Comparison of acoustic monitoring of bird species and point counts in the Mt Kenya National Park

Ciira Maina[1,], David Muchiri[1], Dominic Chesire[2] and Peter Njoroge[2]*

[1]Dedan Kimathi University of Technology, [2]National Museums of Kenya

[*]ciira.maina@dkut.ac.ke

Mt Kenya at Dawn

October 2019

Abstract

Birds species serve as important indicators of ecosystem health and efforts to effectively monitor them are important for ecosystem management. This report describes the results of a study to test the feasibility of using audio recorders to monitor bird species in the Mt Kenya ecosystem. Between November 2017 and July 2018 we conducted 60 point counts at 10 locations within the Mt Kenya National Park near the Naro Moru gate (0° 10' 29.1828" S, 37° 8' 37.6944" E) and mounted audio recorders at the same locations that the point counts were conducted. We compared the species richness estimates obtained from the point counts to the estimates obtained from annotating a subset of the audio recordings of an equal duration to the point counts. The species richness estimate from the point counts was 48 while that from the audio annotation was 35. There was an overlap of 21 species between audio annotation and point counts. A comparison of species frequency of occurrence estimates revealed that there was no statistical difference between audio annotation and point counts. Our audio recorders were also able to detect a number of species of interest including the Crowned Eagle which is listed as near threatened and species whose range is predicted to contract as a result of climate change such as the Hartlaub's Turaco.

Introduction

Long term biodiversity monitoring is crucial to ensure the protection of ecosystems around the world (Lindenmayer and Likens 2010). Traditional ecosystem monitoring methods involve the survey of several taxa and are labour intensive and difficult to apply on a large scale. This has led to the adoption of approaches such as rapid biodiversity assessment which rely on the survey of indicator taxa (Kerr, Sugar, and Packer, 2000). Bird species have been widely used as indicator taxa since they are relatively easy to census (Pereira and Cooper, 2006). However, there are still challenges associated with the survey of birds. The traditional approach to monitoring bird species involves conducting point counts which are labour intensive and require skilled ornithologists. This limits the frequency and the coverage of the surveys.

Bioacoustic approaches provide a means of surveying a large number of ecosystems by exploiting the fact that several species produce characteristic vocalizations that can be used to identify them (Aide et al., 2013). These methods have been adopted by a number of authors for ecosystem monitoring and monitoring certain species (Frommolt and Tauchert, 2014). In our case, we aimed to investigate the use of audio recorders to monitor bird species in Kenya. We exploit the fact that several bird species vocalise and these vocalisations can be used to accurately identify them. Also, recordings from the natural habitat can be collected remotely or by people with limited training thus freeing up time for ornithologists to perform other tasks.

We report on a study conducted in the Mt Kenya National Park between November 2017 and July 2018 whose aim was to determine if bird species can be accurately monitored using

acoustic recordings collected autonomously from the park. In particular the objectives of the study were:

1. To collect audio recordings from the Mt Kenya ecosystem from which we could identify bird species.
2. To compare the species richness and relative abundance estimates obtained from manual annotation of audio recordings to those obtained from point counts conducted in the same area.
3. To explore the use of machine learning methods to automatically identify species present in audio recordings.
4. To prepare an annotated dataset representative of vocalisations from the bird species present in the Mt Kenya ecosystem.

Study Area

The study was conducted in the Mt Kenya National Park in the area near the Naro Moru gate (0° 10' 29.1828" S, 37° 8' 37.6944" E) on the Western side of Mt Kenya (see Figure 1). The study area is dominated by mountain bamboo forest (Arundinaria alpina) and podo trees (Podocarpus latifolius). Other species that are common in the area include giant ferns (Pteridium aquilinum) and stinging nettles (Urtica massaica). The area is also home to game like elephants and cape buffaloes.

