground-dwelling bird species in either forest. Naïve occupancy was generally low across most bird species (Table 1), with Gishwati Forest supporting a greater number of species with non-zero occupancy than Mukura. The distribution of naïve occupancy was skewed, with Mukura dominated by a few species with high occupancy (e.g., Blue-spotted Wood Dove, *Turtur afer*) while many others were absent, whereas Gishwati showed a broader spread of species with low to moderate occupancy, highest in the Handsome Francolin (*Pternistis nobilis*; Table 1).

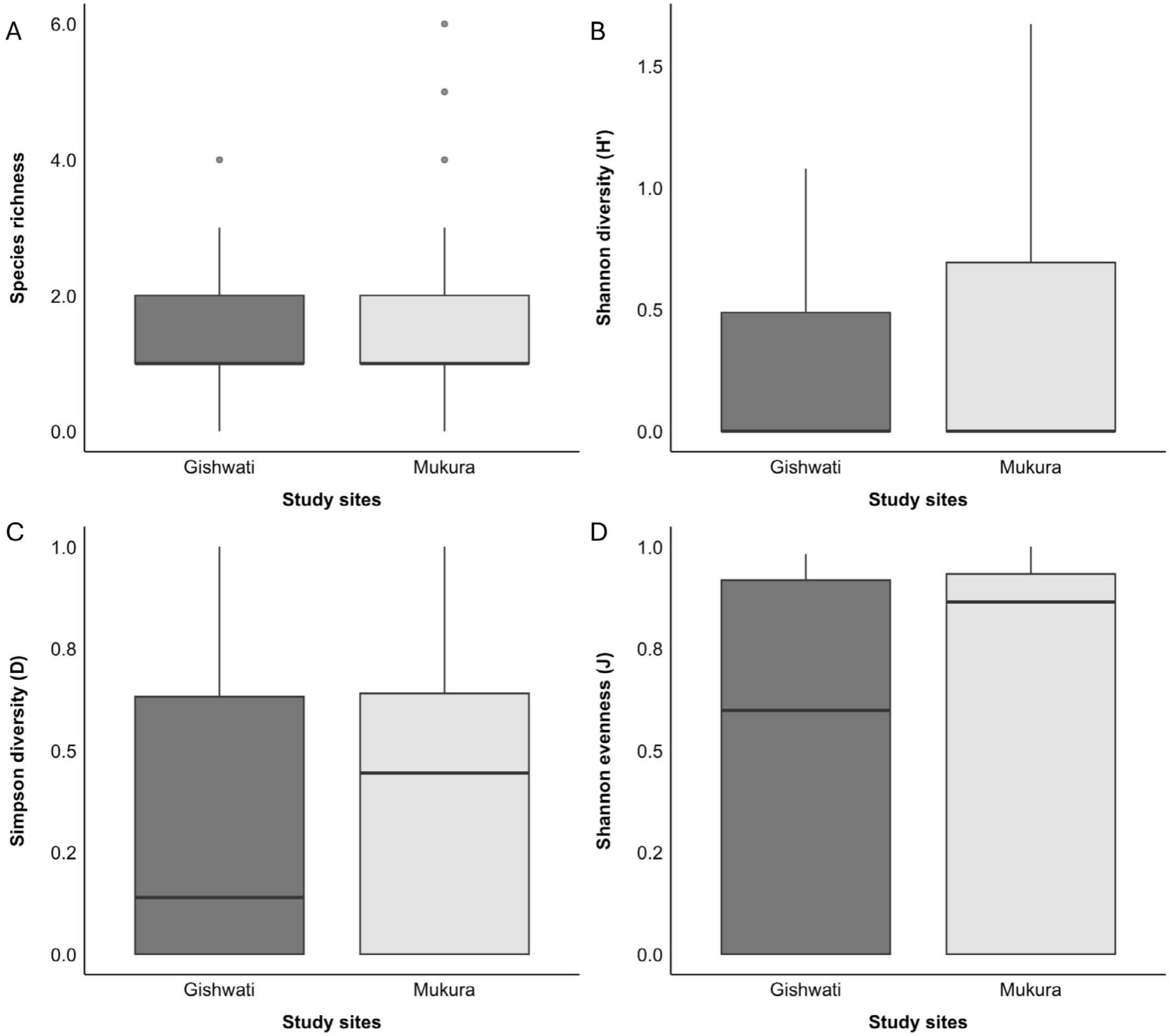

FIGURE 4 | Diversity metrics of ground-dwelling birds in Gishwati Forest and Mukura Forest: Species richness (A), Shannon diversity index (B), Simpson diversity index (C) and Shannon evenness index (D).

