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Microhabitat variables influencing the presence and abundance of birds in floodplain grassland of the lower Ganges and Brahmaputra rivers, Bangladesh

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ABSTRACT

Grassland bird communities are likely declining in all major grassland ecosystems globally due to habitat loss and modification, yet knowledge of the status of many tropical grassland bird communities is relatively poor. This study investigated the bird community structure and its associations with vegetation characteristics and potential human impacts in seasonal floodplain grassland along the lower Ganges and Brahmaputra Rivers, Bangladesh (part of the Indo-Gangetic Plain) during 2018–2019 through point counts of birds combined with vegetation surveys. Bird responses were assessed by diversity indexes, non-metric multidimensional scaling ordination and linear models. Results show that the total resident bird community (31 grassland specialists, 34 generalists and 10 waterbirds) overlapped among the four major vegetation types in the study area (forbs and bushes, *Saccharum* sp., *Cynodon* sp. and cropland). The diversity of the total bird community increased with cover of forbs and bushes, while the overall diversity of grassland specialists (those adapted to and reliant on some variety of grassland habitat for part or all of their life cycle whether feeding or breeding.) increased with *Saccharum* sp. cover but decreased with increased crop cover. The diversity of the total bird community and all grassland specialist birds showed no variation with vegetation height. However, the abundance of grassland specialists showed a strong increase with increases in vegetation height. Among the grassland specialists, nine species that were entirely dependent on tall grasses for breeding were considered as obligate tall grass breeders. The abundance of these tall grass breeders decreased with greater cover of both *Cynodon* sp. and crops but increased with greater cover of *Saccharum* sp. The retention of vegetation with heights > 150 cm was therefore important to conservation and management of this community. Regular seasonal herding of cattle in these floodplain grasslands was widespread and it was therefore difficult to compare grazed with ungrazed areas. The diversity of neither the total bird community nor the overall grassland specialists showed any association with grazing intensity. However, grazing impacted negatively on the abundance of obligate tall grass breeders.

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Limited grass harvesting increased the overall diversity of the grassland specialist bird community. The estimated density of nine species of obligate tall grass breeders ranged from 0.19 to 4.41 birds/ha. Continuing rapid agricultural expansion was observed and is a prominent threat to these birds. More habitat-specific information and monitoring are required to quantify risks and aid conservation planning.

1. Introduction

Grass-dominated ecosystems, covering about 25 % of the Earth's land surface (Liu et al., 2021), play a crucial role concomitantly as wildlife habitat (Wang et al., 2018) and for the livelihoods of nearly 800 million people globally (FAOSTAT, 2015). However, increasing demands for food and energy production (Shaffer et al., 2019) are placing enormous pressures on natural grassland systems (Egoh et al., 2016), driving their rapid conversion to cropland (Godreau et al., 1999). Consequently, grassland-associated wildlife world-wide is facing mounting challenges due to the loss, fragmentation, and modification of grassland ecosystems (Rosenberg et al., 2019). Particularly, grassland birds are experiencing major population declines due to land use changes (Marques et al., 2020).

Birds of floodplain grasslands are associated most strongly with vegetation composition and structure for their survival and reproduction (Azpiroz and Blake, 2016). Vegetation productivity and growth cycles maintained by intermittent natural floods in floodplain grasslands, creates heterogeneity (Wright et al., 2015) which is often critical in supporting a full suite of grassland-dependent species (Davis et al., 2020; Fuhlendorf et al., 2006). Grazing (Porensky et al., 2020) and harvesting (Hossain and Li, 2020), may also enhance vegetation heterogeneity which benefits the diversity and abundance of grassland bird communities (Ahlering and Merkord, 2016). However, floodplain grassland specialist birds (species adapted to and reliant on some variety of grassland habitat for part or all of their life cycle, be it breeding, migration or wintering) are reported to be strongly declining (Besnard et al., 2013) as they are unable to cope with conversion to agriculture (Brinson and Malvarez, 2002). Agricultural practices in grasslands alter plant community composition, involving the loss of dominant species and an increase in ruderal plants (Lekberg et al., 2021). Long-term and excessive use of fertilizer diminishes the soil quality of wet grassland (Vargová et al., 2020) and eventually reduces grassland productivity (Basto et al., 2015).

One of the world's largest floodplain grassland ecosystems comprises the seasonally flooded grasslands at the base of the Himalayan foothills and in the floodplains of the Ganges and Brahmaputra rivers in northern India, southern Nepal and Bangladesh (also known as the Indo-Gangetic Grasslands). This ecoregion supports a distinctive bird community (Baral, 2001; Rahmani et al., 2016), with several species restricted to this system (BirdLife International, 2003, 2015). Seasonally flooded alluvial soil supports unique vegetation characterized by dense, tall grasses (Rawat and Adhikari, 2015) which have a significant influence on bird community composition (Baral, 2001; Akash et al., 2018). As observed in many other grass-dominated ecosystems, most of this region's grassland-dependent birds are in jeopardy due to clearance for agriculture, overgrazing, and grass harvesting (Baral, 2001; Gopi Sundar, 2011; Grimmett et al., 2012).

In Bangladesh, human pressure on grassland is particularly intense as the high productivity of alluvial soils encourages their continued conversion to cropland which continues to threaten grassland birds. As a consequence, ten globally threatened grassland-dependent species have probably already been extirpated from the country (IUCN Bangladesh, 2015a). Within Bangladesh, the least disturbed Indo-Gangetic grasslands are now restricted to a few wetlands in the north-east and to the main rivers bordering the north-west where riverine flooding limits access seasonally. Livestock grazing occurs most of the year (October to June); grass (*Saccharum* sp.) harvesting for feeding livestock occurs year-round at a small scale, and at a larger scale in June, immediately prior to the onset of flooding, when sale of *Saccharum* sp. serves as an important livelihood source for villagers. Ecologically, this grass provides soil binding services, stabilizing riverbeds and reducing bank erosion (Chandran, 2015). Although some areas of floodplain grassland in the Indo-Gangetic Plain fall within protected areas in India and Nepal, no government policies have been implemented to protect grassland habitats in Bangladesh. Furthermore, no quantitative information on how human disturbances impact grassland bird communities is available to support management actions.

This study investigated how the resident bird community was affected by changes in the available grasslands. We begin by investigating the overall bird community structure (species richness and abundance), then focus on grassland specialists (those adapted to and reliant on some variety of grassland habitat for part or all of their life cycle whether feeding or breeding), habitat generalists, and waterbirds, and estimated the density of obligate grassland breeders (birds entirely dependent on grassland for breeding). Estimates of density/abundance are particularly useful for establishing baseline information to support conservation. Finally, we investigated the associations of different bird groups with vegetation characteristics and human use (livestock grazing, grass harvesting, and conversion of natural floodplain grassland habitats to agricultural crops) to explain habitat impacts, hypothesizing that bird species composition is directly affected by floodplain grassland vegetation structure.

We predicted that (a) the Shannon diversity of the total resident bird community would depend on the vegetation type and would be higher in areas with a mix of forbs and bush cover than in single vegetation cover types e.g., *Saccharum* sp. (taller grasses) or *Cynodon* sp. (shorter grasses) or cropland, because vegetation complexity accounts for a significant amount of variation in avian richness and abundance in floodplain grasslands (Azpiroz and Blake, 2016). However, this may not be the case for grassland specialists including obligate tall grass breeders (Vickery et al., 1999). The diversity of the total bird community was predicted not to change with increased cropland cover, but numbers of grassland specialists and obligate tall grass breeders would decrease with increased crop cover because agricultural expansion will likely reduce their breeding success (Gopi Sundar, 2011). We also predict that (b) areas dominated by taller vegetation (>100 cm) would have a less diverse bird community than areas dominated by shorter vegetation (<25 cm). However, the diversity of grassland specialist birds and obligate tall grass breeders would be higher in taller (>100 cm) vegetation areas than in shorter (<25 cm) vegetation areas because vegetation height is likely positively correlated with survival and reproduction of such specialists (Azpiroz and Blake, 2016). We also hypothesized that bird species composition is affected by human disturbance. We predicted that (c) overall bird diversity would be higher in areas of moderate cattle grazing relative to ungrazed areas, but that diversity of grassland specialist birds and obligate tall grass breeders would be higher in ungrazed areas because specialists and obligate grassland breeders are typically associated with taller grasses (Baral, 2001); and (d) that, as with cattle grazing, overall bird diversity would be higher in areas of moderate grass harvesting relative to unharvested areas, but that diversity of grassland specialist birds and obligate tall grass breeders would be higher in unharvested areas relative to harvested areas (Leston and Koper, 2017).