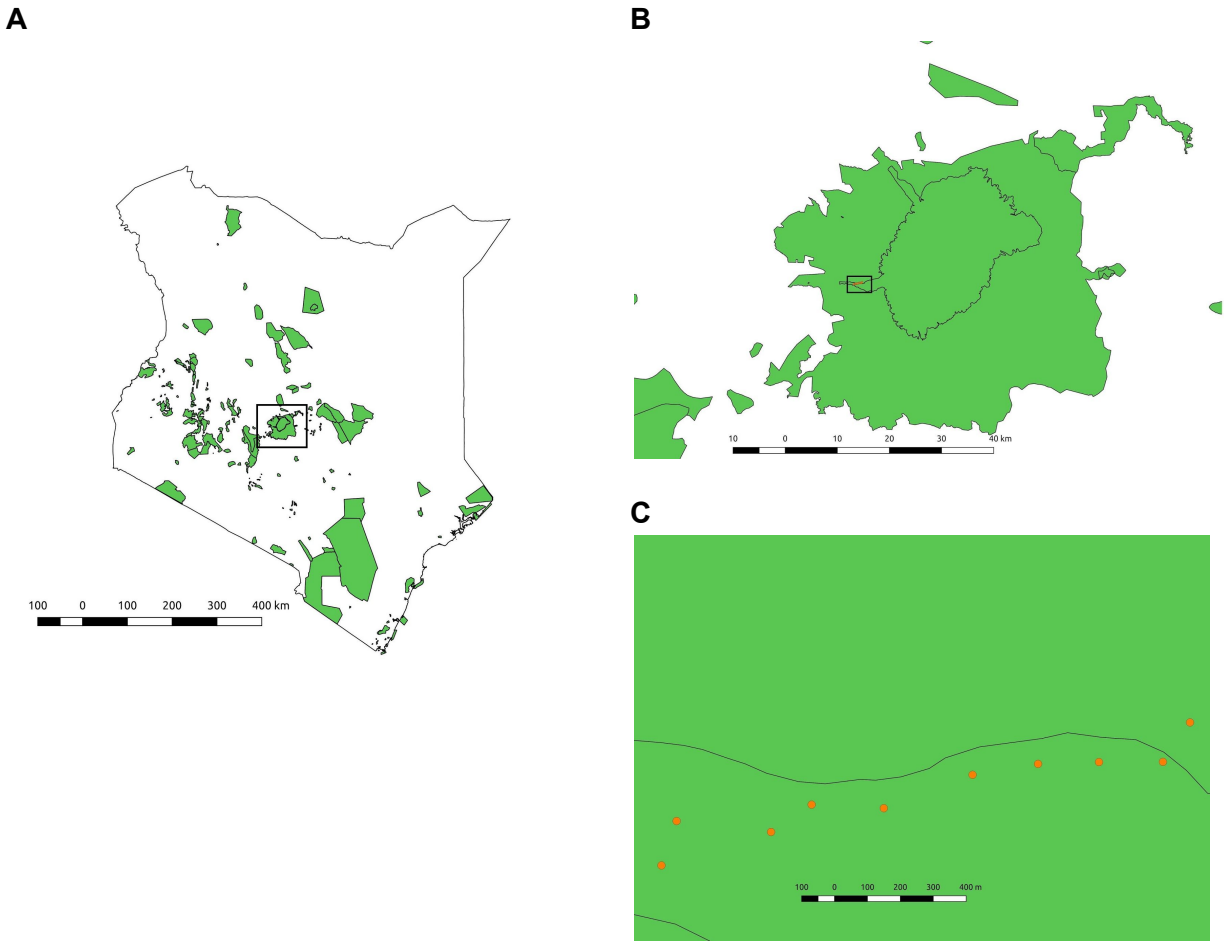

Figure 1 - A) A map of Kenya with the Mt Kenya National Park indicated by the black rectangle. B) A close up of the Mt Kenya National Park. The dots indicate the recorder locations in the national park.C) A close up of the recorder locations within the park.

The Team

The team consisted of members drawn from Dedan Kimathi University of Technology, The National Museums of Kenya and The Kenya Wildlife Service. The team members were:

1. Dr Ciira Maina (DeKUT)
2. Dr Peter Njoroge (NMK)
3. Mr. David Muchiri (DeKUT)
4. Mr Dominic Chesire (NMK)
5. Mr Dickson Muriithi (KWS)
6. Mr Samuel Kaguchia (KWS)

Figure 2: The team during data collection at the Mt Kenya National Park. Left to right: David Muchiri, Dickson Muriithi, Dominic Chesire and Ciira Maina

Data Collection

Ten Point count sites were set up along a 1.2km transect (Figure 1 c) at intervals of about 200m within the Mt Kenya National Park approximately 1 km from the Naro Moru gate. At each

site, we conducted 6 fixed-width point counts on different dates (seeTable 1) and mounted acoustic recorders to record audio signals from the environment.