3.2 | Species Richness, Diversity and Composition

In total we recorded 18 ground-dwelling bird species in both forest fragments, of which five were Albertine Rift endemics and none were classified as threatened (Table 1). Twenty-five cameras (out of 32) captured 13 species in Gishwati Forest, while 24 cameras (out of 29) captured 12 ground-dwelling bird species in Mukura Forest. Using the Jackknife-2 method for true species richness estimation, Gishwati Forest was estimated to comprise 21.78 (±3.22 SE) ground-dwelling bird species (Figure 3A), while Mukura Forest had an estimated richness of 18.76 (±2.91 SE) species (Figure 3B).

Species richness (mean ± SD) of ground-dwelling birds recorded in Gishwati Forest was 1.25 ± 1.05, and similar to that recorded in Mukura Forest (1.69 ± 1.49; Figure 4A). However, a Mann–Whitney U test revealed no significant difference between the two forests fragments ($W = 394$, $p = 0.29$). Mukura Forest had a higher species diversity (mean ± SD) of ground-dwelling birds (Shannon diversity: 0.38 ± 0.51, Simpon diversity: 0.40 ± 0.39) than Gishwati Forest (Shannon diversity: 0.22 ± 0.37, Simpon diversity: 0.35 ± 0.41, Figure 4B,C), but a Mann–Whitney U tests revealed diversity to not be significantly different (Shannon diversity: $W = 388.8$, $p = 0.20$; Simpon diversity: $W = 430.5$, $p = 0.61$). Moreover, mean ± SD evenness of ground-dwelling birds was higher in Mukura Forest (Shannon evenness: 0.62 ± 0.42) than in Gishwati Forest (Shannon evenness: 0.47 ± 0.44, Figure 4D). Again, a Mann–Whitney U test showed no significant difference ($W = 108.5$, $p = 0.32$).

The DCA ordination highlights subtle but meaningful variation in bird assemblage structure across the two forest fragments (Figure 5). A moderate separation along Dimension 1 suggests little differences in the compositions of ground-dwelling bird assemblages between Gishwati and Mukura Forest. Mukura sites extended further to the right, indicating compositional

