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RESEARCH ARTICLE

Red-naped Ibis *Pseudibis papillosa* density across time and space in south Asian farmlands: the influence of location, season, and rainfall

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Abstract South Asian landscapes are dominated by farmlands, crowded with high human density, experience seasonal changes in crops and retain relatively few wetlands. Nuanced understanding of resident waterbirds' responses to these conditions is increasing in individual locations, but there is sparse understanding of how species respond to conditions across the region. We surveyed five agriculture-dominated landscapes spanning nine districts across South Asia simultaneously over 2014 - 2021 to understand the habits of a poorly studied endemic Red-naped Ibis *Pseudibis papillosa*. We assessed if seasonal variations in density were consistent across locations, and if seasonal densities correlated with rainfall. Red-naped Ibis density varied greatly with location and season, with winter densities being the highest in all locations. Average density of ibis, using seasonal densities across all focal areas, was 0.7 (95% C.I. = 0.57; 0.83) which extrapolates to an estimated 20,81,868 (17,45,340; 25,41,460) Red-naped Ibis across their distribution range. Combined across the full study area, density increased as rainfall declined only during the winter ($p = 0.005$). The same relationship was seen in each district separately as well, with the relationship being statistically significant in only three districts (Kheda, Rohtak and Rupandehi; $p < 0.01$). We provide the first population estimates for Red-naped Ibis, show substantial seasonal fluctuations in density, and complex relationship with rainfall. These findings suggests that tracking population trends for this species will be challenging. Our work provides novel understanding of Red-naped Ibis biology while underscoring the utility of South Asian agricultural landscapes for yet another resident waterbird species.

Keywords Agricultural biodiversity, population estimate, rainfall, South Asia, waterbirds.

Introduction

A global understanding of the relationship between agriculture and waterbird diversity and abundance is currently incomplete and biased by many more studies in North America and Europe (Parejo and Sánchez-Guzmán 1999; Fasola *et al.* 2010; Essian *et al.* 2022). Studies of the value of agricultural areas for birds in other parts of the world are increasing, especially studies that focus on waterbirds living in Asian farmlands (Kim and Koo 2009; Roshnath and Sinu 2017; Frank *et al.* 2021). These studies are finding that many Asian farmlands sustain not only a high species richness of birds but also support substantial and healthy populations of waterbirds despite relatively high human densities and long histories of multiple cropping over the year (Sundar and Kittur 2012; Katuwal *et al.* 2022a,b; Menon and Mohanraj 2022). Contrary to what was previously assumed,

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several waterbird species use south Asian farmlands as primary foraging and breeding habitats and are supported by agriculture rather than suffer deleterious consequences due to farming (Sundar 2004, 2006, 2011; Sundar *et al*. 2016; Koju *et al*. 2019; Katuwal *et al*. 2020; Ghimire *et al*. 2021; Kittur and Sundar 2021). Many of these studies, however, are restricted to single locations making it difficult to understand if waterbirds can thrive on agricultural landscapes across their distribution range. A small but growing number of studies have begun to explore the influence of location on waterbird survival alongside farming, showcasing substantial complexities with species abundance and habitat use varying with location, despite having similar cropping patterns (Sundar and Kittur 2019; Katuwal *et al*. 2020; Kittur and Sundar 2020). These studies are underscoring the need for multi-location studies conducted simultaneously in order to fully comprehend the factors that benefit or deter species survival on agricultural landscapes. Many resident waterbird species outside north America and Europe remain poorly studied making it additionally difficult to know how individual species fare on agricultural landscapes (Gula *et al*. 2022; Marcot *et al*. 2022; Sundar 2022).