Fixed-width point counts (with distance sampling) were the primary survey method. Point counts are ideal for monitoring purposes and for making comparisons with habitat variables around each point. The point counts were conducted between 0630hr and 1130 hrs with allowances made due to the difficulty in traversing the steep terrain. At every point, observers waited for 1 minute (settling-in period) before counting all the birds seen or heard within a 25m radius for the next 9 minutes. Opportunistic observations were used to supplement the point counts and help build a complete checklist of the study area.

For audio monitoring, we used recorders generously provided by Prof Alex Rogers from Oxford University which are an early version of the Audiomoth devices (Hill et al., 2018) The gadgets are low power devices powered by 3 AAA batteries (see Figure 3). The audio recorders were programmed to record for one minute every 5 minutes between 5.30am and 11pm and again between 5.30pm and 6.30pm.

Over 20,000 recordings were collected and of these, approximately 1,000 were annotated by an ornithologist from the National Museums of Kenya with the identities of bird species vocalizing. These 1,000 recordings were a random subset from the recordings at each location (100 each) recorded between 6.30am and 11am, the same time that the point counts were conducted. For each recording, if species were detected, they were classified as either foreground or background depending on how clear the call was.

Figure 3: The acoustic recorder in the lab (left) and installed in the field (right)

Figure 4: Conducting point counts and mounting recorders.

Activities

Data collection was performed on six days between November 2017 and July 2018. The schedule of activities is listed below.

Table 1: Schedule of activities conducted during the study.

#	Date	Activity
1	18th November 2017	10 Point counts, Acoustic Recorder Mounting
2	19th November 2017	10 Point counts
3	23rd December 2017	10 Point counts, Acoustic Recorder Retrieval
4	16th June 2018	10 Point counts, Acoustic Recorder Mounting
5	17th June 2018	10 Point counts
6	27th July 2018	10 Point counts, Acoustic Recorder Retrieval

Results

Species Richness

From the 60 point counts conducted in the ten study locations (six each), a total of 48 species were recorded. From the annotated audio recordings, 35 species were recorded. In addition to these, 20 species were recorded from opportunistic observations. In all, 71 species were observed during the study. Table 2 shows a list of all species observed as well as information on whether the observation was during the point coint (PC), audio annotation (AA) or opportunistic (OP).

Table 2: List of species observed during the study as well as information on whether the observation was during the point coint (PC), audio annotation (AA) or opportunistic (OP).

#	Common Name	Scientific Name	PC	AA	OP
1	Abyssinian Crimsonwing	*Cryptospiza salvadorii*		✓	
2	Abyssinian Ground Thrush	*Zoothera piaggiae*	✓		
3	African Black Duck	*Anas sparsa*	✓		
4	African Dusky Flycatcher	*Muscicapa adusta*	✓	✓	✓
5	African Emerald Cuckoo	*Chrysococcyx cupreus*			✓
6	African Goshawk	*Accipiter tachiro*	✓	✓	
7	African Hill Babbler	*Pseudoalcippe abyssinica*	✓		
8	African Olive Pigeon	*Columba arquatrix*	✓		
9	African Paradise Flycatcher	*Terpsiphone viridis*		✓	
10	Baglafecht Weaver	*Ploceus baglafecht*			✓
11	Bar-tailed Trogon	*Apaloderma vittatum*	✓	✓	
12	Black Cuckooshrike	*Campephaga flava*	✓		
13	Black Saw-wing	*Psalidoprocne pristoptera*	✓		✓

