Density Estimation and Habitat Selection of Obligate Grassland Species in D'Ering Memorial Wildlife Sanctuary, Arunachal Pradesh

By

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Enrolment no: 50BB24A73024

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For the partial fulfilment for the degree

Master of Science

in

Wildlife Science

Under the supervision of

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भारतीय वन्यजीव संस्थान
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AcSIR

July 2026

DECLARATION

I hereby declare that the research work presented in this dissertation entitled "Density Estimation and Habitat Selection of Obligate Grassland species in D'Ering Memorial Wildlife Sanctuary, Arunachal Pradesh" is an original and independent piece of research carried out by me for the partial fulfilment of the requirements for the award of the degree of Master of Science in Wildlife Science at the Academy of Scientific and Innovative Research (AcSIR).

This research was conducted under the guidance and supervision of Dr. Anukul Nath, Scientist-C, Wildlife Institute of India, Dehradun, and Dr. Sutirtha Dutta, Scientist-E, Wildlife Institute of India, Dehradun.

The work presented in this dissertation has not been submitted, either wholly or partly, for the award of any other degree, diploma, or qualification at any university or institute. I further declare that this dissertation embodies my own work, analysis, observations, and interpretations, and that all sources of information used have been duly acknowledged.

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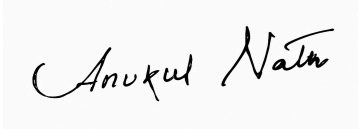

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CERTIFICATE

This is to certify that the dissertation entitled **"Density Estimation and Habitat Selection of Obligate Grassland Species in D'Ering Memorial Wildlife Sanctuary, Arunachal Pradesh"**, submitted by **Nama Sunny** to the **Academy of Scientific and Innovative Research (AcSIR)** in partial fulfilment of the requirements for the award of the degree of **Master of Science in Wildlife Science**, is a record of original research carried out under our guidance and supervision.

The work embodied in this dissertation has not been submitted previously, either in part or in full, to any other university or institute for the award of any degree, diploma, or other academic qualification.

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Executive Summary

Riverine alluvial grasslands of the Brahmaputra floodplains are among the most dynamic and threatened ecosystems in India. These floodplain grasslands, maintained by annual flooding and sediment deposition, host a unique assemblage of obligate grassland birds dependent on early and mid-successional habitats. However, quantitative information on the population status and habitat requirements of these species is limited especially in the riverine grasslands of D'Ering Memorial Wildlife Sanctuary, Arunachal Pradesh. In this context, the present study was designed to estimate the population density of obligate grassland birds and to explore the influence of habitat characteristics on their distribution in this dynamic floodplain ecosystem.

The study was conducted across the three management ranges of D'Ering Memorial Wildlife Sanctuary using 252 systematically distributed point count stations. Bird surveys were conducted using passive point counts and call-playback surveys while acoustic triangulation was used to estimate the position of vocalising birds for distance sampling analyses. Habitat selection was assessed using micro-habitat variables, grass species composition, vegetation structure and landscape attributes such as island age and island size. Generalized Linear Models (GLMs) were used to identify habitat variables associated with species occurrence while community level responses were assessed using Non-metric Multidimensional Scaling (NMDS).

When comparing survey methods, call playback greatly enhanced detectability of all four focal species by eliciting vocal responses from individuals hidden in dense grasslands. However, passive aural point counts produced more precise density estimates with consistently lower coefficients of variation, indicating that observations made under natural behavioural conditions better satisfied the assumptions of distance sampling. The successful application of acoustic triangulation further demonstrated its usefulness for estimating detection distances of vocally active grassland birds in dense alluvial grasslands where direct visual observations were often not possible.

Habitat‐selection analyses indicated that obligate grassland birds were influenced primarily by vegetation structure, grass composition and floodplain succession rather than simply habitat area. The Saccharum spontaneum–Typha latifolia grass assemblage was the most important predictor of species occurrences for all four focal species, and taller grasslands were consistently favoured over shorter vegetation. Three of the four focal species had higher probabilities of occurrence on younger alluvial islands, indicating a strong association with early-successional floodplain habitats maintained by natural flooding.

Community-level analyses further demonstrated a clear ecological separation between obligate grassland birds and habitat generalists along vegetation and successional gradients. Obligate species were associated with younger islands dominated by tall-grass communities, whereas habitat generalists occurred more frequently on older islands characterised by increasing woody vegetation. These results emphasize the importance of flood-driven succession in structuring both species-specific habitat selection and overall composition of the grassland bird community .

The results demonstrate that conservation of obligate grassland birds requires the maintenance of the ecological processes that sustain floodplain grasslands rather than simply protecting static habitat patches. Passive aural point counts combined with acoustic triangulation provide a robust structure for long-term monitoring of cryptic grassland birds, while maintaining natural flood regimes and a heterogeneous mosaic of grasslands across different successional stages is likely to be fundamental for sustaining the tall-grass bird guild of D'Ering Memorial Wildlife Sanctuary. The study provides the first quantitative baseline on population density and habitat selection of obligate grassland birds from this protected area and offers a foundation for future ecological research and long-term monitoring of riverine grassland ecosystems.

1. Introduction

1.1 Grassland ecosystems:

Grassland ecosystems are among the largest terrestrial biomes on earth covering about 25-40% of the world's land surface (Miao et al., 2025). They offer a broad spectrum of ecosystem services including carbon sequestration, regulation of hydrological processes, control of soil erosion and provision of food through livestock grazing to support the livelihoods of some 800 million people around the world (FAOSTAT, 2015; Yu & Lu, 2005; Bengtsson et al., 2019; Zhao et al., 2020). However, grasslands are among the most disproportionately threatened ecosystems, with their ecological and socio-economic value often obscured by a 'biome awareness disparity' leading to under-protection relative to forested landscapes (Lahiri, 2023). These biomes across the Indian subcontinent are exposed to intense anthropogenic pressures due to conversion for agriculture, urbanisation, industrialisation and unsustainable grazing practices leading to extensive habitat fragmentation and degradation (Lahiri, 2023; Nath et al., 2025).

1.2 Dynamic Floodplains and the Brahmaputra River Landscape

Globally Dynamic riverine landscapes and associated floodplains are characterised by spatial heterogeneity and temporal volatility. These ecosystems are characterised by recurrent cycles of hydrological expansion and contraction and function as a shifting habitat mosaic created by periodic flood pulses (Robinson et al., 2002). The natural disturbance regime is ecologically critical, continually resetting the successional clock, preventing climax vegetation from dominating the landscape, and maintaining a continuum of early-to-mid successional habitats that support highly specialised biodiversity (Robinson et al., 2002).

Among such dynamic systems are the alluvial floodplains of the Brahmaputra River and its tributaries in North-east India, which are a uniquely massive and globally threatened example. The Brahmaputra

River system is a complex network of alluvial grasslands extending over 2,900 km from the Tibetan Plateau to the Bay of Bengal (Kumar & Ambastha, 2016) and encompasses important protected areas in Arunachal Pradesh and Assam. The mature landmasses are eroded and fresh alluvium is deposited locally called chaporis riverine islands by the annual monsoon floods. Such disturbance suppresses woody encroachment and maintains a continuous successional gradient of tallgrass vegetation. Seasonal flooding is the process that maintains the productivity and structural heterogeneity of floodplain vegetation (Wright et al., 2015; Davis et al., 2020). The vegetation is important to stabilise soil and protect the riverbanks (Rawat & Adhikari, 2015) and at the same time provide critical niches for a highly specialised disturbance-dependent avifauna (Wright et al., 2015; Davis et al., 2020).

1.3 Ecological Indicators and the Vulnerability of Obligates

Among the broad spectrum of fauna residing in these dynamic landscapes, avian communities are broadly recognised as indicators of ecosystem. Birds are sensitive to fine-scale changes in vegetation structure, micro-habitat quality, and anthropogenic land-use practices, and can serve as a useful proxy for indicating broader ecological changes in grassland ecosystems (Browder et al., 2002; Fisher & Davis, 2010; Cunningham & Johnson, 2019). Their spatial occurrence, abundances and reproductive success are linked to specific floristic architecture such as vegetation density, vertical canopy structure and litter depth (Herkert, 1994; Maphisa et al., 2017).

Obligate grassland birds, a habitat-specialized ecological guild, are particularly susceptible in the larger avian assemblage (Knopf, 1994; Peterjohn & Sauer, 1999; Vickery et al.,1999). Unlike habitat generalists which can adapt to fragmented or transitional landscapes, these obligate species depend heavily on structurally suitable grasslands for breeding and survival (Herkert, 1994; Lehmkuhl, 1994; Fisher & Davis, 2010). Because of their narrow ecological niches (Wiens, 1989), small structural changes resulting from unsustainable grazing intensity, proliferation of invasive plants, habitat

fragmentation, or natural successional shifts such as woody encroachment can severely impair habitat suitability and threaten population persistence (Coppedge et al., 2001; Grant et al., 2004; Flanders et al., 2006; Derner et al., 2009).

1.4 Habitat Selection in Changing Landscapes

Habitat selection is the hierarchical process by which individuals select environments that maximise their survival and reproductive success (Johnson, 1980; Wiens et al., 1987). Grassland birds choose based on features of local vegetation as well as broader landscape features that respond to environmental variables at different spatial scales (Wiens et al., 1987; Fisher & Davis, 2010).

Vegetation structure has been identified as a key determinant of habitat suitability at the local micro-habitat scale (Fisher & Davis, 2010). Grass height, vertical canopy density, litter depth and specific floristic composition are variables that strongly influence foraging opportunities, predator avoidance and nest-site selection (Fisher & Davis, 2010; Maphisa et al., 2017). But selection is not controlled only by local floristics. Landscape-level characteristics such as island size of grasslands, spatial connectivity and extent of woody vegetation encroachment also fundamentally limit occurrence patterns of many grassland species (Herkert, 1994; Coppedge et al., 2001; Grant et al., 2004).

Furthermore, habitat selection is inherently linked to natural disturbance processes within alluvial floodplains (Jahan et al., 2022). Also, the seasonal monsoon floods perpetually change the vegetation structure, and an ever-changing mosaic of successional stages is created on the landscape (Rahmani et al., 2022). These structural dynamics, therefore, define the spatial occurrence and nesting distribution of diverse obligate bird species (Jahan et al., 2022; Rahmani et al., 2022).

1.5 Population Density Assessment

Estimates of population density are vital for knowledge about population status, monitoring of temporal trends and evaluation of the effectiveness of conservation and management interventions (Buckland et al., 2001; Nichols & Williams, 2006). Unlike species occurrence, which simply indicates the presence/absence of a species, or raw counts, which are simply the number of individuals detected, population density provides a standardised estimate of the number of individuals per unit area and incorporates the effects of imperfect detection mathematically (Buckland et al., 2001; Royle et al., 2004). Density estimates therefore make it possible to make meaningful comparisons between habitats and populations over time, and are one of the most informative measures for assessing the population status of threatened species (Buckland et al., 2001; Nichols & Williams, 2006).

However, density estimation is particularly difficult for grassland birds. Many obligate grassland species are secretive, use dense vegetation, vocalise intermittently, and are more often detected by sound than by direct visual observation (Ralph et al., 1995; Conway, 2011). Hence, the probability of detection varies according to vegetation structure, observer experience, and bird behaviour and weather conditions, resulting in observed counts that can greatly underestimate true abundance if imperfect detection is not explicitly accounted for (Buckland et al., 2001; Buckland et al., 2015).

Traditional methods have mainly used line transects and point counts, frequently with distance sampling to account for the reduction in detectability with increasing distance from the observer (Buckland et al., 2001; Buckland et al., 2004). Distance sampling has been extensively used to estimate densities of grassland birds and other avian taxa because it provides statistically robust estimates while modelling detection probability (Thomas et al., 2010; Buckland et al., 2015). Furthermore, active call-playback surveys have been adopted for cryptic species in dense vegetation to enhance detection rates by stimulating vocal responses of undetected individuals (Conway, 2011). Playback increases encounter rates, but effects vary across species, season, and behavioural context. It can also influence

bird movement, potentially violating the key assumptions required for traditional distance sampling approaches (Conway, 2011; Buckland et al., 2015).

Acoustic-based methods are increasingly important for species that are mainly detected using acoustic signals. Passive acoustic monitoring (PAM) with fixed microphone arrays can deliver estimates of animal density with high statistical precision but often involves specialised equipment, large deployment grids, and significant logistical effort, especially in remote or difficult landscapes. One way of estimating the location of calling individuals is acoustic triangulation, in which simultaneous bearings recorded by two or more observers are used to estimate the location of the calling individuals. This technique has been successfully employed to estimate densities of vocally active primates such as Kloss' Gibbons (*Hylobates klossii*) and Müller's Gibbons (*Hylobates muelleri*) in dense tropical forests where visual observations are often impossible (Höing et al., 2013; Gilhooly et al., 2015).

The use of traditional distance sampling methods combined with the acoustic triangulation to obtain the distances of a species may improve the density estimate for vocal species (Theuerkauf et al., 2025). Rather than estimating distances directly by ear, simultaneous bearings from two observers are used to triangulate the precise position of calling individuals, after which the triangulated distances are incorporated into a distance-sampling framework. This approach reduces estimation errors while retaining the statistical advantages of distance sampling, providing a robust alternative for estimating densities of cryptic species in dense habitats. The authors also suggest that this combined approach can be applied to a wide range of vocally detectable taxa inhabiting structurally complex environments.

The quantitative estimates of absolute population density for obligate grassland birds inhabiting the alluvial floodplains of northeastern India remain scarce. Most of the regional studies have focused on qualitative species occurrence, distribution or broad habitat associations (Jahan et al. 2022; Rahmani et al. 2022) and relatively few have estimated population densities using analytical frameworks that account for imperfect detection. Also, sophisticated methods like acoustic triangulation combined with distance sampling have not yet been applied to obligate grassland birds in these dense floodplain conditions.

1.6 Aim:

To estimate the densities of obligate grassland birds and identify the habitat and landscape factors influencing their habitat selection in D'Ering Memorial Wildlife Sanctuary, while evaluating the effectiveness of different survey methods for density estimation.

1.7 Objectives, Research Questions, and Hypotheses

Objective 1 :

To find out the best method among 1. Aural detection during point count; 2.Visual detection during point count and 3. Call playback Aural detection for estimating the densities of obligate grassland birds.

Research Question 1: What is the best method among 1. Aural detection during point count (aural point count); 2.Visual detection during point count (visual point count) and 3. Call playback Aural to find the density of obligate grassland birds.

Research Question 2: What are the densities of obligate grassland species at D'Ering Memorial Wildlife Sanctuary .

Hypothesis 1: Due to the visually dense nature of tall grass habitats, the call-playback surveys will yield higher Detection Probabilities and larger Effective Detection Radius (EDR) compared to passive counts.

Hypothesis 2 : The densities of obligate grassland birds will be less compared to generalist species.

Objective 2:

To understand the factors influencing habitat selection of obligate grassland birds at D'Ering Memorial Wildlife Sanctuary.

Research Question 1: How micro habitat variables(grass height, grass assemblage, invasive plant species and associated flora) determine the habitat selection of obligate grassland species?

Research question 2: How landscape features (island island size and island age) influence the habitat selection at a broader scale?

Hypothesis 1: Grass Structure and Assemblage positively influences the habitat selection.

Hypothesis 2: Invasives and Tree species in grasslands will have a negative effect on their habitat selection.

Hypothesis 3: With the increase of Island size and island age the obligate bird occupancy will decrease.

2. Study Area and Taxa

2.1 Study Area

The present study was carried out in D'Ering Memorial Wildlife Sanctuary (DWLS) with an area of 190 sq. km, located in East Siang district of Arunachal Pradesh, India (Rahmani et al; 2022). The sanctuary is located near Pasighat, which lies on the border of Assam and Arunachal Pradesh and is flanked by the Siang and Sibya rivers (Mize et., 2014). DWLS is world famous Important Bird and Biodiversity Area (IBA) as it harbors rare and threatened species like Bengal Florican (*Houbaropsis bengalensis*) and Swamp Grass-babbler (*Laticilla cinerascens*) (Rahmani, 2022). The sanctuary is connected to the Kobo Chapori of Assam, which is connected to the Dibru-Saikhowa National Park on the other side of the Brahmaputra River. This connection forms a large uninterrupted stretch of riverine land, which is significant for wildlife conservation over the larger landscape and for the movement of large herbivores (Jahan et al., 2022; Kumar, 2018). For management purposes, the sanctuary is divided into three ranges, namely Borguli, Sibiamukh and Anchalghat (Rahmani et al., 2022).

The area has a hot and humid (tropical) climate, strongly affected by both the southwest and northeast monsoons. The sanctuary receives heavy rainfall every year, often more than 2,000-3,000 mm, mostly between May and September (Dhar et al., 2004). The land is shaped by extreme seasonal changes in water levels. Heavy yearly monsoon floods act as powerful natural disturbances. These flood waters erode the old land and deposit new silt. This process continuously changes the shape of the land and initiates natural growth (succession) of plants on river islands (Jahan et al., 2022).

