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RESEARCH ARTICLE

Comparing abundance and habitat use of Woolly-necked Storks *Ciconia episcopus* inside and outside protected areas in Myanmar

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Abstract Protected areas form the backbone of biodiversity conservation especially in south-east Asia which is both a global biodiversity hotspot and is facing extreme developmental pressures. The ability of large waterbirds to use habitats outside protected areas is poorly understood in most south-east Asian countries despite the potential of human-modified areas such as agricultural fields to provide alternative habitats. We assessed abundance and habitat use inside and outside protected areas of Woolly-necked Storks, a large waterbird species thought to be declining due to deterioration of forested reserves, in five regions of Myanmar. Woolly-necked Stork abundance (birds/km) and use of three habitats (agriculture fields, forests, wetlands) were compared using transects within and outside protected areas, each monitored six times annually for three continuous years (2016 – 2018). Specifically, we assessed if abundance and habitat use varied due to protection status and whether location, season (summer, winter, and rainy season) and time of day (morning and evening) additionally influenced measured metrics. Woolly-necked Storks were seen in 55% of all transects, but in the 990 total transect runs, were seen in only 44% of transects with a higher frequency of sightings on transects outside (61%) compared to inside protected areas (25%). Encounter rates were, on average, 1.5 times higher outside compared to inside protected areas. Encounter rates also varied significantly with season with most storks being encountered in summers and the least in the winters, and seasonal patterns were similar inside and outside protected areas. Encounter rates showed weak declining trends in the majority of transects with measured declines being more than twice inside protected areas than outside. Woolly-necked Storks were mostly observed in wetlands (53%) and in agricultural fields (35%) and used forested areas and wetlands significantly more inside protected areas. Storks displayed plasticity outside protected areas by using agricultural fields. This study provides the first formal comparison of Woolly-necked Stork ecology inside and outside protected areas. In addition to continuing to secure protected areas for biodiversity conservation in Myanmar, expanding the conservation paradigm into agricultural landscapes with unprotected wetlands is essential for the long-term persistence of large waterbird species such as the Woolly-necked Storks.

Keywords Agricultural fields, protected versus unprotected areas, unprotected wetlands, Woolly-necked Stork.

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Introduction

The biodiversity crisis in south-east Asia is now deemed to be critical as increasing developmental pressures threaten biodiverse habitats including forests and wetlands (Donald *et al*. 2015; Harrison *et al*. 2018). The problem is exacerbated by the sparse amount of scientific research in many south-east Asian countries including Myanmar. The status of taxa such as large waterbirds, that can use human-modified land uses like agriculture are particularly poorly known in south-east Asia since the majority of conservation research and attention are focused largely on species and habitats that are within forested protected areas (Wilcove *et al*. 2013). Several bird species are suspected to be strongly associated with forested protected areas and therefore declining due to expansion of agricultural areas. One large waterbird species that was recently elevated to the conservation status “Vulnerable” due to suspected declines following conversion of its forested habitats to cultivation is the Woolly-necked Stork *Ciconia episcopus* (BirdLife International 2020). In south-east Asia Woolly-necked Storks have most commonly been reported from ephemeral shallow waterbodies inside protected forest areas and there is no published information from outside protected areas with which to evaluate its status (BirdLife International 2020; Sundar 2020).

Though Myanmar is well known to be part of the distribution range of the Woolly-necked Storks, there is exceedingly little understanding of its habits and requirements from this country (BirdLife International 2020; Gula *et al*. 2020; Sundar 2020). However, recent observations of Sarus Crane *Antigone antigone* populations using agricultural areas of Myanmar have provided optimism that other large waterbird species, including Woolly-necked Storks, are likely found outside protected areas in this country (Anon 2017). This situation is similar to other locations in Asia where agricultural landscapes supporting populations of Sarus Cranes also support other large waterbird species (Sundar 2006; Kittur and Sundar 2020).