2. Materials and methods

2.1. Study site

This study was conducted in two seasonally flooded riverine grasslands of north-west Bangladesh with historical records of many grassland bird species (Ali and Ripley, 1969, 1987; Thompson et al., 1993; 2003 Thompson and Johnson, 2003). Surveys focused on riverine grassland (mainly *Saccharum* spp.) in the Ganges-Padma River floodplain in Rajshahi district and in the Brahmaputra-Jamuna River floodplain in Kurigram district (Fig. 1). The section of the Ganges studied at Rajshahi was ~40 km long and ~4.0 km wide, and the focal area of the Brahmaputra was approximately ~27 km long and ~10 km wide at Kurigram. Both rivers have numerous islands which are partly or fully submerged during the monsoon, and subject to frequent changes from erosion and silt deposition. There is little recent information on the extent of floodplain grasslands in either river, however, the area of river islands was estimated at 148 km^2 in the Ganges and 447 km^2 in the Brahmaputra in 1993 (EGIS, 2000).

After reconnaissance visits to 12 riverine islands during April 2018, two sample islands (chars) were selected: Char Majardia

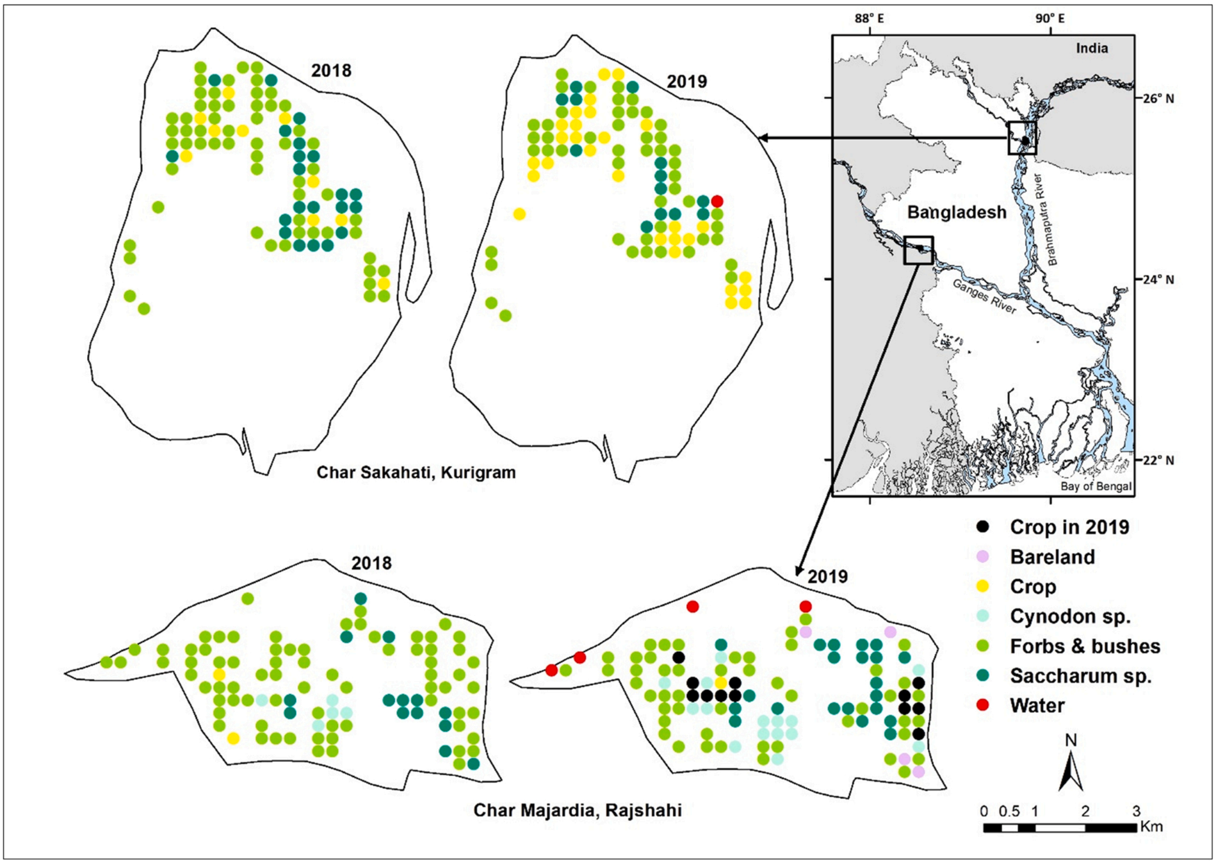

Fig. 1. Locations and maps of the survey areas in Ganges and Brahmaputra River, Bangladesh with survey points. Multiple colored dots represent areas covered with different vegetation types: *Saccharum* sp. (dark green), *Cynodon* sp. (blue green), various forbs and bushes including mixed vegetation with grasses (light green), cultivated crops (yellow), and the additional 12 points were surveyed in cropland in 2019 (black dots). In 2018, Char Sakahati was surveyed at 91 and Char Majardia was surveyed at 94 points. In 2019, Char Sakahati was surveyed at 91 and Char Majardia was surveyed at 94 points plus 12 points purposefully added in cropland (black dots). (Map created using ArcGIS 10.3).

Table 1
Bird list recorded during point count surveys in two seasonally flooded grasslands of north-west Bangladesh between 2018 & 2019 (Char Majardia in the Ganges-Padma River floodplain in Rajshahi district and Char Sakahati in the Brahmaputra-Jamuna River floodplain in Kurigram district). Based on habitat associations bird species were characterized as generalist (eurytopic/broad habitat requirements), grassland specialist or waterbird. Grassland specialist birds are defined here as those adapted to and reliant on some variety of grassland habitat for part or all of their life cycle whether feeding or breeding. Waterbirds are those that habitually feed on open water. Floodplain grasslands at both study islands in the Ganges and Brahmaputra River contained a mosaic of patches of short (*Cynodon* sp.) and tall (*Saccharum* sp.) grasses with a mix of forbs, bushes, and crops. Among the grassland specialists, nine species that were entirely dependent on tall grasses for breeding were considered as obligate tall grass breeders (Table S1). Other grassland specialists were predominantly associated with open, short grass areas. Taxonomy of recorded birds followed the IOC World Bird List (Anon, 2021) and global threat status followed BirdLife International (2021).

