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BREEDING DENSITY AND HABITAT SELECTION OF THE GREY-HEADED FISH-EAGLE IN NOAKHALI DISTRICT, BANGLADESH

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ABSTRACT.—The Near Threatened Grey-headed Fish-Eagle (GHFE, *Ichthyophaga icthyaetus*) has undergone a moderately rapid population decline due to habitat degradation. We studied population density and nest-site characteristics of the GHFE at Noakhali, Bangladesh, between November 2015 and January 2016. We used distance sampling along eight line transects to estimate GHFE breeding density. At each nest, we recorded height and crown density of nesting tree, and distances from nearest human settlement, waterbodies with commercial fisheries (hereafter, commercial waterbodies), and waterbodies without commercial fisheries (hereafter, noncommercial waterbodies). We estimated 0.27 (95% CI: 0.15–0.49) GHFE nests or 0.54 individuals per km^2. We detected a total of 26 nests, with 85% built on siris (*Albizia* spp.) trees. All nests were built on the tallest tree within the vicinity of the nesting site, with an average height of 12.5 ± 1.5 m, and on trees with open (69%, $n = 18$) canopy structure. We found that 76.9% of nests were located within 100 m of human settlements ($\chi^2 = 4.13$, df = 1, $P = 0.04$) and 73.1% were located closer to a commercial waterbody than a to noncommercial waterbody ($\chi^2 = 13.4$, df = 1, $P = 0.0002$). Total area of commercial waterbodies within 500 m of nests was higher than that of noncommercial waterbodies ($W = 507$, $P = 0.001$). These results indicate that GHFEs do not require undisturbed or natural waterbodies and can survive well in some human-modified landscapes if adequate food (e.g., commercial fisheries) and tall trees for nesting are available; thus the species may be less vulnerable to environmental changes than previously thought.

KEY WORDS: *Grey-headed Fish-Eagle*; Ichthyophaga icthyaetus; *Bangladesh*; *distance sampling*; *density*; *fisheries*.

DENSIDAD REPRODUCTIVA Y SELECCIÓN DE HÁBITAT DE *ICHTHYOPHAGA ICTHYAETUS* EN EL DISTRITO NOAKHALI, BANGLADESH

RESUMEN.—El águila *Ichthyophaga icthyaetus,* categorizada como casi amenazada, ha experimentado una disminución poblacional moderadamente rápida como resultado de la degradación de su hábitat. Estudiamos la densidad poblacional y las características de los lugares de cría de *I. icthyaetus* en Noakhali, Bangladesh, entre noviembre 2015 y enero 2016. Usamos muestreos por distancia a lo largo de ocho transectos lineales para estimar la densidad reproductiva de *I. icthyaetus.* En cada nido, registramos la altura y la densidad de la copa del árbol usado para anidar y las distancias al asentamiento humano más cercano, a los cuerpos de agua con pesquerías comerciales (en adelante, cuerpos de agua comerciales) y a los cuerpos de agua sin pesquerías comerciales (en adelante, cuerpos de agua no comerciales). Estimamos 0.27 (95% IC: 0.15–0.49) nidos de *I. icthyaetus* o 0.54 individuos por km^2. Detectamos un total de 26 nidos, con un 85% de estos nidos construidos en árboles del género *Albizia.* Todos los nidos fueron construidos en el árbol más alto dentro de la vecindad del sitio de anidación, con una altura promedio de 12.5 ± 1.5 m, y en árboles con una estructura abierta del dosel (69%, $n = 18$). Encontramos que el 76.9% de los nidos estuvieron localizados a menos de 100 m de los asentamientos humanos ($\chi^2 = 4.13$, gl = 1, $P = 0.04$) y que un 73.1% de estos nidos fueron localizados más cerca de un cuerpo de agua comercial que de un cuerpo de agua no comercial ($\chi^2 = 13.4$, gl = 1, $P = 0.0002$). La superficie total de los cuerpos de agua comerciales dentro de los 500 m de los nidos fue más alta que la de los cuerpos de agua no comerciales ($W = 507$, $P = 0.001$). Estos resultados indican que *I. icthyaetus* no requiere de cuerpos de agua no perturbados o naturales y que puede sobrevivir bien en algunos paisajes modificados por el ser humano si disponen de alimento adecuado (e.g., pesquerías comerciales) y árboles altos para anidar; por ende, la especie puede ser menos vulnerable a los cambios ambientales de lo que se pensaba anteriormente.