One waterbird species that has been very poorly researched is the Red-naped Ibis *Pseudibis papillosa* which is endemic to South Asia (Ali and Ripley 2007; Hancock *et al*. 1992). Species accounts of this ibis species are dominated by anecdotal observations with carefully conducted studies being rare (Soni *et al*. 2009). Based on volunteer winter counts at wetlands, the population of this species is estimated at 10,000 individuals (in Wetlands International 2023, which refers to a much older reference but provides no new revision). However, the majority of existing information shows this species to largely frequent farmlands, urban areas and other drier landscapes away from wetlands suggesting that population estimates based on counts at wetlands are likely severe underestimates (Ali and Ripley 2007; Hancock *et al*. 1992). Most of the existing studies on Red-naped Ibis have been carried out over multiple seasons offering insights into year-long habits of the species. Red-naped Ibis abundance varied greatly across seasons in each location notwithstanding the disparate settings in which studies have been carried out. Locations included an urban area (Churu city of Rajasthan state in India; Soni *et al*. 2009), a landscape influenced by floodplains dominated by farmlands (lowland Nepal; Katuwal and Quan 2022), and two semi-arid and relatively rocky landscapes where agriculture was limited (Udaipur and Dungarpur districts of Rajasthan state in India; Ameta *et al*. 2022; Asawra *et al*. 2022). Outside of urban areas, more Red-naped Ibis frequented areas dominated by wetlands relative to areas with agriculture, but largely used agriculture fields in all areas (Ameta *et al*. 2022). In another semi-arid landscape, Red-naped Ibis abundance was positively correlated with extent of wetlands on the landscape (Asawra *et al*. 2022). These studies suggest that wetland presence at larger spatial scales positively influenced Red-naped Ibis abundance in semi-arid areas, that they use wetlands as foraging habitats relatively rarely, and that they use a variety of habitats including human-dominated cities and farmlands.

Studies describing Red-naped Ibis habits outside of the semi-arid and arid areas of Rajasthan are rare. Ibis responses to seasons on wetter landscapes with seasonally varying crops are known from one study, and abundance on farmlands was the most during the monsoon or rainy season and the least during the summer (Katuwal and Quan 2022). Ibis responses to seasonal rainfall in such wetter areas is unknown. Does Red-naped Ibis density remain similar across seasons in other relatively wet landscapes since availability of wetlands is less varied relative to drier landscapes? Also, on wetter landscapes, do Red-naped Ibis respond positively to rainfall, analogous to increased wetland extent on landscapes? Finally, do these interactions with season and rainfall remain identical across multiple landscapes that have similar cropping patterns? We addressed these questions using a systematic multi-year monitoring framework spread across nine districts in lowland Nepal and north-central India between 2014 and 2021. We also developed population estimates for the species for each surveyed districts and extrapolated estimated densities to the distribution range of the species to obtain a crude, but conservative population estimate for the species.

Study area

We surveyed four landscapes in India (the contiguous Rohtak and Jhajjar districts in Haryana state, the contiguous Anand and Kheda districts in Gujarat state, Etawah district and a part of the contiguous Unnao and Rae Bareli districts in Uttar Pradesh state) and one in Nepal (covering parts of the contiguous Rupandehi and Kapilabastu districts) for Red-naped Ibis (Figure 1). Agriculture was the major land use of all focal districts with seasonally changing crops. The primary crop during the rainy or monsoon season (July to October) was rice *Oryza sativa*, followed by winter (November to February) wheat *Tritium aestivum* along with mustard *Brassica juncea* (though other crops were also planted with patterns differing by district), and most fields left fallow during the hot summer (March to June). The surveyed districts also had relatively high human densities varying from 520 to 680 people/ km^2 (Kittur and Sundar 2020). Additional details relating to district sizes, major crops planted, human population density and weather are provided in Kittur and Sundar (2020).

Methods

Field surveys

Each landscape was surveyed extensively per season between winter 2014 - 2015 and winter 2021 - 2022. One person drove slowly on a motorcycle on existing road networks in each district enumerating all encountered ibises and noting the location using a handheld GPS device (see Figure 1). Number of Red-naped Ibis in each observation was noted and survey effort (km surveyed) was recorded each season as GPS tracks.

Rainfall

Total monthly precipitation data for each of the study districts from 2014 to 2021 was downloaded from NASA Prediction of Worldwide Energy Resources (POWER) website (NASA Langley Research Center, 2022). Seasonal and annual precipitation for the survey period in each district were obtained by summing the monthly precipitation.