Sl	Species	Code	Family	Scientific Name	Local status	Habitat association	Global status
1	Asian Openbill	AO	Ciconiidae	*Anastomus oscitans*	Resident	Generalist	Least Concern
2	Asian Pied Starling	APS	Sturnidae	*Gracupica contra*	Resident	Generalist	Least Concern
3	Bank Myna	BMy	Sturnidae	*Acridotheres ginginianus*	Resident	Generalist	Least Concern
4	Barn Swallow	BSw	Hirundinidae	*Hirundo rustica*	Non-breeding resident	Generalist	Least Concern
5	Barred Buttonquail	BBQ	Turnicidae	*Turnix suscitator*	Resident	Grassland specialist	Least Concern
6	Baya Weaver	Bwe	Ploceidae	*Ploceus philippinus*	Resident	Generalist	Least Concern
7	Bengal Bush Lark	BBu	Alaudidae	*Mirafra assamica*	Resident	Grassland specialist	Least Concern
8	Black Drongo	BDr	Dicruridae	*Dicrurus macrocercus*	Resident	Generalist	Least Concern
9	Black Kite	Bki	Accipitridae	*Milvus migrans*	Resident	Generalist	Least Concern
10	Black-breasted Weaver	BbrW	Ploceidae	*Ploceus benghalensis*	Resident	Grassland specialist (Obligate)	Least Concern
11	Black-hooded Oriole	BhoO	Oriolidae	*Oriolus xanthornus*	Resident	Generalist	Least Concern
12	Black-winged Kite	BWK	Accipitridae	*Elanus caeruleus*	Resident	Generalist	Least Concern
13	Blue-tailed Bee-eater	BTBe	Meropidae	*Merops philippinus*	Breeding Summer migrant	Generalist	Least Concern
14	Bristled Grassbird	BGr	Locustellidae	*Schoenicola striatus*	Breeding Summer migrant	Grassland specialist (Obligate)	Vulnerable
15	Chestnut Munia	CM	Estrildidae	*Lonchura atricapilla*	Resident	Grassland specialist (Obligate)	Least Concern
16	Cinnamon Bittern	CB	Ardeidae	*Ixobrychus cinnamomeus*	Resident	Grassland specialist	Least Concern
17	Common Myna	Cmy	Sturnidae	*Acridotheres tristis*	Resident	Generalist	Least Concern
18	Common Quail	CQ	Phasianidae	*Coturnix coturnix*	Resident	Grassland specialist	Least Concern
19	Common Tailorbird	CT	Cisticolidae	*Orthotomus sutorius*	Resident	Generalist	Least Concern
20	Eastern Cattle Egret (Cattle Egret)	CE	Ardeidae	*Bubulcus coromandus*	Resident	Generalist	Least Concern
21	Eurasian Collared Dove	ECD	Columbidae	*Streptopelia decaocto*	Resident	Generalist	Least Concern
22	Golden-headed Cisticola	GhC	Cisticolidae	*Cisticola exilis*	Resident	Grassland specialist (Obligate)	Least Concern
23	Graceful Prinia	GP	Cisticolidae	*Prinia gracilis*	Resident	Grassland specialist (Obligate)	Least Concern
24	Greater Coucal	GC	Cuculidae	*Centropus sinensis*	Resident	Generalist	Least Concern
25	Greater Painted-snipe	GPSn	Rostratulidae	*Rostratula benghalensis*	Resident	Grassland specialist	Least Concern
26	Green Bee-eater	Gbe	Meropidae	*Merops orientalis*	Resident	Generalist	Least Concern
27	Grey-throated Martin (Asian Plain Martin)	APM	Hirundinidae	*Riparia chinensis*	Resident	Grassland specialist	Least Concern
28	Grey Francolin	GF	Phasianidae	*Francolinus pondicerianus*	Resident	Grassland specialist	Least Concern
29	Grey Heron	GH	Ardeidae	*Ardea cinerea*	Resident	Waterbird	Least Concern
30	Grey-bellied Cuckoo	GbeC	Cuculidae	*Cacomantis passerinus*	Summer migrant	Generalist	Least Concern
31	House Crow	HC	Corvidae	*Corvus splendens*	Resident	Generalist	Least Concern
32	House Sparrow	HS	Passeridae	*Passer domesticus*	Resident	Generalist	Least Concern
33	Indian Cormorant	IC	Phalacrocoracidae	*Phalacrocorax fuscicollis*	Non-breeding resident	Waterbird	Least Concern
34	Indian Pond Heron	IPH	Ardeidae	*Ardeola grayii*	Resident	Generalist	Least Concern
35	Indian Silverbill	IS	Estrildidae	*Euodice malabarica*	Resident	Grassland specialist	Least Concern
36	Indian Spot-billed Duck	ISBD	Anatidae	*Anas poecilorhyncha*	Resident	Waterbird	Least Concern
37	Indian Stone-curlew (Indian Thick-knee)	ISc	Burhinidae	*Burhinus indicus*	Resident	Grassland specialist	Least Concern
38	Jacobin Cuckoo (Pied Cuckoo)	PiCu	Cuculidae	*Clamator jacobinus*	Summer migrant	Grassland specialist	Least Concern
39	Jungle Babbler	JB	Leiothrichidae	*Argya striata*	Resident	Generalist	Least Concern
40	Large-billed Crow	LBC	Corvidae	*Corvus macrorhynchos*	Resident	Generalist	Least Concern
41	Lesser Coucal	LeC	Cuculidae	*Centropus bengalensis*	Resident	Grassland specialist	Least Concern
42	Lesser Whistling-duck	LWD	Anatidae	*Dendrocygna javanica*	Resident	Waterbird	Least Concern

(*continued on next page*)

Table 1 (*continued*)

43	Little Cormorant	LiC	Phalacrocoracidae	*Microcarbo niger*	Resident	Waterbird	Least Concern
44	Little Egret	LE	Ardeidae	*Egretta garzetta*	Resident	Generalist	Least Concern
45	Little Pratincole	LP	Glareolidae	*Glareola lactea*	Resident	Waterbird	Least Concern
46	Long-tailed Shrike	LTS	Laniidae	*Lanius schach*	Resident	Generalist	Least Concern
47	Oriental Magpie-Robin	OMR	Muscicapidae	*Copsychus saularis*	Resident	Generalist	Least Concern
48	Oriental Skylark	OS	Alaudidae	*Alauda gulgula*	Resident	Grassland specialist	Least Concern
49	Paddyfield Pipit	PFP	Motacillidae	*Anthus rufulus*	Resident	Grassland specialist	Least Concern
50	Painted Stork	PS	Ciconiidae	*Mycteria leucocephala*	Non-breeding resident	Waterbird	Near Threatened
51	Pheasant-tailed Jacana	PtJ	Jacanidae	*Hydrophasianus chirurgus*	Resident	Waterbird	Least Concern
52	Pied Kingfisher	PK	Alcedinidae	*Ceryle rudis*	Resident	Waterbird	Least Concern
53	Plain Prinia	PP	Cisticolidae	*Prinia inornata*	Resident	Grassland specialist (Obligate)	Least Concern
54	Plaintive Cuckoo	PlCu	Cuculidae	*Cacomantis merulinus*	Resident	Generalist	Least Concern
55	Rain Quail	RQ	Phasianidae	*Coturnix coromandelica*	Resident	Grassland specialist	Least Concern
56	Red Avadavat	RA	Estrildidae	*Amandava amandava*	Resident	Grassland specialist (Obligate)	Least Concern
57	Red-necked Falcon	RnF	Falconidae	*Falco chicquera*	Resident	Generalist	Near Threatened
58	Red-rumped swallow	RSw	Hirundinidae	*Cecropis daurica*	Resident	Generalist	Least Concern
59	Red-vented Bulbul	RvB	Pycnonotidae	*Pycnonotus cafer*	Resident	Generalist	Least Concern
60	Red-wattled Lapwing	RwL	Charadriidae	*Vanellus indicus*	Resident	Grassland specialist	Least Concern
61	Rock Dove	RD	Columbidae	*Columba livia*	Resident	Generalist	Least Concern
62	Rose-ringed Parakeet	RrP	Psittaculidae	*Psittacula krameri*	Resident	Generalist	Least Concern
63	Sand Lark	SLa	Alaudidae	*Alaudala raytal*	Resident	Grassland specialist	Least Concern
64	Streak-throated Swallow	SSw	Hirundinidae	*Petrochelidon fluvicola*	Non-breeding resident	Grassland specialist	Least Concern
65	Striated Babbler	SBa	Leiothrichidae	*Argya earlei*	Resident	Grassland specialist	Least Concern
66	Striated Grassbird	SGr	Locustellidae	*Megalurus palustris*	Resident	Grassland specialist	Least Concern
67	Striated Heron (Little Heron)	LH	Ardeidae	*Butorides striata*	Resident	Waterbird	Least Concern
68	Tricolored Munia	TrM	Estrildidae	*Lonchura malacca*	Resident	Grassland specialist (Obligate)	Least Concern
69	Watercock	WCo	Rallidae	*Gallicrex cinerea*	Resident	Grassland specialist	Least Concern
70	Western Spotted Dove	WSD	Columbidae	*Spilopelia suratensis*	Resident	Generalist	Least Concern
71	White-throated Kingfisher	WtK	Alcedinidae	*Halcyon smyrnensis*	Resident	Generalist	Least Concern
72	White-eyed Buzzard	WEB	Accipitridae	*Butastur teesa*	Resident	Generalist	Least Concern
73	White-tailed Stonechat	WtS	Muscicapidae	*Saxicola leucurus*	Resident	Grassland specialist (Obligate)	Least Concern
74	Yellow Bittern	YB	Ardeidae	*Ixobrychus sinensis*	Resident	Grassland specialist	Least Concern
75	Zitting Cisticola	ZC	Cisticolidae	*Cisticola juncidis*	Resident	Grassland specialist	Least Concern

*Grassland specialist birds detected in the study sites but not recorded during point count surveys included King Quail *Excalfactoria chinensis*, Sykes's Nightjar *Caprimulgus mahrattensis*, Common Grasshopper Warbler *Locustella naevia*, Short-eared Owl *Asio flammeus*, Spotted Bush Warbler *Locustella thoracica*, White-throated (Hodgson's) Bushchat *Saxicola insignis* (globally vulnerable), Siberian Stonechat *Saxicola maurus*, Mongolian Short-toed Lark *Calandrella dukhunensis* (Eastern Short-toed Lark). Species detected beyond the 100 m survey radius during point counts included: Black-headed Ibis & Black-tailed Godwit (globally near threatened), Indian Spotted Eagle (vulnerable); and two uncommon records: Amur Falcon (probably passage migrants) & Eurasian Cuckoo at Char Sakahati.

*Notable records at Char Majardia were Streak-throated Swallow, Rain Quail and Grey Francolin (photographic evidence). Grey Francolin was previously declared as regionally Extinct by IUCN Red List of Bangladesh in 2015 and rediscovered during this study. We found an adult with seven juveniles exiting from *Solanum linnaeanum* bushes. As the observation site was close to the Indian border, these individuals may have possibly dispersed from that country.

*Winter migrants (non-breeding visitors) occur in the study area chiefly during December to March. Five of these migrants (Common Kestrel *Falco tinnunculus*, Kentish Plover *Charadrius alexandrinus*, Lesser Sand Plover *Charadrius alexandrinus*, Pied Harrier *Circus melanoleucos* and Sand Martin *Riparia riparia*) were found over-summering through the area during the execution of point counts but were excluded from our analysis.