14	Black-fronted Bushshrike	*Chlorophoneus nigrifrons*		✓	
15	Brown Woodland Warbler	*Phylloscopus umbrovirens*	✓	✓	
16	Brown-chested Alethe	*Alethe poliocephala*	✓		
17	Cabanis's Greenbul	*Phyllastrephus cabanisi*	✓	✓	
18	Chestnut-throated Apalis	*Apalis porphyrolaema*	✓	✓	
19	Chin-spot Batis	*Batis molitor*	✓		
20	Cinnamon Bracken Warbler	*Bradypterus cinnamomeus*	✓	✓	
21	Cinnamon-chested Bee-eater	*Merops oreobates*		✓	✓
22	Collared Sunbird	*Hedydipna collaris*		✓	
23	Common Bulbul	*Pycnonotus barbatus*	✓	✓	✓
24	Crowned Eagle	*Stephanoaetus coronatus*	✓	✓	
25	Crowned Hornbill	*Tockus alboterminatus*			✓
26	Dusky Turtle Dove	*Streptopelia lugens*	✓		
27	Eastern Double-collared Sunbird	*Cinnyris mediocris*	✓	✓	✓
28	Fine-banded Woodpecker	*Campethera tullbergi*	✓		
29	Giant Kingfisher	*Megaceryle maxima*	✓		
30	Grey Apalis	*Apalis cinerea*	✓	✓	✓
31	Grey Cuckooshrike	*Coracina caesia*	✓		
32	Grey-backed Camaroptera	*Camaroptera brachyura*		✓	
33	Grey-capped Warbler	*Eminia lepida*		✓	
34	Grey-headed Negrofinch	*Nigrita canicapillus*	✓		
35	Hartlaub's Turaco	*Tauraco hartlaubi*	✓	✓	

36	Hunter's Cisticola	*Cisticola hunteri*			✓
37	Jackson's Francolin	*Francolinus jacksoni*	✓		✓
38	Klaas's Cuckoo	*Chrysococcyx klaas*	✓		
39	Malachite Sunbird	*Nectarinia famosa*	✓		
40	Montane Oriole	*Oriolus percivali*	✓	✓	
41	Montane White-eye	*Zosterops poliogastrus*	✓	✓	
42	Mountain Buzzard	*Buteo oreophilus*	✓		✓
43	Mountain Greenbul	*Andropadus nigriceps*	✓	✓	
44	Mountain Yellow Warbler	*Chloropeta similis*	✓	✓	
45	Narina Trogon	*Apaloderma narina*	✓	✓	✓
46	Olive Sunbird	*Cyanomitra olivacea*	✓	✓	
47	Olive Thrush	*Turdus olivaceus*		✓	
48	Orange Ground Thrush	*Zoothera gurneyi*	✓		
49	Oriole Finch	*Linurgus olivaceus*	✓		
50	Plain Martin	*Riparia paludicola*	✓		
51	Red-eyed Dove	*Streptopelia semitorquata*			✓
52	Red-fronted Parrot	*Poicephalus gulielmi*	✓	✓	
53	Red-fronted Tinkerbird	*Pogoniulus pusillus*		✓	
54	Red-winged Starling	*Onychognathus morio*		✓	
55	Scaly Francolin	*Francolinus squamatus*	✓		
56	Scarce Swift	*Schoutedenapus myoptilus*	✓		
57	Streaky Seedeater	*Crithagra striolata*			✓
58	Sulphur-breasted Bushshrike	*Chlorophoneus sulfureopectus*		✓	
59	Tacazze Sunbird	*Nectarinia tacazze*	✓		

60	Tambourine Dove	*Turtur tympanistria*		✓	
61	Thick-billed Seedeater	*Crithagra burtoni*			✓
62	Variable Sunbird	*Cinnyris venustus*	✓		
63	White-bellied Tit	*Parus albiventris*	✓		
64	White-eyed Slaty Flycatcher	*Melaenornis fischeri*			✓
65	White-headed Saw-wing	*Psalidoprocne albiceps*			✓
66	White-headed Wood-hoopoe	*Pheoniculus bollei*	✓	✓	
67	White-starred Robin	*Pogonocichla stellata*	✓	✓	
68	White-tailed Crested Flycatcher	*Eliminia albonotata*		✓	
69	Yellow-crowned Canary	*Serinus flavivertex*	✓		✓
70	Yellow-rumped Tinkerbird	*Pogoniulus bilineatus*		✓	
71	Yellow-whiskered Greenbul	*Andropadus latirostris*	✓		✓

Comparison of Observation Methods

Figure 5 shows the overlap in species detected by the different observation methods namely point counts, audio annotation and opportunistic observations.