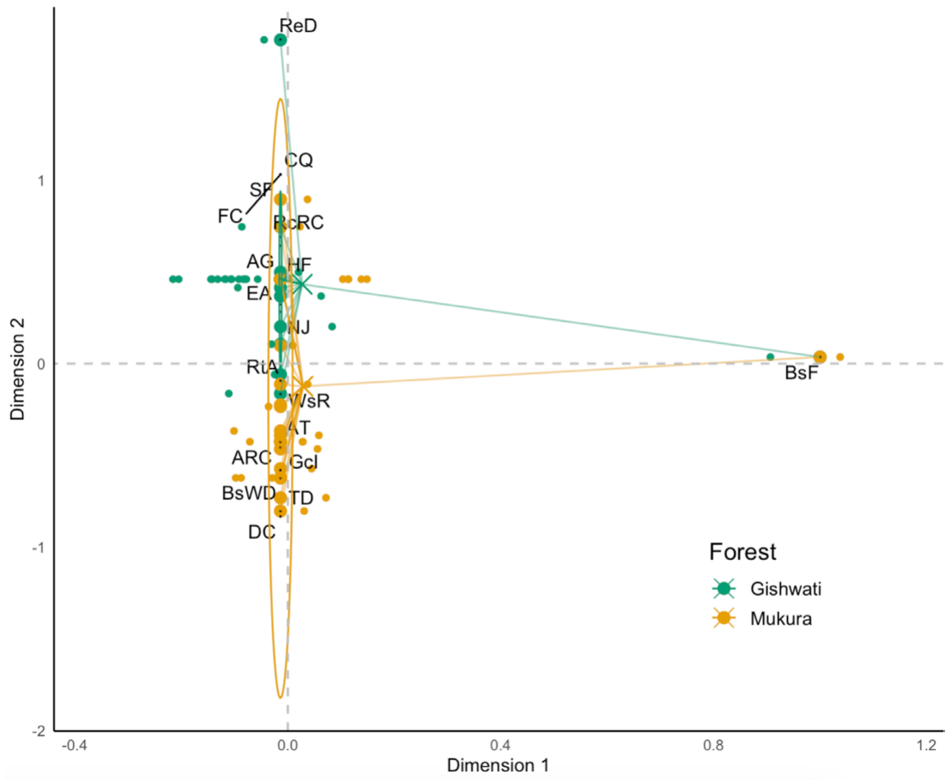

FIGURE 5 | First two axes obtained from the detrended correspondence analysis (DCA) of ground-dwelling bird species in Gishwati-Mukura National Park plotted against number of camera trapping sites. Each point represents a camera trapping site, coloured by forests: Gishwati (green) and Mukura (orange). The ellipses indicate the 95% confidence intervals around the site scores for each forest, illustrating variation in species composition. Bird species are represented by abbreviated codes: Handsome Francolin (HF); African Thrush (AT); Red-throated Alethe (RtA); Nightjar spec. (NJ); Archer's Robin-Chat (ARC); Tambourine Dove (TD); Equatorial Akalat (EA); Common Quail (CQ); Scaly Francolin (SF); African Goshawk (AG); Red-capped Robin-Chat (RcRC); Blue-spotted Wood-Dove (BsWD); Dusky Crimsonwing (DC); Familiar Chat (FC); Grey-chested Illadopsis (GcI); Red-eyed Dove (ReD); White-starred Robin (WsR); Buff-spotted Flufftail (BsF).

divergence and a potential gradient in species turnover between the two forests. The Buff-spotted Flufftail (*Sarothrura elegans*), for example, was strongly associated with this axis, indicating its distribution may help distinguish the two forest fragments. Dimension 2 accounted for variation within each forest. Gishwati sites were more tightly clustered, reflecting a relatively homogeneous bird community, while Mukura sites exhibited a wide dispersal along Dimension 2, suggesting greater variability in species composition. Several bird species, for example, Red-eyed Dove (*Streptopelia semitorquata*) and Common Quail (*Coturnix coturnix*), were positioned higher along Dimension 2, indicating these species contribute more to within-forest differences in Mukura than in Gishwati. By contrast, the tighter clustering of Gishwati sites along Dimension 2 reflects a more consistent species composition across sites.

4 | Discussion

In our study, we analysed camera trapping images of ground-dwelling forest birds across two forest fragments of pristine Afromontane rain forest in Gishwati-Mukura NP in Rwanda. Using the frequent detection of non-target species from camera trapping images, our study aimed to investigate whether species richness of ground-dwelling birds can be reasonably established using camera traps and to compare the diversity and community composition of ground-dwelling birds between Gishwati and Mukura Forest fragments.

In total we recorded 18 ground-dwelling (including ground visiting and ground-foraging) bird species which were all reported by previous studies (Vande Weghe and Vande Weghe 2011; Inman and Ntoyinkama 2020; Table 1). In Gishwati Forest, 13 species were captured, corresponding to only 11.2% (out of 116 species) of potentially ground-dwelling birds listed by Vande Weghe and Vande Weghe (2011), while in Mukura Forest 12 species were recorded, consistent with 11.9% of species listed for Mukura Forest (101 species; Vande Weghe and Vande Weghe 2011; Table S1). These numbers appear very low, which was attributed to selecting bird species from Vande Weghe and Vande Weghe (2011) list that usually do not occur on the ground, but that are potentially captured by camera traps since they occasionally forage, hunt or drink on the ground (e.g., African Goshawk; *Aerospiza tachiro*; Table 1). Nevertheless, our findings showed that the camera trapping effort, as a measure of sampling sites or sampling days, was not sufficient to capture most ground-dwelling birds (Figure 2). This was further substantiated by calculating the true bird richness using Jackknife-2 estimations, which were slightly higher than the observed richness, but that undoubtedly revealed our sampling to be incomplete, and that species richness could reach more than 20 species if camera trapping effort would be increased (i.e., > 30 sites or trapping days; Figure 3).

FIGURE 6 | Seven Albertine Rift endemics observed during this study: (A) Handsome Francolin (*Pternistis nobilis*), (B) Dusky Crimsonwing (*Cryptospiza jacksoni*), (C) Archer's Robin-Chat (*Cossypha archeri*), (D) Grey-chested Illadopsis (*Kakamega poliothorax*), (E) Equatorial Akalat (*Sheppardia aequatorialis*), (F) Red-throated Alethe (*Alethe poliophrys*), (G) White-starred Robin (*Pogonocichla stellata*) and (H) the widespread Red-capped Robin-Chat (*Cossypha natalensis*).