Emerging information on Woolly-necked Stork ecology suggests that this species uses agricultural areas readily where even artificial structures such as irrigation canals and cell-phone towers are used for foraging and nesting respectively (Sundar 2006; Hasan and Ghimire 2020; Katuwal *et al*. 2020; Roshnath and Greeshma 2020). Systematic surveys using transects (1 - 1.5 km in length) across agricultural landscapes have shown Woolly-necked Storks to be sparse in India and Nepal (Sundar and Kittur 2012; Katuwal *et al*. 2020), though surveys across larger landscapes using road routes have been useful to understand ecological aspects such as seasonal variations in density and habitat use (Sundar 2006; Kittur and Sundar 2020). Woolly-necked Storks have also been observed to commonly use agricultural fields to forage while also using golf courses and gardens in suburban areas and unprotected wetlands in agricultural landscapes (Sundar and Kittur 2013; Thabethe 2018; Tiwary 2020). Empirical estimates of abundance and habitat use of Woolly-necked Storks from inside protected forest areas are not available making it impossible to contrast with metrics available from outside protected areas. Such a comparison is essential to confirm existing assumptions regarding Woolly-necked Stork reliance on protected forested areas.

We set up 55 transects inside and outside protected areas across five regions in Myanmar and evaluated Woolly-necked Stork abundance and habitat use over three years of continuous monitoring. We were primarily interested to understand if abundance metrics and habitat use of this species changed on landscapes with different protection status. However, since Woolly-necked Stork ecology from Myanmar is practically unknown, we also use the information to understand if these metrics varied by location, season, and time of day. Finally, we assessed temporal trends in abundance metrics in each transect to evaluate whether abundance of Woolly-necked Storks was changing over the study’s duration and whether these changes varied with protection status.

Study area

Woolly-necked Storks were observed in five locations of Myanmar: Kachin State and in four Regions namely Magway, Mandalay, Sagaing and Yangon (Figure 1). The study area was therefore spread practically across the entire north-south length of Myanmar, and spanned a very wide range of conditions, habitats, and landscapes. In Myanmar, three seasons based on precipitation and temperature were recognized namely summer (February - May), the rainy (June - September) and winter (October - January). These three seasons are also referred to as “hot”, “rainy” and “cold” seasons respectively. The primary crop grown during the rainy season was rice *Oryza sativa* and the primary winter crop was peas *Pisum sativum*. Wetlands were scattered across the landscape in all the locations surveyed for this study. We describe each location briefly to primarily highlight the differences in vegetation and weather. Information was derived from the World Database on Protected Areas of the IUCN (https://www.iucn.org/theme/protected-areas/our-work/quality-and-effectiveness/world-database-protected-areas-wdpa) and updated climatic detail were taken from the website climate-data.org.

Kachin State was the northernmost location and is 89,041 km^2 in size. The state has various protected areas, and our study was conducted in two of these: Indawgyi Wildlife Sanctuary and the Hukuang Valley Wildlife Sanctuary. Indawgyi Sanctuary is a biosphere reserve and includes Myanmar’s largest lake, the Indawgyi Lake, as well as moist deciduous and semi-evergreen forests on the mountainous regions. The Hukuang Sanctuary is Myanmar’s largest protected reserve and extends into Sagaing Region. We refer to the combination of both the original and the extension as a single protected area. The average temperature range was 17.9 - 34° C with an annual rainfall of 2000 mm.

The Magway Region is the second largest of Myanmar's seven Regions with an area of 44,820 km^2. This study included survey locations in the Shwesettaw Wildlife Sanctuary that is dominated by mixed deciduous forests. The average temperature range in the Region was 21.9 - 32.2° C with an average annual rainfall of 849 mm.

The Mandalay Region, located in the center of the country, has an area of 37,946 km^2 with a strongly seasonal climate including very warm summers and cooler winters with an average temperature range of 13.3 - 38.4° C and with an average annual rainfall of 812 mm with most of the rainfall falling in September. This study was restricted to areas outside protected areas in the Mandalay Region.