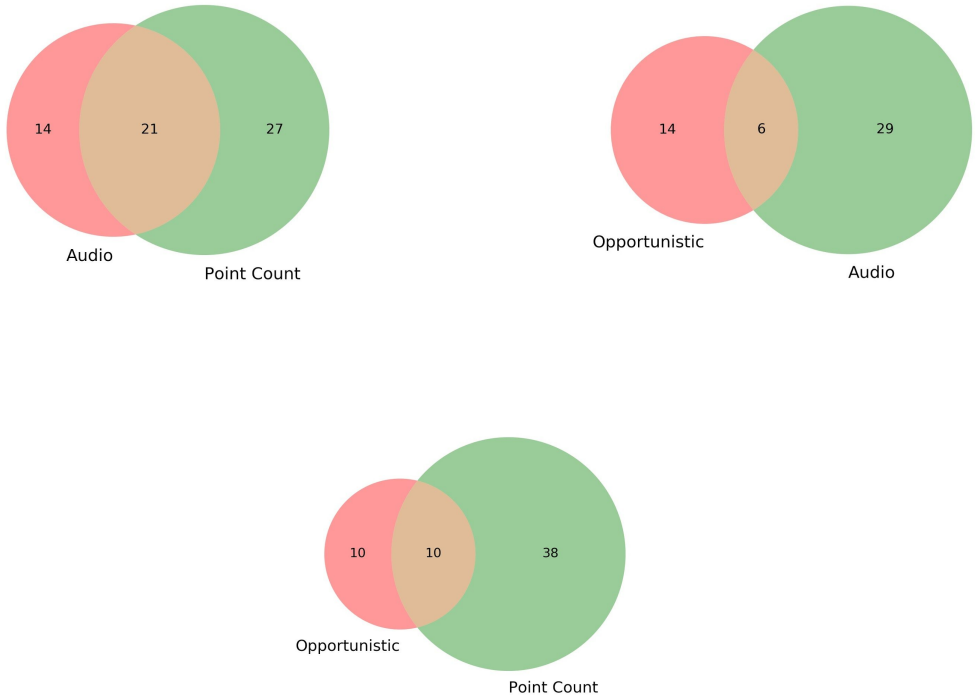

Figure 5: Comparison of overlap in species detected by audio annotation, point counts and opportunistic observation

Frequency of Occurrence

We compare the frequency of occurrence of the 62 species observed in both the audio annotation and point counts. By comparing the frequency of occurrence we can test the hypothesis that the population observed by both methods is the same. We determine if there is evidence against the null hypothesis that the frequencies of occurrence from audio annotation and point counts result from sampling the same population. To determine the frequency of occurrence for the point counts, we count the number of times a species is observed in the 60 point counts (six point counts in each of the 10 point count stations). For audio recordings, we sample 10 one minute recordings per point count location and treat this as equivalent to a single point count. We then determine the number of times a species is observed in six such samples per location. This simulates equal effort observation between the audio annotation and the point counts (on each trip, one recorder location failed and thus we use 9 locations resulting in 54 equivalent point counts). Table 3 shows the frequency of occurrence for the 62 species observed in the point counts and audio annotations ordered according to decreasing point count frequency.

Table 3: Frequency of occurrence for the 62 species observed in the point counts and audio annotations

#	Common Name	*Scientific Name*	Point Count	Audio Annotation
1	Brown Woodland Warbler	*Phylloscopus umbrovirens*	0.65	1
2	Chestnut-throated Apalis	*Apalis porphyrolaema*	0.53	0.74
3	Montane White-eye	*Zosterops poliogastrus*	0.5	0.57
4	Cinnamon Bracken Warbler	*Bradypterus cinnamomeus*	0.45	0.5
5	White-starred Robin	*Pogonocichla stellata*	0.37	0.41
6	Red-fronted Parrot	*Poicephalus gulielmi*	0.28	0.5
7	Hartlaub's Turaco	*Tauraco hartlaubi*	0.27	0.15
8	Mountain Yellow Warbler	*Chloropeta similis*	0.23	0.46
9	Olive Sunbird	*Cyanomitra olivacea*	0.13	0.06
10	Black Saw-wing	*Psalidoprocne pristoptera*	0.12	0
11	Crowned Eagle	*Stephanoaetus coronatus*	0.1	0.11
12	Chin-spot Batis	*Batis molitor*	0.1	0
13	White-bellied Tit	*Parus albiventris*	0.08	0
14	Common Bulbul	*Pycnonotus barbatus*	0.08	0
15	Klaas's Cuckoo	*Chrysococcyx klaas*	0.07	0
16	Cabanis's Greenbul	*Phyllastrephus cabanisi*	0.07	0.02
17	Scarce Swift	*Schoutedenapus*	0.07	0