The land of DWLS is mainly composed of ever-changing river plains. Approximately 80% of the sanctuary is covered by alluvial grasslands (grasslands formed by river-deposited soil), mixed with fast-flowing river channels, seasonal marshes, and river islands (locally called *chaporis*). The remaining 20% is composed of semi-evergreen riverine forests and secondary woodlands (Mize et.,

2014). Grasslands have a highly varied structure. They consist of tall perennial grasses such as Saccharum spp., *Narenga porphyrocoma* (syn: *Saccharum narenga*) and *Imperata cylindrica* and a variety of sedges including Cyperus spp. In mature patches scattered trees like *Dillenia indica* and *Bombax ceib*a are slowly replacing (Jahan et al., 2022).

Along with the rare grassland birds, the DWLS also harbours a large variety of mammals well suited to the tall-grass river ecosystem. The sanctuary has a population of mega-herbivores, especially the Asian Elephant (*Elephas maximus*) and the Asiatic Water Buffalo (*Bubalus arnee*). These animals are important to sustain the health of grasslands by grazing and trampling on vegetation (Kumar, 2018). Other common hoofed animals include the Hog Deer (*Axis porcinus*) and sambar (*Rusa unicolor*). Carnivores include the Common Leopard (Panthera pardus) and Leopard Cat (*Prionailurus bengalensis*). Recent camera trap surveys have confirmed the return of the endangered Bengal Tiger (*Panthera tigris*), which has been absent from the area for many decades (The Hindu news, 2026).

Like many floodplains in the Indian subcontinent, DWLS and the adjacent unprotected chaporis are under heavy pressure from human activities (Nath et al., 2025). The land has long been connected, both historically and culturally, with local indigenous communities mainly the Adi and Mising tribes, who depend on the river's resources (Crémin, 2012). One of the biggest human impacts in the region is the grazing of domestic livestock, especially from local cattle camps (Khutis) (Rahmani et al., 2022). Uncontrolled cattle grazing and trampling often damage the microhabitat structures that ground-nesting birds require to survive (Jahan et al., 2022).

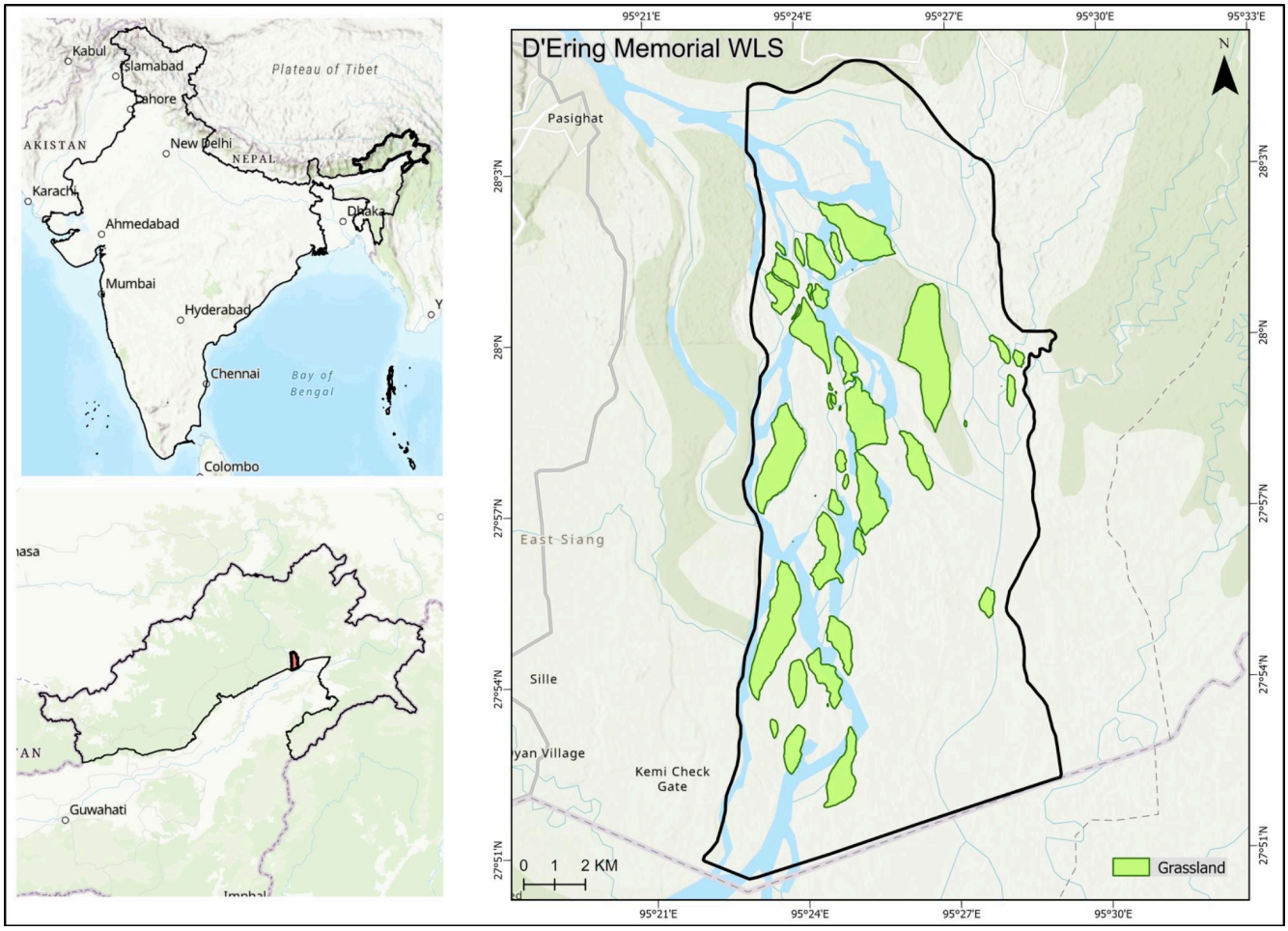

Figure 1. *Location of D'Ering Memorial Wildlife Sanctuary in East Siang District, Arunachal Pradesh, India,*

2.2 Focal Taxa

The present study selected nine obligate grassland bird species that are known to occur in alluvial grasslands of D'Ering Memorial Wildlife Sanctuary. These species are strongly associated with tall riverine grasslands and depend on structurally suitable grassland habitats for breeding, foraging and shelter (Rahmani et al., 2022). Owing to their habitat specialization, several of these species are considered conservation priorities within the Brahmaputra floodplain ecosystem and are threatened by habitat degradation and changes in natural floodplain dynamics.

During field surveys, all nine target species were surveyed using passive point counts and call-playback. However, only four species Black-breasted Parrotbill (*Paradoxornis flavirostris*),

Chestnut-capped Babbler (*Timalia pileata*), Swamp Grass-babbler (*Laticilla cinerascens*), and Jerdon's Babbler (*Chrysomma altirostre*) recorded sufficient detections for robust density estimation and habitat selection analyses. The remaining species were recorded too infrequently to permit reliable statistical analyses but are reported as part of the overall survey observations

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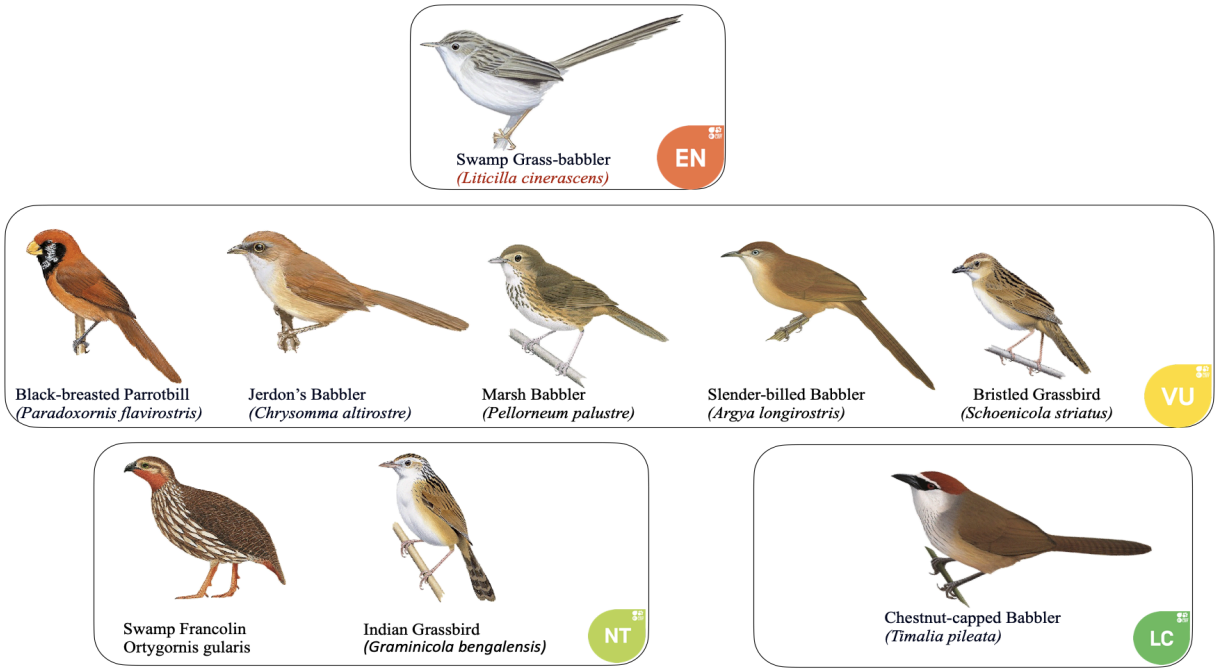

Figure 2. *The nine obligate grassland bird species targeted during field surveys in D'Ering Memorial Wildlife Sanctuary. The figure also indicates the current IUCN Red List conservation status of each species (EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern).*

3. Methods

3.1 Study Design

To capture the spatial heterogeneity of the riverine landscape, a systematic sampling design was employed. Prior to field surveys, the entire extent of the sanctuary's grasslands was mapped using Normalized Difference Vegetation Index (NDVI) data derived from Sentinel satellite imagery. Distinct grassland patches (*chaporis*) were manually digitized and assigned unique identifiers.

A total of 54 distinct grassland patches, covering an effective area of approximately 39 sq. km, were systematically surveyed. To account for the influence of island size on bird occurrence (Vickery et al., 1999), these surveyed grasslands were categorized into three size classes: Small (≤ 1 sq. km; n=42), Medium (1 to 4 sq. km; n=11), and Large (> 4 sq. km; n=1).

Within these 54 patches, a systematic layout was utilized to place the survey point counts. To ensure spatial independence and avoid the simultaneous double counting of avian individuals, adjacent point count locations were spaced at fixed intervals 500 meters apart in the Medium grassland island, and 400 meters apart in the small grassland patch .The larger patch were divided into 500x500 meter square grids and in each grids one point count station survey was conducted . This systematic spatial coverage resulted in a total of 252 independent sampling points distributed across the 39 sq km sanctuary.

3.2 Objective 1: Field Methods

3.2.1 Avian Point Counts and Call-Playback Surveys

Standard passive point counts often result in low detection probabilities for obligate marsh and grassland birds due to their secretive and skulking nature and dense habitat preferences (Conway, 2011). To maximize detectability, we used a combination of passive point counts and targeted acoustic call-playback (Conway, 2011). Surveys were conducted from dawn to four hours post-sunrise and three hours pre-sunset, corresponding to the peak period of avian activity (Ralph et al., 1995). On overcast days, sampling was extended up to seven hours to account for prolonged foraging activity. Prior to the

formal study, both observers underwent rigorous training during a reconnaissance survey to accurately identify the specific vocalizations of the focal taxa.

Acoustic Triangulation in Dense Habitats

Estimating accurate perpendicular distances to target species is the most critical assumption of distance sampling (Buckland et al., 2001). However, in the alluvial floodplains of D'Ering Memorial Wildlife Sanctuary, the extreme structural density and height of the successional grasses (often exceeding 3 meters) render visual distance estimation and standard laser rangefinders ineffective. To overcome this limitation, we adapted an acoustic triangulation protocol also known as fixed-point auditory counting to map local bird clusters.

Acoustic triangulation was initially developed for the survey of loud-calling and highly territorial forest species such as gibbons (Brockelman & Ali, 1987), and has subsequently been used for the survey of Himalayan Galliformes in rugged terrain where visual confirmation is impossible (Gaston et al., 1980; Thunhikorn et al., 2016).

In our survey a structured dual observer protocol was implemented, adapted from the methodology described by Theuerkauf et al. (2025). Upon arriving at a sampling location at the periphery of a grassland patch, two observers established independent stations exactly 50 meters apart. This baseline observer distance was verified in the field using a laser rangefinder. Before initiating the bird count, metadata-including island ID, point ID, observer name, date, time, GPS coordinates, wind speed, and weather conditions were synchronously recorded by both observers using the EpiCollect mobile application. Both observers maintained a 180-degree field of view facing the grassland patch.

Passive Point Counts (5-Minutes)

Following metadata entry, a 5-minute passive point count was initiated. All birds detected visually and aurally were recorded. For distance sampling assumptions, exact radial distances to visually detected birds were measured directly using a laser rangefinder (Nikon laser rangefinder). For aural detections

(singing or calling), observers recorded simultaneous compass bearings to the sound source using handheld Suunto compasses. To ensure deduplication, both observers communicated to assign the exact same unique identification code (e.g., "jb1" for Jerdon's Babbler1) to the same individual bird. Acoustic triangulation was performed by two observers recording simultaneous bearings to pinpoint the exact location of the vocalizing bird and the bearing angle was recorded using a handheld Suunto compass. Birds were visually confirmed using Zeiss Terra ED (8x42) binoculars. Environmental covariates known to affect detectability including wind speed, cloud cover, and time of day were recorded at each point (Conway, 2011).

Call-Playback Surveys(6-minute and 43-second)

Immediately following the passive count, an active acoustic survey was conducted to draw responses from visually concealed individuals due to dense grass. A broadcast speaker was placed exactly midway between the two observers (25 meters from each point station) and oriented directly toward the grassland patch. The initiation of the playback sequence was coordinated synchronously between the observers via two-way radios (walkie-talkies).

A 6-minute and 43-second structured audio track was broadcasted, targeting 9 specific grassland species. The playback protocol allocated exactly 15 seconds of species-specific vocalization followed by 30 seconds of silence to listen for responses, repeated sequentially for each species (Conway, 2011). The sequence of bird calls are as follows Black-breasted Parrotbill (*Paradoxornis flavirostris*) (BBP), Jerdon's Babbler (*Chrysomma altirostre*)(JB), Swamp Grass-babbler (*Laticilla cinerascens*)(SGB),Marsh Babbler(*Pellorneum palustre*)(MB), Chestnut-capped Babbler (*Timalia pileata*)(CCB), Slender-billed Babbler (*Argya longirostris*)(SBB), Swamp Francolin (*Ortygornis gularis*)(SF), Indian Grassbird (*Graminicola bengalensis*)(IGB), and Bristled Grassbird (*Schoenicola striatus*)(BGB).When a bird responded to the playback, simultaneous bearings were again recorded by both observers using the acoustic triangulation method and assigned a unique ID. This standardized Call play back methodology expands the effective detection radius for highly cryptic species without

violating distance sampling assumptions (Buckland et al., 2001; Conway, 2011).Species like SGB listed in Endangered, BBP,JB,MB,SBB,SF are listed Vulnerable,IGB in listed Near Threatened, CCB listed in Least Concern.

3.2.2 Objective 1: Analytical Methods

Data Preparation and Triangulation of Acoustic Detections

Prior to density estimation, raw point count and call-playback data underwent cleaning to standardise species nomenclature and resolve duplicate records. Due to the highly cryptic nature of the four focal obligate grassland species (Black-breasted Parrotbill, Swamp Grass-babbler, Jerdon's Babbler, and Chestnut-capped Babbler), standard visual distance estimation was frequently low. During the 5-minute passive point counts, detections for these focal species were aural.

While radial distances for visual detections were directly measured using a laser rangefinder, distance estimation based purely on human hearing is prone to severe observer bias and spatial error (Alldredge et al., 2007). To overcome this and to meet the assumptions of distance sampling an acoustic triangulation approach was used, which allowed for the mathematical derivation of exact radial distances, without the need for distance estimation (Theuerkauf et al., 2025).