The Sagaing Region is in the north-western part of the country and has an area of 93,527 km^2. The average annual temperature range was 23 - 32° C with an average annual rainfall of 807 mm. Our surveys included the two protected areas Htamanthi Wildlife Sanctuary and Alaungdaw Kathapa National Park. The latter included elevated mountainous areas extending to 1,335 m above mean sea level and a variety of forest types including mixed deciduous, evergreen and pine.

The Yangon Region was the southern-most area in Myanmar covered during this study and includes extensive coastal habitats. The Region’s average temperate range was 17.9 – 37° C with a relatively large annual average rainfall of 2,378 mm owing to heavy coastal rainfall. The surveys included the Hlawga Park which was an open zoo around which a natural buffer zone was maintained.

Methods

Field methods

In the five locations described above, we marked transects of 1.5 km inside protected areas and 2 km outside protected areas. These permanent transects were part of another ongoing project, and observations of Woolly-necked Storks made during the project work have been used in this paper. Distribution of transects in each location ensured coverage of as many different habitat types as possible. For these reasons, the number of transects varied with location and were also unequally distributed within and outside protected areas. Of the 55 transects, 15 each were in Kachin State and Sagaing Regions, 10 each were in Magway and Mandalay Regions, and five in Yangon Region. Transects were only outside protected areas in Mandalay Region and only inside protected areas in Yangon region. A total of 19 transects were located inside and 36 were located outside protected areas. Transects were not distributed systematically and were therefore clumped to different extents in each location (see Figure 1). Protected areas varied in the levels of protection each had and in other important aspects such as size of areas protected and time since protection. In this study it was not possible to evaluate whether Woolly-necked Storks responded to differing aspects of protection and habitat availability in protected areas. Similarly, unprotected areas also varied in cropping patterns, human densities, hydrology and other aspects. Results of this study are therefore to be interpreted as being relevant to the range of variations across protected and unprotected areas we covered. To achieve much more specific understanding of how species such as Woolly-necked Storks respond to individual aspects of protected and unprotected areas, studies will require a different resolution of planning suited to specific questions.

Transect observations were made either in the morning (0700 - 1000h) or evening (1400 - 1700h) with two people walking slowly and counting all observed storks. Observations included number of storks and whether storks were using one of three broad habitats (agriculture, forests, wetlands). Each transect was run twice every season annually between January 2016 to December 2018 for a total of 990 transect runs.

Analyses

Abundance of Woolly-necked Stork was estimated per transect as encounter rate (number of storks seen/ km). Since transects were unequally distributed, and because a large number of transects did not have any storks (see Results), we used non-parametric permutational