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The Grey-headed Fish-Eagle (hereafter, GHFE; *Ichthyophaga icthyaetus*) is classified as globally Near Threatened because the species has undergone a moderately rapid population decline due to habitat degradation, pollution, pesticide, and overfishing (Tingay et al. 2010, BirdLife International 2017). Though still widely distributed throughout South and Southeast Asia, the GHFE is now only locally common in the latter region, and is declining in other regions such as northeastern India, Nepal, Philippines, and Java, Indonesia (BirdLife International 2017). Although a broad decline is apparent, the species utilizes human-made reservoirs and impoundments in parts of Southeast Asia, including within densely urbanized Singapore (Yong 2012, Yong et al. 2014). If the GHFE is able to survive and adapt in human-dominated landscapes (Naoroji 2006, Yong et al. 2014), then population declines due to habitat loss and development (BirdLife International 2017) might possibly be mitigated by expansions elsewhere into human-altered landscapes.

We studied the population in Bangladesh, where the GHFE is listed as Near Threatened and uncommon. Inland pond aquaculture contributes almost half (44%) of Bangladesh's fish production, covers 377,968 ha, and appears to be increasing (Shamsuzzaman et al. 2017). The GHFE occupies fishponds surrounded by well-wooded areas and homestead wetland habitats of Chittagong, Dhaka, Khulna, Barisal, and Sylhet Divisions (Siddiqui et al. 2008). We investigated whether the presence of GHFE was correlated with human-modified landscapes, especially waterbodies with commercial fisheries (commercial waterbodies), and whether those landscapes influenced nest-site selection. We also examined whether GHFE in Bangladesh preferred tall nest trees with open crown structures, which appear to allow unencumbered parental access in Cambodia (Tingay et al. 2010).

METHODS

Study Area. We conducted surveys for nesting GHFE at Companiganj sub-district (hereafter Companiganj) of Noakhali district, Chittagong Division in south-central Bangladesh (Fig. 1). We chose Companiganj for our surveys because we discovered four GHFE nests during an opportunistic visit to the area in January 2015. We initiated the study during the following breeding season to understand factors for such a high density of GHFE in an area of 305 km^2 with between 183,000 and 183,500 people (Karim et al. 2013). Our study area covered 104 km^2, located approximately 100 km north of the Bay of Bengal where approximately 3700 km^2 of waterbodies, agricultural cropland, homestead patches, and human settlements, and approximately 70,500 ponds (Karim et al. 2013) dotted the landscape. The average annual precipitation in the study area ranged from 6.6 mm during the dry season (January) to 723.4 mm during the monsoon season (July) in 1999–2010, and mean annual temperature ranged from 21 to 31°C (1981–2010; Khatun et al. 2016).

Breeding Density. We used distance sampling to estimate GHFE breeding-pair density within the study area, as distance sampling is a simple and widely used approach to estimate densities of biological populations in defined areas (Buckland et al. 2001, Thomas et al. 2010, Cornils et al. 2015, Buckland et al. 2016). We searched for nests between 15 November 2015 and 31 January 2016 along eight transect lines that we established following relatively straight roads through homestead forest and village landscapes with no natural or artificial barriers. We conducted the surveys in winter (November and December), the primary breeding season of the GHFE (Naoroji 2006, Siddiqui et al. 2008). Transects were placed 1 km apart and transect length varied from 9.2–15.5 km. We surveyed each transect by walking slowly (3 km/hr) in a two-person team, while each person searched for GHFE nests on one side of the transect. We used a Garmin e-Trex (Garmin, KS, USA) handheld global positioning system unit to follow transects and to record nest locations. We recorded a nest structure as occupied when at least one GHFE was present, or if the size, structure, and height of a nest we observed was consistent with a GHFE nest but no GHFE was present. In the latter cases, we visited the nest location later for further verification. In all cases, we used 10×42 binoculars to examine nests. We measured perpendicular distance between the transect lines and each GHFE nest we found, and we calculated the total area surveyed for GHFE as a polygon with a 1-km buffer around our transect survey area (Fig. 1).

