Rufford Small Grant: Final Report

Acoustics and conservation: Bats and birds in semiarid landscapes

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Introduction

Semi-arid and arid landscapes comprise 41 percent of the world's land mass (Safriel, 2005). Tropical semi-arid regions experience harsh environmental conditions in the form of high daytime temperatures, low humidity levels, less than 400 mm of precipitation per annum (Wickens 1998) and high average temperatures observed in summers. In India, semi-arid landscapes alone cover an area of 956,750 km^2 and comprise grassland, thorn-scrub and deciduous forests. Grassland and scrubland are some of the most neglected and threatened habitats in India, due to a number of factors. Pressures from large-scale development projects combined with agricultural land-use change, have negatively affected both the extent and quality of these habitats. These habitats typically serve as grazing lands for cattle and livestock of pastoralists, but are often categorised as 'fallow' or 'wastelands' in government revenue documents (Joshi et al. 2018). This misclassification of land in semi-arid landscapes often overlooks the biological diversity they sustain and their crucial functions in carbon sequestration. Furthermore, climate change is predicted to result in further warming of the semi-arid regions of the globe, increasing their aridity. Hence, there is an urgent need to monitor the impact of these environmental pressures on semi-arid landscapes.

India's grassland and scrubland habitats are unique for their animal communities that are adapted to survive in harsh environments. The semi-arid landscapes of India are home to some of the most endangered fauna in the country which include the Great Indian Bustard (*Ardeotis nigriceps*), Lesser florican (*Sypheotides indicus*) and Black buck (*Antilope cervicapra*). Most research and conservation efforts in these landscapes are targeted towards these endangered species and the impact of anthropogenic pressures on their survival. On the other hand, there has been relatively little long term research on community ecology in these habitats, to understand the impact of human activities and climate change on the entire faunal community. Studying species composition, interaction and dynamics across spatial features and seasons can provide important insights into long-term responses of animal communities to such environmental stressors.

In the present study, we attempted to develop a paradigm to monitor echolocating bats and birds as indicators of habitat health. Both bats and birds rely on acoustic communication as part

of territorial defence and reproductive behaviour. Echolocating bats additionally rely completely on ultrasonic vocal signals for navigation and hunting insect prey. These unique characteristics render them suitable to study using acoustic monitoring techniques. With the advent of remotely triggered sound recorders, acoustic monitoring presents a non-intrusive method of data collection. Bat monitoring studies have been previously conducted in arid and semi-arid regions of Africa, North and South America. However, there is a complete lack of knowledge on habitat use and activity patterns of bats from the arid and semi-arid regions of India. For birds, although there exist a wide number of studies using bioacoustic monitoring and interpreting using broad soundscape indices, there are very few studies that have actually integrated bioacoustic monitoring with community ecology and phylogenetic analysis, under the broader theme of community bioacoustics. To our knowledge, our studies are some of the first in these habitats, and lay the framework for a longer-term conservation and acoustic monitoring program in the region.

This report encloses the findings from our study on the bat and bird communities of semi-arid grassland and scrubland habitats in the Northwest of India.

Objectives:

The project aimed to fulfil and provide insights into the following objectives during the research on bats and birds.

Bats:

1. Quantify diversity and activity patterns across seasons for bats at waterholes and adjacent semi-arid habitats, using passive acoustic monitoring technique.
2. Locating and monitoring roost sites for bats, and building a call library for bat species.

Birds:

1. Establishing an acoustic monitoring paradigm for birds in Northwest Indian thorn scrub forests and semi-desert grasslands.

2. Quantifying acoustic community diversity and dynamics in these habitats.

3. Studying habitat occupancy and associations with anthropogenic activity for threatened and endemic bird species, and identifying priority areas for their conservation.

4. To develop the threatened White-naped tit (*Machlolophus nuchalis*) of thorn scrub and Stoliczka's Bushchat (*Saxicola macrorhynchus*) of semiarid grasslands as flagships of their respective habitats for awareness and conservation.

Methodology:

Study area:

The study was conducted in two locations, the Tal Chhapar Blackbuck Sanctuary and the Nahargarh Biological Park, Jaipur District, Rajasthan in the state of Rajasthan in Northwest India. Additional pilot surveys were also conducted in the Bikaner and Jaisalmer regions over the span of two years.

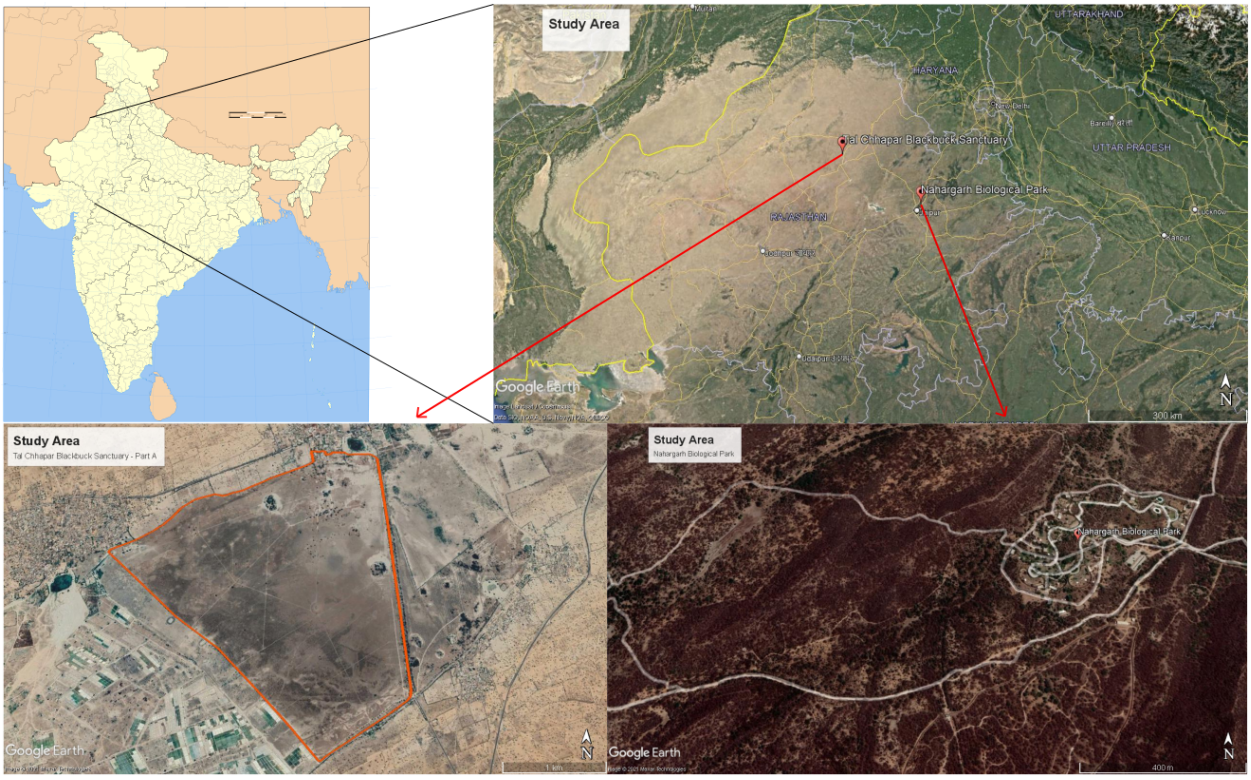


Image: Map with the two study areas of our project: Tal Chhapar Blackbuck Sanctuary and Nahargarh Biological Park

Tal Chhapar Blackbuck Sanctuary

The Tal Chhapar Sanctuary (coordinates 27.798490 N, 74.434921 E) is a 719ha grassland in the Sujangarh Tehsil of Churu district of Rajasthan, primarily established and managed for the conservation of the blackbuck antelope. This study site is a small patch of semiarid savanna grassland on the edge of the Thar Desert. The sanctuary possesses typical vegetation of arid and semiarid landscapes, including *Acacia, Capparis, Calotropis* and *Zizyphus*. The region experiences an influx of winter migrant aquatic and terrestrial birds. There are also regular records of the threatened Stoliczka's Bushchat (*Saxicola macrorhynchus*) from the sanctuary, a focal species of this study. The presence of four well maintained, permanent waterholes make

the park an ideal place to monitor bats that may be dependent on the water sources. Given its small area, accessibility and the diversity of avifauna recorded here, this site is of great importance in establishing a conservation monitoring program.