Analysis

We estimated Red-naped Ibis density in each district (or landscape where parts of two districts were covered) seasonally. This metric was calculated each season in each district using a conservative effective count width of 150 m on either side of the road (density = ibis counted/ (track length x 0.3 km)) similar to that used for other large waterbird species in the same region (Kittur and Sundar 2020). The entire distribution range for the species was calculated to 30,62,000 km^2 by combining distribution information available on ebird.org and BirdLife International (2022). Range distribution for the species was different in these two sources, so we combined them obtaining a crude and conservative range. Carefully estimated distribution range for Red-naped Ibis based on robust field information is not currently available. We used the average of seasonal densities (and 95 % C.I.) obtained across all focal districts to derive a central population

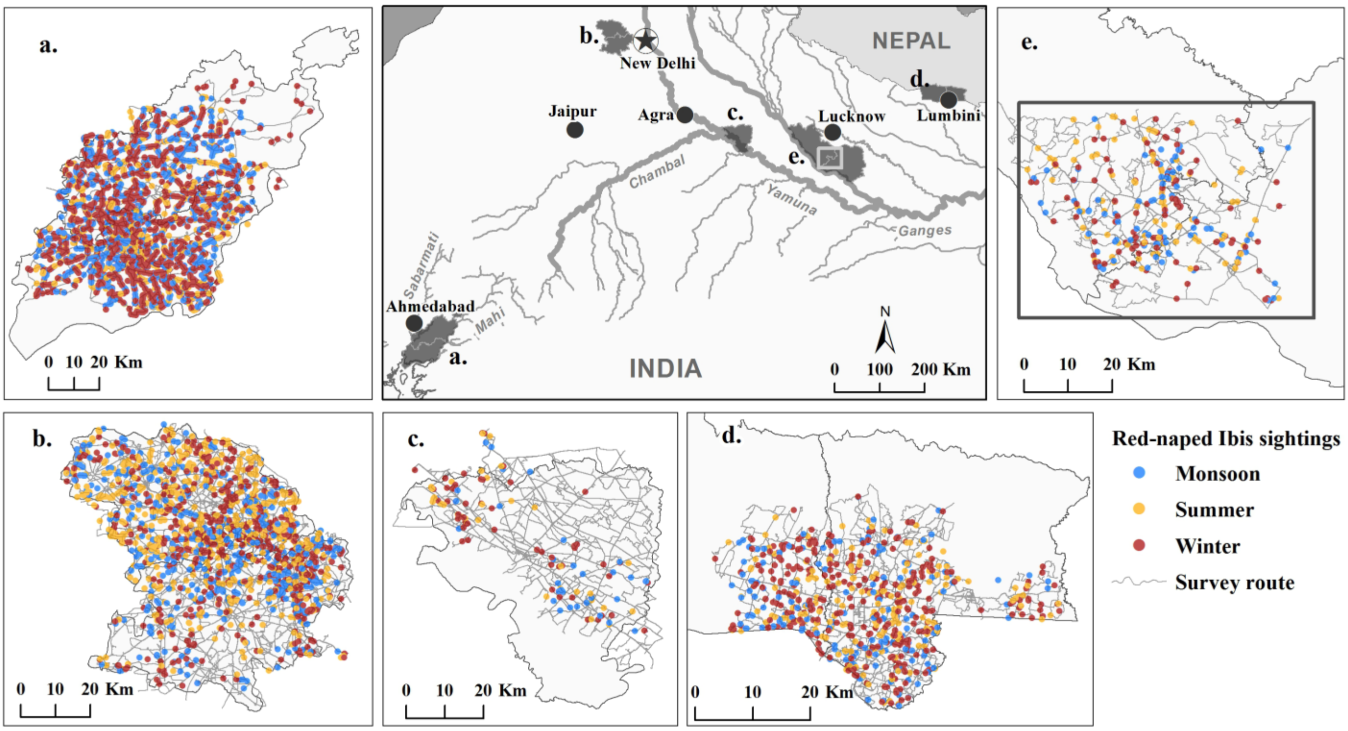

Figure 1. Map showing the districts (center) surveyed in south Asia for Red-naped Ibis from 2014 to 2022, survey routes and season-wise locations of ibises in each of the study locations: Anand and Kheda districts (a), Rohtak and Jhajjar districts (b), Etawah district (c), Rupandehi and Kapilabastu districts in Nepal (d) and Unnao and Rae Bareli districts (e).

estimate for the species across its distribution range. We could not correct for potential detection bias due to individuals conducting the counts or varying crop cover in different seasons. Additionally, surveys were not restricted to mornings and the potential role of time of day in counts due to varying behaviours was not controlled for. Computed population estimates are therefore greatly conservative. Information from these surveys have been analysed previously for other large waterbird species using the same methods (Kittur and Sundar 2020, 2021; Sundar and Kittur 2019). As discussed in previous papers, we are closely aware of and acknowledge the limitations of extrapolating abundance estimates beyond the focal work areas to the full distribution range of the Red-naped Ibis. The estimates of total abundance we present of the species are therefore to be considered coarse but are the first estimates based on multi-year robust field surveys across multiple locations and covering all potential available habitats.