During surveys, two independent observers (Observer 1 and Observer 2) maintained spatially separated 50m. Upon hearing a vocalizing bird, both observers recorded simultaneous compass bearings (θA and θB) to the call source. The exact GPS coordinates of both observers were recorded and projected into UTM Easting (x) and Northing (y). The exact radial distance from each observer to the bird (dA and dB) was then calculated using a trigonometric intersection algorithm programmed in R. The intersection distances were derived using the following geometric framework:

$$dA = \Delta x \cdot \cos(\theta B) - \Delta y \cdot \sin(\theta B) / \sin(\theta A)\cos(\theta B) - \cos(\theta A)\sin(\theta B)$$

$$dB = \Delta x \cdot \cos(\theta A) - \Delta y \cdot \sin(\theta A) / \sin(\theta A)\cos(\theta B) - \cos(\theta A)\sin(\theta B)$$

Where Δx and Δy represent the spatial difference in Easting and Northing between Observer 1 and Observer 2. This approach extends traditional distance sampling methods to include spatial triangulation and results in a large improvement in the accuracy of aural point counts of cryptic species in dense habitats.

3.2.3 Density Estimation and Distance Sampling

We used standard and Multiple Covariate Distance Sampling (MCDS) frameworks to estimate species densities and to compare the efficiency of passive and playback methods using the Distance package in R (Buckland et al., 2015; Thomas et al., 2010). Distance sampling is based on the key mathematical assumption that the detection probability (p) decreases with the distance from the observer to the animal (Buckland et al., 2001).

Each observer had independent detections and unique bearings, and triangulated distances were explicitly associated with unique detection IDs. Distance data were truncated for each species specifically (80-120 m) to remove distant outliers and improve the fit of the model (Buckland et al., 2001) to robustly model the detection function (p). Key detection functions including the Half-Normal and Hazard-Rate models were fitted to the distance histograms.

3.3 Objective 2: Field Methods

3.3.1 Microhabitat and Vegetation Sampling

Vegetation sampling (n = 252) was done at the same time as the point-count locations to measure the structural composition of the micro-habitat which is highly influential on the presence and distribution of obligate grassland birds (MacArthur & MacArthur, 1961; Jahan et al., 2022).

A nested circular plot methodology was employed to capture different vegetation strata. A 1-meter radius plot was used to visually estimate the percentage cover of grasses, as well as grass species richness. A 3-meter radius plot was utilized to count saplings, shrubs, herbs and specific herbaceous invasive species (including *Ageratum conyzoides, Chromolaena odorata, Lantana camara, Mikania*

micrantha, and Leea asiatica). Finally, the density of mature trees was measured using a plot of 10 meter radius (Jahan et al., 2022)

The vertical structure profile (grass height) was measured by using a standardized 4-m bamboo pole with high-visibility tape (Jahan et al., 2022). At 10 random points along a transect within the plot, the pole was placed vertically and vegetation contacts (hits) were recorded across six vertical bins: 0–25 cm, 25–50 cm, 50–100 cm, 100–200 cm, 200–300 cm, and 300–400 cm. This technique resulted in a vertical density profile for each survey point, which was used to evaluate fine-scale structural preferences of the focal avian species.

3.3.2 Objective 2: Analytical methods

To evaluate the micro-habitat drivers of obligate grassland bird occurrence, site-level environmental variables were quantified. These included woody encroachment (tree, sapling, and shrub counts) invasive species and herbaceous count. Following methodologies adapted from Nath et al. (2019), Principal Component Analysis (PCA) was employed to address multi-collinearity among the highly correlated vegetation variables and landscape variables to reduce dimensionality.

Two separate PCAs were conducted on centered and scaled correlation matrices; the first evaluated vertical vegetation structure across eight height strata, and the second evaluated floristic composition based on the percent cover of primary grass species. Component retention was determined using the Kaiser-Guttman criterion, retaining principal components with eigenvalues greater than 1.0. The extracted site-level principal component scores representing synthesized, independent gradients of vegetation volume (e.g., short vs. tall) and distinct grass assemblages *Saccharum spontaneum* and *Typha latifolia(*SS_TL) ,*Saccharum narenga*, *Saccharum ravennae*, and *Phragmites karka(*SN_SR_PK), *Saccharum narenga and Saccharum spontaneum*(SN_SS), *Saccharum ravennae(*SR) *Phragmites karka* and *Saccharum spontaneum(*PK_SS) , were subsequently utilized as continuous predictor variables in site-occupancy Generalized Linear Models (GLMs).

Landscape-Level Spatial and Successional Metrics:

To evaluate the probability of occurrence micro-habitat structural data was supplemented with macro-level landscape variables, specifically spatial extent (island size) and successional stage (island age).

To account for the effect of the spatial extent on the occupancy of grassland birds (Vickery et al., 1999), the extent of each grassland patch surveyed was derived from digitized spatial polygons. A total of 54 unique grassland patches with an effective area of about 39.1 sq. km were selected for systematic surveys. For analysis, the surveyed grasslands were considered as a categorical variable and classified into three discrete size : Small (≤ 1 sq. km; n=42), Medium (1 to 4 sq. km; n=11), and Large (> 4 sq. km; n=1).

To quantify the successional stage of the dynamic riverine habitat, landscape island age (time-since-disturbance) was calculated using Google Earth Engine (GEE). Multi temporal satellite imagery was utilized to track the historical formation, stabilization, and vegetative colonization of each island following catastrophic flood scouring events. This remote sensing approach generated a continuous age metric (in years) for each specific patch. As validated by ground-truthed structural data, this time-since-disturbance metric served as a robust spatial proxy for the successional chronosequence of the Brahmaputra floodplains.

These landscape-level variables (categorical island size and continuous island age) were subsequently integrated with the point-level micro-habitat for the multivariate Generalized Linear Models (GLMs).

4. Results

4.1 Objective 1: Population Density Estimation

4.1.1 Exploratory Analysis of Distance Data

Preliminary exploration of the distance data was used to evaluate observer consistency, overall detectability patterns, and species-specific distance decay prior to model fitting.The distribution of recorded detection distances between the two observers (Figure 3)are almost the same. Density curves for both observers exhibited overlap, peaking at approximately 25 to 40 m, indicating that observer bias in spatial distances were minimal.

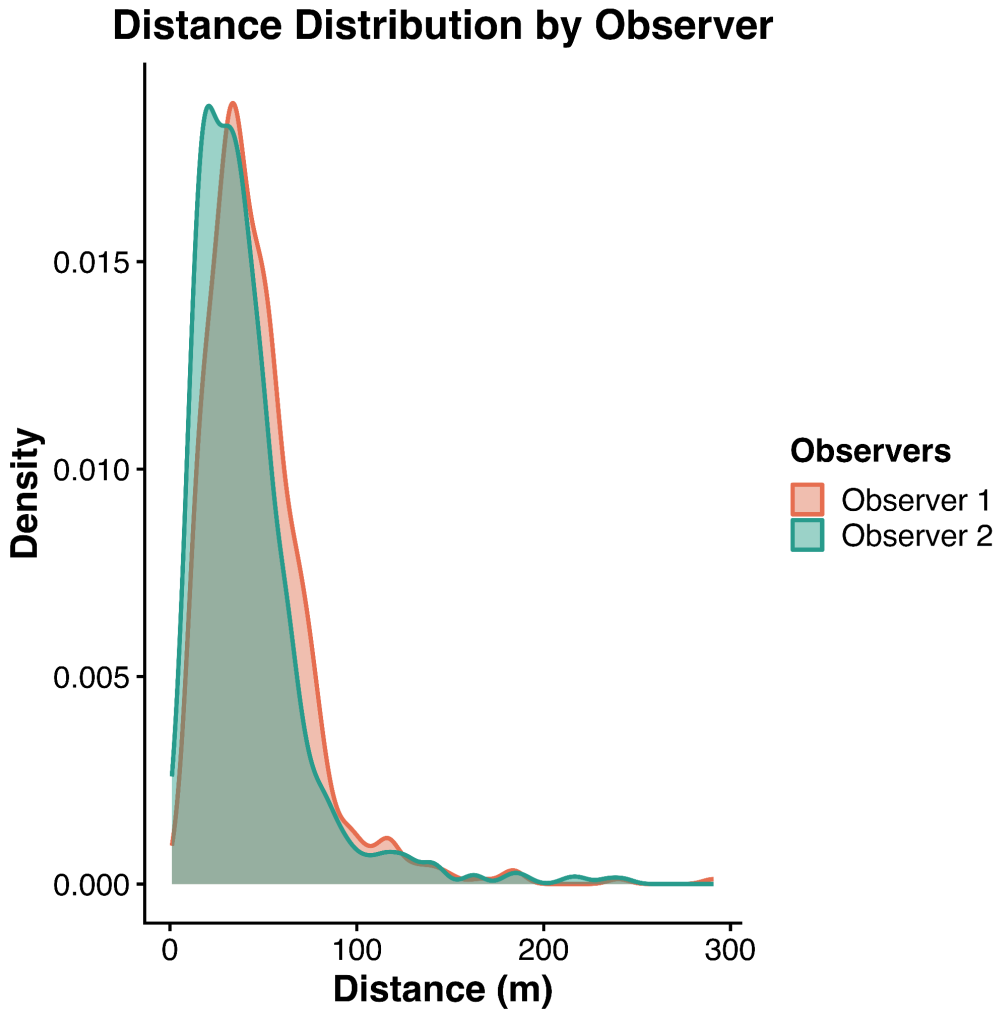

Figure 3: *Density plot comparing the distribution of recorded detection distances (m) between the two primary observers.*

The overall frequency distribution of detection distances (truncated at ≤ 150 m) exhibited a distance decay curve (Figure 4). Detections peaked between 25 and 50 m forming the requisite shoulder for distance sampling followed by a steady decline in detection frequency as distance increased.

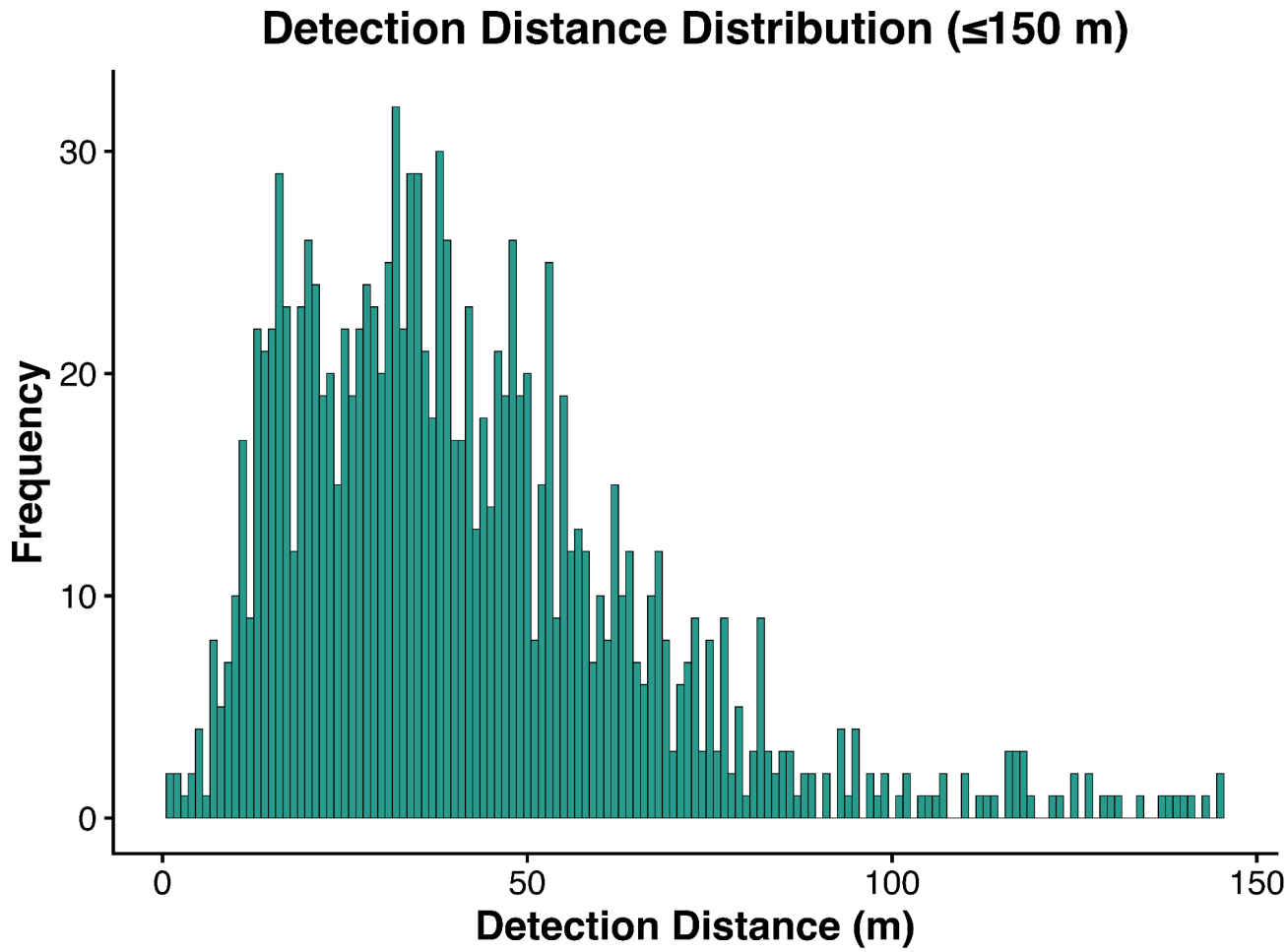

Figure 4: *Frequency histogram illustrating the overall distribution of detection distances across all surveys, truncated at 150 m. The distribution exhibits a clear shoulder near the observer followed by a steady decay, satisfying the core assumptions of distance sampling.*

Detection distances varied considerably across the three survey methodologies (Figure 5). Call Playback (aural) yielded the highest median detection distance and the widest interquartile range, indicating that active acoustic stimulation resulted in detections at greater spatial scales. Conversely, Point Count (visual) was restricted entirely to close range encounters,occurring under 50 m. Passive Point Count (aural) distances occupied an intermediate range.

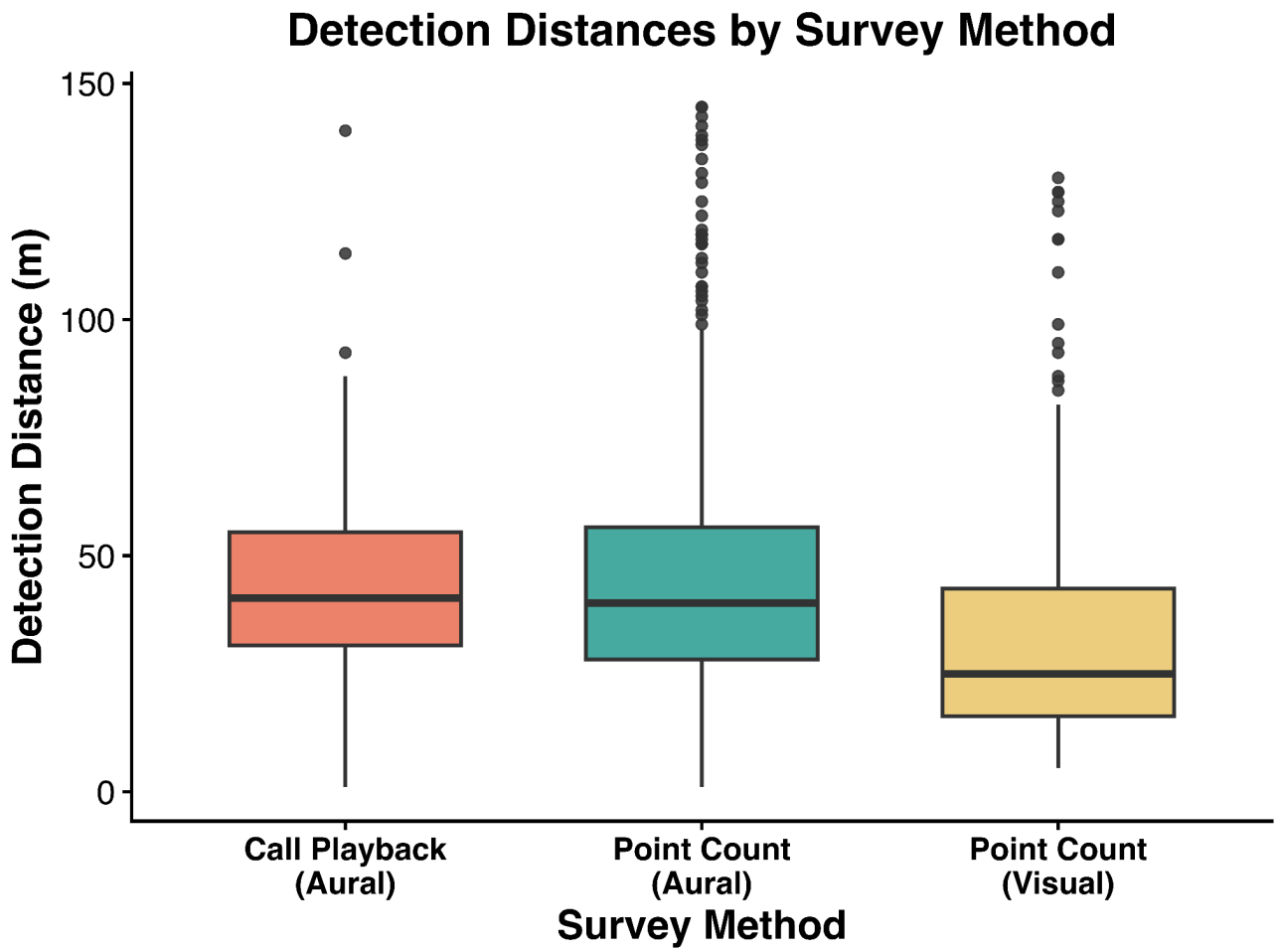

Figure 5: *Boxplot demonstrating the variation in detection distances across three survey methodologies: Call Playback (aural), Point Count (aural), and Point Count (visual).*

Histograms for each of the species indicated the distance decay for each of the four target obligate species (Figure 6). Although the number of detections differed, with the Chestnut-capped Babbler (*Timalia pileata*) having the most sightings, all four taxa showed the required decrease in detectability with distance to meet the basic assumption for fitting specific detection functions (g(x)).