		myoptilus		
18	African Hill Babbler	*Pseudoalcippe abyssinica*	0.07	0
19	African Dusky Flycatcher	*Muscicapa adusta*	0.07	0.09
20	Abyssinian Ground Thrush	*Zoothera piaggiae*	0.05	0
21	Dusky Turtle Dove	*Streptopelia lugens*	0.05	0
22	Fine-banded Woodpecker	*Campethera tullbergi*	0.05	0
23	White-headed Wood-hoopoe	*Pheoniculus bollei*	0.05	0.06
24	Orange Ground Thrush	*Zoothera gurneyi*	0.03	0
25	Narina Trogon	*Apaloderma narina*	0.03	0.02
26	Tacazze Sunbird	*Nectarinia tacazze*	0.03	0
27	Mountain Greenbul	*Andropadus nigriceps*	0.03	0.02
28	Mountain Buzzard	*Buteo oreophilus*	0.03	0
29	Jackson's Francolin	*Francolinus jacksoni*	0.03	0
30	Yellow-whiskered Greenbul	*Andropadus latirostris*	0.03	0
31	Grey Cuckooshrike	*Coracina caesia*	0.03	0
32	Brown-chested Alethe	*Alethe poliocephala*	0.03	0
33	Grey-headed Negrofinch	*Nigrita canicapillus*	0.02	0
34	Oriole Finch	*Linurgus olivaceus*	0.02	0
35	Yellow-crowned Canary	*Serinus flavivertex*	0.02	0
36	African Black Duck	*Anas sparsa*	0.02	0
37	African Goshawk	*Accipiter tachiro*	0.02	0.04
38	African Olive Pigeon	*Columba arquatrix*	0.02	0

39	Variable Sunbird	*Cinnyris venustus*	0.02	0
40	Bar-tailed Trogon	*Apaloderma vittatum*	0.02	0.02
41	Scaly Francolin	*Francolinus squamatus*	0.02	0
42	Plain Martin	*Riparia paludicola*	0.02	0
43	Black Cuckooshrike	*Campephaga flava*	0.02	0
44	Malachite Sunbird	*Nectarinia famosa*	0.02	0
45	Montane Oriole	*Oriolus percivali*	0.02	0.11
46	Eastern Double-collared Sunbird	*Cinnyris mediocris*	0.02	0.04
47	Grey Apalis	*Apalis cinerea*	0.02	0.17
48	Giant Kingfisher	*Megaceryle maxima*	0.02	0
49	Black-fronted Bushshrike	*Chlorophoneus nigrifrons*	0	0
50	Tambourine Dove	*Turtur tympanistria*	0	0
51	Yellow-rumped Tinkerbird	*Pogoniulus bilineatus*	0	0.02
52	Grey-backed Camaroptera	*Camaroptera brachyura*	0	0.04
53	White-tailed Crested Flycatcher	*Eliminia albonotata*	0	0.02
54	African Paradise Flycatcher	*Terpsiphone viridis*	0	0.04
55	Olive Thrush	*Turdus olivaceus*	0	0.02
56	Sulphur-breasted Bushshrike	*Chlorophoneus sulfureopectus*	0	0
57	Collared Sunbird	*Hedydipna collaris*	0	0
58	Red-winged Starling	*Onychognathus morio*	0	0.02

59	Red-fronted Tinkerbird	*Pogoniulus pusillus*	0	0.06
60	Grey-capped Warbler	*Eminia lepida*	0	0
61	Cinnamon-chested Bee-eater	*Merops oreobates*	0	0.02
62	Abyssinian Crimsonwing	*Cryptospiza salvadorii*	0	0.02

A t-test comparing the proportions for each species shows that there is no evidence to reject the null hypothesis that the proportions observed result from sampling the same population (t = -0.49, p-value = 0.63)
.