Nesting Habitat. At each occupied nest, we recorded date, species, height, and crown density of the nest tree, GPS coordinates, distance from nearest human settlement, distance from the nearest commercial and noncommercial waterbodies (>50 m^2), and the number of commercial and noncommercial waterbodies within 500 m of the nest. If a

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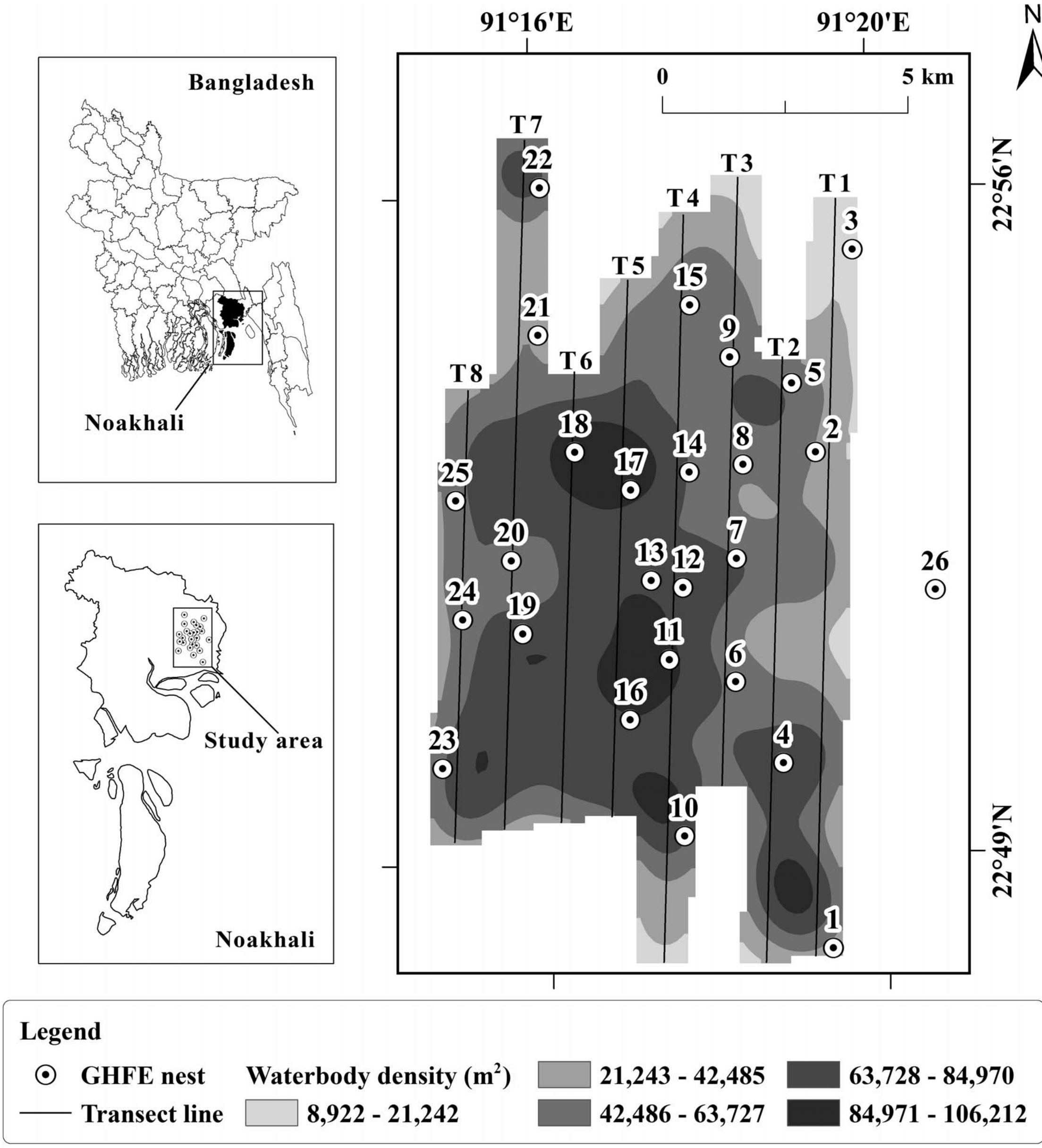