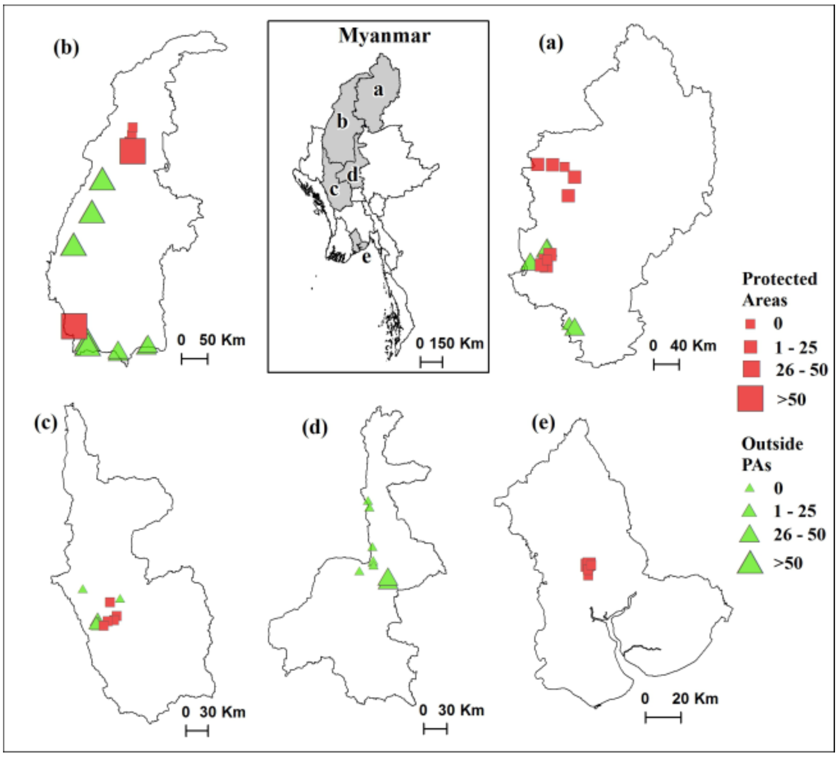

Figure 1. The map shows the five major locations where transects were laid to count Woolly-necked Storks in Myanmar (inset, in box). Along with location of the transects, the map illustrates the distribution of transects inside (pink squares) and outside (green triangles) protected areas. The size of the squares and triangles correspond to the number of sightings of Woolly-necked Storks that were made over 18 runs on each transect between 2016 and 2018. Major locations where transect surveys were carried out (from the northern-most to the southern-most) were Kachin State (a), Sagaing Region (b), Magway Region (c), Mandalay Region (d) and Yangon Region (e).

analysis of variance (PERMANOVA) tests to assess differences, if any, due to protection status and other variables. The non-parametric tests allowed us to work with data that did not conform to strict distribution patterns that are essential for parametric tests. We carried out statistical tests using function 'aovp' in R-package 'lmPerm' (Wheeler and Torchiano 2016). Using the full data, encounter rates were similar across years (p = 0.69) and in different times of day (p = 0.89), and we did not consider these two variables for the rest of the analyses. We tested the hypotheses that Woolly-necked Stork abundance varied due to protection status (transects located in protected/ unprotected areas), and that this difference remained in different locations and seasonally.

Using the 18 continuous counts on each transect we estimated the linear trend in encounter rates using linear least-squares and computed slopes for each transect. The slope of the fitted line indicates both the directionality and the rate of change in encounter rate over the 18 counts. We deliberately assumed linear fits to allow direct comparisons across transects notwithstanding varied scales of difference in individual transects.

For each transect we computed the proportion of Woolly-necked Storks seen in each of the three habitats – agriculture, forests, and wetlands. Proportions of use of each habitat type was significantly and negatively correlated with the other two habitat types (Spearman's $r < -0.3$, $p < 0.001$). Wetlands were the only habitat types used by storks in all locations, and we therefore used proportions of wetlands used to assess differences in habitat use with PERMANOVA tests due to protection status, and also whether differences existed across locations and seasonally.

Results

Encounter rate

A total of 1,118 Woolly-necked Storks were counted during the 990 transect runs with storks being sighted in all locations (Figure 1). Storks were seen at least once in 56% of the transects and were seen in all 18 runs in 18% of transects. Woolly-necked Storks were seen at least once in similar proportions of transects inside (53% of 19 transects) and outside (56% of 36 transects) protected areas. However, frequency of sightings differed with protected status. Woolly-necked Storks were seen in 44% of the 990 transect runs, with a much higher frequency of sightings in transects outside (61% of 648 transect runs) relative to those inside (25% of 342 transect runs) protected areas.

Encounter rates varied significantly by location ($p < 0.001$) with the highest rates in Sagaing Region and Kachin State (Figure 2a). The largest count of Woolly-necked Storks in a single transect run was 12 birds and occurred in two different protected areas, both in Sagaing Region. The average number of storks seen in a single transect was 1 bird (± 2 SD). Total stork counts using all 18 runs on a transect varied widely across the 55 transects (average = 20 ± 30 SD; range = 0 - 130; see Figure 1). Encounter rates of Woolly-necked Storks were significantly more outside protected areas ($p < 0.001$). Woolly-necked Storks were seen both