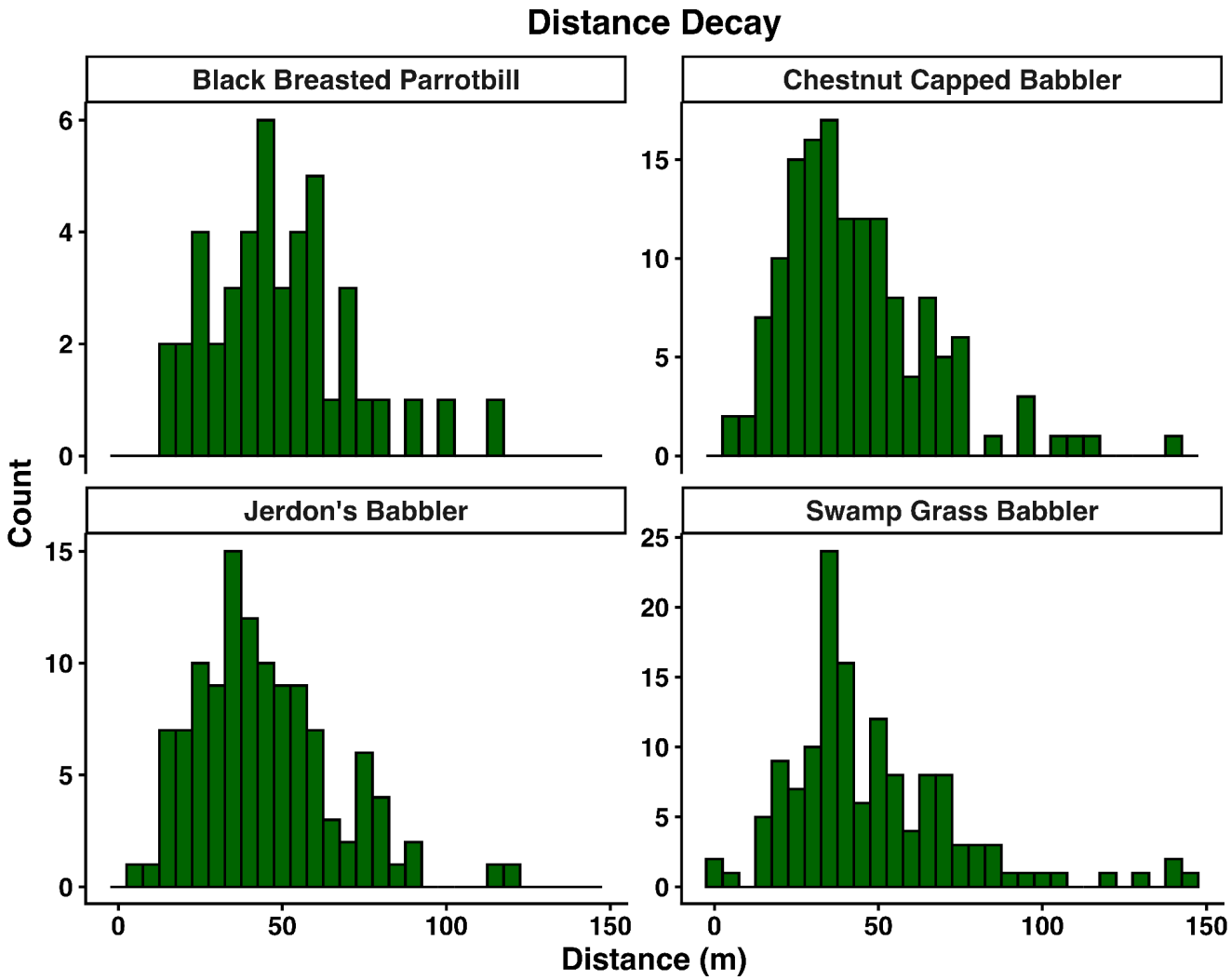

Figure 6: *Species-specific frequency histograms illustrate the distance decay of detections for the four focal obligate grassland birds: Black-breasted Parrotbill, Chestnut-capped Babbler, Jerdon's Babbler, and Swamp Grass-babbler.*

4.1.2 Overview of Survey Effort and Detections

A total of 252 point count stations distributed across 54 grassland patches were surveyed. A summary of independent detections for species (n ≥15) is presented in Table 1. For all the four focal obligate grassland species, aural cues constituted the primary mode of detection, with passive visual encounters remaining marginal (n=0 for both the Swamp Grass-babbler and Black-breasted Parrotbill). The Black-breasted Parrotbill recorded the highest proportion of its total detections during active Call Playback surveys (42.9%, n=42). This was followed by Jerdon's Babbler (32.1%, n=112), the Swamp Grass-babbler (25.4%, n=142), and the Chestnut-capped Babbler (16.8%, n=143). In contrast,

non-target and generalist species, such as the Yellow-bellied Prinia (n=434) and Siberian Stonechat (n=98), were detected almost entirely during passive point counts (≤ 0.5% playback detections), with the Siberian Stonechat recorded exclusively via visual cues. Mean overall detection distances for the focal obligate guild ranged from 44.6 m for the Chestnut-capped Babbler to 54.3 m for the Swamp Grass-babbler (Table 1).

Species	Point Count Aural	Point Count Visual	Call Playback Aural	Mean Distance (m)	Max Distance (m)
Black Breasted Parrotbill	24	0	18	53.6	161
Chestnut Capped Babbler	112	7	24	44.6	181
Delicate Prinia	45	8	0	39	85
Golden Headed Cisticola	16	7	0	35.3	73
Indian Grassbird	6	5	4	25.2	52
Jerdon's Babbler	71	5	36	46.2	234
Red-whiskered Bulbul	4	16	0	70.4	220
Siberian Stonechat	0	98	0	33	123
Striated Babbler	63	26	0	57.4	180
Swamp Grass Babbler	106	0	36	54.3	291
Yellow Bellied Prinia	345	87	0	35.9	145

Table 1: *Summary of field detection data for the avian community (n≥15), categorized by survey methodology and sensory cue (Point Count Aural, Point Count Visual, and Call Playback Aural).*

4.1.3 Detection Functions and Model Selection

Detection probability functions (g(x)) were modeled to account for imperfect detection across the four focal species (Figures 7-10). Distance sampling models were stratified to compare Passive Point Count (aural), Passive Point Count (combined), and Call Playback (aural) methods.

Passive count methods generally exhibited a rapid decay in detection probability at close distances from the observer. Conversely, call-playback changed the shape of the detection curves, increasing the effective detection range. For the Chestnut-capped Babbler (*Timalia pileata*), passive aural detections

decayed at distances greater than 20 m, whereas call playback resulted in high detection probabilities up to 80 m. During call playback, Jerdon's Babbler (*Chrysomma altirostre*) had high detectability (p ≈1.0) up to 20–30 m, after which it decayed. For the Swamp Grass-babbler (*Pellorneum palustre)*, playback stabilized detection probabilities at mid-range distances (30–60 m). The Black-breasted Parrotbill (*Paradoxornis flavirostris*) exhibited narrow detection functions during passive counts, which expanded to 100 m under call playback.

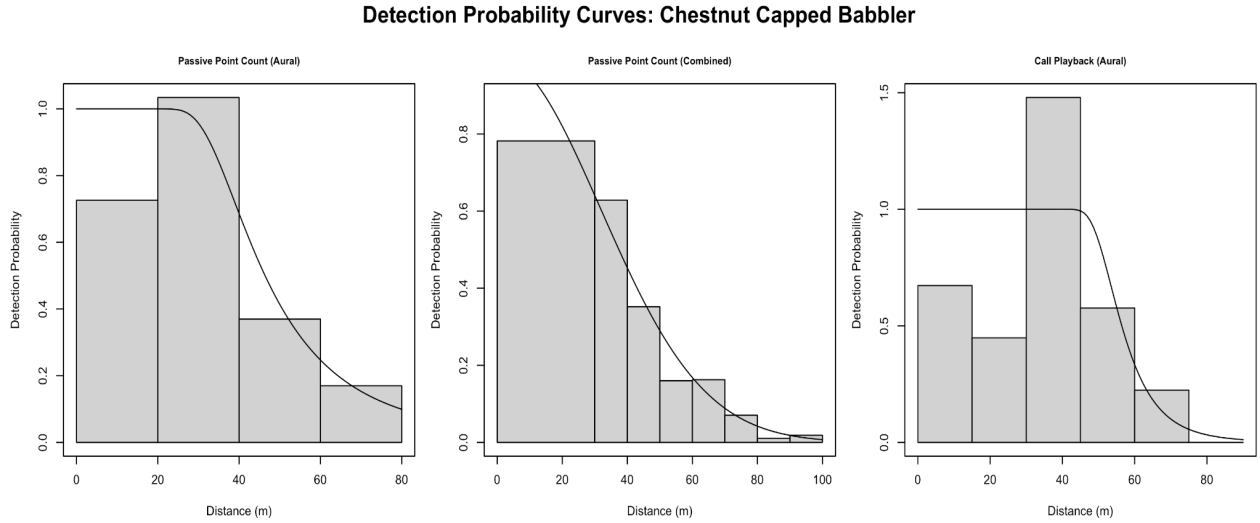

Figure 7. Detection probability curves and distance histograms for the Chestnut-capped Babbler (Timalia pileata) across three survey methods. Plots represent passive point counts via aural cues only (left), combined passive point counts (center), and active call playback via aural cues (right).

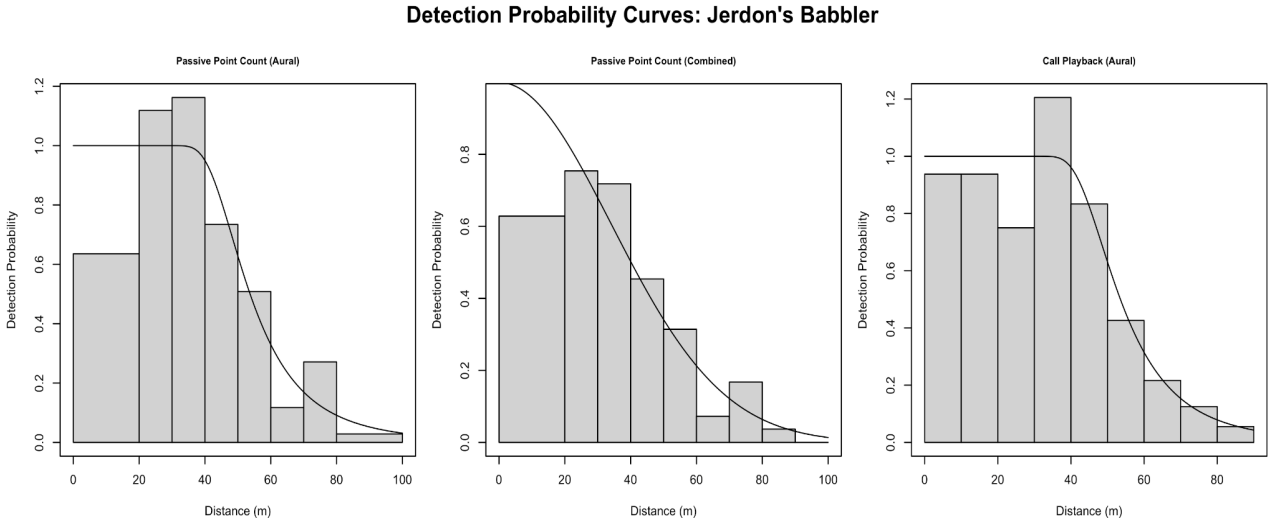

Figure 8. Detection probability curves and distance histograms for Jerdon's Babbler (Chrysomma bhamoense) across three survey methods. Plots represent passive point counts via aural cues only (left), combined passive point counts (center), and active call playback via aural cues (right).

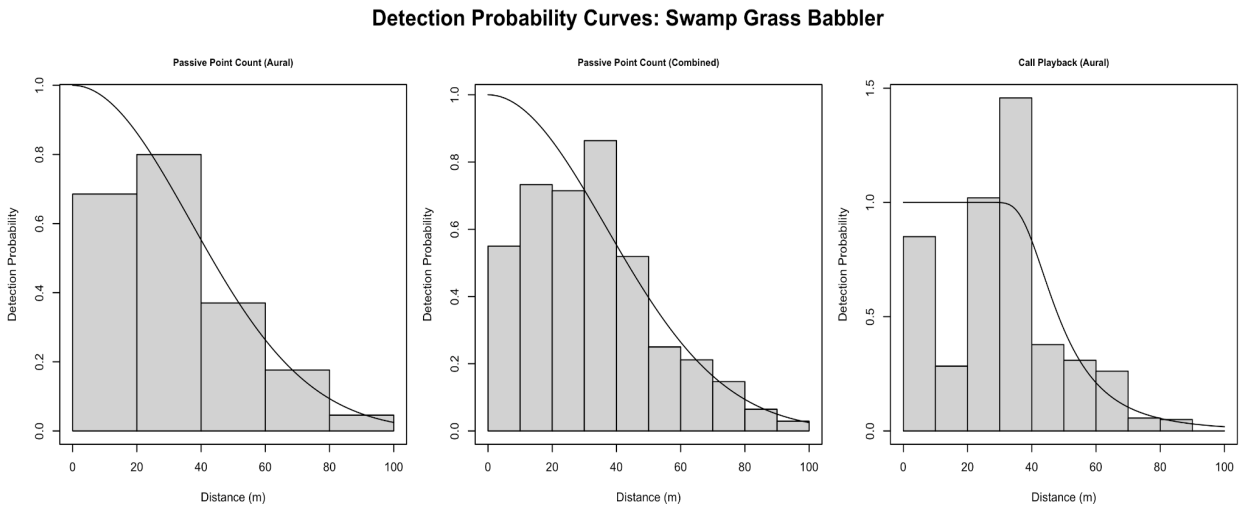

Figure 9. Detection probability curves and distance histograms for the Swamp Grass Babbler (Laticilla cinerascens) across three survey methods. Plots represent passive point counts via aural cues (left), combined passive point counts (center), and active call playback via aural cues (right).

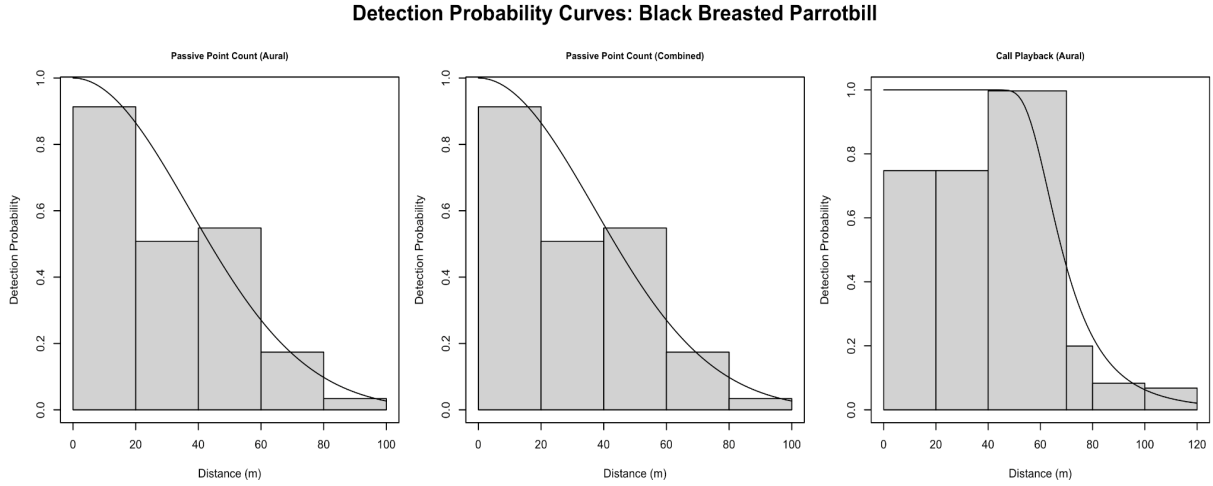

Figure 10. Detection probability curves and distance histograms for the Black-breasted Parrotbill (Paradoxornis flavirostris) across three survey methods. Plots represent passive point counts via aural cues only (left), combined passive point counts (center), and active call playback via aural cues (right).