Species of interest

IUCN Red List of Threatened Species

Two species are on the IUCN red list. The species are listed in Table 4.

Table 4: Species on the IUCN red list of threatened species.

#	Common Name	Scientific Name	Conservation Status
1	Crowned Eagle	Stephanoaetus coronatus	Near Threatened (population decreasing)
2	Mountain Buzzard	*Buteo oreophilus*	Near Threatened (population decreasing)

Audio Data Analysis

Foreground Species Distribution

Table 5 shows a list of 29 species with at least one recording in which the species is judged to be in the foreground of a recording. We see that the Brown Woodland Warbler is the most represented species in the foreground of recordings.

Table 5: Species observed in the foreground of recordings with the number of recordings indicated.

#	Common Name	*Scientific Name*	Count
1	Brown Woodland Warbler	*Phylloscopus umbrovirens*	330
2	Mountain Yellow Warbler	*Chloropeta similis*	61
3	Red-fronted Parrot	*Poicephalus gulielmi*	54
4	Cinnamon Bracken Warbler	*Bradypterus cinnamomeus*	54
5	Chestnut-throated Apalis	*Apalis porphyrolaema*	50
6	Montane White-eye	*Zosterops poliogastrus*	33
7	White-starred Robin	*Pogonocichla stellata*	26
8	Hartlaub's Turaco	*Tauraco hartlaubi*	12
9	Grey Apalis	*Apalis cinerea*	7
10	Red-fronted Tinkerbird	*Pogoniulus pusillus*	7
11	African Dusky Flycatcher	*Muscicapa adusta*	6
12	Crowned Eagle	*Stephanoaetus coronatus*	6
13	Yellow-rumped Tinkerbird	*Pogoniulus bilineatus*	4
14	Olive Sunbird	*Cyanomitra olivacea*	3
15	Mountain Greenbul	*Andropadus nigriceps*	3
16	White-headed Wood-hoopoe	*Pheoniculus bollei*	3
17	Cabanis's Greenbul	*Phyllastrephus cabanisi*	2
18	African Goshawk	*Accipiter tachiro*	2
19	Montane Oriole	*Oriolus percivali*	2
20	White-tailed Crested Flycatcher	*Eliminia albonotata*	2
21	Grey-capped Warbler	*Eminia lepida*	1

22	Sulphur-breasted Bushshrike	*Chlorophoneus sulfureopectus*	1
23	Red-winged Starling	*Onychognathus morio*	1
24	Black-fronted Bushshrike	*Chlorophoneus nigrifrons*	1
25	Olive Thrush	*Turdus olivaceus*	1
26	Tambourine Dove	*Turtur tympanistria*	1
27	Bar-tailed Trogon	*Apaloderma vittatum*	1
28	Common Bulbul	*Pycnonotus barbatus*	1
29	Grey-backed Camaroptera	*Camaroptera brachyura*	1

Spectrogram Analysis

Spectrograms provide a means of identifying bird species using a time-frequency representation of the audio signal. We visualised the spectrograms from the audio recordings we obtained. From listening experiments and visual inspection of the spectrograms it was noticed that the recordings were corrupted by low frequency noise centered at around 500Hz. To reduce this noise a notch filter was used. Figure 6 shows spectrograms of the Brown Woodland Warbler and Cinnamon Bracken Warbler. Despite the similarity of the spectrograms it can be seen that the two are visually distinct.