We used seasonal density estimates to ask whether densities in each district varied by season. We used the non-parametric permutational ANOVA (PERMANOVA) to compare seasonal densities (at 95 % confidence levels) using the R-package ‘lmPerm’ (Wheeler and Torchiano 2016). We did not conduct similar statistical analyses across districts, instead used boxplots to make visual assessments. To understand if Red-naped Ibis densities were related to seasonal rainfall, we used simple linear regressions and stratified this analysis by season to understand whether relationships were consistent across seasons. Analyses were carried out for the full data set separately, and for each district separately. All analyses were carried out using the freely available R-platform.

As shown in other studies (Ameta *et al*. 2022; Asawra *et al*. 2022), it is possible that Red-naped Ibis abundance varied due to differing amounts of wetlands present. Many more wetlands were formed during the monsoon, with most of these retained during the winter, and several drying during the summer (personal observations). However, we were not able to obtain high resolution wetland maps for each district for each of the seasons. A separate analysis will be needed to assess if wetlands affected Red-naped Ibis abundance, whether these relationships changed with location, and what the relative influence is of wetlands over rainfall at each location

Results

We covered a total of 3,42,092 km of road across the 14,800 km^2 of area (total area of all the surveyed districts) between 2014 and 2022 and obtained 9,440 observations of 54,067 Red-naped Ibis (Figure 1). Except for Etawah district where Red-naped Ibis seemed spatially restricted, they were distributed widely across all the other districts in all three seasons (Figure 1). Ibises were observed using a wide variety of habitats especially fallow fields, periphery of wetlands and grassland patches (Figure 2).

Density across locations and seasons

Red-naped Ibis density was substantially higher in the western most districts, Anand and Kheda, throughout the study (Figure 3). Densities were lower but comparable in all the other locations (Figure 3; Table 1). Winter densities were consistently and significantly higher in all