4.1.4 Population Density Estimates

Density estimates and detection parameters were obtained for the focal species (Tables 2, 3 and 4). Model selection based on Akaike's Information Criterion (AIC) indicated that the Half-Normal (HN) and Hazard-Rate (HR) key functions best fit the distance data.

Under the Passive Point Count (Aural) methodology (Table 1), the Chestnut-capped Babbler recorded the highest density at 0.396 birds/ha (± 0.08 SE). The Swamp Grass-babbler occurred at 0.275 birds/ha (± 0.04 SE), achieving the highest statistical precision of the aural models (CV = 15.9%). Jerdon's Babbler occurred at a density of 0.148 birds/ha (± 0.02 SE). The Black-breasted Parrotbill recorded the lowest density of the guild at 0.073 birds/ha (± 0.02 SE, CV = 35.8%). Effective Detection Radii (EDR) for passive aural counts ranged between 51.28 m and 59.25 m.

Method	**Point Count (Aural)**								
Species	n	(p)	SE	EDR (m)	EDA (ha)	Density (ha)	SE	CV	Best Model
Black Breasted Parrotbill	22	0.268	0.076	51.77	0.842	0.0734	0.0263	0.3582	Half Normal_Null
Chestnut Capped Babbler	104	0.429	0.079	52.4	0.8626	0.3965	0.0835	0.2106	Hazard Rate _Null
Jerdon's Babbler	69	0.351	0.048	59.25	1.1029	0.1487	0.0271	0.1826	Hazard Rate_Null
Swamp Grass Babbler	96	0.263	0.032	51.28	0.8261	0.2757	0.0438	0.159	Half Normal_Null

Table 2: Passive Point Count Aural (PC-Aural) density estimates, detection probabilities, and best-fitting distance sampling models.

integrating visual detections in the Passive Point Count (Merged) models (Table 3) increased number of detections (n) for two species. This adjustment yielded higher density estimates for the Chestnut-capped Babbler (0.610 birds/ha ± 0.08 SE) and Jerdon's Babbler (0.247 birds/ha ± 0.04 SE). Density estimates for the Swamp Grass-babbler and Black-breasted Parrotbill remained comparable to their aural-only models.

Method	Point Count (Merged) Aural +Visual								
Species	n	(p)	SE	EDR (m)	EDA (ha)	Density (ha)	SE	CV	Best Model
Black Breasted Parrotbill	22	0.268	0.076	51.77	0.842	0.0734	0.0263	0.3582	Half Normal_Null
Chestnut Capped Babbler	114	0.201	0.02	44.83	0.6314	0.6106	0.0857	0.1403	Half Normal_Null
Jerdon's Babbler	73	0.229	0.033	47.85	0.7193	0.2472	0.0471	0.1905	Half Normal_Null
Swamp Grass Babbler	96	0.264	0.032	51.38	0.8294	0.2751	0.0433	0.1574	Half Normal_Null

Table 3: Passive Point Count Merged (PC-Merged) density estimates, detection probabilities, and best-fitting distance sampling models.

The Call Playback (aural) method (Table 4) expanded the EDR across all species, ranging from 55.59 m (Swamp Grass-babbler) to 73.39 m (Black-breasted Parrotbill). However, the total number of independent detections (n) recorded during the 15 seconds playback intervals was lower than passive counts. This resulted in elevated Coefficients of Variation (CV) across the guild, ranging from 23.26% to 42.66%.

Method	Call Playback (Aural)								
Species	n	(p)	SE	EDR (m)	EDA (ha)	Density (ha)	SE	CV	Best Model
Black Breasted Parrotbill	18	0.374	0.132	73.39	1.6921	0.1705	0.0727	0.4266	Hazard Rate_Null
Chestnut Capped Babbler	23	0.43	0.073	59.02	1.0943	0.2801	0.0815	0.2909	Hazard Rate_Null
Jerdon's Babbler	36	0.417	0.076	58.12	1.0612	0.3399	0.079	0.2326	Hazard Rate_Null
Swamp Grass Babbler	34	0.309	0.061	55.59	0.9708	0.3156	0.0775	0.2457	Hazard Rate_Weather

Table 4: Call Playback aural (CP_aural) density estimates, detection probabilities, and best-fitting distance sampling models.

4.1.5 Comparison of Survey Methods

Comparison across the three methodologies (Figure 11) Call Playback showing an overall higher detection probability but larger standard errors in population estimates. The Passive Point Count methods provided density estimates with relatively smaller error margins. The densities derived from the Passive Point Count (aural) method were therefore can be used as a baseline density, as they had lower variance and higher statistical precision.

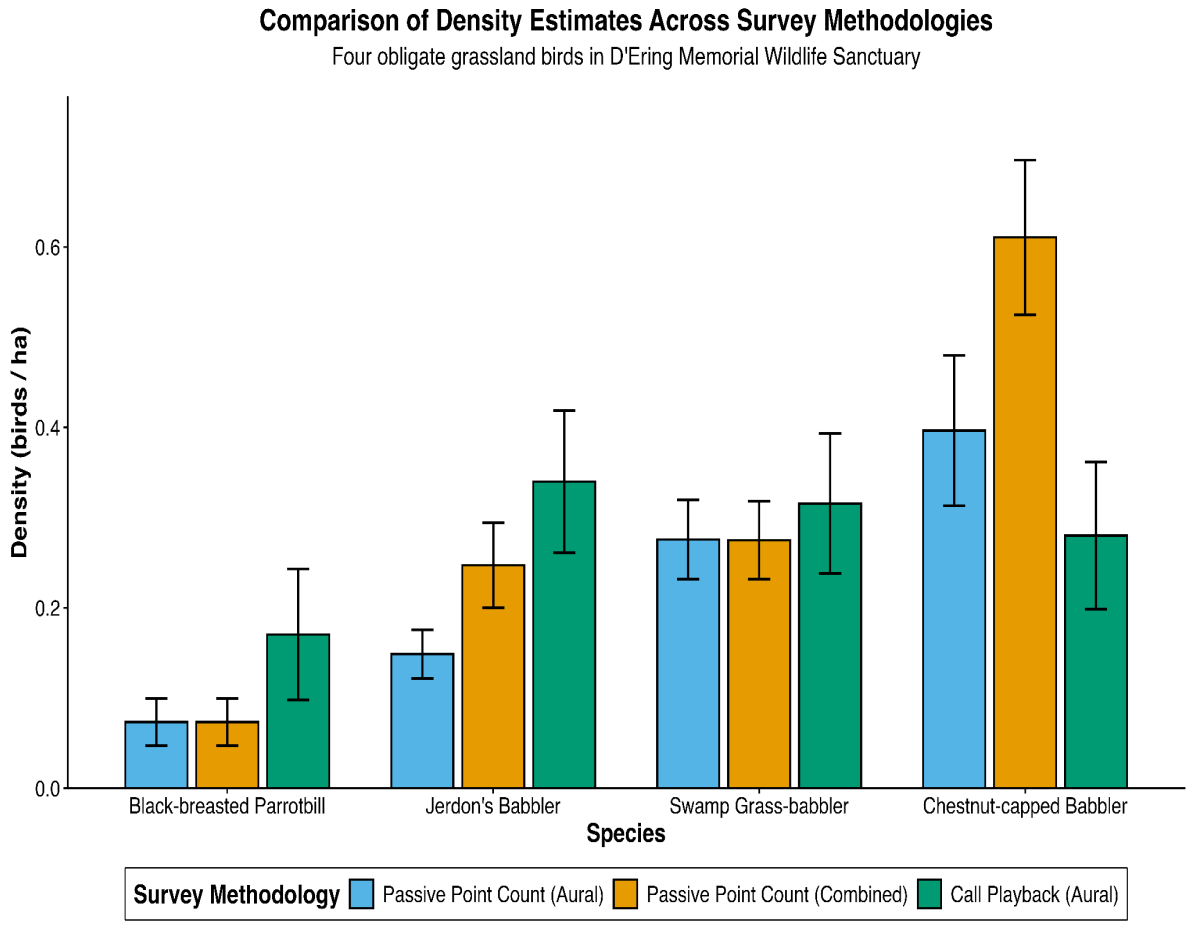

Figure 11: Comparison of density estimates (birds / ha) and standard errors for four focal obligate grassland bird species, grouped by survey methodology (PC_aural, PC_Combined, and CP_aural) in D'Ering Memorial Wildlife Sanctuary.

From this comparison passive point count (aural)method can be used to derive the point level densities. To accurately reflect the true population size at each point, these passive point densities can be mathematically adjusted by multiplying the estimated group density by the species-specific mean group size.

In distance sampling, the reliability of a density estimate is heavily dependent on the sample size of raw detections (n). As highlighted in the comparative tables, Passive Point Count (aural) yielded higher natural encounter rates (e.g., n=104 for Chestnut-capped Babbler; n=96 for Swamp Grass-babbler) compared to the 15-second playback intervals. The high number of independent detections reduced significantly the variance of the model. In spatial ecology, the model with the lowest Standard Error (SE) and a Coefficient of Variation (CV) below the threshold of 20% is the most important (Thomas et al., 2010; Buckland et al., 2015). The passive acoustic approach had the highest statistical confidence

for the whole guild. A fundamental assumption of distance sampling is that individuals are detected at their initial locations, prior to any movement in response to the observer (Buckland et al., 2001).

This assumption is deliberately broken by call playback in that it adds a potent artificial stimulus to the landscape. Broadcast vocalizations tend to generate approach responses of an aggressive nature that draw territorial individuals away from their natural micro-habitats and toward the sound source (Conway, 2011). Consequently, although playback successfully increases the Effective Detection Radius (EDR) and confirms species presence, the spatial clumping produced distorts the real, unperturbed density at the point of origin.

The emphasis on passive point count (aural) data in this study makes the derived point level densities reflective of the natural, unstimulated carrying capacity of the tall-grass habitats. This passive acoustic method is most often recommended in the avian literature as the best way of producing unbiased densities for highly vocal, territorial species without artificially inflating local abundance (Farnsworth et al., 2002; Ralph et al., 1995).

4.2 Objective 2: Habitat Selection

4.2.1 Habitat Characteristics

Habitat characteristics were quantified across all 252 point count stations. Vegetation density varied among the sampling stations (Table 5). The invasive plants had the highest mean density (0.178 ± 0.438 individuals m-2) and the herbs the second highest (0.160 ± 0.361 individuals m-2). Saplings (0.022 ± 0.060 individuals m-2) and shrubs (0.014 ± 0.061 individuals m-2) had comparatively lower densities while the trees had the lowest mean density (0.004 ± 0.011 individuals m-2). Summary statistics of vegetation density for all vegetation layers are given in Table 5.

Vegetation layer	Mean density (individuals m^{-2})	SD	Range (individuals m^{-2})
Herbs	0.160	0.361	0–2.334
Shrubs	0.014	0.061	0–0.531
Saplings	0.022	0.060	0–0.389
Trees	0.004	0.011	0–0.067
Invasive plants	0.178	0.438	0–3.997

Table 5. Summary of vegetation density (individuals m^{-2}) for herbs, shrubs, saplings, trees, and invasive plants across the 252 sampling stations

Eight dominant grass species were recorded across the study area (Table 6). *Saccharum spontaneum* was the most widespread species, occurring at 88.49% of the sampling points, and also exhibited the highest mean cover (39.11 ± 28.54%). *Typha latifolia* (53.17%) and *Imperata cylindrica* (33.33%)

were the next most frequently encountered species. *Saccharum narenga* (17.06%), *Phragmites karka* (13.10%), and *Saccharum fastigiatum* (10.32%) occurred at relatively lower frequencies, whereas *Saccharum ravennae* (4.76%) and *Scleria terrestris* (3.17%) were the least frequently recorded grass species. The frequency of occurrence and mean percent cover of the dominant grass species are presented in Table 6.

Grass species	Frequency (%)	Mean cover (%)	SD
Saccharum spontaneum	88.49	39.11	28.54
Typha latifolia	53.17	9.88	16.98
Imperata cylindrica	33.33	14.42	26.51
Saccharum narenga	17.06	4.86	14.80
Phragmites karka	13.10	1.67	6.68
Saccharum fastigiatum	10.32	1.17	4.22
Saccharum ravennae	4.76	1.92	9.88
Scleria terrestris	3.17	0.24	1.39

Table 6. Frequency of occurrence (%) and mean percentage cover (± SD) of the dominant grass species recorded across the 252 point count stations.

4.2.2 Principal Component Analysis of Grass Composition

Principal component analysis (PCA) of grass species composition identified five ecologically distinct grass assemblages that were used as habitat covariates in subsequent analyses. Based on the dominant species loadings, the principal components were designated as PC1 represented a grass assemblage dominated by *Saccharum spontaneum* and *Typha latifolia* (SS_TL), PC2 represented an assemblage characterized by *Saccharum narenga*, *Saccharum ravennae*, and *Phragmites karka* (SN_SR_PK), PC3represented a combined assemblage of *Saccharum narenga* and *Saccharum spontaneum* (SN_SS), PC4 primarily represented *Saccharum ravennae* (SR), and PC5 represented an assemblage comprising *Phragmites karka* and *Saccharum spontaneum* (PK_SS). These five principal components were retained as distinct grass habitat gradients for subsequent habitat modelling.

Principal component	Dominant grass species	Abbreviation used in GLMs
PC1	*Saccharum spontaneum + Typha latifolia*	SS_TL
PC2	*Saccharum narenga + Saccharum ravennae + Phragmites karka*	SN_SR_PK
PC3	*Saccharum narenga + Saccharum spontaneum*	SN_SS
PC4	*Saccharum ravennae*	SR
PC5	*Phragmites karka+ Saccharum spontaneum*	PK_SS

Table 7. *Grass assemblages identified from principal component analysis (PCA) of grass species composition and their corresponding abbreviations used as habitat covariates in generalized linear models (GLMs).*

PC	Eigenvalue	Variance_pct	Cumulative_pct
PC1	2.2473	28.09	28.09
PC2	1.3356	16.7	44.79
PC3	1.1183	13.98	58.76
PC4	0.9835	12.29	71.06
PC5	0.9455	11.82	82.88
PC6	0.7612	9.52	92.39
PC7	0.389	4.86	97.25
PC8	0.2196	2.75	100

Table 8. *Eigenvalues, percentage of variance, and cumulative variance explained by the principal components derived from the principal component analysis of grass species composition*

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Grass_Imperata.Cylindrica	-0.5319	0.0266	0.0415	0.1093	-0.0266	0.5967	0.1064	0.5785
Grass_Saccharum.Fastigiatum	-0.5154	-0.2895	-0.1163	-0.0827	0.029	-0.2534	-0.7509	-0.0357
Grass_Saccharum.Spontaneum	0.416	-0.5444	0.1753	0.0944	0.2291	-0.2169	-0.0607	0.6226
Grass_Sclera.Terrestris	-0.47	-0.3033	-0.1445	-0.0902	-0.0359	-0.499	0.6386	0.0048
Grass_Saccharum.Narenga	-0.0889	0.5263	0.5234	-0.3705	-0.1579	-0.3966	-0.0706	0.3415
Grass_Typha.Latifolia	0.2165	0.0211	-0.5935	-0.2478	-0.6639	-0.0342	-0.0662	0.3044
Grass_Phragmites.Karka	0.0334	0.2523	-0.4675	-0.4742	0.6832	0.013	0.019	0.1568
Grass_Saccharum.Ravennae	-0.0403	0.4312	-0.2972	0.7353	0.1107	-0.3536	-0.0598	0.2064

Table 9. Loadings of the dominant grass species on the principal components derived from the principal component analysis (PCA).

4.2.3 Principal Component Analysis of Vegetation Height

Principal component analysis (PCA) of the vertical vegetation structure identified two principal components that were retained as habitat covariates for subsequent analyses. Based on the dominant vegetation height classes, PC1represented vegetation dominated by height classes below 200 cm and was designated as the Short Grass gradient (Short), whereas PC2 represented vegetation dominated by height classes above 200 cm and was designated as the Tall Grass gradient (Tall). These two principal components were retained as distinct vegetation height gradients for subsequent habitat modelling.

Principal component	Dominant vegetation height classes	Abbreviation used in GLMs
PC1	Vegetation height < 200 cm (1–25, 26–50, 51–100, 101–150 and 151–200 cm)	Short
PC2	Vegetation height > 200 cm (201–300 and >300 cm)	Tall

Table 10. Vegetation height gradients identified from principal component analysis (PCA) of the vertical vegetation structure and their corresponding abbreviations used as habitat covariates in the generalized linear models (GLMs).