Nahargarh Biological Park

The second study site is the thorn scrub forest part of a public zoo (coordinates 27.016312 N, 75.864505 E), located near the Nahargarh fort situated in the outskirts of Jaipur city. The park encompasses an area of 720ha and is dominated by dry thorn forest species, notably *Acacia, Prosopis, Boswellia serrata, Ziziphus sp*, home to a population of the threatened White-naped tit (*Machlolophus nuchalis*).

Sampling period:

The sampling for monitoring bat communities was done during early winter in November 2019, late winter in March 2020 and mid winter in January 2021.

On the other hand, the sampling periods for bird data were conducted during the months November 2019 and January 2021.

Acoustic monitoring at study sites

Acoustic monitoring of birds:

Based on information acquired from local bird watchers at Nahargarh Biological Park, we narrowed down our area of sampling to the more intact thorn forest patches, where there have been regular sightings of the White-naped tit in the past. We recorded at 3 sites, but were unable to detect the bird. Local information suggests that the bird is rare at this site, particularly after the construction of the zoological park on the premise of the sanctuary. The high tourist activity, as well as conversion of intact thorn forest patches have left very little habitat for the White-naped tit and other thorn forest inhabitants like the Marshall's iora and the white-bellied minivet, which were also absent from our recordings. Furthermore, owing to security reasons and presence of mammals like leopards, we were unable to explore further sites for the White-naped tit. We have collected data on the bird communities of the remaining areas of thorn forest, and are analyzing this dataset to determine the composition and diversity of thorn forest bird communities.

Our sampling period at Tal Chhapar WLS spanned a total of 9 days over the field session. For monitoring birds, our recorders were placed at 4 locations inside the sanctuary, as well as 2

locations outside of it (*Gaushala*). While the area inside the sanctuary is primarily grassland, with isolated patches of trees, the area outside is a mosaic of grassland and short trees like *Prosopis* and *Acacia*. Inside the sanctuary, we placed our recorders close to the 3 water bodies within the area, and one on the far north side of the sanctuary. This had two major advantages: first, this minimizes the risk of the equipment being lost, and second, we were able to maximise our bird species detection by recording sounds from both the grassland as well as the water body and patch of trees surrounding it. The fourth recorder placed at the north boundary also had two advantages- firstly, it ensured an even spread of each of our recorders relative to each other. Secondly, this patch is also the most reliable known site for the white-browed bushchat.

We followed a similar sampling strategy for our next field season in January 2021. We spent a total of 7 days in Tal Chhapar, with sampling efforts in the *Gaushala* as well as an additional sampling day at the 'salt pan', an area of scrubland situated next to Tal Chhapar and adjacent to salt pans that are used for commercial extraction of salt. This area is yet another known site for the Bushchat and other birds, notably the Graceful prinia which does not regularly occur inside the sanctuary itself.

For analysis, we downloaded the passive recordings and divided them into 10-minute samples. Each sample was censused by ear, and species presence/absence were noted following established protocols (see Krishnan 2019, Lahiri et al. 2021). We calculated species abundance matrices, phylogenetic diversity as well as community measures for dry grasslands of Tal Chhapar.

Image: Sampling location inside Tal Chhapar Sanctuary, Rajasthan

Image: Monitoring location at Gaushala, Chhapar village, Rajasthan

Image: Acoustic monitoring of bats over a water body in Tal Chhapar Sanctuary

Recce surveys for Stoliczka's bushchat in additional sites:

We also conducted a recce visit to the Desert National Park Wildlife Sanctuary in Jaisalmer, Rajasthan in January 2021. One of our prime targets was to survey additional habitats and sites for the Stolickza's Bushchat, with the goal of monitoring the species across larger landscapes. With the help of local bird guides and ornithologists/wildlife researchers, we conducted our survey in various parts of Desert National Park for 6 days. We covered several major ranges, including Sudasari, Khabha, Netsi, Bhuwana representing different kinds of habitats including grasslands, agriculture, fallow lands, regenerating fallows. Other than the Bushchat, we also surveyed for other desert specialists (the goal being a larger bird community monitoring and conservation project) including the Greater Hoopoe-lark, Black-crowned Sparrow-Lark, Desert Lark, Red-tailed Wheatear, Trumpeter Finch, Black-bellied Sandgrouse and Spotted Sandgrouse. From June 2021, we initiated a remote data collection regime effort by employing local bird guides at Desert National Park- in collaboration with researchers at the Wildlife Institute of India- to carry out additional, longer term monitoring of the bushchat and other species of interest. We discuss preliminary results from this effort below.

We also conducted additional short visits to Bikaner district to find the bushchat. We visited the areas of Jorbeer and Diyatra in Bikaner district in late November 2019. These are areas with potential habitats and previous confirmed records of the Bushchat (Rahmani 1996; Singh et al. 2019).

Image: Regenerating fallow land, one of the many habitats we surveyed.

Image: Fences divide agricultural lands and fallows from protected enclosures of grasslands. Desert National Park, Jaisalmer, India.

Acoustic monitoring of bats:

We monitored bats in the scrub forests of Nahargarh Biological Park in November 2019 by placing two Songmeter SM4 BAT ultrasound recorders (Wildlife Acoustics, Maynard, MA, USA), one along a forest trail and another on a forest edge. This ensured that we equally recorded bats from both open habitats as well as cluttered habitats. The acoustic data was collected between 18:00 and 6:00 hrs, based on published methods (Muthersbaugh 2019).

We surveyed the Tal Chhapar Sanctuary for bats in November 2019, March 2020 and January 2021 which comprised the winter dry season in Northwest India. We deployed the Songmeter SM4 BAT ultrasound recorders (Wildlife Acoustics, Maynard, MA, USA) at three major waterholes and 4 randomly placed locations in the adjacent grasslands in the sanctuary. Bat activity in the grassland habitat as well as over water bodies were recorded for a total of 20 days in the months of November 2019 and January 2021 and for 16 days in the month of March 2020.

The recorders' audio settings were set to a 12dB gain, 384 kHz sampling rate, and triggers of a minimum duration of 1.5ms and a minimum 10 kHz trigger frequency. Twelve hours of acoustic data was collected every sampling night. Each sampling night was further subsampled by selecting six 5-minute subsamples spanning each hour of recording (0-5 minutes, 10-15

minutes, 20-25 minutes, 30-35 minutes, 40-45 minutes, 50-55 minutes) which provided us a total of 30 minutes of acoustic data for analysis.

Bat roost scouting:

We scouted for bat roosts in Jaipur city and Chhapar village in November 2019 and in Chhapar village in March, 2020. In Jaipur, we visited archaeological sites, temples and old buildings for bat roosts. We explored Jantar Mantar, Amer fort, and old buildings adjoining the forts in Jaipur. Many of the previously known sites where bats were known to roost were found to be empty owing to renovation works or movement of bat colonies due to natural circumstances. In Chhapar village we took help from members of the village to locate bat roosts in the vicinity of the village.

Results:

Bird passive acoustic monitoring:

Our acoustic surveys in Tal Chhapar, Rajasthan yielded a total of 68 species of birds, of which 37 were detected in more than 5% of our recording samples (Table 1 and 2, respectively). This data is based mainly on the November 2019 field season, and has recently been published as part of a larger comparison of grassland bird communities in India (Lahiri et al 2021). We are still analyzing the January 2021 dataset, which should provide us with an indicator of the year-on-year stability of these grassland bird communities. We found evidence of dispersed acoustic communities within the dry grassland community, owing to divergent calls and lack of overlap of signal space between species. This suggests an easily quantifiable community level pattern that can be used to track long-term community change in the region (Chhaya et al 2021). Our data also revealed evidence of spatial heterogeneity among different grassland bird species, with some species being detected unequally among different sampling sites. Although preliminary, this can be scaled up along with our 2021 data (and future projects) to understand how heterogenous grassland bird distributions are. This has important implications in conservation paradigms, using acoustics to non-invasively assess habitat preferences (which serves as proof-of-principle to study threatened species in future). In all, our data suggests that vocal bird species in dry grasslands partition acoustic space, as a means to overcome competitive overlap.