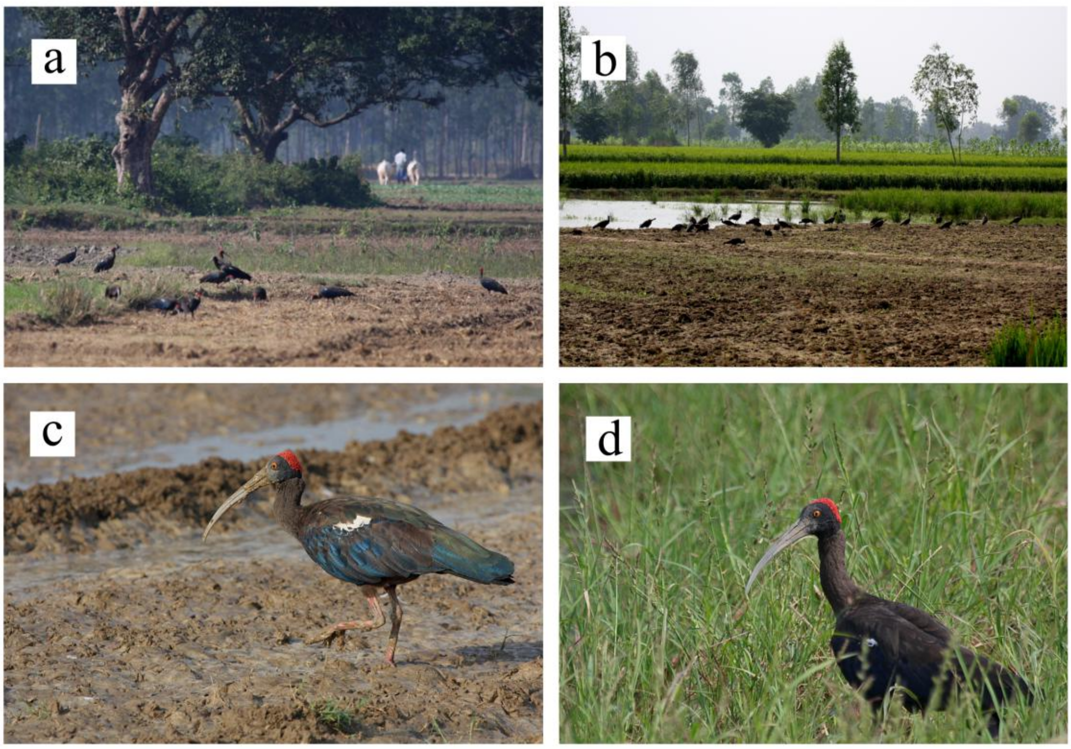

Figure 2. The general landscape and habitats used by Red-naped Ibis in the study area. Images show ibises using croplands interspersed with trees (a); fields and wetland edges (b), flooded fallow fields (c), and grassland patches amid cultivation (d). (All photographs by K. S. Gopi Sundar.).

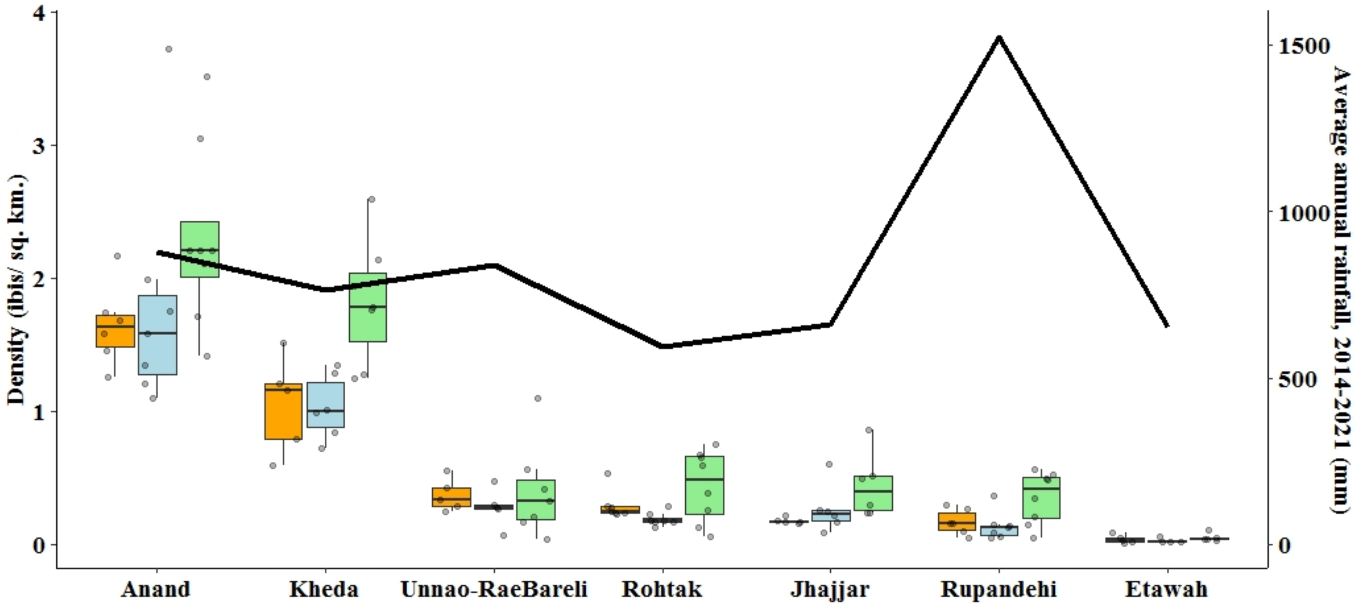

Figure 3. Box plots showing seasonal density of Red-naped Ibis (primary y-axis) and line indicating average annual precipitation (secondary y-axis) in the study districts from 2014 to 2022. The plots show median values (central horizontal line), inter-quartile range of estimates (25% and 75% respectively, lower and higher horizontal lines), and vertical lines that extend to minimum and maximum values. Jittered filled circles are estimated seasonal densities and are included to show spread of the data including outliers. Colours represent different seasons (yellow: summer; blue: monsoon; green: winter). Annual average rainfall recorded during the study period in each location is drawn to illustrate relative rainfall volumes in study sites. ("Rupandehi - Kapilvastu" has been shortened.)