(24°20'52.41"N & 88°32'59.09"E) located in Rajshahi and Char Sakahati (25°32'16.40"N & 89°42'32.68"E) in Kurigram. Char Sakahati has year-round human occupants, approximately ~2000 people, inside the study area. At Char Majardia, a village named Nobinagar located in the south of the island held approximately ~2500 people. The aerial distance between the two sample islands was about 170 km. The area of Char Majardia covered 19.4 sq km and was about 1.2 km from the mainland while Char Sakahati covered 35.2 sq km and was about 3.4 km distant from the mainland based on 2018 Google Earth data. The soils of Char Sakahati are mainly noncalcareous alluvium and silty with sand close to the surface while the soils of Char Majardia are mainly calcareous alluvium and silty with sand on some ridges and clays in some depressions (Brammer, 1996). Both islands retain typical grassland dominated by *Saccharum* sp. and *Cynodon* sp. Livestock (Cows *Bos indicus*, Goats *Capra hircus*, Sheep *Ovis aries*, and Water Buffaloes *Bubalus bubalis*) grazing and grass (*Saccharum* sp.) harvesting by local people were observed at both sites: there was no government involvement in habitat protection. No wild grazers were observed except Indian Hare (*Lepus nigricollis*), considered regionally endangered (IUCN Bangladesh, 2015b). There is historic evidence of other wild grazers including One-horned Rhinoceros *Rhinoceros unicornis*, Swamp

Deer *Rucervus duvaucelii*, Hog Deer *Hyelaphus porcinus*, Pygmy Hog *Porcula salvania*, Hispid Hare *Caprolagus hispidus*, and Wild Water Buffalo *Bubalus arnee* in floodplain grasslands of the Indo-Gangetic plain (IUCN Bangladesh, 2015b). Crop cultivation was observed to be spreading based on our 2018–2019 surveys. Bird trapping (mostly herons, storks and egrets caught using traps made locally) was noticed at Char Majardia while trapping was more evident at Char Sakahati, due to the number of people making a subsistence living on the island. Local bird watchers and local bird guides at Char Majardia have been promoting conservation awareness which has reduced bird hunting in and around study area.

2.2. Bird surveys

Birds were surveyed using 100-m fixed-radius point-counts (Hutto et al., 1986) of 10-min duration without a waiting period (Savard and Hooper, 1995) during 21 May to 2 July in 2018 and 22 May to 16 July in 2019, covering the breeding season for most resident species. Points were sampled by overlaying a grid of 250 × 250 m on Google Earth imagery of 2018 of the two target islands; grid size was decided from field work to minimize double counting the same birds in adjacent points. Based on image interpretation and field checking, grid points that fell on water, bare sand, woodland, forest plantations and human settlements were excluded, and the remaining points were in grassland patches and other available vegetation (bushes, reed, swamp, scrub, cultivation) around the grassland habitat. Sampling points were chosen randomly following our grid. Successive points were spaced 250 m apart. Birds were only counted to a distance of 100 m at each point, leaving a 50 m buffer such that likelihood of double-counting of the same individual was reduced. Note of individuals at adjacent points were also taken to avoid double-counting individuals during counts on the same morning. Sample points were chosen as far from the edge of each island as possible to minimize the influence of edge to river channel (to the north of Char Majardia and to the east of Char Sakahati). Char Majardia was surveyed at 94 points which were sampled twice (once in each survey year), and the additional 12 points in cropland were surveyed in 2019 (Fig. 1). Char Sakahati was surveyed at 91 points which were also sampled twice. Points were surveyed between 06h00 and 10h00 in good weather (i.e., no rain or strong winds). Weather conditions (wind and cloud cover) were also recorded. Wind velocity was estimated following the Beaufort scale, cloud cover (visual percentage approximation) and survey time and duration were recorded. Birds detected beyond 100 m and during movements between sample points were also noted to estimate detection rates per species but were not included in the counts. To minimize observer bias, all surveys were carried out by the lead author using binoculars and a digital sound recorder. Audio recordings were made during the surveys to later check identifications and for species missed at the time. Distances between observer and birds were estimated directly using a rangefinder if birds were visible, otherwise in 5 m bands to 30 m, then 10 m bands to 100 m, and > 100 m for aural detections (Rosenstock et al., 2002). Taxonomy of recorded birds followed the IOC World Bird List (Anon, 2021). Based on habitat associations bird species were characterized as either generalist (eurytopic/having broad habitat requirements), grassland specialist or waterbird. Grassland specialist birds were defined as those adapted to and reliant on some variety of grassland habitat for part or all of their life cycle whether feeding or breeding. Waterbirds were defined as those that habitually feed on open water. Floodplain grasslands at both study islands contained a mosaic of patches of short (*Cynodon* sp.) and tall (*Saccharum* sp.) grasses with a mix of forbs, bushes, and crops. Among the grassland specialists, nine species that were entirely dependent on tall grasses for breeding were considered as obligate tall grass breeders (Table 1). Other grassland specialists were predominantly associated with open, short grass areas.

2.3. Habitat sampling

All vegetation variables were sampled at each bird survey point using 100-m radius plots. Vegetation was sampled using an ocular tube (a simple sighting device consisting of cylinder with crosshairs (James and Shugart, 1970). Vegetation was sampled at 5 m intervals starting from the point count center up to a 100 m radius in the four cardinal directions for a total 80 vegetation samples per bird survey point. At each interval point the single dominant vegetation species seen through ocular tube when pointed down from 100 cm above the ground was recorded. This gave 80 vegetation samples per bird survey point. Vegetation was classified according to four categories (*Saccharum* sp., *Cynodon* sp., forbs and bushes or cropland) and any bird survey point in which a single one of these four vegetation types contributed ≥ 80 % cover of vegetation cover was labelled accordingly. Forbs and bushes included *Solanum* sp., *Tamarisk* sp., *Ipomoea carnea*, *Lippia nodiflora*, *Persicaria* sp. and *Xanthium strumarium*, among others, and were usually mixed with grasses. Vegetation species were identified by comparing voucher specimens from a herbarium with photos taken during the survey. Crops included varieties of rice, lentil, jute, maize, sesame, dhaincha (*Sesbania bispinosa*), berries (*Ziziphus mauritiana*), pointed gourd, bitter gourd, chili, and other vegetables. Sparse trees were also observed. Sparse trees were also observed. Vegetation height (cm) was recorded as an average for each sample point in a 50 cm radius at each 5 m interval. Vegetation structure (plant species, status (live/dead) and height) were recorded in both 2018 and 2019. Grazing intensity for all sample points, based on a count of livestock dung (Sheidai-Karkaj et al., 2022) in a 1.5 m radius at each 5 m interval along the four cardinal direction sampling transects, was recorded only in 2019. Similarly, grass harvesting intensity was recorded based on a count of grass cutting signs in 2019. Some changes in habitat were observed between 2018 and 2019: four points previously covered with *Saccharum sp*. or forbs and bushes in 2018 became bare land in 2019 and an additional five points previously covered with *Saccharum sp*. or forbs and bushes were inundated in 2019. Crop cultivation increased in 2019 (29 points) compared to 2018 (12 points). This comparison does not include the additional 12 points which were surveyed in cropland in 2019 in order to increase the sample of cultivated points. In total, the survey points covered about 17 % of Char Majardia and 8 % of Char Sakahati.

2.4. Data analysis

Densities of obligate tall grass breeding birds which had ≥ 30 detections were estimated using Program DISTANCE (Buckland et al., 2001) testing the four key functions: uniform, half normal, hazard-rate, and/or negative exponential to determine the detection model of best fit. Hazard-rate models were not considered when the output gave implausible shapes (Thomas et al., 2010). All detection models were run with the cosine adjustment. Models were evaluated using AICc (Buckland et al., 2001). The detection model with the lowest AICc value was considered to have the most support and was used to determine the density of individuals within that specific habitat category (McCollum et al., 2018). Kolmogorov-Smirnov goodness-of-fit (GOF) tests were used to evaluate models in which $P < 0.05$, considered well-fitted to the data (Buckland et al., 2001).

Shannon's diversity index (Shannon and Weaver, 1949) was computed as a measure of overall bird diversity. Hutcheson's t-test (Hutcheson, 1970) was used to compare the bird diversity between the two islands. All diversity calculations were conducted in MS Excel.

Differences in bird communities in relation to vegetation structure were examined following the Bray-Curtis dissimilarity calculation based on square-root transformed species relative abundance data (Borcard et al., 2011). This metric was then used to assess community similarity across habitat variables using a non-metric multidimensional scaling (NMDS) analysis (Minchin, 1987) using the metaMDS function of package vegan in program R. Each habitat variable was then fitted to the resulting NMDS to examine the relationships of the bird community to habitat variables (envfit function in package vegan). Finally, vegetation structure variables were chosen based on the NMDS ordinations.