Table 1- list of all bird species detected in Tal Chhapar WLS as part of our acoustic monitoring.

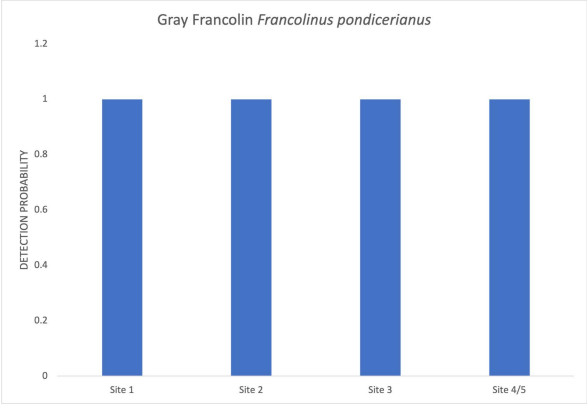
Tal Chhapar WLS	***Scientific name***
Black Francolin	*Francolinus francolinus*
Gray Francolin	*Francolinus pondicerianus*
Common Quail	*Coturnix coturnix*
Indian Peafowl	*Pavo cristatus*
Bar-headed Goose	*Anser indicus*
Lesser Whistling Teal	*Dendrocygna javanica*
Green-winged Teal	*Anas crecca*
Indian Spot-billed Duck	*Anas poecilorhyncha*
Black Ibis	*Pseudibis papillosa*
Common Kestrel	*Falco tinnunculus*
Shikra	*Accipiter badius*
Black winged Kite	*Elanus caeruleus*
Demoiselle Crane	*Grus virgo*
Common Crane	*Grus grus*
Indian Thick-knee	*Burhinus indicus*
Black-winged Stilt	*Himantopus himantopus*
Red wattled Lapwing	*Vanellus indicus*
Common Redshank	*Tringa totanus*
Green Sandpiper	*Tringa ochropus*
Common Sandpiper	*Actitis hypoleucos*
Chestnut-bellied Sandgrouse	*Pterocles exustus*
Eurasian Collared Dove	*Streptopelia decaocto*
Rose-ringed Parakeet	*Psittacula krameri*
Asian Koel	*Eudynamys scolopaceus*
Indian Roller	*Coracias benghalensis*
White-throated Kingfisher	*Halcyon smyrnensis*
Green Bee-eater	*Merops orientalis*
Black-rumped Flameback	*Dinopium benghalense*
Coppersmith Barbet	*Psilopogon haemacephalus*
Common Woodshrike	*Tephrodornis pondicerianus*
Small Minivet	*Pericrocotus cinnamomeus*
Bay-backed Shrike	*Lanius vittatus*
Great Gray Shrike	*Lanius excubitor*
Black Drongo	*Dicrurus macrocercus*
White-browed Fantail	*Rhipidura aureola*
Rufous Treepie	*Dendrocitta vagabunda*

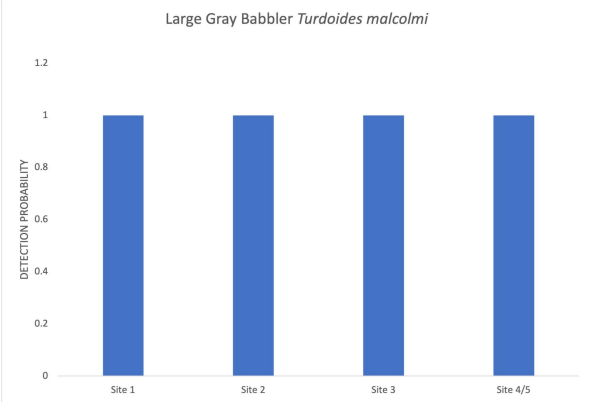
House Crow	*Corvus splendens*
Greater Short-toed Lark	*Calandrella brachydactyla*
Ashy-crowned Sparrow lark	*Eremopterix griseus*
Crested Lark	*Galerida cristata*
White-eared Bulbul	*Pycnonotus leucotis*
Red-vented Bulbul	*Pycnonotus cafer*
Plain Prinia	*Prinia inornata*
Rufous-fronted Prinia	*Prinia buchanani*
Graceful Prinia	*Prinia gracilis*
Common Tailorbird	*Orthotomus sutorius*
Hume’s Leaf Warbler	*Phylloscopus humei*
Lesser Whitethroat	*Sylvia curruca*
Large Gray Babbler	*Turdoides malcolmi*
Common Babbler	*Turdoides caudata*
Common Myna	*Acridotheres tristis*
Brahminy Starling	*Sturnia pagodarum*
Rosy Starling	*Pastor roseus*
Indian Robin	*Saxicoloides fulicatus*
Rock chat/wheatear	*Oenanthe sp.*
Red-breasted Flycatcher	*Ficedula parva*
Purple Sunbird	*Cinnyris asiaticus*
House Sparrow	*Passer domesticus*
Yellow-throated Sparrow	*Gymnoris xanthocollis*
Indian Silverbill	*Euodice malabarica*
Scaly-breasted Munia	*Lonchura punctulata*
White-browed Wagtail	*Motacilla maderaspatensis*
Gray Wagtail	*Motacilla cinerea*
White Wagtail	*Motacilla alba*
Long-billed Pipit	*Anthus similis*
Tawny Pipit	*Anthus campestris*
Tree Pipit	*Anthus trivialis*
Blyth's Pipit	*Anthus godlewskii*

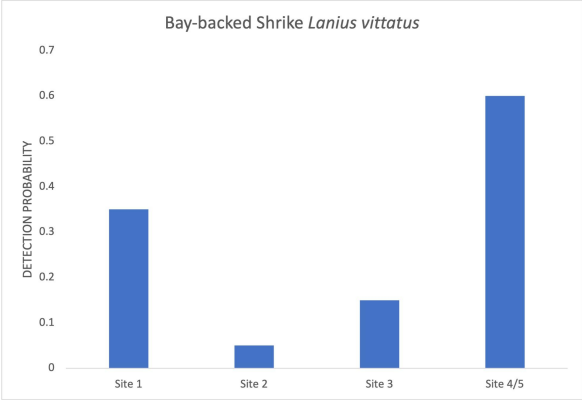
Table 2- The table contains species names in order of their detection rates, for species that were detected in more than 5% of censused samples..

Species by rank
Turdoides malcolmi
Sylvia curruca
Francolinus pondicerianus
Psittacula krameri
Corvus splendens
Lanius excubitor
Anthus campestris
Pycnonotus cafer
Streptopelia decaocto
Dicrurus macrocercus
Pavo cristatus
Prinia buchanani
Vanellus indicus
Ficedula parva
Pycnonotus leucotis
Halcyon smyrnensis
Turdoides caudata
Calandrella brachydactyla
Pastor roseus/Acridotheres tristis
Tringa ochropus
Dendrocitta vagabunda
Lanius vittatus
Euodice malabarica
Anthus similis
Prinia inornata
Copsychus fulicatus
Pericrocotus cinnamomeus
Anthus trivialis
Cinnyris asiaticus
Oenanthe sp.
Gymnoris xanthocollis
Passer domesticus
Grus grus
Anser indicus
Pterocles exustus

Motacilla cinerea
Merops orientalis







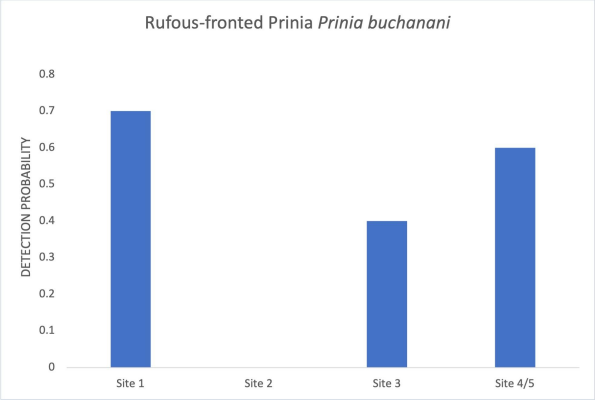


Fig: Detection probability across recording sites of different bird species at Tal Chhapar. Data from the 2019 field season suggested some patterns of spatial heterogeneity among different species. For example, while the Gray Francolin and Large gray Babbler were detected throughout the park, Bay-backed Shrike and Rufous-fronted Prinia were tied to certain sites more than the rest.