locations ($p < 0.05$; Figure 3) and were similar in the other two seasons in each location (Table 1). Estimated population sizes varied greatly and inconsistently within and between seasons across locations and years (Table 1). Maximum seasonal population estimates were up to 13 times that of the minimum estimate in the same season at some locations underscoring the high degree of variation of ibis numbers even within a season (Table 1). The total population of Red-naped Ibis across the study area was estimated to be 9,053 ± 10,653 SD (range: 1,601 - 19,706). Average density of Red-naped Ibis, combining seasonal densities across all focal districts, was 0.7 (95 % C.I. = 0.57; 0.83). Extrapolating these density estimates to the full distribution range of the Red-naped Ibis provides a population estimate of 20,81,868 (17,45,340; 25,41,460) for the species.

Density and rainfall

For the full data set, Red-naped Ibis density and rainfall showed a negative association during the summer (not statistically significant) and winter (strongly significant; Figure 4). Within each district, the relationship was also negative with statistically significant relationships ($p < 0.005$) in only Kheda ($r^2 = 0.26$), Rohtak ($r^2 = 0.2$) and Rupandehi ($r^2 = 0.24$) districts.

Discussion

We present the largest field data set on Red-naped Ibis collected over multiple years using robust and repeatable field methods across multiple sites in south Asia. The analyses showcase very wide variations in density between and within locations, and also between and within seasons. Monitoring population trends of Red-naped Ibis will be challenging given these observed fluctuations.

Population sizes

We present the first estimates of density and population of Red-naped Ibis in multiple locations across south Asia. We use estimated densities to develop a coarse but conservative population estimate across the species' distribution range. All surveyed locations showed highly variable densities both within and across seasons. Clearly, a multi-season and multi-year monitoring framework will be essential to understand population dynamics of this species in any location. Two previous studies in lowland Nepal and in the Gangetic floodplains of north India used 500 m - 1 km long transects, respectively, to count Red-naped Ibis and found that ibises were uncommon (a low proportion of transects had ibises, Sundar and Kittur 2012; Katuwal and Quan 2022). In this study where we covered entire

Table 1. Estimated population sizes of Red-naped Ibis in focal districts of south Asia.

District	Survey period	Estimated population size (Average ± SD; min-max)		
		Winter	Summer	Monsoon
Anand	2014-22	6,107 ± 1,807; 3,748-9,330	4,368 ± 817; 3,340-5,754	4,807 ± 2,384; 2,908-9,877
Etawah	2014-19	110 ± 63; 66-220	81 ± 65; 13-179	62 ± 42; 35-125
Jhajjar	2016-22	816 ± 445; 438-1,595	325 ± 44; 286-399	485 ± 329; 157-1,112
Kheda	2015-22	5,872 ± 1,534; 4,010-8,384	3,393 ± 1,170; 1,921-4,883	3,334 ± 781; 2,335-4,335
Rohtak	2014-22	729 ± 444; 102-1,257	484 ± 179; 373-881	311 ± 84; 212-470
Rupandehi - Kapilvastu	2014-22	329 ± 184; 45-527	159 ± 90; 46-280	128 ± 102; 42-345
Unnao - Rae Bareli	2014-21	973 ± 853; 94-2,665	886 ± 298; 587-1,332	673 ± 347; 168-1,145

landscapes, Red-naped Ibis densities in lowland Nepal were amongst the lowest of all the locations we covered but varied with location in the Gangetic floodplains (Etawah, Unnao - Rae Bareli; Table 1). We estimated Red-naped Ibis to number in the low hundreds each in lowland Nepal and Etawah and low thousands in Unnao – Rae Bareli (Table 1). The Red-naped Ibis is clearly widely spread out across agricultural landscapes and uses a diversity of habitats including an increasing use of cities and novel foods (Ameta *et al*. 2022; Asawra *et al*. 2022; Charan *et al*. 2022; Sinha 2022). Using relatively small transects to monitor the species appears to be inefficient likely reflecting relatively large territory sizes of breeding pairs, and possibly also local movements. Similar findings have emerged for several other south Asian large waterbirds including Sarus Cranes *Antigone antigone* (Sundar 2005), Black-necked Storks *Ephippiorhynchus asiaticus* (Sundar 2004, 2005), Lesser Adjutants *Leptoptilus javanicus* (Koju *et al*. 2019; Katuwal *et al*. 2022a), and Woolly-necked Storks *Ciconia episcopus* (Kittur and Sundar 2020).