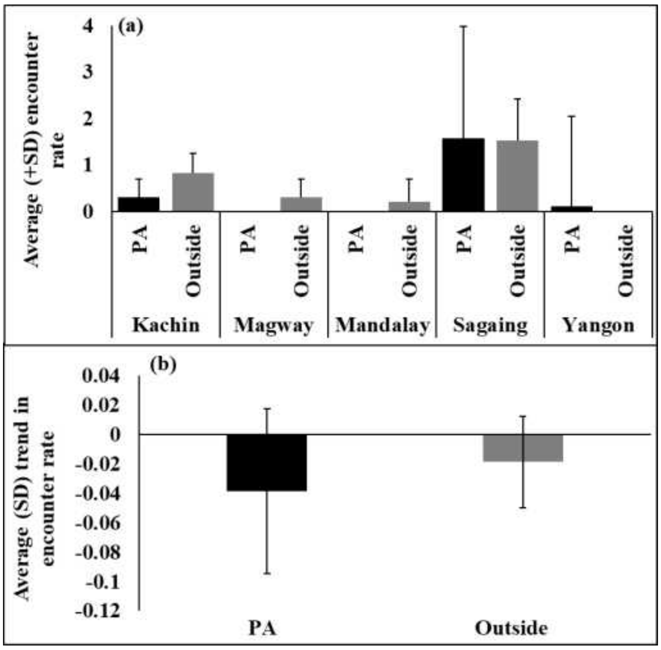

Figure 2. Estimated encounter rates (birds/ km) of Woolly-necked Storks in five locations of Myanmar. (a) Average + SD encounter rates were estimated differently for transects that were located inside ("PA") and outside protected areas ("Outside"). (b) Trends in encounter rates were estimated using 18 consecutive surveys in each transect, and average values of slopes (± SD) are provided for transects that were located inside and outside protected areas.

inside and outside protected areas in two locations and in these locations were significantly more abundant outside protected areas in Kachin State ($p < 0.001$) but did not vary with protection status in Sagaing Region ($p = 0.32$).

On the 31 transects where Woolly-necked Storks were observed, trends in abundance were weakly negative on average (-0.02 ± 0.04 SD) with negative trends in 68% of transects. Decline in abundance inside protected areas (-0.039 ± 0.06 SD) was on average more than twice that observed outside (-0.019 ± 0.03 SD; Figure 2b). Differences in average trends, however, were not significant with standard deviations overlapping zero both inside and outside protected areas.

Habitat use

Combining all observations, most Woolly-necked Storks were seen in wetlands (53%) and agriculture fields (35%) with few seen in forests (12%). Forests were used mostly inside protected areas, while agriculture fields and wetlands were used more outside protected areas ($p < 0.001$; Figure 3a). Use of habitats inside and outside protected areas was similar across seasons ($p = 0.61$) and locations ($p = 0.92$; Figure 3b). Use of different habitats by Woolly-necked Storks were photographed where possible and a small selection is curated in Figure 4.

Discussion

Woolly-necked Storks were observed in all the five locations of Myanmar where transect-based surveys were carried out. Abundance measured as encounter rates were significantly higher outside protected areas, and storks were seen in many more transects outside protected areas. Trends in encounter rates were negative in nearly all transects in Myanmar, though protected areas appeared to be witnessing a much faster decline in Woolly-necked Storks relative to areas outside protected areas (Figure 2b). While negative trends were very weak and not statistically significant, our observations provide additional support to growing observations of habitat deterioration in the protected areas and wetlands of Myanmar (e.g. Su and Jassby 2002; Donald *et al*. 2015). It is not clear what is responsible for these negative trends in abundance, though naturally occurring seasonal and inter-annual variations in numbers cannot be entirely ruled out (as seen in other south Asian populations; Kittur and Sundar 2020).

There was no seasonal variation in estimated encounter rates in Myanmar. In other locations, Woolly-necked Storks were seen much more during winter and the least in summer suggesting local movements potentially brought about by changes in local conditions (Kittur and Sundar 2020; Roshnath and Greeshma 2020). Despite strong seasonality in Myanmar, the apparent absence of local movements of Woolly-necked Storks is suggestive of foraging conditions being suitable throughout the year in many locations. This appears to be an unusual setting for Woolly-necked Storks and is worthy of detailed studies.