We did not record or observe the Stolickza's bushchat at Tal Chhapar. On the occasions that we did sight a bushchat (during reconnaissance at Desert National Park), we did not record vocalizations. In fact, there are very few published recordings of the bird, or even descriptions of its vocalisations. This suggests that the bird is infrequently vocal, at least during the seasons under consideration, and may be better surveyed using conventional methodology. Longer-term, year-round studies (which we are now beginning) will help confirm this. We did, however, record the Indian Spotted Creeper-*Salpornis spilonota*- in both field seasons, with detections on our recorders in January 2021 (as per preliminary examination of these data). A species that has a patchy and disjunct distribution and distinctive vocalizations, we therefore identify this species as a suitable candidate for longer-term monitoring.

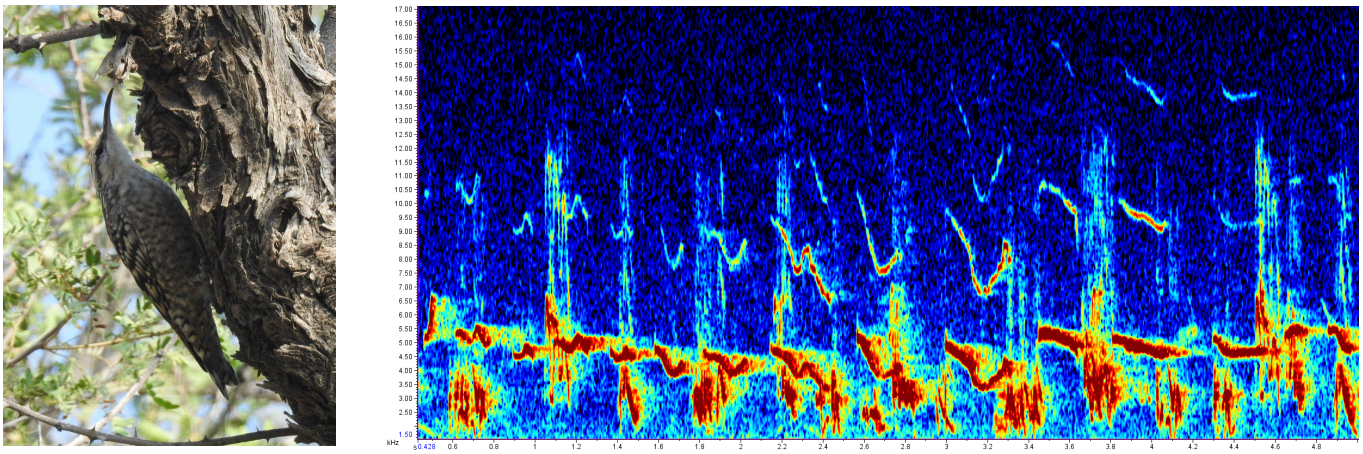


Image: The Indian Spotted Creeper *Salpornis spilonota* and a spectrogram of its song, made using Raven Pro 1.5 (cornell Laboratory of Ornithology, Ithaca, USA)

Finally, as mentioned above, our acoustic monitoring efforts at Nahargarh Biological Park revealed a diverse thorn-scrub bird community. However, we did not record the White-naped tit in this area, suggesting that it has either become rare at the site or has shifted to more remote, inaccessible localities. Because of the COVID 19 pandemic, we were unable to continue our monitoring efforts there beyond November 2019. However, we also plan in future to scout for additional sites for a broader, long-term monitoring program just as we did for Stoliczka's bushchat.






Images: Birds from semi-arid landscape (left to right): Chestnut-bellied sandgrouse, Greater short-toed lark, Great grey shrike, Common babbler, Lesser whitethroat, White-eared bulbul. Photos by Sutirtha Lahiri.

Recce surveys for Stoliczka's bushchat in additional sites:

Visits to Bikaner district in November 2019- Although Dr. Asad Rahmani (Rahmani 1996) reported a large number of bushchats sighted at several parts of Bikaner district, most notably Diyatra; we did not locate any birds during our brief survey there. There has been a large transformation of habitat since, and further intensive surveys are therefore required to ascertain the true distribution of the bushchat in Bikaner district.

Visit to Desert National Park in January 2021- Our visit to Desert National Park, Jaisalmer, yielded multiple sightings of Stoliczka's bushchat. We found the bushchat in Kalimali, located within Desert National Park. The Kalimali area is a regenerating fallow land, dominated by *Aerva javanica*, along with *Capparis sp.* and *Crotalaria burhia*.

Image: Habitat photo of the Stolickza's bushchat at Desert National Park, Jaisalmer, Rajasthan.

Notes on Stoliczka's bushchat

The bushchat, once detected, was a good subject for detailed observation. The bird was mostly seen perched on tree or bush tops, making flights from these perches to catch its prey. We observed the bird hovering at a spot before diving into the bushes for its meal. The combination of plumage, long bill and behavior helped us identify Stolickza's bushchat in the field. We visited the same site the next day, taking observations of its movement and feeding behavior. We spotted two individuals on this day in total. Again, this highlights the scarcity of this bird, as we were unable to find good numbers at any site we visited, in line with Rahmani's observations. Coupled with the lack of vocalizations, our observations suggest that this species is best surveyed by intensive conventional surveys repeating Rahmani's survey routes. There is a need for highly trained observers capable of identifying the species and equipped with cameras, to minimize uncertainties in identification (particularly in the winter plumage).

Image: Stolickza's bushchat, with its characteristic white throat, white supercilium and long bill.

Image: Stolickza's bushchat hovering before diving into the bushes, Desert National Park, Jaisalmer, January 2021.

Our preliminary remote data collection at Desert National Park began in June 2021, and is ongoing after the end of the Rufford project as well. This work is being undertaken by local field collaborators- Mr Musa Khan and team- and as a broader effort with Dr. Sutirtha Dutta of the Wildlife Institute of India, Dehradun. The aim is to empower and train local expertise in long-term monitoring and conservation of this and other threatened species Preliminary results indicate that the species was absent from the region between June and September. Our field collaborators first detected bushchats on September 6th (Khabha) and September 8th 2021 (Sudasari). This confirms earlier observations that suggested seasonal migrations of the species (either local or long-distance), and further suggests that these patterns should be studied in detail before implementing a longer-term conservation and monitoring program. There is an urgent need to identify the species' breeding grounds.

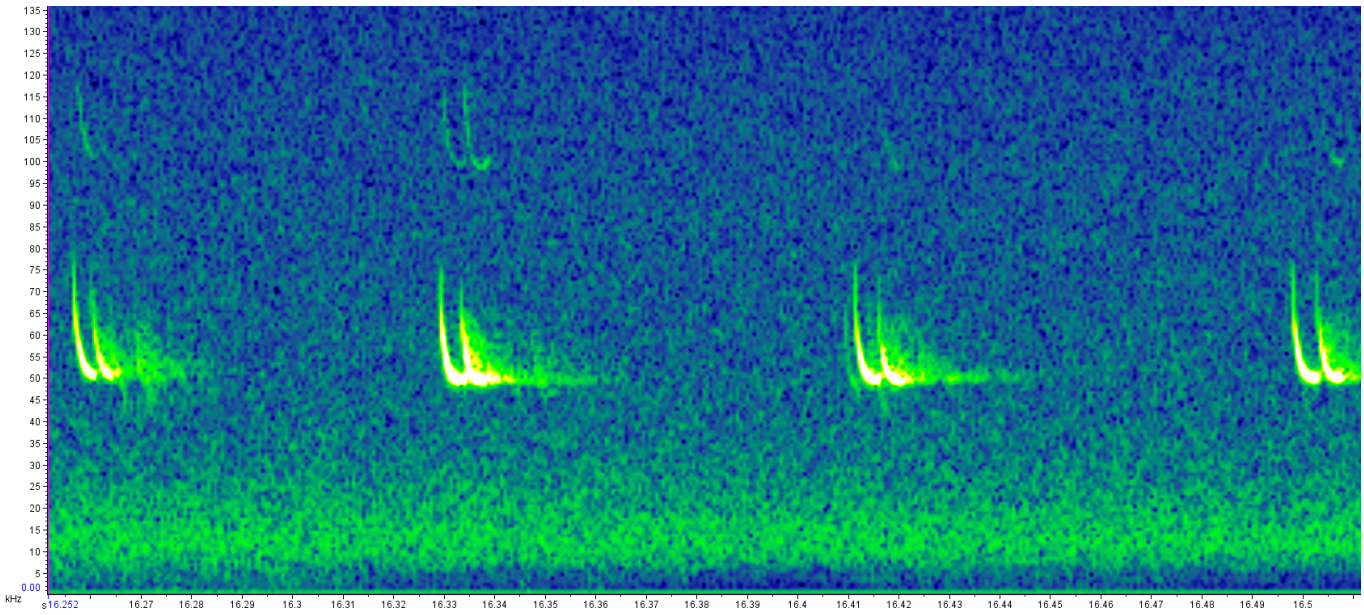
Bat passive acoustic monitoring:

We recorded just two detections of bats in the Nahargarh Biological Park, Jaipur in November 2019. The detections were from Blyth's horseshoe bat (*Rhinolophus lepidus*) and Greater Asiatic yellow bat (*Scotophilus heathii*). We were unable to sample in Nahargarh Biological Park in the latter months due to the COVID 19 pandemic, and thus concentrated efforts in Tal Chhapar, that had relatively higher bat activity.

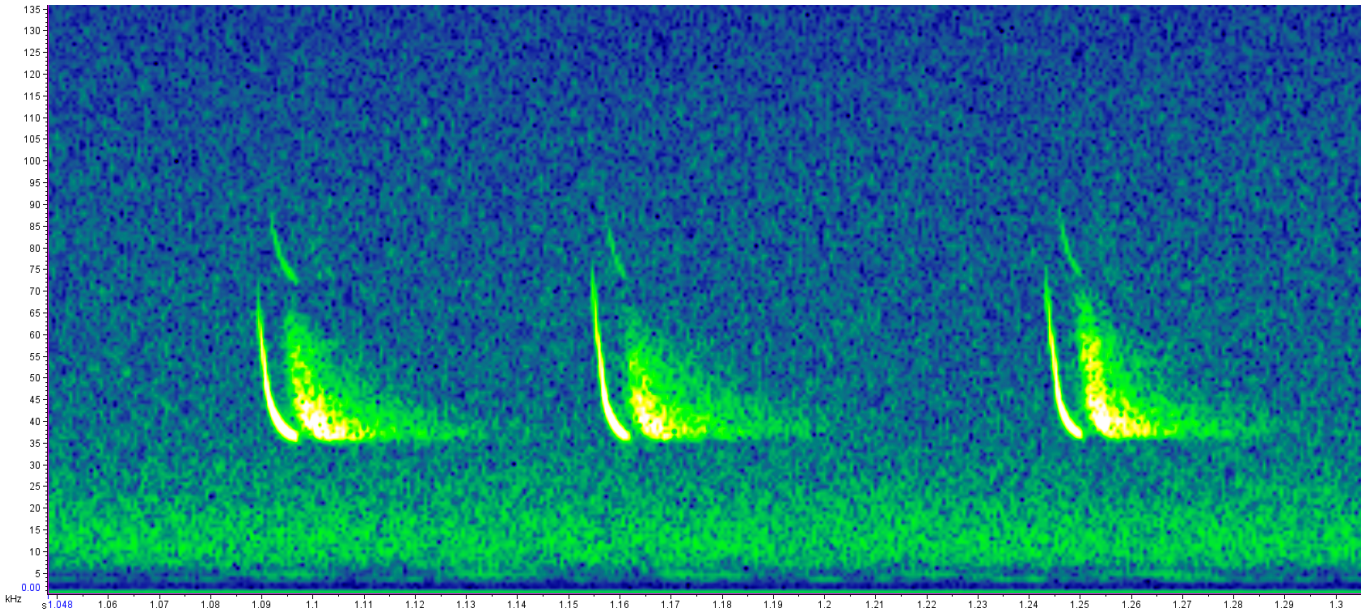
In Tal Chhapar Blackbuck Sanctuary, we recorded 6 species of bats in the study area, namely, Least pipistrelle (*Pipistrellus tenuis*), Greater Asiatic yellow bat (*Scotophilus heathii*), Egyptian free-tailed bat (*Tadarida aegyptiaca*), Blyth's horseshoe bat (*Rhinolophus lepidus*), Lesser mouse-tailed bat (*Rhinopoma hardwickii*) and Naked-rumped tomb bat (*Taphozous nudiventris*) (Mohan et al, *in prep*). The species were identified tentatively from existing data on echolocation calls of bats from India, based on previous research articles. *P. tenuis* was by far the most commonly detected species, followed by *S. heathii*. *T. aegyptiaca* and *R. lepidus* were detected regularly, albeit less frequently, whereas *R.hardwickii* and *T.nudiventris* were detected too rarely for further analysis.

We also observed a stark variation in the bat activity patterns across seasons. Total bat detections during November and March were comparable, but there was a sharp dip during the coldest part of the dry season, with very little bat activity in January 2021. We also detected considerably higher bat activity at water bodies compared to grasslands, represented as percentages of total recording minutes in the pie chart. Our data highlights the known importance of water bodies in arid habitats as excellent sites for bat monitoring efforts.

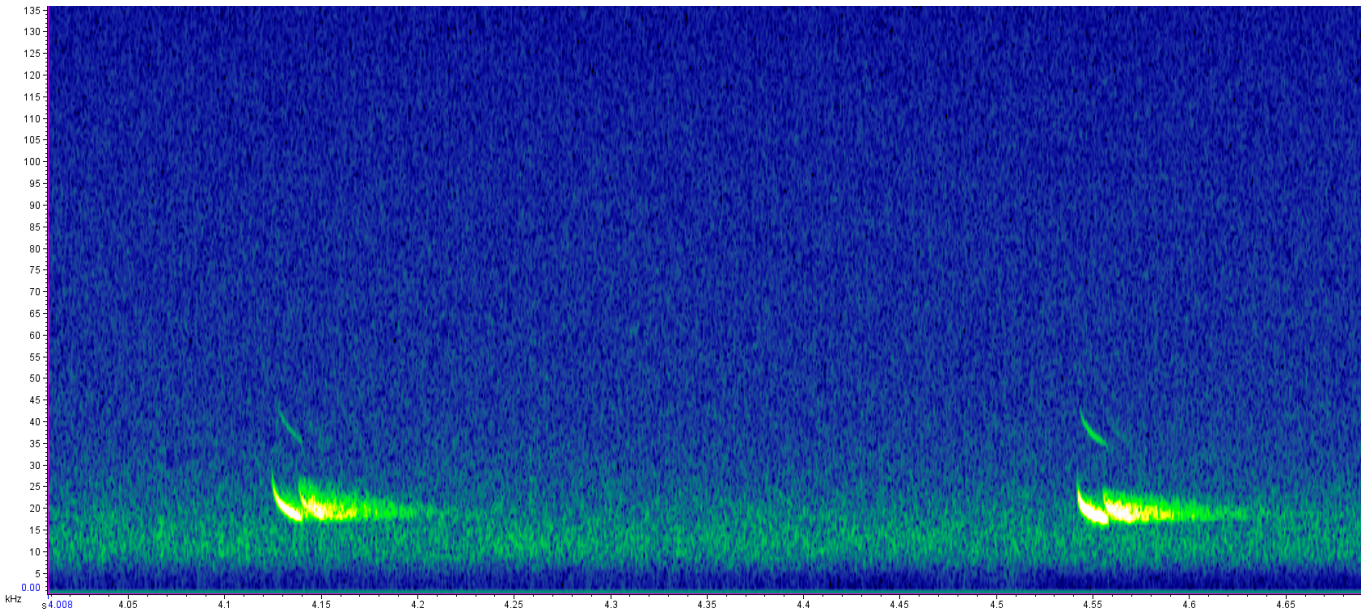
During bat roost monitoring, we observed preliminary evidence of seasonality in occurrences of bats in some roosts. In November 2019, in Jaipur we observed indirect signs (guano) of insectivorous bats previously occupying old ramparts near Amer fort, adjacent to our study area, Nahargarh Biological Park. The guano cover in the ramparts indicated the occupancy of thousands of bats. Additionally, we observed six individually roosting *Rhinopoma hardwickii* bats in the Amer fort. None of the other sites visited in Jaipur showed signs of insectivorous bat presence. In our second study area, we found *Rhinopoma hardwickii* in two colonies in Chhapar village. The roosts had more than 100 bats occupying them. Although *R. hardwickii* presence was confirmed in the vicinity of the study area, they were rarely detected in the recordings indicating inactivity in the study area due to a distant foraging grounds or hibernation.