Multivariate linear regression models were applied to investigate bird-habitat associations. The entire bird community was assessed using Shannon diversity. Grassland specialist birds (both obligate tall grass breeders and others) were first grouped together and assessed using both Shannon diversity and abundance, but due to the small number of species, the obligate tall grass breeders versus other grassland specialists were compared using abundance only. We used the same set of randomly sampled points to replicate the survey in both years (apart from the 12 additional selected points in cropland in 2019). However, the impact of the differing extent of flooding and changes in vegetation on bird usage during the two years meant that these sets could reasonably be considered to be independent of one another. Two sets of models were developed to assess the explanatory power of vegetation structure including vegetation type, vegetation height (cm), vegetation status (live/dead), and human disturbance including grazing intensity and grass harvesting intensity. In first set of models, predictor variables were vegetation type, vegetation height and their combination, using data recorded in 2018 and 2019. In the second set of models, predictor variables included the effects of vegetation type, vegetation height, cattle grazing, harvesting and their combination, the data being recorded in 2019 only. AIC Model comparison methods (Burnham and Anderson, 2002) were used to evaluate the relative ability of all models to explain variation in Shannon diversity for the total bird community and grassland specialist birds, and abundance for grassland obligate breeding birds. All models were checked for the homogeneity of their residuals. Models were compared and ranked using Akaike's information criterion corrected for small sample size (AICc) following Burnham and Anderson (2002). Models and their relative importance were also assessed using Arnold (2010) to

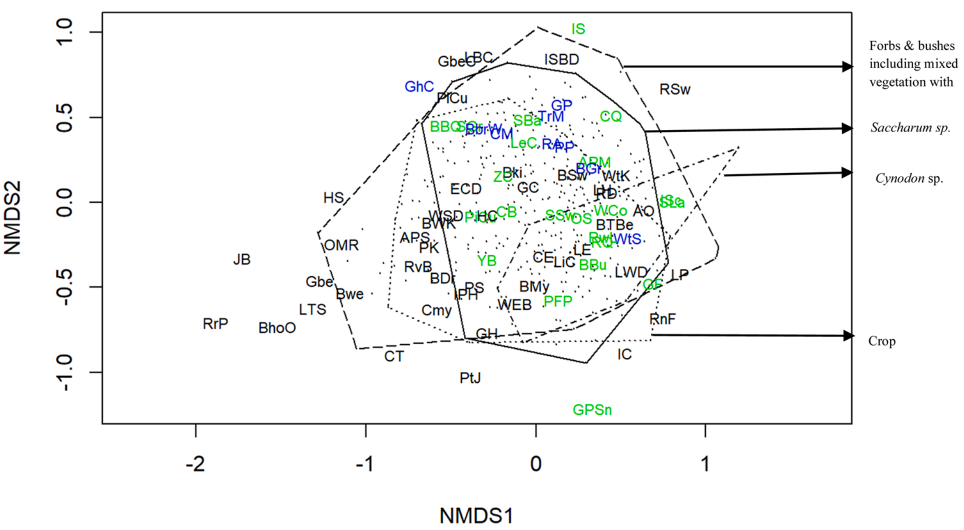

Fig. 2. The NMDS (Non-metric multidimensional scaling) plot of Bray-Curtis dissimilarity matrix for the bird communities (black=generalist & waterbirds; green & blue = grassland specialist birds [blue = obligate tall grass breeders & green = other grassland specialists]) recorded at the two study areas in 2018–2019. The STRESS is equal to 0.259 with K= 2. Bird species added using weighted averages (abundance data). Bird codes are listed in Table 1. Hulls are around each vegetation type (longdash line= Forbs & bushes including mixed vegetation with grasses, dotted line=Crops, solid line= *Saccharum* sp., dotdash line= *Cynodon* sp.). Vegetation categories were based on > 80 % cover of the particular category. Birds are at the center of the hulls outlining each vegetation type in the NMDS plot and indicate the species most likely to be detected in each vegetation type. Birds farthest from each other on the plot are less likely to be found together in same community. The small number of detections (n = 2) of Greater Painted-snipe (GPSn) put it out of the hull, but it was most likely to occur at sites with forbs and bushes cover and *Cynodon sp.* cover.

avoid the inclusion of uninformative parameters. AICc weights (wAICc) provided relative weight of any particular model (Burnham and Anderson, 2002). All statistical analyses were carried out in the Program R version 4.1.0 (The R Core Team, 2020) using tidyverse, ggpubr, rstatix, AICcmodavg packages. Collinearity was ascertained among explanatory variables; variables with correlations below 0.60 were retained per Dormann et al. (2013). Model coefficients (β) with 95 % confidence intervals (CI) from AICc selected models (Burnham and Anderson, 2002; Arnold, 2010) were reported and considered predictor variables to be strongly influential on response variables if CI for β did not overlap zero (Bolker, 2008; Arnold, 2010).

3. Results

Point counts limited to 100 m radius recorded a total of 75 resident bird species at Char Majardia and Char Sakahati combined during 2018–2019. These counts consisted of 382 samples (including replicates) which covered 618.9 ha in total on the two islands. These 75 presumed breeding birds comprised 31 grassland specialists, 34 generalists and 10 waterbirds (Table 1). Among grassland specialists, 22 were mainly associated with open, short grass areas, and 9 were obligate tall grass breeders (birds entirely dependent on taller grassland for breeding). The exponential of Shannon diversity (e^H), directly compared among sites using Hutcheson's t-test, indicated that diversity was not significantly different between two islands (Table S1).

3.1. Bird community

The community NMDS analysis, with a stress of 0.259, indicated reasonable fit in two dimensions, and showed overlap in bird communities among the four major vegetation types (Fig. 2). The area of the hull for *Cynodon* sp. (short grasses) was notably smaller than for all other habitats, which indicated survey points in *Cynodon* sp. habitat tended to have a less diverse bird community than the others. The area of the hull for forbs and bushes was largest, overlapping *Saccharum* sp. (tall grasses) cover and cropland cover.

Obligate tall grass breeders (9 species) made up 20.5 % of the total observations. Densities of seven of these ranged from 0.19 to 4.41 birds/ha based on the surveyed area of 618.9 ha of floodplain grassland (combining both study sites and pooling data from two years). Bristled Grassbirds were mainly detected from song, so the estimated density (0.52 birds/ha) mostly applied to displaying males (Female Bristled Grassbirds were chiefly detected when calling in alarm in response to an intruder approaching the nest). Although both Plain Prinia and Graceful Prinia also sang they were mostly identified by visual observation. Other species (Black-breasted Weaver, Chestnut Munia, Tricoloured Munia and White-tailed Stonechat) rarely sang and were visually counted when perched on top of vegetation. Chestnut Munia had the highest density (4.41 birds/ha) with the next highest 3.47 birds/ha for Graceful Prinia (Table 2). Two Obligate tall grass breeders, Golden-headed Cisticola (n = 5) and Red Avadavat (n = 28), had less than 30 detections. Golden-headed Cisticola (a rare species in Bangladesh) was noted only on 21 and 22 June 2018 at Char Sakahati, Kurigram in small patches of *Saccharum* sp. (about 3 m tall) surrounded by agricultural fields. None were observed in the same location in 2019 as it had by then been converted to jute cultivation. However, a few calls were recorded from other points far from the previous location at Char Sakahati, Kurigram on 27 and 28 May 2019. Red Avadavat appeared scarce but may have been under-recorded because of its secretive behavior and because it does not engage in obvious song or display. The effective detection radius (EDR) of the seven obligate tall grass breeders with sufficient detections was ≤ 55 m. The estimated population sizes of these birds for the study area are presented in Table 2.

3.2. Bird associations with vegetation characteristics

3.2.1. Vegetation types

Linear regression models for the Shannon diversity of total bird community ranked the combination of vegetation type and vegetation height as the top model. However, examining the coefficients value only vegetation types had influence on the diversity of total bird community (Table S3). The other candidate models received little support judging by their AICc values (Table 3). For the

Table 2
Densities of seven (out of 9) obligate tall grass breeding birds (individuals/ha) in the sample floodplain grassland. Two obligate tall grass breeders, Golden-headed Cisticola (n = 5) and Red Avadavat (n = 28), had less than 30 detections. A total of 197 sample points were surveyed (total effort of 377 point counts), which covered 618.9 ha in total on the two islands. Values reported are: number of birds, number of points detected, estimated density (birds/ha), selected detection Model, 95 % confidence intervals (95 % CI), percentage coefficient of variation (%CV), effective detection radius (EDR) and detection probability (P).