Abundance estimates for Woolly-necked Storks are available for very few locations, and encounter rates that we estimated for Myanmar are unfortunately not comparable with estimated densities in lowland Nepal and India (see Kittur and Sundar 2020). On average, nearly two Woolly-necked Storks were seen every km of surveys in Sagaing that suggests a relatively high abundance. All the other locations surveyed had much fewer encounters suggesting that conditions in Sagaing Region, relative to the other areas, were most optimal for Woolly-necked Storks. More careful studies can help with understanding the conditions

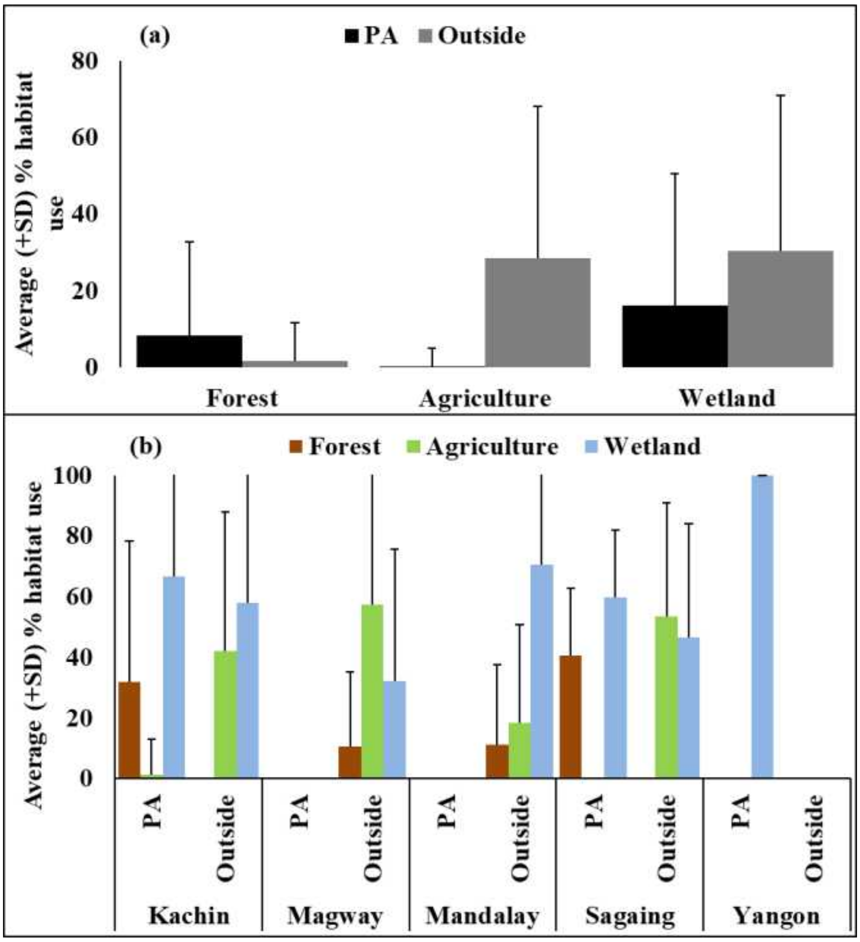

Figure 3. Woolly-necked Stork use of three primary habitats inside and outside protected areas in Myanmar. (a) Average (+ SD) % habitat use combining information from all transects; and (b) average (+ SD) % habitat use in five locations.

in Sagaing Region that were favourable for storks. With our study, we are unable to provide population estimates, though observations on transects that covered a relatively miniscule proportion of the country suggest that Woolly-necked Storks could number in the thousands in Myanmar. It will be useful to undertake robust field studies directed at collecting data with which to estimate population sizes of Woolly-necked Storks in different locations of Myanmar.

Encounter rates of Woolly-necked Storks were much higher outside protected areas raising the possibility that this species favours open areas, and that will likely be resilient to deterioration of forested protected areas in Myanmar. Our findings contrast existing assumptions that Woolly-necked Storks favour protected forested areas, and that agriculture is detrimental for the species (BirdLife International 2020). Instead, our findings in Myanmar support the growing evidence of human-modified open areas such as agriculture fields and unprotected wetlands being primary habitats for Woolly-necked Storks in several locations across Asia and Africa (Thabethe 2018; Katuwal *et al*. 2020; Kittur and Sundar 2020; Tiwary 2020).