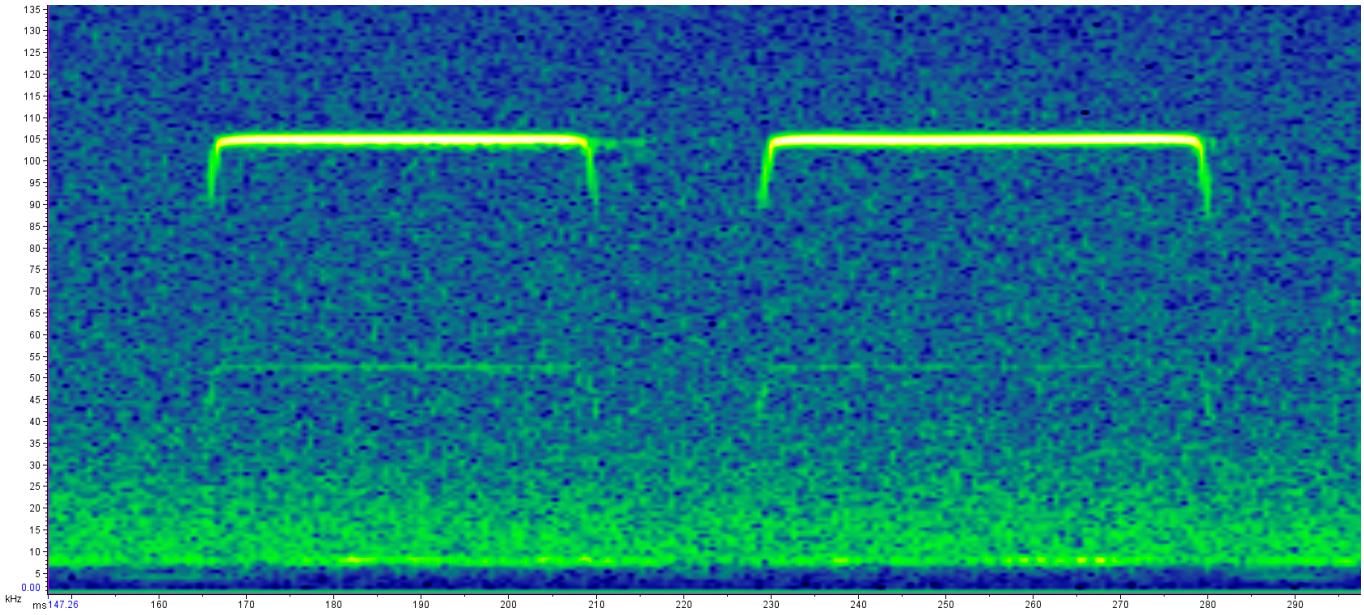
Spectrogram of *Pipistrellus tenuis*



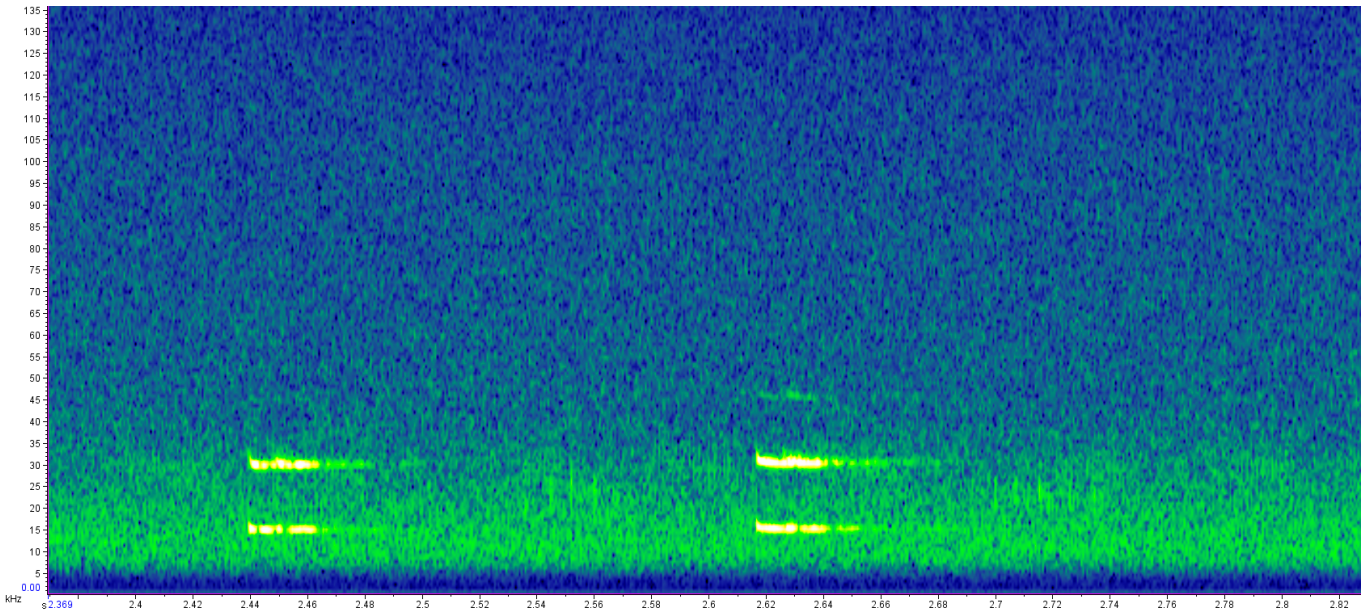
Spectrogram of *Scotophilus heathii*



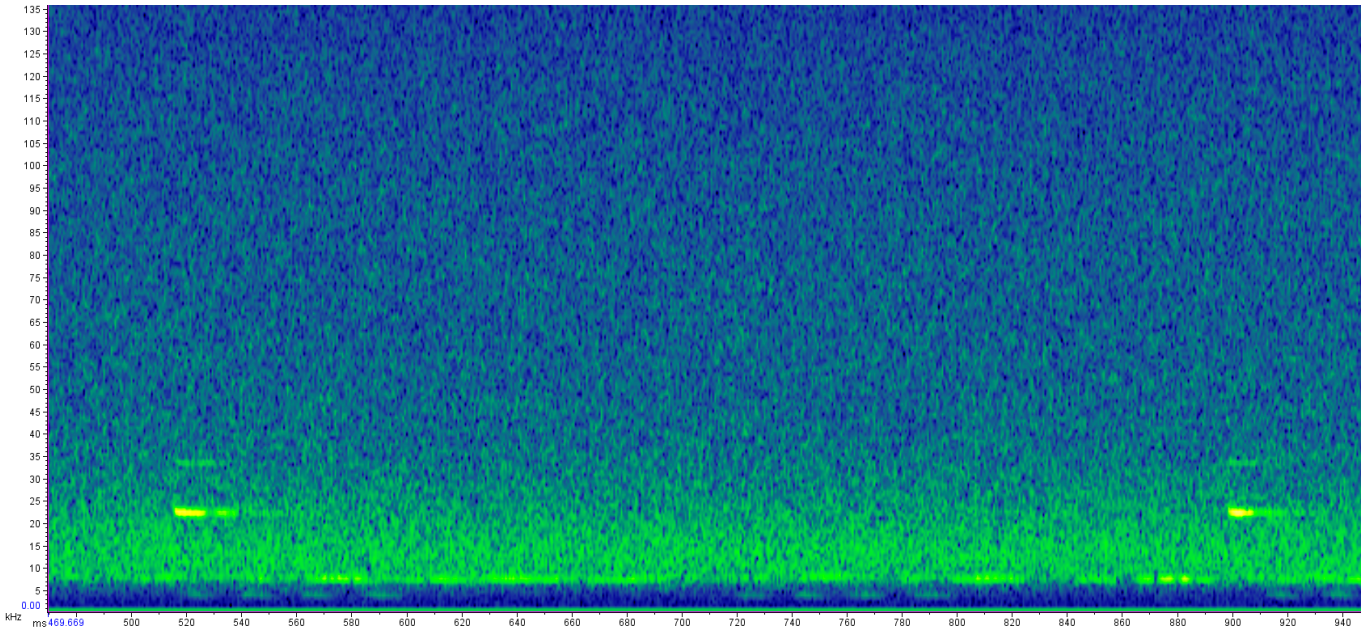
Spectrogram of *Tadarida aegyptiaca*



Spectrogram of *Rhinolophus lepidus*



Spectrogram of *Rhinopoma hardwickii*



Spectrogram of *Taphozous nudiventris*

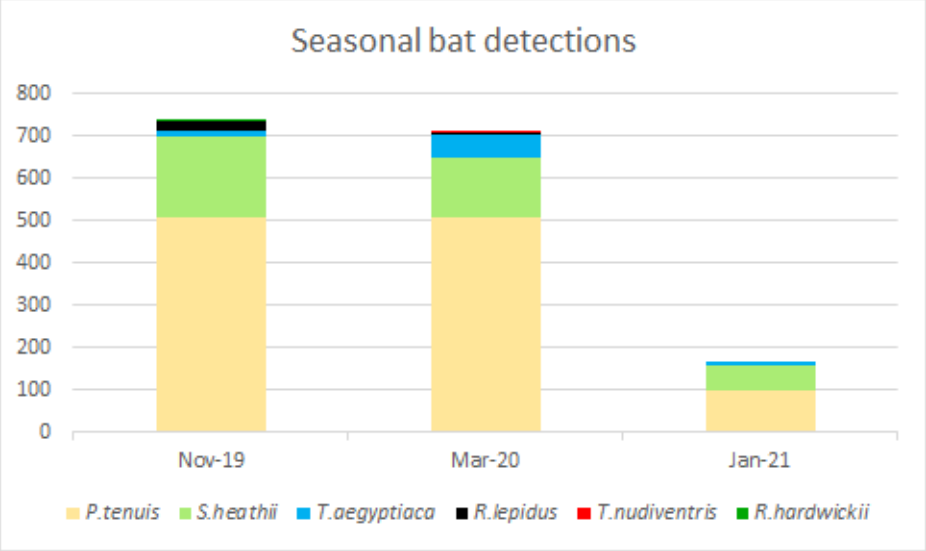