Figure 1. Grey-headed Fish-Eagle (*Ichthyophaga icthyaetus*) nest locations, transects (T1–T8) and density of waterbodies within the study area at Noakhali, Bangladesh.

waterbody was used for fish cultivation by the local community, we defined that waterbody as commercial. If a human-made or natural waterbody was not used for fisheries then we defined it as noncommercial. We used Google Earth and World Imagery basemap in ArcGIS 10.3 (Esri Inc., CA, USA) to measure distances from human settlements (single residence, village, local bazaar etc.) and from waterbodies for each nest. We also used ArcGIS 10.3 to create polygons around each waterbody ($n = 8726$, >50 m^2) and to calculate the size of the waterbodies in plots around each nest. We used Ahmed et al.

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Table 1. Results of three different distance-sampling models used to estimate nest density (nest/km^2) of Grey-headed Fish-Eagles (*Ichthyophaga icthyaetus*) at Noakhali, Bangladesh, with Akaike information criterion (AIC) values of each model, encounter rate (ER) per kilometer of transect, standard error (SE), coefficient of variation (CV), 95% confidence interval (CI) and degrees of freedom (df).

CANDIDATE MODELS	AIC	NEST/km^2	ER	SE	CV	95% CI	df
Half-normal key function	308.96	0.27	0.24	0.07	0.28	0.15–0.49	30.55
Uniform key function with cosine adjustment term	308.99	0.26	0.24	0.09	0.34	0.13–0.52	30.84
Hazard-rate key function	310.18	0.28	0.24	0.05	0.18	0.19–0.42	14.64

(2009) to identify tree species. We determined tree height using a clinometer. We visually estimated the crown density of the nest tree as the amount of light that was blocked by branches and foliage in four categories: open (0–25%), partially open (26–50%), partially dense (51–75%), and dense (76–100%), following Tingay et al. (2006).

Statistical Analysis. We used perpendicular distances between GHFE nests and transect lines in the "Distance" package in R statistical software (R Core Team 2016) to determine density of GHFE breeding pairs. We started the analysis with a truncation of the data at a distance of 480 m from the transect lines, which was the maximum distance at which a nest was detected (Buckland et al. 2001, Cornils et al. 2015). Due to the presence of tall trees in the study area, visibility was poor (Reuleaux et al. 2013, Buckland et al. 2016) beyond 480 m. We used three models in the "Distance" package of R software: (1) half normal with cosine adjustments, (2) uniform with cosine adjustments and (3) hazard-rate with simple polynomial adjustments (Buckland et al. 2001, Thomas et al. 2010, Reuleaux et al. 2013). We used Akaike information criterion (AIC) and visual evaluation of quantil-quantil plots to select the model that best fit our data as these are widely used and simple approaches to determine the most suitable model (Buckland et al. 2001, 2016, Thomas et al. 2010, White et al. 2012). We used linear regression to quantify the relationship between the number of nests recorded on a transect and the number and area of waterbodies.