These results are consistent with previous studies (O'Brien and Kinnaird 2008; Randler and Kalb 2018; Kays et al. 2020; Zamora-Marín et al. 2021), which indicated that precision improves with increased number of sampling sites and repeated measurements at each location. Moreover, it was also highlighted that trapping rates are a function of distance and size of the bird species, and that indices should be calibrated for each species and location, making a rigorous application to camera trap forest birds rather impractical (O'Brien 2010; Vargas-Daza et al. 2023). However, the fact that our camera traps recorded some rare, Albertine Rift endemics—such as Handsome Francolin, Dusky Crimsonwing (*Cryptospiza jacksoni*), Archer's Robin-Chat (*Cossypha archeri*), Grey-chested Illadopsis (*Kakamega poliothorax*), Equatorial Akalat (*Sheppardia aequatorialis*), Red-throated Alethe (*Alethe poliophrys*), White-starred Robin (*Pogonocichla stellata*; Figure 6) or the elusive Buff-spotted Flufftail (*Sarothrura elegans*)—highlights the role of camera trapping as a supplementary method to increase the detectability of rare or cryptic species in forest habitats (O'Brien and Kinnaird 2008; Moore et al. 2020; Vargas-Daza et al. 2023; Kanka et al. 2023). Camera trapping should be therefore regarded an ideal addition to enhance the trajectories obtained from traditional survey methods, such as visual or acoustic point counts (Dinata et al. 2008; O'Brien and Kinnaird 2008; Burton et al. 2015; Murphy et al. 2018; Vargas-Daza et al. 2023; Kanka et al. 2023).

Given the above, we decided to further analyse our camera trapping data and to compare species richness, diversity, naïve occupancy and community composition between the two forest fragments. Neither species richness nor species diversity (established as Shannon and Simpson diversity) or evenness differed between Gishwati and Mukura Forest fragment (Figure 4). However, Mukura Forest showed a slightly higher mean naïve occupancy, driven by a few species that were more widely distributed there. The presence of species unique to each forest suggests compositional differences, likely influenced by time since isolation, habitat condition or disturbance level and history (Kisioh 2015; Sun et al. 2022, 2025). However, these differences are negligible since Gishwati Forest (14.4 km^2) is only slightly smaller than Mukura Forest (19.9 km^2) and a bit closer to the next protected area (27 km to Volcanoes NP) than Mukura Forest (33 km to Nyungwe NP). Both forest fragments experienced significant human disturbance from nearby communities, primarily through hunting, tree cutting and firewood collection (RDB 2015; Sun et al. 2022), which is also reflected by high incidence rates of human wildlife conflict, especially in Gishwati Forest that has higher mammal abundance and diversity than Mukura Forest (Sun et al. 2022, 2025). Overall, the low naïve occupancy values for most species suggest rarity, patchy distributions or limitations in detection, highlighting the need for improved survey methods or repeated sampling to better estimate true occupancy.

The community structure of ground-dwelling bird species in Gishwati and Mukura Forest differed only slightly, showing some strong overlap between the two forest fragments (dimension 1 in Figure 5). Within-forest comparison revealed Gishwati Forest to show a more homogeneous ground-dwelling bird community structure (more clustered) than Mukura Forest, which demonstrated greater heterogeneity, that is, less clustered along dimension 2 (Figure 5). Apart from the Buff-spotted Flufftail—the only species occurring in both forest fragments with an incidence of one—all other species were not associated with a particular forest. By contrast, the ordination shows that some separation exists along dimension 1, suggesting a potential gradient in species turnover between the two forest fragments. On the one hand, a Mukura-specific assembly with Dusky Crimsonwing, Tambourine Dove, Blue-spotted Wood-Dove, Archer's Robin-Chat, African Thrush and Grey-chested Illadopsis; on the other hand, a Gishwati assembly that was largely nested within the Mukura cluster (Figure 5).

In conclusion, our study implies that the ground-dwelling avifauna of both forest fragments was very similar regarding species richness, diversity and evenness. However, the bird assembly of Mukura Forest was more heterogeneous, encompassing the bird community of Gishwati Forest but including some Albertine Rift endemics that were not recorded in Gishwati (Table 1). In contrast to mammalian abundance and diversity of Gishwati-Mukura NP (Sun et al. 2022), the ground-dwelling bird community seems to be still in a healthy state in both forest fragments, but further systematic sampling is recommended to verify this deduction.

Author Contributions

P.S.: formal analysis, validation, visualisation, roles/writing – original draft; T.W.: funding acquisition, conceptualization, data curation, methodology, project administration and writing – review and editing.

Acknowledgements

We are grateful to the Rwanda Development Board for granting permission to conduct research in Gishwati-Mukura National Park, and we thank the management and staff of both protected areas for facilitating access to often remote forest locations. Special thanks go to Prosper Umuntunundi for his valuable assistance during fieldwork, and to the late Prof. Dr. Ann Apio of the University of Rwanda for her practical support throughout the study. This research was financially supported by a Rufford Small Grant (Rufford Ref. 20936-1). Open Access funding enabled and organized by Projekt DEAL.

Ethics Statement

Permission to carry out this study in Gishwati-Mukura National Park was granted by the Rwanda Development Board—Tourism and Conservation Section. Ethical approval was provided by the Review Group for the Use of Non-regulated Animals at Liverpool John Moores University (approval number: TW/2025–6).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** aje70137-sup-0001-TableS1.xlsx.