Fig. : Total bat detections in the months of November 2019 , March 2020 and January 2021. Note the seasonal changes in activity of certain species.

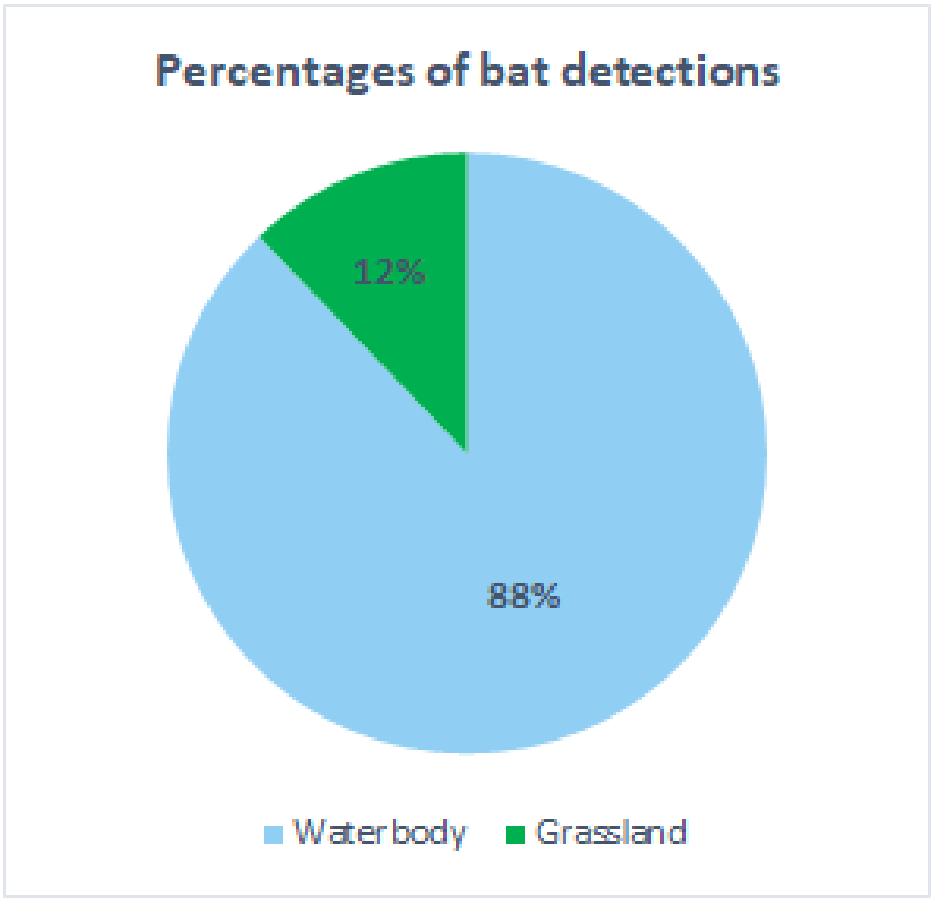


Fig. : Percentages of bat detections observed over grasslands vs water bodies.

Image: *Rhinopoma hardwickii* colony in a roost in Chhapar village.

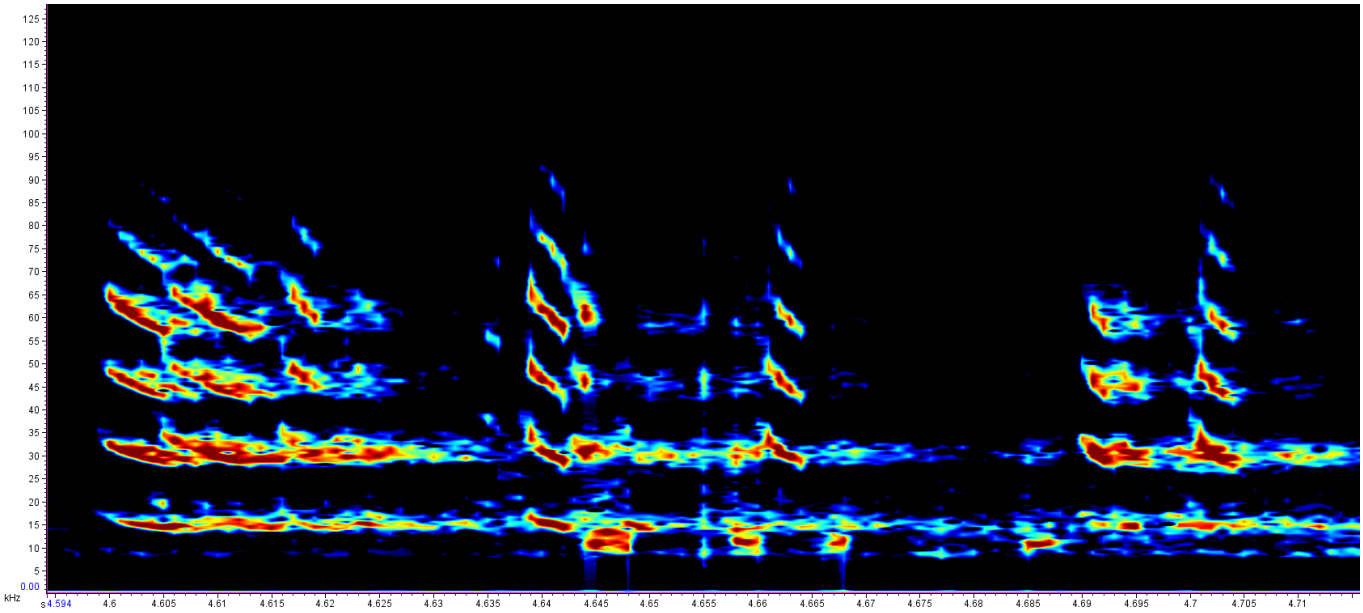


Image: Spectrogram of echolocation calls of *Rhinopoma hardwickii* from a roost in Chhapar village.