Species	No. of birds	No. of point detected	Density (birds/ha)	Selected detection model	95 % CI	%CV	EDR (m)	P
Black-breasted Weaver	277	114	1.42	Uniform	1.02–1.97	16.85	37.58	0.14
Bristled Grassbird	177	165	0.52	Half-normal	0.36–0.76	19.32	55.07	0.31
Chestnut Munia	587	157	4.41	Hazard	2.93–6.63	21.03	31.60	0.10
Graceful Prinia	380	320	3.28	Hazard	2.41–4.46	15.75	31.19	0.10
Plain Prinia	39	28	0.91	Neg Exp	0.47–1.75	33.84	19.46	0.05
Tricoloured Munia	56	24	0.78	Half-normal	0.41–1.45	32.63	27.34	0.08
White-tailed Stonechat	45	41	0.19	Half-normal	0.09–0.38	36.72	47.04	0.23

Table 3
Model selection table for predicting Shannon diversity index for the total bird community and for grassland specialist birds, and abundance for grassland obligate breeding birds in floodplain grasslands of the lower Ganges and Brahmaputra Rivers, data recorded in 2018 & 2019. Predictor variables included vegetation type, vegetation height and their combination. Four main categories of vegetation types: *Saccharum* sp., *Cynodon* sp., various forbs and bushes, and cultivated crops were used to represent vegetation types. Models are in order of best fit to worst fit. Values reported include number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AICc), difference in AICc from the best fitting model (DAICc), model weight (wAICc), and the log-likelihood (LL).

Total bird community (Shannon diversity index, H)					
Models	**K**	**LL**	**AICc**	**DAICc**	**wAICc**
~Vegetation type + Vegetation height	6	-170.70	353.63	0.00	0.52
~Vegetation type	5	-172.27	354.71	1.09	0.30
~Null	2	-176.14	356.31	2.68	0.13
~Vegetation height	3	-176.13	358.33	4.71	0.05
Grassland specialist birds (Shannon diversity index, H)					
Models	**K**	**LL**	**AICc**	**DAICc**	**wAICc**
~Vegetation type + Vegetation height	6	-238.50	489.25	0.00	0.91
~Vegetation type	5	-241.81	493.79	4.54	0.09
~Vegetation height	3	-253.33	512.73	23.48	0.00
~Null	2	-254.62	513.27	24.02	0.00
Grassland obligate breeding birds (Abundance)					
Models	**K**	**LL**	**AICc**	**DAICc**	**wAICc**
~Vegetation type + Vegetation height	6	-531.63	1075.56	0.00	1.00
~Vegetation height	3	-540.79	1087.67	12.11	0.00
~Vegetation type	5	-543.97	1098.16	22.60	0.00
~Null	2	-560.89	1125.82	50.26	0.00

grassland specialists, the model including both vegetation type and vegetation height had the most support and most of the weight (wAICc > 0.90). The Shannon diversity of the total bird community significantly increased with increases in forbs and bushes cover, while overall diversity of both classes of grassland specialists significantly increased with *Saccharum* sp. cover. Likewise, the abundance of obligate tall grass breeders significantly increased with *Saccharum* sp. cover but decreased with *Cynodon* sp. cover, while the abundance of other grassland specialists did not change with increased *Saccharum* sp. cover but significantly increased with increases in forbs and bushes cover and *Cynodon* sp. cover (Fig. 3). Diversity of the total bird community did not change with increased crop cover, but diversity of grassland specialists significantly decreased with increased crop cover. Likewise, the abundance of both obligate tall grass species and other grassland specialists significantly decreased with increased crop cover (Fig. 3).

3.2.2. *Vegetation height*

Neither Shannon diversity of the total bird community nor that for grassland specialists varied significantly with vegetation height. However, the abundance of obligate tall grass breeders increased significantly with increasing vegetation height while the abundance of other grassland specialists decreased significantly with increasing vegetation height (Fig. 3). Based on the linear models, the effect of vegetation height appeared to be relatively weak compared to vegetation type in models of the total bird community and grassland specialist birds, although height was found to have clear model support for obligate grassland breeders (Table 3).

3.3. *Bird associations with human influences*

3.3.1. *Cattle grazing*

The diversity of neither the total bird community nor the grassland specialists showed any association with grazing intensity (grazing data collected in 2019 only). However, abundance of obligate tall grass breeders significantly decreased with grazing intensity while the abundance of other grassland specialists increased significantly with grazing intensity (Fig. 4). Based on the linear models, the effects of grazing (as indexed by cattle dung) appeared to have a relatively weak effect compared to other measured parameters (Table 4).

3.3.2. *Harvesting*

The diversity of both the total bird community and the diversity of grassland specialists was significantly increased with harvesting intensity (harvesting data collected in 2019 only), but when both classes of grassland specialists, obligate tall grass breeders and other grassland specialists, were analyzed separately neither showed any association with harvesting intensity (Fig. 4). However, based on the total bird community, the effect of harvesting was ranked as having the greatest model support (Table 3). Models for grassland specialist birds ranked the combination of effects of vegetation type and harvesting at the top (Table 4).

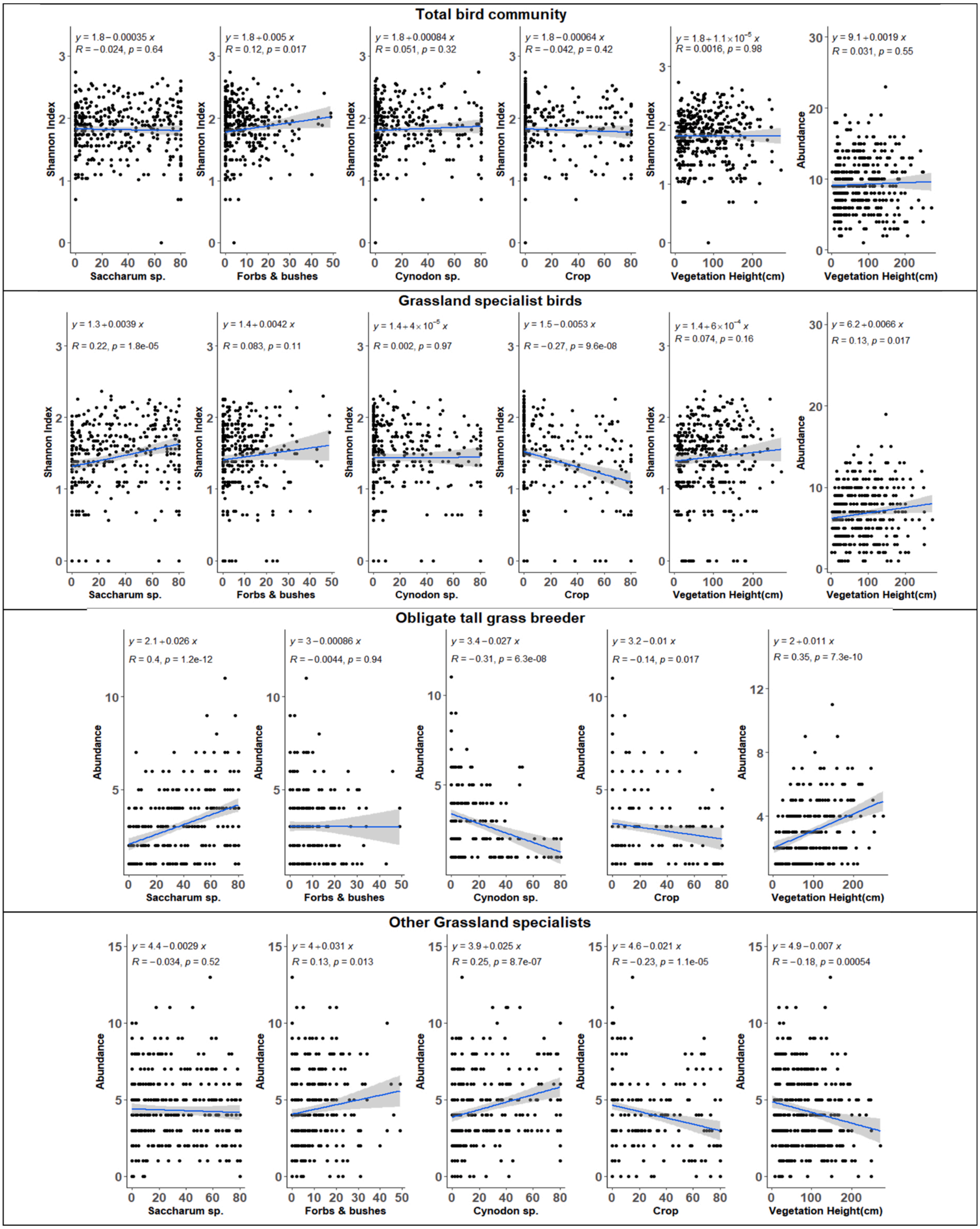

Fig. 3. Relationship between diversity (Shannon index) and abundance (number of birds counted) of different bird communities with different amounts of different vegetation types (based on 80 vegetation samples per vegetation plot) and vegetation height (cm) at floodplain grassland at lower Ganges and Brahmaputra River, Bangladesh, based on data recorded in 2018 and 2019. The total bird community included 31 grassland specialists, 34 generalists and 10 waterbirds. Grassland specialists included 9 obligate tall grass breeders and 22 other grassland specialists.