PC	Eigenvalue	Variance_pct	Cumulative_pct
PC1	4.0357	50.45	50.45
PC2	1.7184	21.48	71.93
PC3	0.8452	10.57	82.49
PC4	0.6347	7.93	90.43
PC5	0.2854	3.57	93.99
PC6	0.2078	2.6	96.59
PC7	0.1601	2	98.59
PC8	0.1127	1.41	100

Table 11: Eigenvalues and cumulative variance explained by the Principal Component Analysis (PCA) for vertical vegetation structure. Only components with eigenvalues > 1.0 were retained for occupancy modeling.

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Bare_Ground	0.2446	0.0754	0.8602	0.4405	-0.0142	0.0084	-0.0096	-0.0084
Veg_1_25cm	-0.3283	-0.4504	0.2314	-0.1815	0.5756	0.5086	0.1127	-0.0107
Veg_26_50cm	-0.3636	-0.4137	0.2202	-0.1599	-0.0675	-0.5589	-0.5512	0.0429
Veg_51_100cm	-0.4195	-0.278	0.0863	0.1116	-0.4621	-0.1479	0.6811	-0.1661
Veg_101_150cm	-0.4351	0.0867	-0.0994	0.4056	-0.3237	0.4271	-0.2895	0.5077
Veg_151_200cm	-0.4043	0.3168	-0.1046	0.3624	0.1913	0.0111	-0.2084	-0.7168
Veg_201_300cm	-0.3473	0.4694	0.0692	0.0148	0.4601	-0.4115	0.2946	0.4315
Veg_Above_300cm	-0.2255	0.4634	0.3535	-0.6625	-0.3119	0.2347	-0.0741	-0.1126

Table 12: Principal Component loadings for the eight micro-habitat strata. Values indicate the correlation of each raw variable with the two retained synthetic axes (PC1 and PC2).

4.2.4 Correlation Analysis of Predictor Variables:

Prior to fitting the Generalized Linear Models (GLMs), a Pearson correlation analysis was conducted on all continuous micro habitat and landscape predictor variables to assess potential multicollinearity. The correlation matrix (Figure 12) revealed the micro-habitat structural gradients (e.g., Short vs. Tall grass) and Grass assemblages principal components were independent, a strong positive correlation was identified between Island Age and Island Size (r=0.82). To satisfy the assumption of predictor independence and prevent variance inflation in the final occupancy models, island size was excluded from subsequent multivariate analysis.

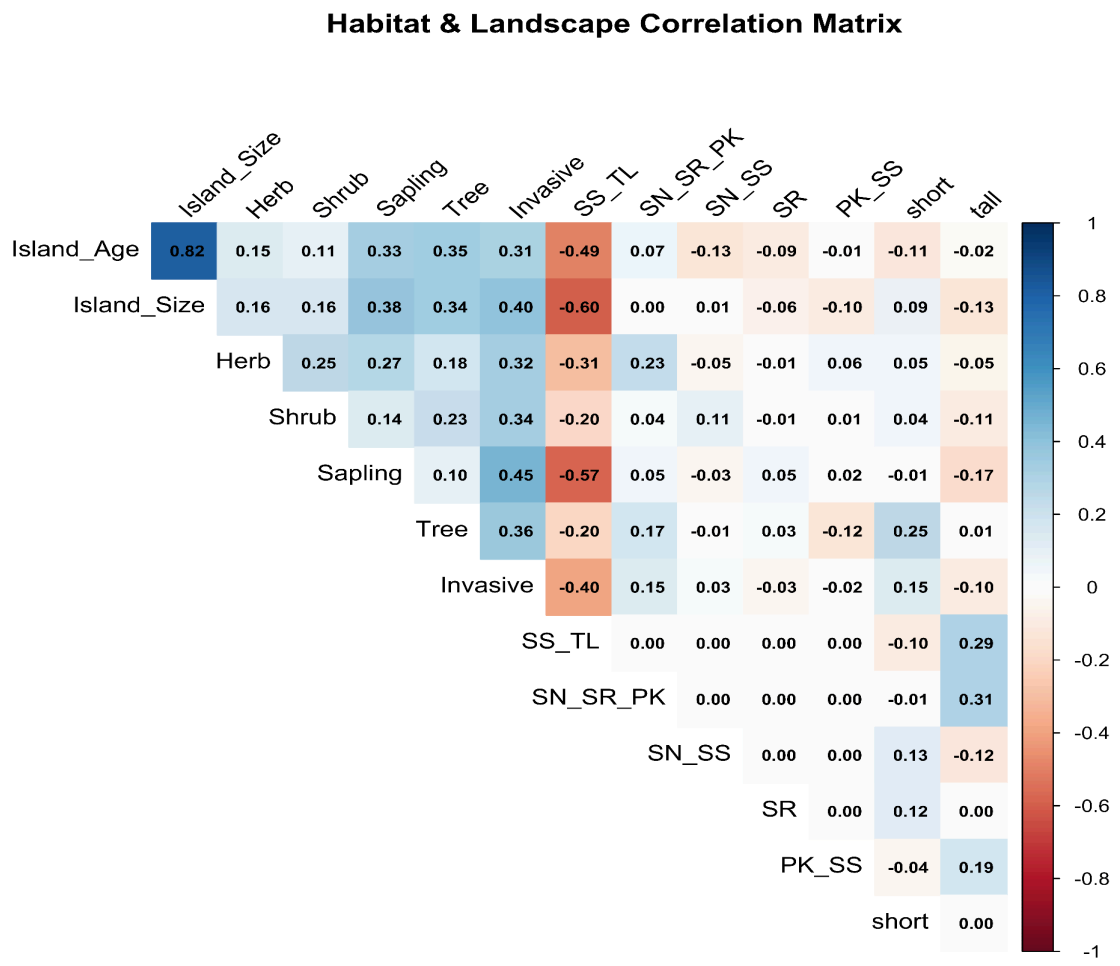

Figure 12: Pearson correlation matrix of micro-habitat, and landscape predictor variables. Numerical values and color intensities denote the strength and direction of the correlation coefficient (r). Red hues indicate negative correlations, while blue hues denote positive correlations. Predictor pairs exhibiting high collinearity (e.g., island Age and island Size) were identified for exclusion prior to occupancy modeling.

4.3 Species wise Habitat selection

4.3.1 Jerdon's Babbler:

Thirteen candidate generalized linear models were evaluated to determine the habitat variables associated with Jerdon's Babbler occurrence (Table 13). The model incorporated short grass , specific grass assemblages (SS_TL and PK_SS), and Island Age received the strongest support (AICc=224.3, ΔAICc=0.00, wi=0.434). A secondary model that additionally included tall grass also received substantial support (ΔAICc=0.47), while all remaining models had considerably lower support (ΔAICc>1.9).

Parameter estimates from the best-supported model (Table 12) revealed that both short grass (β=−0.300,p=0.007) and Island Age (β=−0.164,p=0.049) had a strong negative influence on the occurrence of the species. Conversely, both the *Saccharum spontaneum and Typha latifolia* (SS_TL) and *Phragmites karka and Saccharum spontaneum* (PK_SS) grass assemblages had a strong positive influence on site occupancy (β=1.199, p<0.001 and β=0.317, p=0.044, respectively).

Jerdon's babbler					
Rank	**Candidate model**	**K**	**AICc**	**ΔAICc**	**Akaike weight**
1	Short + SS_TL + PK_SS + Island Age	5	**224.3**	**0.00**	**0.434**
2	Tall + Short + SS_TL + PK_SS + Island Age	6	224.7	0.47	0.343
3	Tall + Short + SS_TL + PK_SS + Invasive + Tree + Island Age	8	226.2	1.95	0.164
4	Tall + SS_TL + PK_SS + Island Age	5	229.4	5.10	0.034
5	SS_TL + PK_SS + Island Age	4	230.4	6.11	0.020
6	Grass assemblages only	6	234.6	10.34	0.002
7	Global model	14	235.3	11.08	0.002
8	Tree + Invasive	3	254.0	29.75	<0.001
9	Invasive	2	255.4	31.14	<0.001
10	Vegetation height	3	258.4	34.16	<0.001
11	Tree	2	261.4	37.17	<0.001
12	Island Age	2	262.9	38.68	<0.001
13	Null model	1	273.9	49.64	<0.001

Table 13. Candidate generalized linear models explaining Jerdon's Babbler occurrence ranked according to Akaike's Information Criterion corrected for small sample size (AICc). Models are ordered from lowest to highest AICc

Predictor	Estimate (β)	SE	z	P-value
Intercept	-1.382	0.404	-3.424	<0.001
Short grass	-0.300	0.112	-2.684	**0.007**
SS_TL	1.199	0.348	3.448	**<0.001**
PK_SS	0.317	0.157	2.013	**0.044**
Island Age	-0.164	0.083	-1.973	**0.049**

Table 14. Parameter estimates of the best-supported generalized linear model explaining Jerdon's Babbler occurrence.

The response curves revealed that the probability of occurrence of Jerdon's Babbler decreased with the increase in values of Island Age and Short Grass (PC Axis) and increased with the increase in values of *Saccharum spontaneum and Typha latifolia* (SS_TL) and *Phragmites karka and Saccharum spontaneum* (PK_SS) grass assemblages (Figure 11). The maximum positive response was recorded for the SS_TL assemblage while the PK_SS assemblage showed a gradual increase in the probability of occurrence.

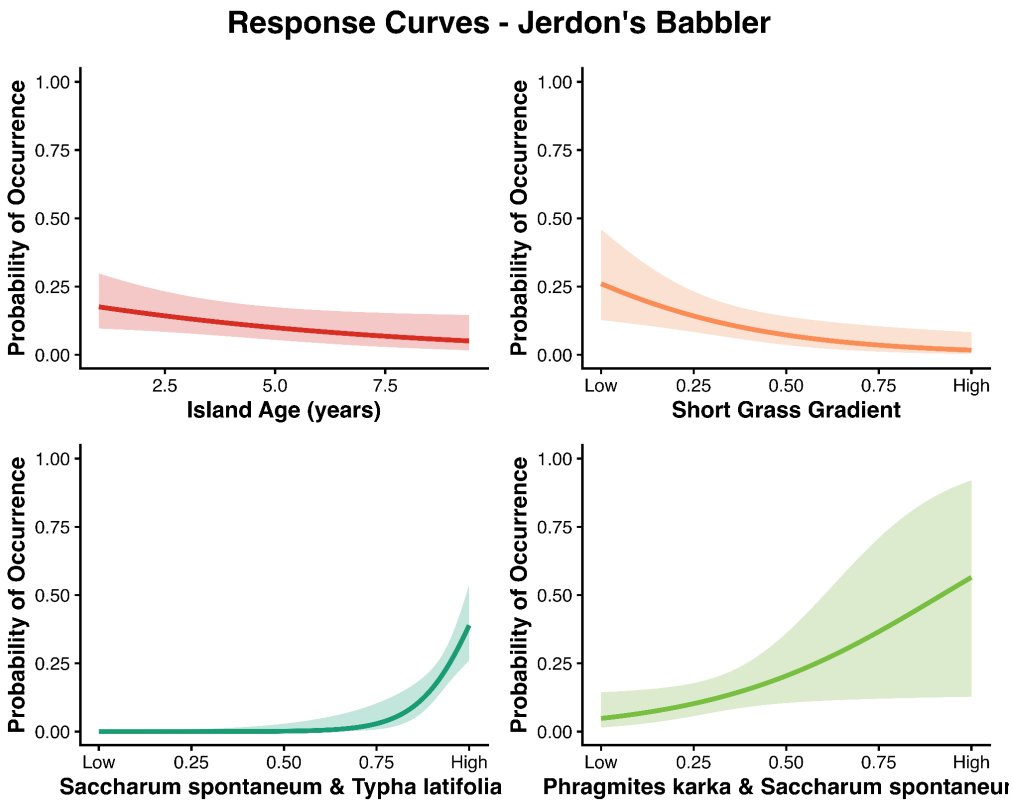

Figure 13. Response curves showing the predicted probability of occurrence of Jerdon's Babbler (Chrysomma altirostre) in relation to the significant habitat variables retained in the best-supported generalized linear model. Shaded areas represent the 95% confidence intervals around the predicted response.

4.3.2 Black Breasted Parrotbill:

Eleven candidate generalized linear models were evaluated to determine the habitat variables associated with Black-breasted Parrotbill occurrence (Table 13). The model comprising only the *Phragmites karka and Saccharum spontaneum*(PK_SS) and *Saccharum spontaneum and Typha latifolia* (SS_TL) grass assemblages best explained the occurrence of the species, receiving primary support (AICc=138.8, ΔAICc=0.00, wi=0.944). All other models yielded ΔAICcvalues > 7.0, suggesting considerably less support.

Parameter estimates of the top ranked model indicated that both PK_SS and SS_TL grass assemblages had a significant positive effect on the occurrence of the Black-breasted Parrotbill (β = 0.658, p = 0.003 and β = 1.030, p = 0.018, respectively).

Black Breasted Parrotbill					
Rank	**Candidate model**	**K**	**AICc**	**ΔAICc**	**Akaike weight**
1	PK_SS + SS_TL	3	**138.8**	**0.00**	**0.944**
2	Island Age + PK_SS	3	146.0	7.20	0.026
3	PK_SS	2	147.0	8.23	0.015
4	SS_TL	2	148.0	9.26	0.009
5	Vegetation height	3	150.2	11.46	0.003
6	Global model	14	151.6	12.85	0.002
7	Tree	2	153.7	14.90	0.001
8	Invasive	2	154.8	15.98	<0.001
9	Island Age	2	155.2	16.44	<0.001
10	Null model	1	156.0	17.19	<0.001
11	Tree + Invasive + Sapling	4	156.4	17.64	<0.001

Table 15. Candidate generalized linear models explaining the occurrence of Black-breasted Parrotbill ranked according to Akaike's Information Criterion corrected for small sample size (AICc).

Predictor	**Estimate (β)**	**SE**	**z**	**P-value**
Intercept	-2.934	0.400	-7.343	<0.001
PK_SS	0.658	0.220	2.994	0.003
SS_TL	1.030	0.436	2.364	0.018

Table 16. Parameter estimates of the best-supported generalized linear model explaining Black-breasted Parrotbill occurrence.

Response curves (Figure 14) indicated that the best-supported generalized linear model (Table 14) revealed a positive relationship between probability of Black-breasted Parrotbill occurrence and grass assemblages. The occurrence probability increased with increasing values of the *Phragmites karka and Saccharum spontaneum* (PK_SS) and *Saccharum spontaneum and Typha latifolia* (SS_TL) assemblages. The PK_SS assemblage was the one with the strongest response, where the occurrence probability increased steadily along the habitat gradient. The occurrence probability also increased with increasing values of the SS_TL assemblage, but confidence intervals widened at higher values of both habitat gradients.

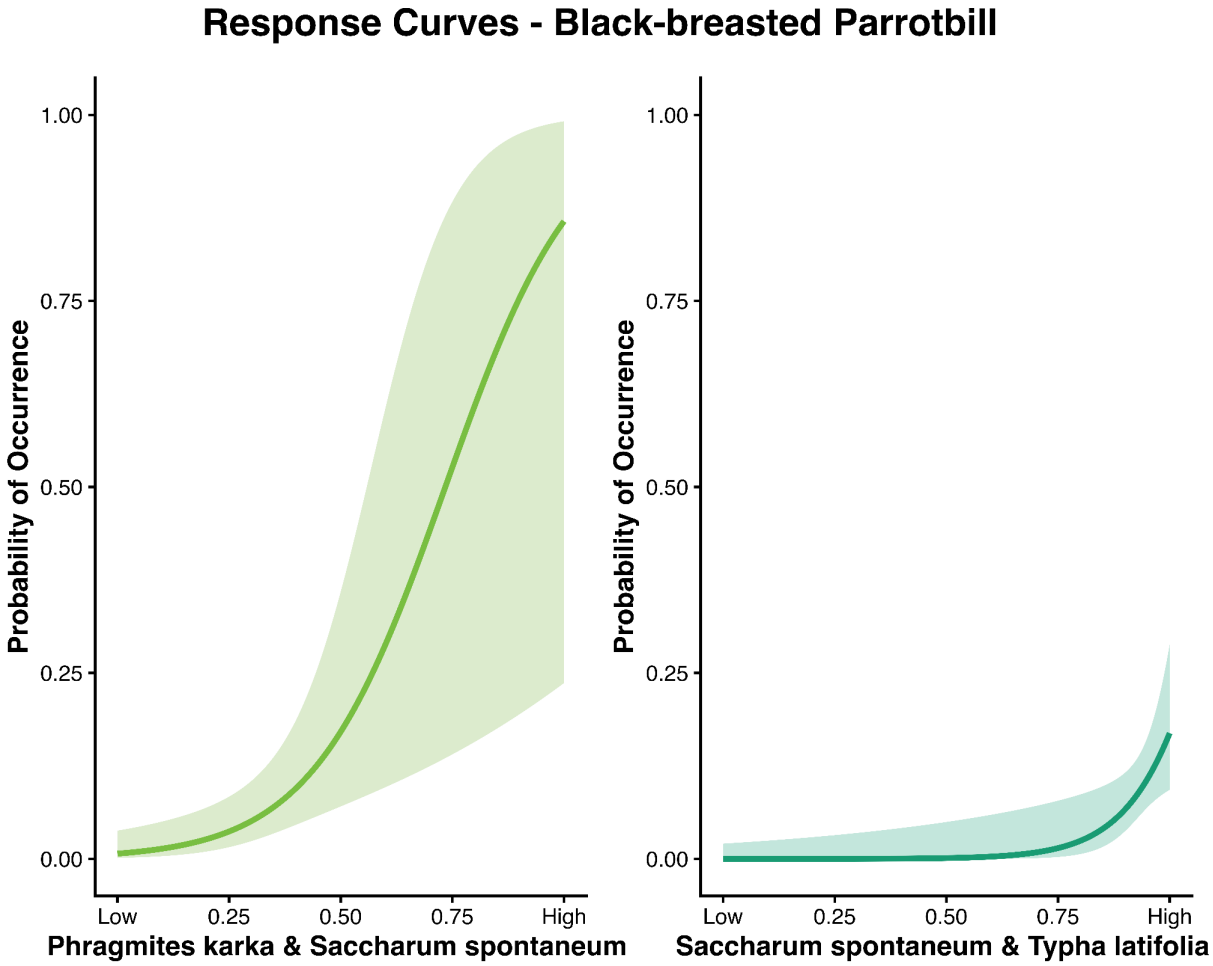

Figure 14. Response curves showing the predicted probability of occurrence of Black-breasted Parrotbill (Paradoxornis flavirostris) in relation to the significant habitat variables retained in the best-supported generalized linear model. Curves represent model-predicted probabilities while holding all other variables constant, and shaded areas indicate the 95% confidence intervals around the predicted probabilities.