Outputs, Outreach and Education efforts:

Due to the interruptions to fieldwork caused by the COVID19 pandemic, we conducted some of our outreach programs via virtual multimedia platforms. Our bat research outreach had to be shifted from acoustics to spreading awareness about bats and the coronavirus. This was mainly due to the reports of mass culling from parts of the country, including Rajasthan (https://www.tribuneindia.com/news/nation/more-than-150-bats-killed-in-rajasthan-owing-to-fear-of-covid-19-spread-81668). Ram Mohan spearheaded the development of educational videos on bats being associated with the coronavirus pandemic. The video informed people about the diversity of bats, their ecosystem functions, importance and bats in the current pandemic. We informed the audience through the video about the associations between bats, humans and environmental health. We explained the "One-health concept", about the importance of environmental health in maintaining the health of the organisms and humans dependent on them and hence the need to protect and conserve crucial bat habitats. The video was produced in collaboration with Vivek Kannadi at the IISER Pune Science Media Center. The video was widely viewed in social media platforms like Youtube, Instagram and Facebook. The video can be accessed from the following link: https://www.youtube.com/watch?v=Sb3WSBPgHbM&t=2s. In addition, Ram Mohan provided material to the Rajasthan forest department for use in their own campaign to stop culling of bats, and undertook an outreach talk to a public audience in social media platforms to communicate some of these concepts. The outreach talk can be accessed at https://www.instagram.com/tv/CGxPYEGgxwN/?utm_medium=share_sheet

The data on seasonal patterns in bat activity represent some of the first such data on bats from the region, and will be an important baseline pattern to design future monitoring and conservation efforts. Seasonality in arid landscapes may, in future, prove highly sensitive to aridification induced by climate change, and our study provides the paradigm to local stakeholders and the forest department to detect these changes. This study is being written up as a manuscript with Ram Mohan as the lead author, and will soon be submitted to a peer-reviewed journal.

For birds, our bioacoustic data from Tal Chhapar was compared with that of a wet grassland in India, the results of which were published as a peer-reviewed paper in an open access journal, *Biology Open* with Sutirtha Lahiri as the lead author (Lahiri et al 2021). This paper elucidated convergent acoustic community structure between two biogeographically distinct grasslands, a second project of our broader research program. These data highlight the neglect in conservation of India's grassland birds, and provide a clear monitoring and conservation paradigm for these threatened ecosystems.

This sampling and analytical framework, with implications for conservation, is generalisable, and easily carried out by stakeholders at all levels of conservation and habitat management. We conceptualise community bioacoustics as a framework for using bioacoustic data across various scales- from individual threatened species to community-level patterns- as well as

across spatial and temporal axes. This framework has also been published as a peer-reviewed scientific paper in *Frontiers in Ecology and Evolution* (Chhaya et al 2021), with both Sutirtha Lahiri and Ram Mohan as authors.

1. Lahiri, S., Pathaw, N.A. and Krishnan, A., 2021. Convergent acoustic community structure in South Asian dry and wet grassland birds. Biology open, 10(6), p.bio058612.
2. Chhaya, V., Lahiri, S., Jagan, M.A., Mohan, R., Pathaw, N.A. and Krishnan, A., 2021. Community Bioacoustics: Studying acoustic community structure for ecological and conservation insights. Frontiers in Ecology and Evolution, p.488.
3. Mohan, R., Chhaya, V. and Krishnan, A. *in prep.* Seasonality and interspecific temporal partitioning in a semiarid grassland bat assemblage

We also carried out outreach work on birds in the field. Sutirtha Lahiri was invited to present and train personnels of the Rajasthan Forest Department to identify and document the avifauna of Tal Chhapar and adjoining waterbodies. Pictures from the talk below-

Sutirtha also wrote and published multiple articles on birds and conservation in several leading outlets, including National Geographic Traveller India and RoundGlass Sustain.

1. Lahiri, S. (2021) One flew over the dune's crest. National Geographic Traveller India, March.
2. https://natgeotraveller.in/rajasthans-dump-yard-of-delight/
3. https://sustain.round.glass/species/white-naped-tit/
4. https://sustain.round.glass/species/spotted-creeper/
5. https://sustain.round.glass/species/montagus-harrier-prowlers-grassland/
6. https://bubobirding.com/species/great-indian-bustard/

Sutirtha Lahiri's published paper on grasslands was also featured as a first-person interview in the journal *Biology Open*.

1. https://journals.biologists.com/bio/article/10/6/bio058851/269214/First-person-Sutirtha-Lahiri

Across the board, our sampling therefore provided important data that can be implemented in a variety of outreach programmes across media, and also provides important inputs for conservation in this understudied landscape.

Discussion:

Our efforts using passive acoustic recorders helped in establishing and publishing a long-term monitoring protocol to study entire communities of sound-producing taxa, as well as species that are otherwise difficult to survey using traditional methods. A method like ours can be scaled up across multiple spatio-temporal axes, and help integrate natural history information into a community bioacoustics framework. This can also aid in conservation efforts, especially if implemented by forest departments or other conservation organizations/institutes since it offers a relatively low-cost alternative to monitor larger areas. These monitoring and conservation methods are becoming more affordable with the advent of lower-cost recorders, and are also more economical in terms of investment in personnel as well as the analytical requirements. Thus, acoustic monitoring of communities presents a compelling alternative method to survey large landscapes.

With regards to individual threatened species, a major finding of our work concerns Stoliczka's bush chat. Importantly, we did not detect the species at our primary field site, and only detected it during reconnaissance in January 2021. Our observations suggest that pending identification of its breeding grounds, this species may be best surveyed by conventional means. Conversely, the Indian Spotted Creeper is an excellent candidate and flagship species for acoustic monitoring in the region. We also did not detect the White-naped tit in our study site at Nahargarh (a known site for the species), highlighting its sensitivity and the need for urgent further surveys to determine its true distribution. In Desert National Park, we detected Stoliczka's Bushchat in a fallow land that is cultivated in certain years. Our field collaborators have since detected and documented the bushchat from multiple locations. In 2021, when the surveys began again after the interruptions from COVID, the Stolickza's bushchat remained undetected through the summer and monsoon season, until September 6th near Khabha and September 8th at Sudasiri. These data suggest possible seasonal movement of this species, something that has been noted previously. Does this species breed in the Thar Desert? If so, where? Is acoustic monitoring more feasible in the breeding grounds? Longer term monitoring, in multiple seasons, and the sustenance of data collection with local field collaborators and experts would be a good way of determining these patterns across years. This would also open up further avenues for collaboration when scaling-up this project for longer term monitoring.

For bats, our major finding is that of distinct seasonality in the activity patterns of bats in Tal Chhapar Blackbuck Sanctuary. These distinct activity patterns indicate seasonal temporal dynamics in the bat assemblage over the study area. This could result from seasonal movement or torpor to cope with changing environmental conditions. We found that *P. tenuis* is the most abundant bat in the sanctuary followed by *S. heathii.* Additionally we also found that the occurrences of bats in the study area was largely driven by availability of water, a limiting resource in the semi-arid landscape. We observed 88 percent of bat detections from the study area were reported over the three waterbody sites monitored, whereas bat activity over grasslands contributed to only 12 percent of total bat detections.

Our findings highlight the importance of small waterholes in semi-arid landscapes that serve as key habitats for bats and other dependent fauna. These small, limiting surface water resources serve as crucial elements in the semi-arid landscape that serve the important function of water availability for desert fauna during the dry seasons. Hence, highlighting the need to conserve and maintain these surface water resources as a perennial source of water that can sustain biodiversity even during the dry periods of the year. Further, the data we collected will serve as an important framework for comparison, to highlight how anthropogenic activities influence the temporal composition of bat communities in subsequent years.

To sum up, we present a multi-taxon acoustic monitoring paradigm with tremendous conservation implications in the region, that can be used to study both individual species and entire communities of vocal animals. Through our research outputs and outreach programs, we detail this framework in a way that is replicable by all stakeholders involved. In spite of the delays caused by the COVID 19 pandemic, we have had success in designing and implementing this framework. In future, we plan to expand this framework spatially and temporally, with the involvement of local stakeholders to use this conservation data as a baseline to study the effects of ecological changes. This will enable a quantitative understanding of the effects of both immediate and longer-term threats to India's semiarid landscapes.

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