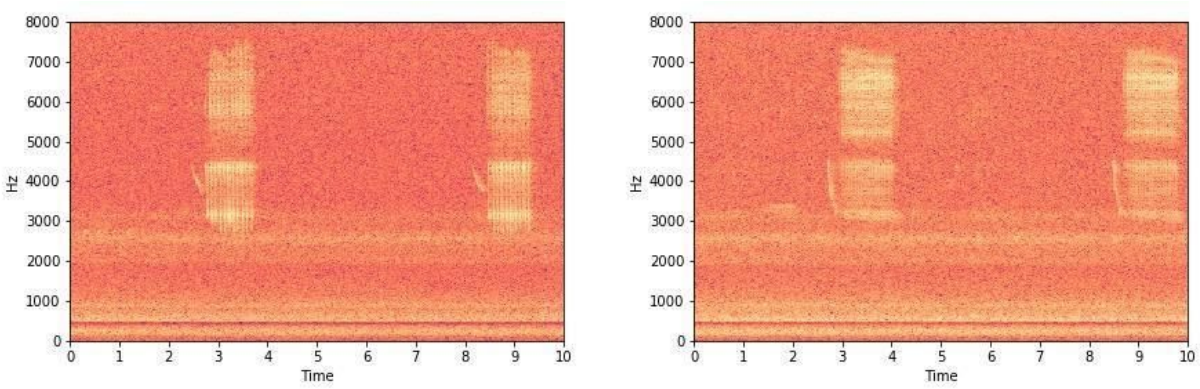

Figure 6: Spectrograms of the Brown Woodland Warbler (left) and the Cinnamon Bracken Warbler (right).

Discussion

71 bird species were recorded via point counts, audio annotation and opportunistic observation. The species richness estimate via point counts was 48 while via audio annotation it was 35. Thus the species richness estimates from the two methods differed in this case. However, when we compare the frequency of occurrence of species, the difference between point counts and audio annotation is not statistically significant. This shows that for certain monitoring tasks, such as the estimation of species prevalence, audio recordings can be used in place of point counts.

A number of species of conservation concern were recorded in our study. Interestingly, the Crowned Eagle which listed as near threatened on the IUCN red list was observed by both point counts and audio recordings showing that it is feasible to monitor specific species via audio recordings mounted in the ecosystem of interest. Another species is the Hartlaub's Turaco which despite being listed as least concern on the red list is predicted to lose range due to climate change (La Sorte and Jetz, 2010). Acoustic recorders can possibly be used to monitor the presence of this species to test the range contraction hypothesis.

Future Work

In future work, we will use the over 100 hours of audio recordings to train automatic bird species models to allow the acoustic monitoring approach to scale. We will use the latest advances in machine learning to automatically recognise species present in the Mt Kenya ecosystem using audio spectrograms as input.

Acknowledgements

We thank the African Bird Club for funding the study. We also thank the Kenya Wildlife Service for granting us access to the study area and Prof Alex Rogers for donating the audio recording devices used in the study.

References

Aide, T. M., Corrada-Bravo, C., Campos-Cerqueira, M., Milan, C., Vega, G., & Alvarez, R. (2013). Real-time bioacoustics monitoring and automated species identification. *PeerJ*, *1*, e103.

BirdLife International 2016. *Buteo oreophilus*. *The IUCN Red List of Threatened Species* 2016: e.T22728020A94968444. http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22728020A94968444.en. Downloaded on 28 September 2019.

BirdLife International 2016. *Tauraco hartlaubi*. *The IUCN Red List of Threatened Species* 2016: e.T22688365A93194716. http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22688365A93194716.en. Downloaded on 28 September 2019.

BirdLife International 2018. *Stephanoaetus coronatus*. *The IUCN Red List of Threatened Species* 2018: e.T22696201A129914678. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22696201A129914678.en. Downloaded on 28 September 2019.

Frommolt, K. H., & Tauchert, K. H. (2014). Applying bioacoustic methods for long-term monitoring of a nocturnal wetland bird. *Ecological Informatics*, *21*, 4-12.

Hill, A. P., Prince, P., Piña Covarrubias, E., Doncaster, C. P., Snaddon, J. L., & Rogers, A. (2018). AudioMoth: Evaluation of a smart open acoustic device for monitoring biodiversity and the environment. *Methods in Ecology and Evolution*, *9*(5), 1199-1211.

Kerr, J. T., Sugar, A., & Packer, L. (2000). Indicator taxa, rapid biodiversity assessment, and nestedness in an endangered ecosystem. *Conservation biology*, *14*(6), 1726-1734.

La Sorte, F. A., & Jetz, W. (2010). Projected range contractions of montane biodiversity under global warming. *Proceedings of the Royal Society B: Biological Sciences*, *277*(1699), 3401-3410.

Lindenmayer, D. B., & Likens, G. E. (2010). The science and application of ecological monitoring. *Biological conservation*, *143*(6), 1317-1328.

Pereira, H. M., & Cooper, H. D. (2006). Towards the global monitoring of biodiversity change. *Trends in Ecology & Evolution*, *21*(3), 123-129.