4.3.3 Swamp Grass Babbler:

Nine candidate generalized linear models were evaluated to identify the drivers of Swamp Grass-babbler occurrence (Table 15). The model containing island age and the SS_TL grass assemblage received the strongest support (AICc=220.2, ΔAICc=0.00, wi=0.945). The global model received weak secondary support (ΔAICc=5.76), whereas all remaining candidate models had substantially lower support (ΔAICc>12.0).

The parameter estimates for the best supported model (Table 16) show that Island Age had a highly significant negative effect on the occurrence of the species (β=−0.371, p<0.001). Conversely, the SS_TL grass assemblage had a strong positive effect on site occupancy (β=1.519, p<0.001).

Swamp Grass Babbler					
Rank	**Candidate model**	**K**	**AICc**	**ΔAICc**	**Akaike weight**
1	Island Age + SS_TL	3	**220.2**	**0.00**	**0.945**
2	Global model	14	226.0	5.76	0.053
3	Grass assemblages only	6	232.6	12.36	0.002
4	Tree + Invasive + Sapling	4	242.0	21.71	<0.001
5	Island Age	2	245.8	25.59	<0.001
6	Invasive	2	247.7	27.49	<0.001
7	Tree	2	255.0	34.78	<0.001
8	Null model	1	285.4	65.19	<0.001
9	Vegetation height	3	287.1	66.83	<0.001

Table 17. Candidate generalized linear models explaining the occurrence of Swamp Grass Babbler ranked according to Akaike's Information Criterion corrected for small sample size (AICc).

Predictor	**Estimate (β)**	**SE**	**z**	**P-value**
Intercept	-0.803	0.414	-1.941	0.052
Island Age	-0.371	0.099	-3.751	**<0.001**
SS_TL	1.519	0.381	3.993	**<0.001**

Table 18. Parameter estimates of the best-supported generalized linear model explaining Swamp Grass Babbler occurrence.

Following the best-supported generalized linear model (Table 15), the response curves showed contrasting relationships between the probability of occurrence of Swamp Grass-babbler and the two significant habitat variables (Figure 13). The probability of occurrence decreased with increasing Island Age, whereas it increased with increasing values of the *Saccharum spontaneum and Typha latifolia* (SS_TL) grass assemblage. The positive response to the SS_TL assemblage was particularly pronounced at higher values of the habitat gradient, while the probability of occurrence declined gradually with increasing island age. At the higher levels of the SS_TL gradient, the confidence intervals increased, reflecting the increased uncertainty at the higher end of the environmental gradient.

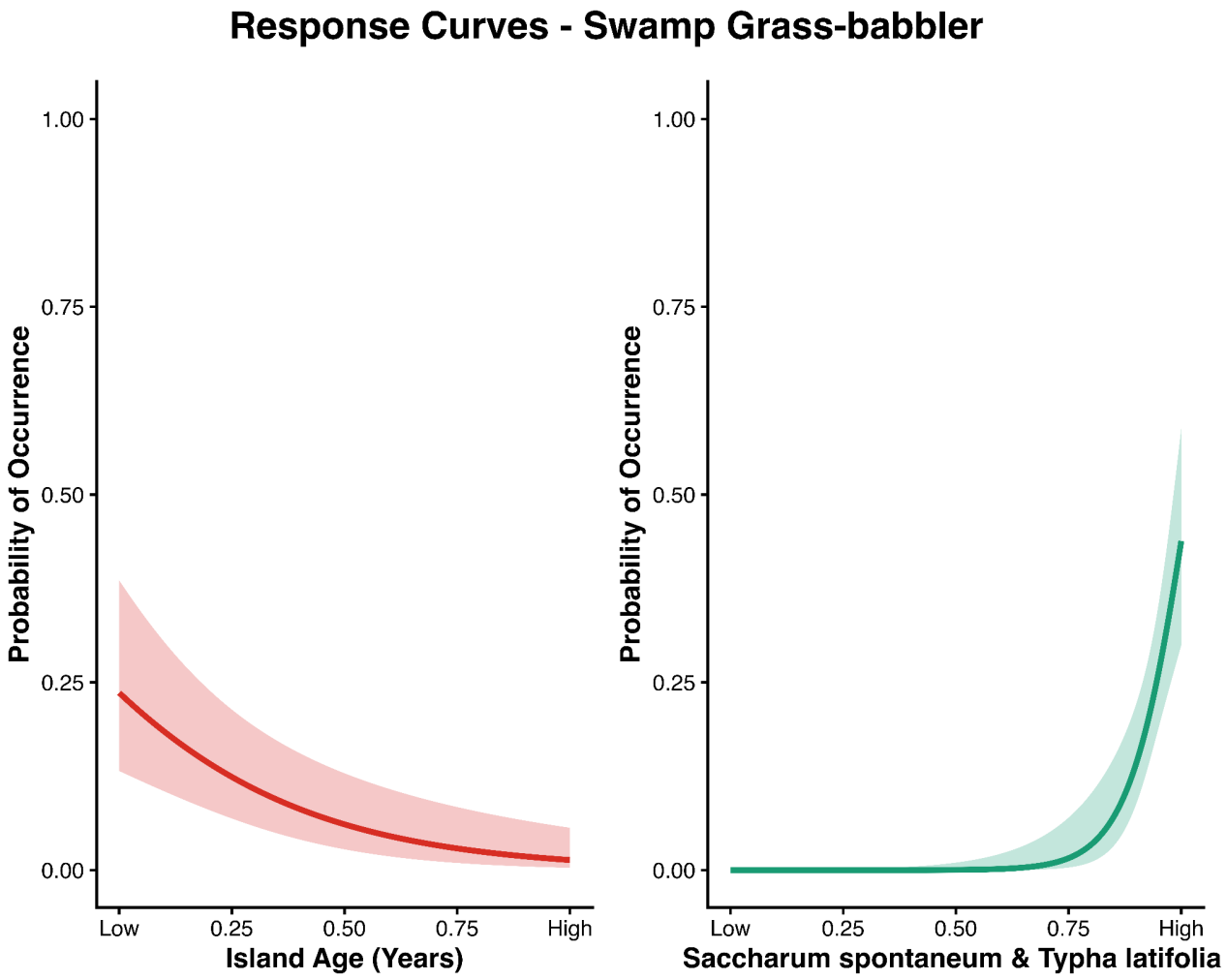

Figure 15. Response curves showing the predicted probability of occurrence of Swamp Grass-babbler (Laticilla cinerascens) in relation to the significant habitat variables retained in the best-supported generalized linear model. Curves represent model-predicted probabilities while holding all other variables constant, and shaded areas indicate the 95% confidence intervals around the predicted probabilities.

4.3.4 Chestnut Capped Babbler:

Twelve candidate generalized linear models were evaluated to identify the habitat variables associated with Chestnut-capped Babbler occurrence (Table 17). The occurrence of the species was best explained by a model integrating both floristic composition and micro-habitat structure. The top-ranked model comprised the SS_TL grass assemblage, the PK_SS grass assemblage, sapling density, and short grass (AICc=275.0, ΔAICc=0.00, wi=0.702). A secondary model additionally including invasive plant density and Island Age received marginal support (ΔAICc=2.59). Parameter estimates from the best-supported model (Table 18) revealed that short grass architecture had a significant negative influence on the occurrence of the species ($\beta=-0.390$, $p<0.001$). Conversely, occurrence was positively influenced by the SS_TL grass assemblage ($\beta=0.537$, $p=0.002$), the PK_SS grass assemblage ($\beta=0.385$, $p=0.021$), and midstory sapling density ($\beta=0.001$, $p=0.001$).

Chestnut Capped Babbler					
Rank	**Candidate model**	**K**	**AICc**	**ΔAICc**	**Akaike weight**
1	**SS_TL + PK_SS + Sapling + Short grass**	5	**275.0**	**0.00**	**0.702**
2	SS_TL + PK_SS + Sapling + Invasive + Island Age	6	277.6	2.59	0.192
3	Global model	14	278.8	3.79	0.106
4	Vegetation height	3	292.4	17.44	<0.001
5	Island Age + SS_TL + PK_SS	4	296.6	21.64	<0.001
6	Island Age + SS_TL	3	302.5	27.52	<0.001
7	Tree + Invasive + Sapling	4	311.0	35.98	<0.001
8	Grass assemblages	6	311.8	36.76	<0.001
9	Island Age	2	314.6	39.62	<0.001
10	Invasive	2	315.0	40.02	<0.001
11	Null model	1	315.4	40.44	<0.001
12	Tree	2	316.6	41.64	<0.001

Table 19. Candidate generalized linear models explaining the occurrence of Chestnut-capped Babbler ranked according to Akaike's Information Criterion corrected for small sample size (AICc). Models are ranked from lowest to highest AICc

Predictor	Estimate (β)	SE	z	P-value
Intercept	-1.255	0.195	-6.431	<0.001
SS_TL	0.537	0.174	3.079	**0.002**
PK_SS	0.385	0.167	2.303	**0.021**
Sapling density	0.00116	0.00035	3.273	**0.001**
Short grass	-0.390	0.098	-3.967	**<0.001**

Table 20. Parameter estimates of the best-supported generalized linear model explaining Chestnut-capped Babbler occurrence

Following the best-supported generalized linear model (Table 18), the response curves illustrated the relationships between the probability of occurrence of Chestnut-capped Babbler and the strongest habitat variables (Figure 16). The probability of occurrence increased with increasing values of the *Saccharum spontaneum–Typha latifolia* (SS_TL) and *Phragmites karka–Saccharum spontaneum* (PK_SS) grass assemblages, as well as with increasing Sapling Density. In contrast, the probability of occurrence decreased with increasing Short Grass (PC Axis). The strongest positive responses among the important predictors were observed for Sapling Density and the PK_SS grass assemblage, whereas the probability of occurrence increased more slowly with the SS_TL assemblage. Confidence intervals expanded toward the upper ends of the habitat gradients, reflecting increased uncertainty at higher values of the predictors.

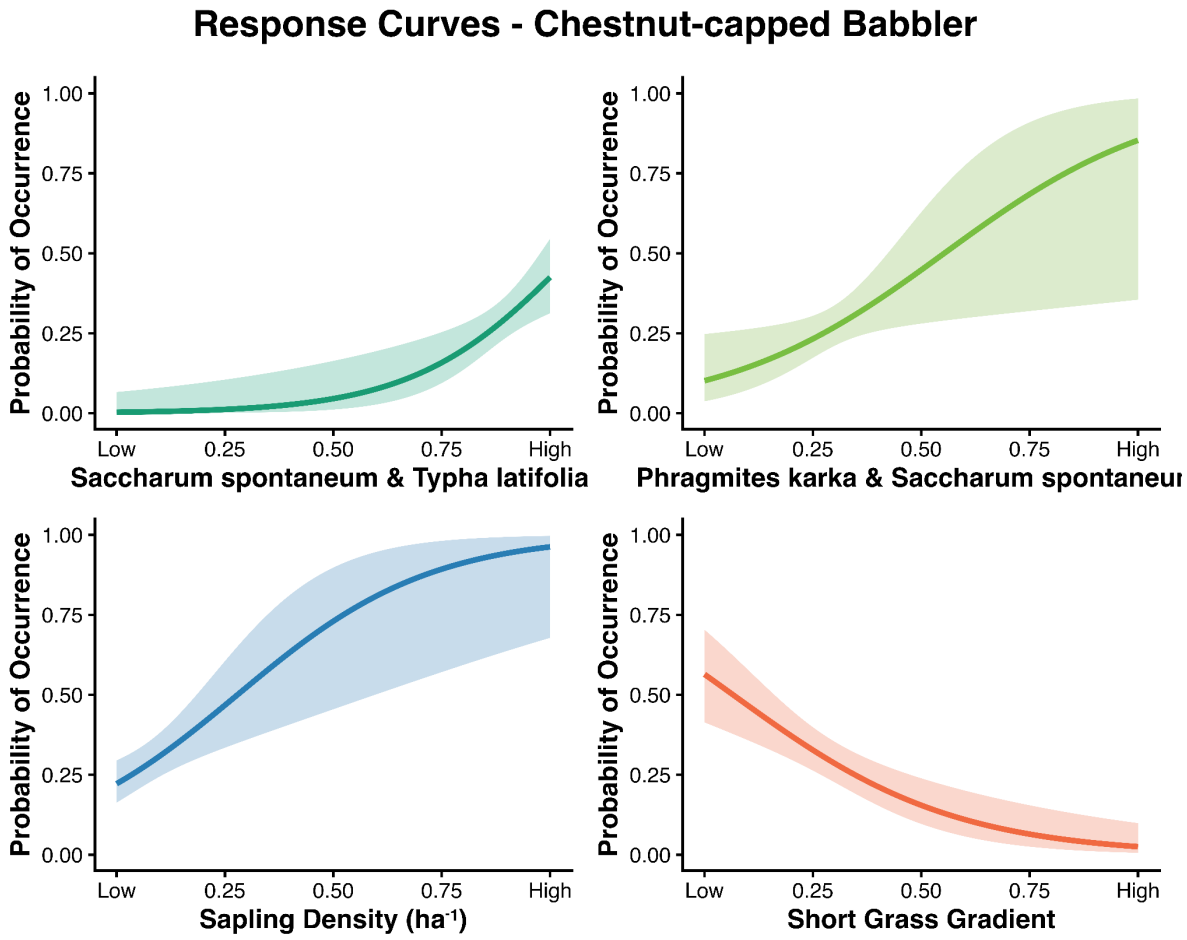

Figure 16. Response curves showing the predicted probability of occurrence of Chestnut-capped Babbler (Timalia pileata) in relation to the significant habitat variables retained in the best-supported generalized linear model. Curves represent model-predicted probabilities while holding all other variables constant, and shaded areas indicate the 95% confidence intervals around the predicted probabilities.

4.4 Community-level Habitat Associations

The overall structure of bird communities was assessed by means of Non-metric Multidimensional Scaling (NMDS) based on a Jaccard dissimilarity matrix (presence/absences data), with an acceptable stress value of 0.197 for a two-dimensional solution (Figure 17). The ordination showed a clear separation in the bird community along successional and structural gradients. The four focal obligate species (JB, SGB, BBP, CCB) clustered closely in the upper left quadrant, showing a similar ecological niche. Environmental fitting demonstrated that this obligate cluster was strongly associated with younger islands, tall-grass volume, and the *Saccharum spontaneum and Typha latifolia* (SS_TL) assemblage. Conversely, generalist and woodland-edge species (eg., JM, RVB, RJF, DW)(Jungle

Myna,Red vented Bulbul, Red jungle fowl, Dusky warbler) were positioned in the lower-right quadrant. This contrasting community was strongly driven by advanced Island Age and higher densities of woody vegetation (Tree, Sapling, and Shrub vectors). To summarize, the NMDS visually supported the site-occupancy models showing a distinct turnover in the community between early-successional tall-grass and late-stage wooded habitats.