RESULTS

Density. We studied nest-site characteristics and population density of GHFE in Companiganj, between November 2015 and January 2016. We found a total of 25 occupied GHFE nests along eight transects of total length 99 km between November 2015 and January 2016 (Figure 1). The lengths of our transect lines varied from 9.2 km to 15.5 km, with 3.12 nests found per transect on average. We used AIC values (Table 1) to identify the half-normal with cosine adjustment model as the best-fit model. The model estimated 0.27 (95% CI: 0.15–0.49) GHFE nests or 0.54 individuals per km^2, with an encounter rate of 0.24 individuals per transect, indicating approximately one nest or two individuals every 4 km^2 across our 104 km^2 study area. The number of nests recorded on a transect was positively correlated with both the total number of waterbodies (commercial and noncommercial; $r^2 = 0.51$, $F = 6.31$, $P = 0.04$, AIC = 28.91) and the total area of waterbodies ($r^2 = 0.53$, $F = 6.91$, $P = 0.03$, AIC = 28.53) within 500 m of the nest.

Nesting Habitat. We collected data on nesting habitat at 26 nests (including one nest outside the main transect study area). Of these, 13 (50%) nests were built on black siris (*Albizia richardiana*), 9 (34.6%) nests were on forest siris (*Albizia procera*), and the rest were on Australian pine *(Casuarina equisetifolia)*, Burma ironwood (*Xylia xylocarpa*), and Indian ash tree (*Lannea coromandelica*). All nests ($n = 26$) were built on the tallest tree within the vicinity (100 m), with an average nest-tree height of 12.5 ± 1.5 m, compared to the surrounding canopy height of approximately 8 m (Table 2). Nests were located at 11.2 ± 1.4 m above ground. The majority of the nests were on trees with open (69%, $n = 18$) or partially open (27%, $n = 7$) structures (Fig. 2). Most (76.9%) nests were located within 100 m of human settlements ($\chi^2 = 4.13$, df = 1, $P = 0.04$) m with an average distance of 89.1 ± 78.0 m (range: 14–384 m; $n = 26$).

The majority of the nests (65%) were located closer to a commercial waterbody than to a noncommercial waterbody, with an average distance between nests and the nearest commercial waterbody of 50.9 ± 34.4 m (range: 13.0–156.2 m); 92.3% of the 26 nests were located within 100 m ($\chi^2 = 13.4$, df = 1, $P < 0.001$) of a commercial waterbody (Table 2; also see Supplemental Material). Only 31% of

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Table 2. Environmental measurements at nests of Grey-headed Fish Eagles (*Ichthyophaga icthyaetus*) at Noakhali, Bangladesh: nest tree species, nest tree height, area of commercial and noncommercial waterbodies surrounding each nest, and distances between each nest and human settlements, commercial waterbodies, and noncommercial waterbodies. Scientific names of nesting tree species: *A.* = *Albizia*, *C.* = *Casuarina*, *L.* = *Lannea*, and *X.* = *Xylia*.

			Waterbody Type and Area (m^2) Within 500 m of Nest		Distance (m) From		
Nest No.	Nest Tree Species	Height of Nest Tree (m)	Commercial	Noncommercial	Human Settlement	Nearest Commercial Waterbody	Nearest Noncommercial Waterbody
1	*A. richardiana*	12.6	46,471	16,332	49	29	74
2	*A. richardiana*	14.4	17,822	15,867	43	97	26
3	*L. coromandelica*	11.2	8781	1127	139	39	203
4	*A. procera*	11.5	46,860	36,988	52	72	18
5	*A. procera*	11.7	19,651	25,614	154	13	112
6	*A. richardiana*	14.1	27,641	26,447	51	140	20
7	*X. xylocarpa*	10.7	29,107	22,446	56	22	177
8	*A. richardiana*	13.4	27,185	12,212	52	35	116
9	*A. richardiana*	11.8	32,588	20,213	14	44	44
10	*A. procera*	11.4	68,742	40,893	131	19	110
11	*A. procera*	13	46,750	28,868	156	28	68
12	*A. richardiana*	13.1	35,280	26,923	73	24	49
13	*A. richardiana*	15.8	30,780	37,359	58	29	150
14	*A. richardiana*	13.2	25,095	29,934	97	76	214
15	*A. procera*	11.1	22,956	11,147	41	60	15
16	*A. procera*	11.8	52,286	11,207	66	33	29
17	*C. equisetifolia*	9.7	61,026	33,345	76	51	158
18	*A. procera*	12.4	62,699	48,505	77	45	60
19	*A. procera*	10.4	61,934	26,628	26	37	72
20	*A. richardiana*	14.7	30,796	11,072	384	41	80
21	*A. richardiana*	14.1	30,800	15,419	26	44	67
22	*A. richardiana*	13.8	54,979	44,607	228	38	29
23	*A. richardiana*	13.5	37,237	42,448	67	40	105
24	*A. richardiana*	12.1	26,452	12,053	76	66	46
25	*A. procera*	13.4	50,074	15,972	96	39	124
26	*L. coromandelica*	11.2	28,549	15,480	23	156	26
	Mean	12.5	37,790	24,196	89.1	50.9	84.5
	SD	1.5	15,788	12,362	78.0	34.4	58.6
	CV	0.1	0.42	0.51	0.88	0.68	0.69