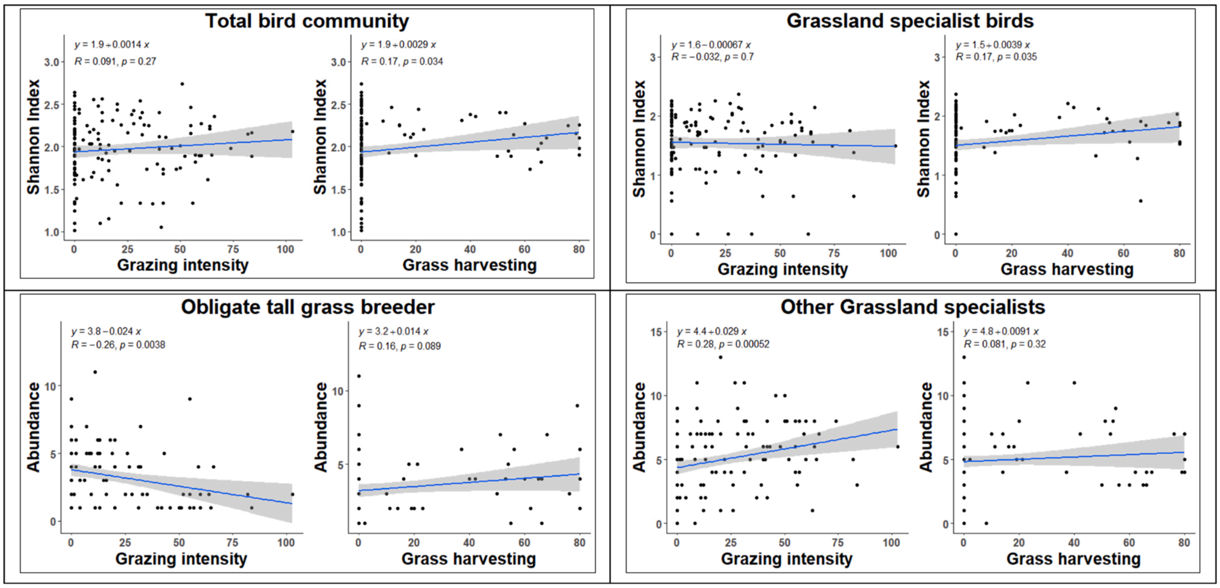

Fig. 4. Relationship between diversity (Shannon index) and abundance (number of birds counted) of different bird communities with grazing intensity (Cattle droppings/point) and grass harvesting effect (Grass cut sign/point) at floodplain grassland at lower Ganges and Brahmaputra River, Bangladesh, based on data recorded in 2019. The total bird community included 31 grassland specialists, 34 generalists and 10 waterbirds. Grassland specialists included 9 obligate tall grass breeders and 22 other grassland specialists.

4. Discussion

4.1. Overall bird community

The overall bird community could be broadly described as using four major vegetation types (forbs and bushes, *Saccharum* sp., *Cynodon* sp. and cropland). The diversity of the overall community was not clearly associated with changes in either *Saccharum sp.*, *Cynodon* sp. or cropland cover, but increased with increases in forb and bush cover. Areas with bushes and crop cover mostly favored generalist bird species: similar results were found in drier grassland of northeast Bangladesh (Akash et al., 2018). Areas covered by short grasses (*Cynodon* sp.) had the lowest bird diversity as also found by Akash et al. (2018). Overall, the diversity of the total bird community showed no variation with vegetation height (combining all vegetation types together). However, the abundance of grassland specialists, controlling for habitat type, showed a strong increase with increases in vegetation height. These results indicate that the retention of vegetation with height > 150 cm was the major factor influencing their abundance, which will require the conservation of patches of taller vegetation in these regularly flooded areas. Lastly, those species entirely dependent on tall grassland for breeding, were also more abundant in taller grasses, mostly preferring *Saccharum sp.* cover. Their abundance decreased with increasing cropland cover, *Cynodon sp.* cover, and cattle grazing intensity, suggesting that obligate grassland breeders can be recommended as indicator species for floodplain grassland.

4.2. Obligate tall grass breeders

We provide the first baseline data on the densities of seven obligate grassland breeding bird species in the floodplain grasslands of the lower Ganges and Brahmaputra Rivers of Bangladesh. This study estimated the density of Bristled Grassbird at 0.52 birds/ha. Displaying males were quite widespread in the two study sites and a nest was found at Char Majardia, Rajshahi. This globally vulnerable (BirdLife International, 2021) species was found at remarkably similar densities at a site in Nepal, 0.54 birds/ha (54 ± 15, km^{-2} ± 95 % CI) (Singh and Buckingham, 2016). Black-breasted Weaver density was estimated at 1.42/ha, consistent with a patchily distributed colonial species that has a relatively low detection probability during the breeding season. The largest flock of Black-breasted Weavers (about 500 birds) was noted in April moving around small patches of tall grasses (*Saccharum* sp.) surrounded by paddy fields at Char Majardia, Rajshahi. In the non-breeding season large flocks > 2000 individuals have been reported elsewhere (IUCN Bangladesh, 2015a). White-tailed Stonechat was recorded breeding at Char Majardia, Rajshahi at a low density of 0.19 birds/ha. None were recorded from similar habitat along the Brahmaputra River during the present surveys although one individual was seen at Char Sakahati during a pilot survey in early May 2018. Although this species is found in the upper Brahmaputra River in India (Rahmani et al., 2016) and is expected to be common locally in riverine grassland (Rasmussen and Anderton, 2005), more intense human use may be a reason for its seeming absence in the lower Brahmaputra of Bangladesh. Further study of this scarce species is needed to better understand its distribution. Density differences between Plain Prinia (0.91/ha) and Graceful Prinia (3.28/ha) reflect their different habitat preferences. In Bangladesh Graceful Prinia is largely restricted to riverine grasslands whereas Plain Prinia occurs

Table 4

Model selection table for Shannon diversity index for total bird community and for grassland specialist birds, and abundance for grassland obligate breeding birds in floodplain grasslands of the lower Ganges and Brahmaputra River, data recorded in 2019. Predictor variables included the effects of vegetation type, vegetation height, cattle grazing, harvesting and their combination effect. Models are in order of best fit to worst fit. Values reported include number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AICc), difference in AICc from the best fitting model (DAICc), model weight (wAICc), and the log-likelihood (LL).

Total bird community (Shannon diversity index, H)					
Models	**K**	**LL**	**AICc**	**DAICc**	**wAICc**
~Harvesting	3	-50.75	107.67	0.00	0.26
~Grazing + Harvesting	4	-49.92	108.12	0.45	0.21
~Vegetation type + Harvesting	6	-47.82	108.22	0.55	0.20
~Vegetation height + Harvesting	4	-50.47	109.22	1.55	0.12
~Vegetation type + Vegetation height + Grazing + Harvesting	8	-46.42	109.88	2.21	0.09
~Vegetation type + Vegetation height + Harvesting	7	-47.75	110.30	2.63	0.07
~ Vegetation type + Grazing	6	-50.82	114.24	6.56	0.01
~Vegetation height + Grazing	4	-53.19	114.66	6.99	0.01
~Null	2	-55.65	115.39	7.72	0.01
~Grazing	3	-54.64	115.45	7.78	0.01
~Vegetation type	5	-52.59	115.60	7.93	0.01
~Vegetation height	3	-55.05	116.27	8.60	0.00
~Vegetation type + Vegetation height + Grazing	7	-50.81	116.42	8.75	0.00
~Vegetation type + Vegetation height	6	-52.59	117.77	10.10	0.00
Grassland specialist birds (Shannon diversity index, H)					
Models	**K**	**LL**	**AICc**	**DAICc**	**wAICc**
~Vegetation type + Harvesting	7	-123.67	261.98	0.00	0.34
~Vegetation type + Vegetation height + Harvesting	7	-123.67	261.98	0.00	0.34
~Vegetation type	6	-126.21	264.88	2.91	0.08
~Vegetation type + Vegetation height + Grazing + Harvesting	9	-123.14	265.30	3.32	0.06
~ Vegetation type + Grazing	7	-125.59	265.80	3.83	0.05
~Vegetation height + Harvesting	5	-128.02	266.37	4.39	0.04
~Vegetation type + Vegetation height	7	-126.05	266.73	4.75	0.03
~Vegetation type + Vegetation height + Grazing	8	-125.33	267.48	5.51	0.02
~Harvesting	4	-129.68	267.58	5.61	0.02
~Grazing + Harvesting	5	-129.63	269.59	7.62	0.01
~Vegetation height + Grazing	5	-129.68	269.69	7.72	0.01
~Grazing	4	-132.52	273.25	11.28	0.00
~Vegetation height	3	-146.51	299.15	37.18	0.00
~Null	2	-148.33	300.73	38.76	0.00
Grassland obligate breeding birds (Abundance)					
Models	**K**	**LL**	**AICc**	**DAICc**	**wAICc**
~Vegetation height	3	-226.51	459.23	0.00	0.44
~Vegetation height + Harvesting	4	-226.22	460.80	1.57	0.20
~Vegetation height + Grazing	4	-226.28	460.93	1.70	0.19
~Vegetation type + Vegetation height	6	-225.01	462.80	3.56	0.07
~Vegetation type + Vegetation height + Grazing	7	-224.36	463.75	4.52	0.05
~Vegetation type + Vegetation height + Harvesting	7	-224.87	464.78	5.55	0.03
~Vegetation type + Vegetation height + Grazing + Harvesting	8	-224.29	465.92	6.69	0.02
~Vegetation type	5	-231.83	474.20	14.97	0.00
~ Vegetation type + Grazing	6	-231.61	476.00	16.77	0.00
~Vegetation type + Harvesting	6	-231.67	476.11	16.88	0.00
~Grazing	3	-242.51	491.24	32.01	0.00
~Null	2	-243.83	491.77	32.54	0.00
~Grazing + Harvesting	4	-241.86	492.09	32.86	0.00
~Harvesting	3	-243.37	492.94	33.71	0.00