Red-naped Ibis used a large variety of habitats on agricultural landscapes (see Figure 2), and largely used crop fields in semi-arid landscapes of Rajasthan despite being attracted to areas with more wetlands at landscape scales (Ameta *et al*. 2022; Asawra *et al*. 2022). The systematic monitoring in two semi-arid districts of Rajasthan in western India provided Red-naped Ibis densities that when extrapolated to Rajasthan state would number in the tens of thousands. Estimating populations of such a species using counts made only at wetlands cannot provide realistic estimates. The extrapolated population estimate we provide for the Red-naped Ibis underscore the severe underestimation in existing literature, identical to findings for other large waterbird species that largely use agricultural landscapes like the Woolly-necked Stork (Kittur and Sundar 2020). The scale of underestimation for Red-naped Ibis (previously estimated to be 10,000; Wetlands International 2023, and our estimate is 20,81,868) is far higher relative to the underestimate that was made for Woolly-necked Storks (previously estimated to be ~ 30,000, and our revised estimate was 2,38,685; Kittur and Sundar 2020). A major consideration of existing population estimates of large waterbirds in literature appears to be the assumption that agriculture is not conducive to the survival of waterbirds. There is now increasing evidence to the contrary from a number of disparate landscapes and species (Parejo and Sánchez-Guzmán 1999; Fasola *et al*. 2010; Sundar 2006, 2011; Sundar and Kittur 2012; Roshnath and Sinu 2017; Koju *et al*. 2019; Koli *et al*. 2019; Kittur and Sundar 2021; Frank *et al*. 2021; Katuwal *et al*. 2022a,b). Multi-year evaluations on Asian farmlands in some areas are also showing numbers of breeding birds to be increasing or remaining largely unchanged, contrasting sharply with declining trends of birds observed on North American and European farmlands (Lin *et al*. 2023). Moving ahead, ornithological literature requires to avoid providing “guesstimates” of population sizes and avoid incorrect ecological assumptions related to trends of bird populations on farmlands. Avoiding such assumptions will assist in improving evidence-based evaluations and can help highlight species that require scientific attention.

Red-naped Ibis densities in the western most districts, Anand and Kheda, were much higher than the other locations where ibis densities were comparable (Table 1; Figure 3). Anand and Kheda also had very high numbers of a sympatric ibis species, the Glossy Ibis *Plegadis falcinellus* (Sundar and Kittur 2019). However, these two districts had amongst the lowest estimated densities of the Woolly-necked Stork relative to the other surveyed districts (Kittur and Sundar 2020). It appears that different factors influence densities of different large waterbird species in each