nests were located closer to a noncommercial waterbody than to a commercial waterbody. Average distance to a noncommercial waterbody was 84.5 ± 58.6 m (range: 14.9–214.0 m), and 61.5% of nests were located <100 m from a noncommercial waterbody. The total area of commercial waterbodies within 500 m of each nest (37,790 ± 15,788 m^2) was higher than that of noncommercial waterbodies (24,196 ± 12,362 m^2; Wilcoxon rank sum test: $W = 507$, $P = 0.001$, $n = 26$ nests).

DISCUSSION

Density. Our study demonstrates that Companiganj, with 25 nests in 104 km^2 (4.2 km^2/nest territory) supports a high density and potentially large population of GHFEs. In comparison, at the Tonle Sap Lake in Cambodia, 32 pairs of GHFE were recorded in an area of around 80 km^2 (2.5 km^2/nest territory; Tingay et al. 2006), indicating somewhat similar densities of GHFEs, although Tonle Sap Lake is a natural swamp forest with little human disturbance (Tingay et al. 2010). Elsewhere, GHFE nests in the Periyar Tiger Reserve in India were spaced an average of 2.5 km apart where the habitat was undisturbed and fish were abundant (Naoroji 2006). Our study area, a highly disturbed human-dominated landscape with 843 people per km^2 (Karim et al. 2013), supported a GHFE density of 4.2 km^2/nest

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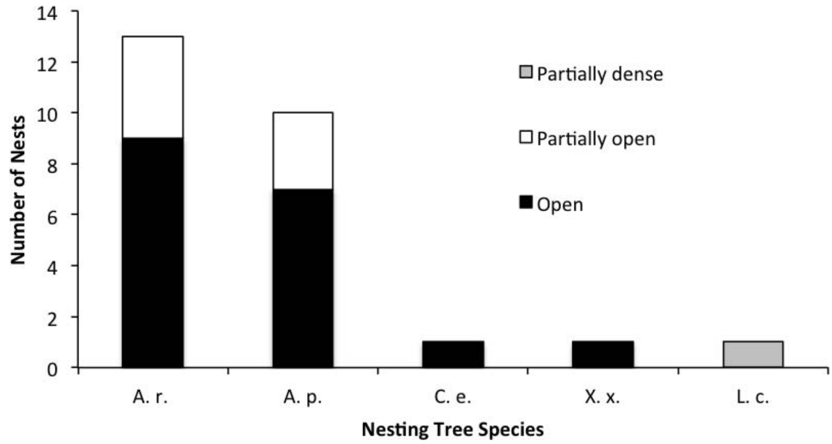

Figure 2. Crown density of nest trees of Grey-headed Fish-Eagles (*Ichthyophaga icthyaetus*) at Noakhali, Bangladesh. Crown density is shown as three categories: Open: 0–25% canopy closure, Partially open: 26–50% canopy closure, and Partially dense: 51–75% canopy closure. A. r.: *Albizia richardiana*, A. p.: *Albizia procera*, C. e.: *Casuarina equisetifolia* , X. x.: *Xylia xylocarpa*, and L. c.: *Lannea coromandelica*.

territory, including nests placed very close to human settlements. These reports (Tingay et al. 2006, Naoroji 2006) indicate that the GHFE density in natural habitats is quite comparable with that documented in our study in a human-dominated environment.