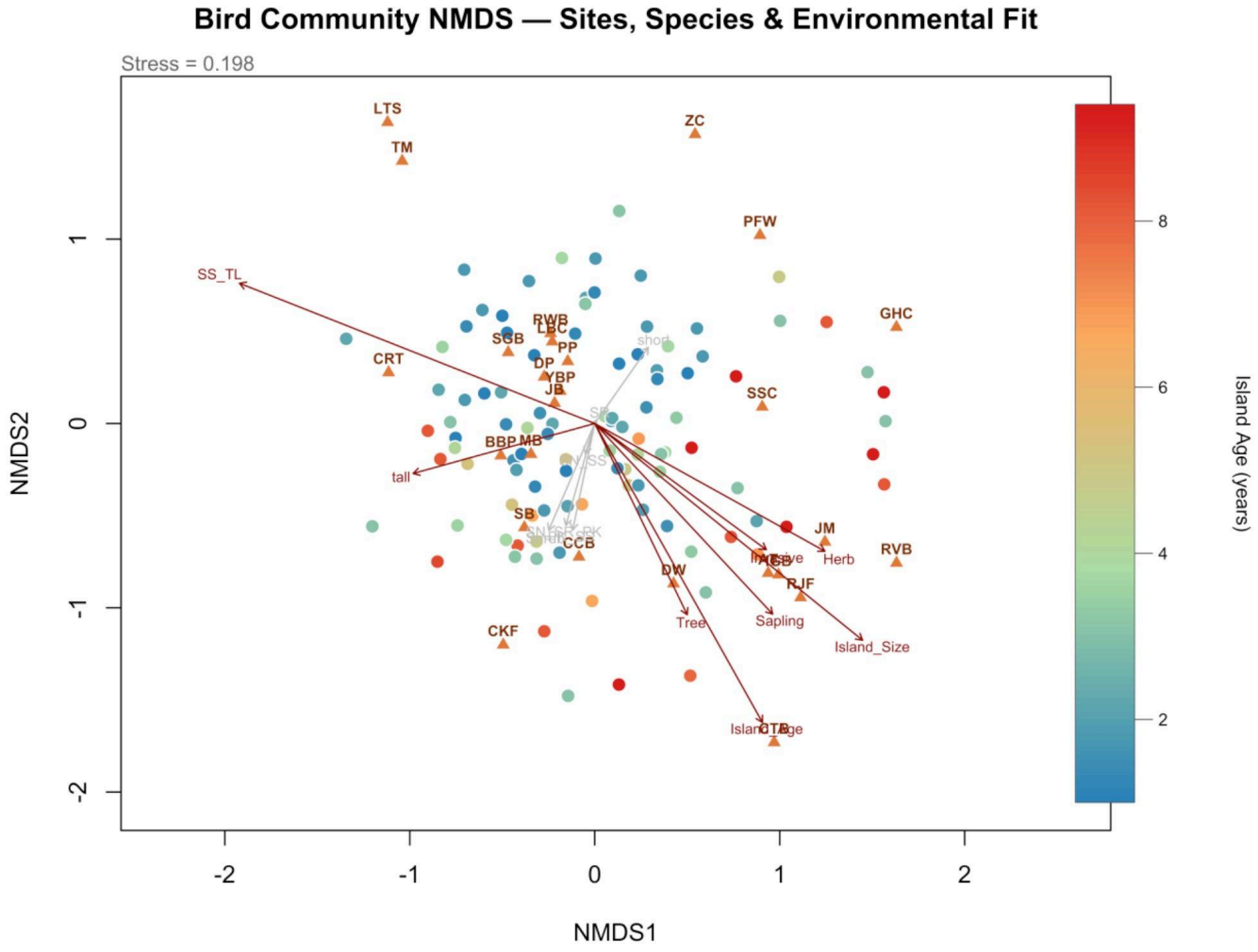

Figure 17: NMDS ordination (Stress = 0.197) of avian community structure across 252 sites. Points represent survey sites colored by Island Age (blue = young; red = old). orange triangles denote species centroids. Solid dark red vectors indicate significant environmental variables ($p<0.05$). Obligate species cluster top-left (associated with young islands and SS_TL grass), while generalists cluster bottom-right (associated with older, woody islands).

5. Discussion

5.1 Summary of Major Findings

The present study provides the first systematic baseline for the population density and habitat selection of four obligate grassland birds in the alluvial floodplains of D'Ering Memorial Wildlife Sanctuary. Methodologically, we established that while call-playback significantly enhances detectability, passive point count aural acoustic triangulation yields higher natural encounter rates, providing the statistical estimates of absolute density (CV < 20%). The habitat analyses revealed that obligate grassland birds responded primarily to grassland composition and successional stage rather than to woody vegetation or island size alone. Across all four focal species, the *Saccharum spontaneum and Typha latifolia* grass assemblage consistently emerged as the strongest positive predictor of occurrence, while older islands generally supported fewer obligate species. These results indicate that early-successional floodplain grasslands that develop through periodic flooding provide the structural environment required by these specialists. NMDS also demonstrated a clear ecological separation at the community level with obligate grassland birds being associated with young, structurally complex grasslands and habitat generalists being associated with older woody islands.

5.2 Comparison of Survey Methods

Population estimates of obligate grassland birds remain challenging because these species spend most of their lives concealed within dense grassland vegetation and are therefore detected primarily through vocalizations rather than direct observations (Ralph et al., 1995; Conway, 2011). Estimating population density under such conditions requires survey methods that maximise detectability while satisfying the assumptions necessary for unbiased density estimation. The present study compared passive point counts and call-playback surveys using an acoustic triangulation framework and demonstrated that different survey methods provide different ecological information.

Call playback consistently increased species detectability across all four focal species, producing higher detection probabilities and larger effective detection radii than passive point counts. Similar improvements in detectability following playback have been reported for secretive marsh and grassland birds, where territorial individuals respond vocally to broadcast calls (Lor & Malecki, 2002; Conway, 2011). In the structurally dense alluvial grasslands of D'Ering Memorial Wildlife Sanctuary, playback enabled the detection of individuals that would probably have remained undetected during passive surveys, particularly for species such as the Black-breasted Parrotbill that naturally vocalize infrequently.

However, increased detectability did not necessarily translate into better density estimates. Despite expanding the effective detection radius, playback surveys produced fewer independent detections and consistently higher coefficients of variation than passive aural point counts. This finding highlights an important distinction between species detection and population estimation. Playback is designed to maximise responses from territorial individuals, but by stimulating movement towards the sound source it may alter the natural spatial distribution of birds, thereby reducing compliance with one of the key assumptions of distance sampling that individuals are detected at their original locations (Buckland et al., 2001). In contrast, passive aural surveys recorded birds under natural behavioural conditions, generating substantially larger sample sizes and more precise density estimates.

A methodological strength of this study was the use of the acoustic triangulation method to estimate detection distances of vocalizing birds in tall grasslands, where visual detection was seldom possible. Simultaneous compass bearings by two observers afforded estimates of bird locations, thereby reducing reliance on subjective auditory distance estimation. Similar acoustic mapping frameworks have been applied historically for vociferous forest taxa such as gibbons (Brockelman & Ali, 1987) and galliformes (Thunhikorn et al., 2016), and more recently, true multi-observer triangulation has been successfully integrated with distance sampling for the density estimation of cryptic species (Theuerkauf et al., 2025).

Together, these findings suggest that passive point counts and call playback can be viewed as complementary rather than competing survey approaches. Passive aural point counts are better suited for generating robust estimates of absolute population density, whereas playback substantially improves the detection of rare and elusive species.

5.3 Habitat Selection of Obligate Grassland Birds

Although the four focal species differed in their abundance and distribution, their habitat associations revealed a remarkably consistent ecological pattern. Habitat selection was driven primarily by vegetation structure, grass composition, and floodplain succession, whereas woody vegetation and island size played comparatively minor roles. Rather than functioning as ecologically independent species, the focal birds formed a distinct tall-grass guild, characterised by a shared dependence on structurally complex, early-successional floodplain grasslands

Among the habitat variables examined, the *Saccharum spontaneum and Typha latifolia grass* assemblage emerged as the strongest positive predictor of occurrence across all four focal species. This result implies that obligate grassland birds are sensitive to the floristic composition in addition to grass height. Tall stands of Saccharum interspersed with Typha probably provide appropriate nesting sites, cover from predators and suitable foraging opportunities. Similar relationships between habitat use and vegetation structure have been observed for grassland specialists (Herkert, 1994; Fisher & Davis, 2010; Jahan et al., 2022).The strong negative association between species occurrence and shorter vegetation emphasizes the significance of tall-grass structure. Taller grasslands provide more vertical complexity, more nesting opportunities and greater protection from predators, all known factors influencing habitat suitability for grassland specialists (Fisher & Davis, 2010).These common responses across four taxonomically distinct species suggest that vegetation structure is a generalized ecological filter that regulates habitat selection within the grassland bird assemblage.However, species-specific differences reflected variation in habitat specialization. The lower densities and more limited distribution of the

Black-breasted Parrotbill are probably due to its more limited ecological niche, and lower detections. The higher densities of the Chestnut-capped Babbler and Swamp Grass-babbler suggest a greater abundance of suitable habitat within the sanctuary. These differences, therefore, appear to be ecologically, and not methodologically, derived, supporting the validity of density estimates achieved with passive surveys.

5.4 Floodplain succession and the successional disturbance paradox

Perhaps the most ecologically significant finding of this study was the consistent influence of floodplain succession on habitat selection. Three of the four focal species exhibited higher probabilities of occurrence on younger riverine islands, while older islands undergoing woody succession supported substantially fewer obligate grassland birds. This pattern is typical of the dynamic character of alluvial floodplain ecosystems where seasonal flooding is a persistent force shaping the landscape and maintaining a mosaic of different successional stages of grassland.

Unlike many terrestrial ecosystems where disturbance is generally associated with habitat degradation, periodic flooding within riverine floodplains performs the opposite ecological function. Floods remove accumulated woody vegetation, deposit fresh alluvium, and create newly established grasslands that are rapidly colonised by pioneer grasses. Consequently, disturbance maintains rather than destroys suitable habitat for obligate grassland birds. As flood frequency declines and islands age, ecological succession gradually promotes shrub establishment and woody encroachment, reducing the availability of structurally suitable grasslands.

This relationship represents what may be described as a successional disturbance paradox. The same disturbance process that periodically removes vegetation also maintains the early-successional habitat conditions upon which obligate grassland birds depend. Thus, habitat stability is not necessarily beneficial for these species. Rather, long-term persistence is probably mediated by continuous renewal of habitat by natural flood dynamics. Similar relationships between flood-driven succession and distribution of grassland birds were reported in Brahmaputra floodplain ecosystems (Jahan et al., 2022;

Sharma et al., 2023) suggesting flood disturbance is an important ecological process in maintaining specialist grassland communities.

At the community level, analyses were consistent with an ecological pattern, with NMDS ordination showing a clear separation between obligate grassland birds and habitat generalists along axes of vegetation and succession. Obligate species were always associated with younger islands dominated by tall grass assemblages, whereas habitat generalists were more abundant in older islands with increasing woody vegetation. These findings indicate that flood-driven succession influences not only the distribution of individual species but also the composition of whole bird communities in riverine grasslands.

Collectively these results highlight that the conservation of obligate grassland birds is not dependent on the conservation of static habitat conditions, but rather on the conservation of ecological processes. Conservation efforts that place emphasis on the protection of existing grassland patches in the absence of natural disturbance regimes may ultimately promote woody succession and reduce habitat suitability. Rather, the maintenance of a heterogeneous mosaic of flood-maintained grasslands across multiple successional stages is likely to be a key to the long-term persistence of the tall-grass bird guild within D'Ering Memorial Wildlife Sanctuary.

5.5 Conservation and Management Implications

The findings of this study have important implications for the conservation and management of riverine grasslands in D'Ering Memorial Wildlife Sanctuary. Habitat quality emerged as a stronger determinant of obligate grassland bird occurrence than habitat area, indicating that maintaining suitable vegetation structure and grass composition should be a priority for grassland management. In particular, the consistent association of the focal species with the *Saccharum spontaneum–Typha latifolia* grass assemblage highlights the importance of conserving alluvial grasslands that provide suitable nesting and foraging habitats.

The preference of several focal species for younger islands further emphasises the ecological importance of natural flood driven succession. Periodic flooding along the Siang River creates and maintains early-successional grasslands that support obligate grassland birds. Management strategies should therefore recognise the dynamic nature of these riverine habitats and maintain the natural ecological processes that sustain grassland heterogeneity.

The survey results also provide practical guidance for future monitoring. Passive Point Count (aural), combined with acoustic triangulation, produced the most reliable estimates of population density, whereas call playback improved the detection of secretive and low-density species. Integrating these complementary approaches can improve long-term monitoring programmes and provide more reliable information on population trends of obligate grassland birds within the sanctuary.

Overall, the conservation of obligate grassland birds in D'Ering Memorial Wildlife Sanctuary depends on maintaining native riverine grasslands and the natural floodplain processes that sustain them. Continued monitoring using standardised survey protocols will be essential for assessing future changes in bird populations and habitat conditions.

5.6 Limitations of the study

In the present study, several constraints should be considered while interpreting the results. First, although the sampling effort was extensive and covered all three ranges of D'Ering Memorial Wildlife Sanctuary, the density estimates for the Black-breasted Parrotbill were based on comparatively fewer detections than the other focal species. Consequently, density estimates for this species should be interpreted with greater caution. However, despite the lower sample size, the precision achieved was sufficient to provide a useful baseline for future monitoring.

Second, the study was conducted during a single field season encompassing the breeding period. Habitat conditions of alluvial floodplains are highly dynamic and are strongly influenced by seasonal

flooding and vegetation succession. Consequently, habitat selection patterns and species densities may vary among years depending on flood intensity, vegetation regeneration, and other environmental conditions. Long-term monitoring across multiple years would therefore provide a better understanding of temporal variation in population dynamics.

Third, although acoustic triangulation substantially improved the estimation of detection distances within dense grasslands, positional accuracy depends on precise bearing measurements by both observers and may decline for distant or simultaneously vocalising individuals. Nevertheless, the method proved to be a practical and effective approach for estimating detection distances under conditions where direct visual observations were rarely possible.

Habitat analyses were based mainly on vegetation structure and landscape features measured during the study period, but other ecological factors such as food availability, predator abundance, interspecific interactions, and annual variation in flood regimes were not explicitly incorporated, and they may also influence habitat use by obligate grassland birds. Future studies incorporating these ecological drivers will help better understand habitat selection in riverine floodplain grasslands

5.7 Future Research

The present study provides a baseline for understanding the population density and habitat associations of obligate grassland birds in D'Ering Memorial Wildlife Sanctuary. Building upon these findings, future research should focus on long-term monitoring to evaluate temporal changes in bird populations and habitat conditions in response to annual flooding and vegetation succession.

Further studies examining breeding ecology, nesting success, and seasonal habitat use would improve our understanding of the ecological requirements of these threatened species. Investigating how natural disturbances and habitat management influence grassland structure and bird communities would also provide valuable information for adaptive conservation planning.

Finally, integrating field-based surveys with remote sensing approaches to monitor changes in grassland extent, vegetation composition, and island dynamics would improve our understanding of habitat change and its influence on obligate grassland birds. Such studies will contribute to more effective conservation and long-term management of the unique riverine grasslands of D'Ering Memorial Wildlife Sanctuary.

6. Conclusion

This study provides the first systematic assessment of population density and habitat selection of obligate grassland birds in the alluvial floodplains of D'Ering Memorial Wildlife Sanctuary. By integrating distance sampling, passive aural point counts, call-playback surveys, acoustic triangulation, and habitat modelling, the study demonstrates that reliable density estimation and ecological interpretation can be achieved even for highly secretive grassland birds inhabiting structurally complex floodplain habitats.

Methodologically, passive aural point counts combined with acoustic triangulation produced the most precise estimates of population density, whereas call playback substantially improved the detection of cryptic species. These findings indicate that the two methods are complementary, and together they offer an effective approach to monitoring obligate grassland birds of dense alluvial grasslands.

Ecologically, the study shows that habitat selection is driven more by grassland composition and floodplain succession than by habitat area alone. The consistent association of all four focal species with tall Saccharum spontaneum and Typha latifolia grasslands and younger alluvial islands indicates that vegetation structure and successional stage are the principal determinants of habitat suitability. Community-level analyses further showed that natural flood-driven succession shapes not only the distribution of individual species but also the composition of the entire grassland bird assemblage.

Our findings show that protecting obligate grassland birds is more than simply preserving patches of grassland. Maintaining suitable habitat for these specialists is fundamentally dependent on maintaining

natural floodplain processes that constantly create and renew early-successional grasslands. The methodological and ecological insights derived from this study together provide a strong baseline for long-term monitoring, and contribute to a better understanding of riverine grassland ecosystems in northeastern India.

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Tall grassland habitat in D'Ering Memorial Wildlife Sanctuary.





Representative habitats and obligate grassland birds of D'Ering Memorial Wildlife Sanctuary showing alluvial grassland, riverine habitat, Black Breasted Parrotbill and Jerdon's Babbler.