Most Woolly-necked Storks observed in Myanmar were in wetlands (53% of 1,118 storks observed) both inside and outside protected areas (Figure 3a), which is different from habitat use observed elsewhere. In lowland Nepal and India, of 1,874 observations of storks, 64% were in agriculture fields with only 9% in wetlands (Kittur and Sundar 2020). Analysis with the use-availability framework showed Woolly-necked Storks in south Asia to be strongly preferring wetlands in nearly all the locations they were studied despite a small proportion of sightings of storks using wetlands (Sundar 2006; Kittur and Sundar 2020). Our observations in Myanmar therefore suggest that Woolly-necked Storks in Myanmar are likely selecting wetlands as foraging habitats even more strongly than in Nepal and India. Though 35% of Woolly-necked Storks were observed in agricultural fields largely outside protected areas in Myanmar, there were considerable location-specific differences in the proportions of storks that used agriculture. In Magway and Sagaing Regions most storks used agriculture, while they mostly used wetlands in Kachin State and Mandalay Region (Figure 3b). These location-specific differences in habitat use are symptomatic of variations in landscape conditions and potentially also of different levels of human activity on the landscape. Variations in habitat use with location could also be due to the unequal distribution of transects inside and outside protected areas and unequal effort in locations. Studies to measure available landscape conditions in different locations to compare against Woolly-necked Stork habitat use can yield nuanced information on the habitat requirements of this species.

We recognize two important aspects of analyses with our data that are important to undertake separately. As we pointed out in the Methods section, the first is the lack of resolution to analyze site-specific differences such as level of protection (for protected areas) and human density (for unprotected areas). This is also part of the reason why we do not provide a nuanced discussion into national policy for conservation. The potential impacts of these variations on species such as Woolly-necked Storks are important but was not possible to incorporate in our study. We also do not include metrics of additional aspects of species biology such as breeding propensity and success. Birds of the year are easily identified using plumage in some large waterbird species such as the Sarus Crane, Painted Storks *Mycteria leucocephala* and Black-necked Storks *Ephippiorhynchus asiaticus* in south Asia (pers. obs.). Locations where immature birds are seen alongside adults can confidently be identified as areas where the species breeds. Such plumage variations also allow for the estimation of metrics important for understanding species population biology. Woolly-necked Stork juveniles, however, are difficult to tell apart from adults except for a short time immediately after fledging (see Sundar 2020). In addition, this species shows local and seasonal movements in response to changing water availability that in turn alters observable metrics such as flock size (Kittur and Sundar 2020; Mandal *et al*. 2020). Using only metrics such as flock size is therefore not a reliable method for Woolly-necked Storks to confirm aspects such as breeding. Careful studies are needed in Myanmar to document and understand critical aspects of Woolly-necked Stork biology such as breeding ecology.

This study is the first from Myanmar to develop a detailed understanding of a large waterbird species capable of using both protected forests and unprotected agricultural areas. Our findings are hopeful in suggesting that the gloom-and-doom that is presented of Myanmar's natural resources is not pertinent to all species, and that at lease some species of birds may be resilient to the dynamism and human presence characteristic of agricultural

Figure 4. Observations of Woolly-necked Storks using different habitats in Myanmar during surveys between 2016 and 2018. Photographs show storks using large waterbodies (a), small shallow ephemeral wetlands alongside other waterbirds (b), pea fields (c), and an agricultural field with harvested crops (d). (Photograph credits: U. Nway Myaing).

landscapes. Findings from this study do not support existing assumptions regarding the conservation requirements and status of Woolly-necked Storks. Our work adds to the sparse amount of research on Woolly-necked Storks globally. It also provides information that suggests that conservation efforts in Myanmar will benefit from including agricultural landscapes to ongoing efforts that seek to preserve forested protected areas critical for the region's biodiversity.

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