Nesting Habitat. We found the number of nests per transect correlated with the number of waterbodies and the total area of waterbodies, suggesting that GHFE nest locations were dependent on the distribution of waterbodies. Specifically, we found that 73.1% of nests were closer to commercial waterbodies than to noncommercial waterbodies, and that the total area of commercial waterbodies was higher than that of noncommercial waterbodies around nests, suggesting that GHFE may utilize human-made commercial waterbodies. We also found that most nests were located very close to (<100 m) or within human settlements, suggesting that the species is not negatively affected by the presence of humans, or by habitat modification due to human activities, at least in this location. This hypothesis is supported by our opportunistic observations from one nest, where 98% of prey items ($n=$ 174) fed to the GHFE nestlings were fish, 53% of which were commercially produced (M. Miron and S. Chowdhury unpubl. data).

GHFEs prefer the tallest trees within the nesting territory for nesting (Naoroji 2006). The average height of nesting trees in Bangladesh was 12.6 m, which was similar to Cambodia, where the majority of the nests (82%) were built on trees with an average height of 7–15 m (Tingay et al. 2010). Naoroji (2006) mentioned that nesting GHFE prefer densely foliaged tree species, including *Albizia* spp. Consistent with that, we found 88% of nests in Bangladesh were on *Albizia* spp. Crown density of GHFE nesting trees in Bangladesh was also similar to that in Cambodia (Tingay et al. 2010), indicating the species' preference for an open crown structure. The high proportion of nests on *Albizia* spp. suggests that this native tree is important for the breeding of GHFE.

Conservation Implications. Given the GHFE's ongoing decline in regions such as northeastern India, Nepal, Philippines, and Java, Indonesia (BirdLife International 2017), Bangladesh appears to be important for GHFE. The country is one of most suitable countries for inland fisheries in the world, with total fish production in 2014–2015 of 3,684,245 metric tons, of which 2,060,408 metric tons (55.9%) were from inland closed systems (i.e., aquaculture; Shamsuzzaman et al. 2017). The Noakhali district (where our study occurred) produced over 40,000 metric tons of commercially raised fish in 2014–2015, one of the highest district productions of freshwater fish in Bangladesh (Shamsuzzaman et al. 2017), which suggests that the density of commercial waterbodies is higher in Noakhali than in other districts of Bangladesh. This might explain the high

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density of nesting GHFE in Noakhali compared to other districts (Siddiqui et al. 2008) of Bangladesh, and suggests a strong association between the GHFE's nest-site choices and commercial inland fisheries.

Our findings therefore indicate that the GHFE is not entirely dependent on undisturbed or forested waterbodies as suggested by various authors (Naoroji 2006, Tingay et al. 2010, BirdLife International 2017), but that the species can survive in human-modified landscapes at least in some regions. We suggest that the species may be more adaptable and less vulnerable to environmental changes than previously thought. There has been little study on the adaptive behavior of the GHFE. However, Yong (2012) and Yong et al. (2014) demonstrated that the species is likely to persist in human-made landscapes such as Singapore, due to its adaptability to novel habitats and prey items.

Our study represents the most complete report on the density of GHFE in Bangladesh. We recommend long-term study in other areas of Bangladesh with high (Sylhet division) and low (Rajshahi division) densities of commercial fisheries (Shamsuzzaman et al. 2017). Moreover, we recommend investigating possible conflicts between the GHFE and local fish farmers. Detailed information on these aspects will allow us to further understand the relationship between local fisheries and the breeding density of GHFEs. In addition, our study demonstrates the importance of tall trees around local fisheries, which underscores the need to preserve native *Albizia* spp. around commercial fisheries to facilitate the long-term conservation of the GHFE.

Supplemental Material

Map of the distribution of commercial and noncommercial waterbodies around each Grey-headed Fish Eagle nest (500-m radius) at Noakhali, Bangladesh (available online).

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