across a wider range of habitats and is common in vegetation at the fringes of cultivation (IUCN Bangladesh, 2015a; Rasmussen and Anderton, 2005). The high densities of both Chestnut Munia (4.41/ha) and Graceful Prinia (3.28/ha) indicate their abundance on the study islands and the suitability of habitat quality for them (Johnson, 2007). However, the observed agricultural intensification was likely a prominent threat to most of the obligate grassland breeders, some of which might completely disappear given a continued trajectory of increased agricultural use (Vickery et al., 1999).

4.3. Bird associations with vegetation characteristics

The results supported predictions regarding the effect of different vegetation types and structures on bird communities.

Though the different bird communities have different vegetation type preferences, the area covered with forbs and bushes cover overlapped areas with both *Saccharum sp.* cover and cropland cover. Forbs and bush cover was the most structurally diverse vegetation category: birds appeared to make use of the greater diversity of foraging heights and substrates found in this vegetation type (Wolf et al., 2012). However, *Saccharum sp.* cover – a more structurally distinctive vegetation category—appeared to have a stronger influence on the diversity of grassland specialist birds and abundance of obligate grassland breeders.

The study confirmed that diversity of grassland specialist birds, and the abundance of obligate tall grass breeding birds, had a significant negative relationship with increasing area of cropland, although the greater area of cropland had no impact on the overall diversity of the total bird community. A comparison of 2019 (29 points covering 91.1 ha) with 2018 (12 points covering 37.7 ha) indicated that cultivation had increased from about 6 % of the surveyed area to about 16 % in 12 months. Noticeably, jute cultivation was observed to have spread at Char Sakahati, Kurigram in 2019 compared with 2018, and may have negatively impacted birds. For example, no Golden-headed Cisticolas were detected in 2019 in areas converted to jute where they were present in 2018. Agricultural expansion reduces the breeding success of birds in grasslands (Wilson et al., 2017; Møller, 2019) including those in the Indo-Gangetic Plain (Gopi Sundar, 2011). The remaining areas of taller grassland at both the study sites are likely to be entirely replaced by agriculture in the near future unless they are strictly managed. Nonetheless cropland is used by part of the bird community: for example, fallow crop fields colonized by *Cynodon sp.* were observed being used as feeding areas, and about 29 % (22 species) of the total bird community fed on crop residues in fallow paddy fields. Loss of some grassland to crop cultivation is probably inevitable, but the impacts could be mitigated by encouraging use of organic fertilizer which maintains grassland soil quality, and is less damaging/more useful for specialist birds (Inskipp and Baral, 2011). Discouraging the use of herbicides, and zoning or restricting new human settlements would also be helpful. In addition, encouraging local farmers to keep a strip of grasses along the margins of arable fields would provide shelter and foraging for grassland species and provide habitat for predators of crop pests (Vickery et al., 2002). Implementing such changes would require extensive education outreach programs to local farmers.

4.4. *Impacts of livestock grazing and grass harvesting*

Hypotheses regarding the impact of grazing on the bird community were not supported because regular seasonal herding of cattle in these floodplain grasslands was widespread and so recently grazed and ungrazed areas appeared to show little difference. However, results supported predictions regarding the impact of harvesting on total bird community.

Cattle grazing appeared to have no significant impact on the diversity of total bird community, nor on the diversity of grassland specialists as a whole. This contradicts previous research which suggested that grazing significantly influenced the structure of bird communities, particularly common species and specialists that prefer tall grasslands (Baral, 2001). However, although grazing may negatively impact obligate tall grass breeders, grassland specialists include many species, such as larks and pipits, that favour the short-grass or mosaic habitats created by grazers. This suggests that limited grazing is not incompatible with the conservation of grassland specialist birds. Grasslands rely on grazers for their structural maintenance (Bischoff, 2002; Fuhlendorf and Engle, 2001). Most of our study area was grazed at some time over the course of each year, and the variety of domesticated grazers (cows, goats, sheep, and water buffaloes) may even contribute to vegetation heterogeneity (Wang et al., 2018), to some extent perhaps mimicking that formerly associated with the native wild grazer community (IUCN Bangladesh, 2015b). Domestic grazers can actually play an important role in habitat maintenance to the point that some protected areas have introduced such species to restructure their grasslands (Boyce et al., 2021; Milchunas et al., 1998). More detailed research that quantifies livestock presence and timing is needed to better examine and quantify the impacts of grazing intensity on floodplain grassland bird communities in the Indo Gangetic plain.

Grass harvesting was an important factor influencing diversity of the bird community in this study. Indeed, such harvesting can be useful for grassland management (Hossain and Li, 2020) as grazing alone may not be enough to create sufficient vegetation heterogeneity (Sliwinski et al., 2020). Other studies have suggested that retaining a mixture of harvested and unharvested grassland habitat make it more suitable for birds (Leston and Koper, 2017). Grassland bird species that preferred vegetation of short to moderate height and low to moderate density were found in harvested areas, while unharvested areas provided habitat for tall grass breeders consistent with Roth et al. (2005). However, early harvest and continuous harvesting can prematurely terminate breeding activity of resident birds that build and hide their nests in dense grasses (Brown and Nocera, 2017). Therefore, annual harvesting is not necessarily recommended (Roth et al., 2005): rather rotational harvesting in alternate years would benefit birds and humans simultaneously. However, *Saccharum* sp. has important economic value (Chandran, 2015, 2000) and it is probably unrealistic to apply this strategy in our study islands where most of the people are poor and need grass continuously to feed their cattle, a major part of their income. In these circumstances, grass harvesting restrictions need to be targeted and agreed with local people: for example, proposing to recognize people's rights to harvest grass provided they do not harvest during the bird breeding season from March to mid-June. Similar actions have been proposed in India (Chandran, 2015). This may be acceptable as already some grassland patches in Char Sakahati, Kurigram are reserved by people who claim ownership of selected areas where they allow grasses to grow taller (>200 cm), which they harvest for sale later in the season for use in thatching and construction. Widespread adoption of similar arrangements might safeguard habitat for obligate grassland bird species. during their breeding season.

5. Conclusion

This study highlights impacts of natural structural and human disturbance factors on birds that are mostly dependent on floodplain grassland. Our study indicates that the argument for management for a range of disturbance frequencies and intensities across the landscape supporting greater vegetation heterogeneity, which in turn will help conserve biodiversity and ecosystem function (Porensky et al., 2020) would disproportionately favor generalist birds; it would support a higher avian diversity but at the cost of some obligate grassland birds which are of greater conservation concern. Outside of areas conserved for tall grass-dependent birds, grazing would continue benefiting the other grassland specialists predominantly associated with short grass. As it is difficult to restore grassland once it is converted to cropland (Bischoff, 2002) and as our study shows that riverine islands in Bangladesh still have grassland habitat important for many Indo-Gangetic grassland birds, government intervention is recommended. Its primary aim should be to conserve existing obligate grassland bird populations and their habitat. In order to support management actions, track their impacts, and better understand the impacts of grazing and grass harvest, regular monitoring and further study of bird-habitat interactions is also recommended.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2022.e02201.

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