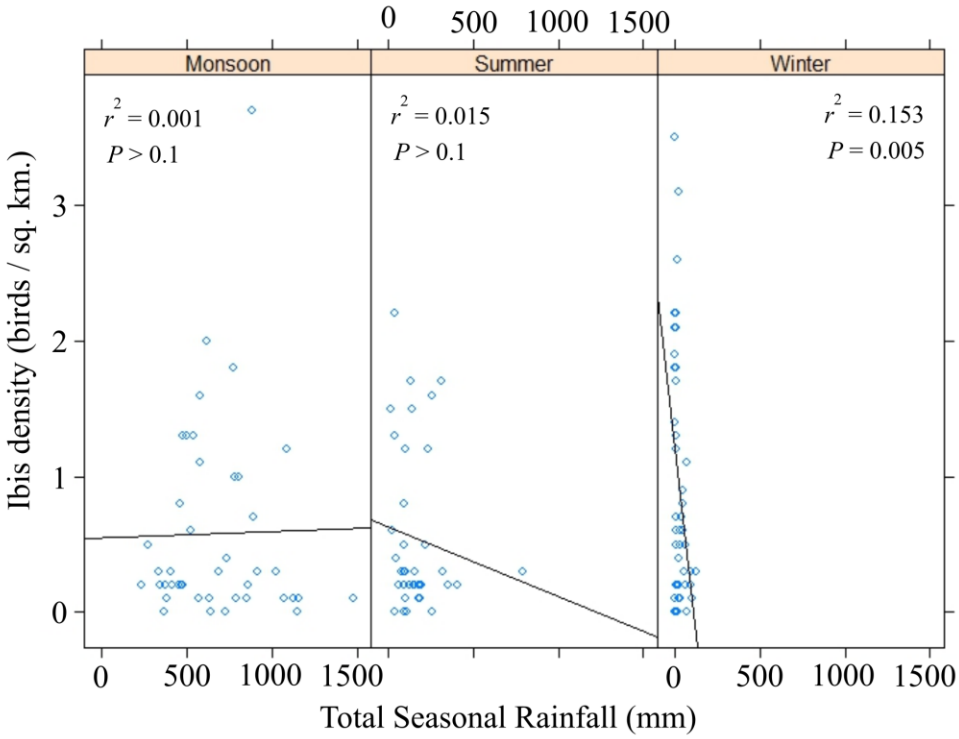

Figure 4. Lattice plots showing relationships between density of Red-naped Ibis and rainfall in three seasons for nine districts of lowland Nepal and north-central India between 2014 and 2022. Dots are seasonal density estimates in districts and simple linear regressions were used to draw lines.

location. Species-specific studies are needed across multiple locations to help locate factors influencing local abundances of waterbird species.

Density and rainfall

The relationship between Red-naped Ibis density and rainfall has not been previously assessed. We show that summer and monsoonal rainfall had no significant influence on seasonal densities in any location, but increased rainfall during the winter was associated with lower densities suggesting local movements in at least three districts (Table 1; Figure 4). Other sympatric large waterbirds also show identical patterns suggesting that seasonal conditions on south Asian farmlands influence habits of several resident species similarly (Sundar 2004, 2006; Sundar and Kittur 2019; Kittur and Sundar 2020; Katuwal *et al*. 2022a). One potential explanation for higher winter densities in all locations is that breeding takes place during the preceding monsoon, and family groups potentially increase local densities during the winter. Red-naped Ibis movements and breeding habits, however, have not been systematically studied anywhere in south Asia. Such studies on resident waterbird species promise to be of great value to understand how waterbirds use farmlands in this region.

Methodological caveats of this study

As briefly described in the Methods section, this study has several methodological shortcomings that bear repetition and discussion. Densities were computed using an effective width of 150 m on either side of the road, which was what we used for other large waterbirds (Kittur and Sundar 2020). Our observations in the field, however, indicated that most Red-naped Ibis sightings were much closer to the road and that an effective width of 150 m on either side of the road provides conservative estimates of density (unpublished information). Additionally, the counts were done without measuring and controlling for detection bias that could vary due to crop height and other aspects related to each location. However, the landscapes had the least crop cover during the summer, but the highest counts were consistently during the winter when the landscape was covered with crops suggesting that a systematic seasonal bias in detection was likely not present or minimal (personal observations). Finally, the distribution range we used to obtain range-wide population estimates combined publicly available information from two sources. The reliability of information from either source is unknown. The combined range was bigger than the range estimated from each source separately. In this study we did not constrain field work to mornings and do not correct for ibis' behaviour (e.g. roosting in trees during the mid-day, personal observations). However, this bias was consistent across all locations, and we suspect that contrasting relative estimates between locations and seasons are still useful to provide an understanding of ibis habits. All estimates were derived without correcting for various biases suggesting that the total population sizes we present are likely to be underestimates. Studies that can incorporate additional methodological nuances such as detection bias can provide improved population estimates.

Conclusions

The Red-naped Ibis is an endemic waterbird species that has not received too much scientific attention. Our work and existing primary literature show that the species is very widely distributed across south Asia, is abundant in most locations, and uses a diverse range of human modified settings. Emerging findings are showcasing complexities related to changes in seasonal densities. The relatively high abundance of the species on human modified areas renders it a useful species to conduct studies that can showcase the idiosyncrasies of south Asian landscapes where people and a few waterbird species appear to live alongside each other. Such work will help provide additional evidence to move away from generic assumptions regarding the supposed inability of waterbirds to survive alongside human presence

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