ACADEMIA JOURNAL OF BIOLOGY 2025, 47(2): 129–143
DOI: 10.15625/2615-9023/20939

FORAGING ECOLOGY OF THE GREATER ADJUTANT STORK, *Leptoptilos dubius* IN CERTAIN WETLANDS AND A GARBAGE DUMP IN ASSAM, INDIA

Purnima Devi Barman[1], D. K. Sharma[2,*]

[1]Aaranyak, Beltola Survey, Guwahati-781028, India
[2]University of Science and Technology Meghalaya, 9th Mile, Baridua, Ri-Bhoi-793101, Meghalaya, India

Received 11 June 2024; accepted 10 June 2025

ABSTRACT

The Greater Adjutant Stork (*Leptoptilos dubius*), a Near Threatened species, was studied from 2012 to 2017 across wetlands, paddy fields, and a garbage dump in Assam's Brahmaputra Valley. Observations during breeding and non-breeding seasons assessed habitat-specific foraging behavior and adaptability. Foraging activity peaked in wetlands during the breeding season, especially in December and February. Foraging rates ranged from 0.7–2.0 minutes in wetlands and 1.0–4.0 minutes at the garbage dump. Wetlands with shallow water (1–10 cm) showed the highest foraging success (85.1%), decreasing with depth; paddy fields had lower success (70.6%). Prey handling time increased with size, particularly for prey ≥ 30 cm (60–140 seconds), and was most efficient at 1–30 cm depth. Handling time correlated positively with water depth (r = 0.860) and number of footsteps (r = 0.478). Storks used visual, tactile, and combined foraging techniques depending on habitat. In captivity, Cyprinids were preferred; *Monopterus cuchia* showed high profitability despite longer handling. Regurgitated food from nests confirmed a diet dominated by *Channa* and Cyprinids. Morphometric traits like long bill/beak and legs support efficient foraging in shallow wetlands. These findings highlight the stork's behavioral flexibility and emphasize wetland conservation as vital to sustaining foraging habitats and guiding conservation efforts.

Keywords: Near threatened *Leptoptilus dubius*, foraging behaviors, foraging techniques, prey handling and prey profitability, diet, morphometric traits.

Citation: Purnima Devi Barman, D. K. Sharma, 2025. Foraging ecology of the greater adjutant stork, *Leptoptilos dubius* in certain wetlands and a garbage dump in Assam, India. *Academia Journal of Biology*, 47(2): 129–143. https://doi.org/10.15625/2615-9023/20939

[*]*Corresponding author email*: dksgu@yahoo.co.uk

INTRODUCTION

Members of the family Ciconiidae are widely distributed across Asia (Hancock et al., 1992), with six resident species in the Indian subcontinent (Ali & Ripley, 1987). Among them, the Greater Adjutant Stork (*Leptoptilos dubius*), once *Endangered* (Luthin, 1987; IUCN, 2018), is now listed as Near Threatened, with a global population of 3,180–3,300 individuals (BirdLife International, 2024). India remains the species' stronghold (Jetz et al., 2014), with 1,070 individuals in Assam's Brahmaputra Valley (Goswami & Patar, 2007; Barman et al., 2020), 2,430–2,550 in Northeast India (Barman, 2024), and about 600 in Bihar (Misra & Mandal, 2009; BirdLife International, 2024). Once widespread across South Asia (Luthin, 1987; Clements et al., 2007), it now persists mainly in Northeast India and Cambodia (BirdLife International, 2023, 2024).

As a carnivore, the Greater Adjutant Stork (GAS) plays a critical ecological role atop wetland food chains (Saikia & Bhattacharjee, 1989; Rahmani et al., 1990). The villages of Dadara, Singimari, and Pachariya in Kamrup district, Assam, host the world's largest breeding colonies (Barman et al., 2020). The species forages in over 50 wetlands in Kamrup and frequently at the Guwahati garbage dump, where 300–450 individuals are often recorded (Barman & Sharma, 2017; Sharma et al., 2021). Despite the absence of known genetic threats (Sharma et al., 2021), populations are impacted by human disturbances (Luthin, 1987; Barman et al., 2020). Conservation efforts in Northeast India and Cambodia have improved its status (Barman, 2024), yet numbers remain below 1% of historical levels, necessitating further research-driven conservation.

Foraging ecology, shaped by spatial and temporal food variation (Kushlan, 1981), is vital to feeding efficiency in wading birds (Whitfield & Blaber, 1979). However, foraging studies on storks are limited and largely species-specific (Maheswaran & Rahmani, 2001; Sundar, 2004; Kalam & Urfi, 2007), with sparse data on the Greater Adjutant. Insights into how its feeding success varies with habitat type and water depth are lacking. Storks adopt diverse strategies including 38 foraging techniques have been documented (Kushlan, 1978), including tactile foraging (Kahl, 1972), prey selection (Kalam & Urfi, 2007), and behavioral flexibility (Golawski & Kasprzykowski, 2021), but GAS-specific observations remain scarce. The Greater Adjutant is both a scavenger and predator, feeding on carrion, fish, rodents, mollusks, snakes, and frogs, either solitarily or in groups across wetlands and dumps (Barman & Sharma, 2017). Its foraging behaviors are influenced by seasonality (Kahl, 1964; Coulter, 1987), habitat features (Maheswaran & Rahmani, 2002), environmental conditions (Odum et al., 1995), and morphology (Coulter & Bryan, 1993; Urfi, 2011). Seasonal food variation affects species differently depending on body size and feeding style (Cairns, 1987). Colonial nesters like GAS require abundant food during breeding, often nesting near productive wetlands (Saikia & Bhattacharjee, 1989; Newton, 1998), with food availability directly impacting reproduction (Martin, 1987; Newton, 1998).

Morphological traits like beak and body size affect locomotion, energy expenditure, and foraging (Schmidt-Nielsen, 1984), influencing niche partitioning and diet specialization (Fairbairn, 2010), especially in colonies (Cook et al., 2013). Beak size determines prey handling (Navalon et al., 2019), while morphological adaptations promote flexible foraging (Grant & Grant, 2014; Norberg, 2021). Foraging modes are linked to such traits (Hancock & Kushlan, 1984), with limb adaptations enabling access to diverse feeding grounds (Norberg, 2021; Norberg & Norberg, 2023). Considering these factors, the present study aims to quantify the Greater Adjutant's foraging ecology by assessing seasonal variation, water depth, time of day, foraging success, prey handling time, prey profitability, and diet across wetlands, paddy fields, and garbage dumps in relation to morphometric traits.

MATERIALS AND METHODS

Study Sites/Areas

This study was conducted across three distinct habitat types in Kamrup District, Assam, India (Figs. 1a, 1b): (A) Wetlands: Six shallow, swampy wetlands: A1: Digheli Beel (Rahman, 2020); A2: Bhoka Beel, Dadara (Das et al., 2009); A3: Pondoba Beel (Barman et al., 2021); A4: Singimari Beel (Das, 2023); A5: Jeng Beel (Barman et al., 2021); A6: Deepor Beel - a Ramsar site; **(**B) Paddy Fields**:** Cultivated areas adjacent to wetlands and (C) Garbage Dump- a municipal solid waste site. Kamrup district (25°46’46”N–26°48’33”N; 90°48’20”E–91°50’23”E) spans 2,740 km², covering both banks of the Brahmaputra River. The region has a humid subtropical climate with annual rainfall around 2135.7 mm (monthly range 1500–2600 mm in summer). Temperatures range from 11.8 °C (January) to 31.8 °C (August) (Google Weather Chart, Kamrup district). Elevation varies between 46–68 m above sea level.

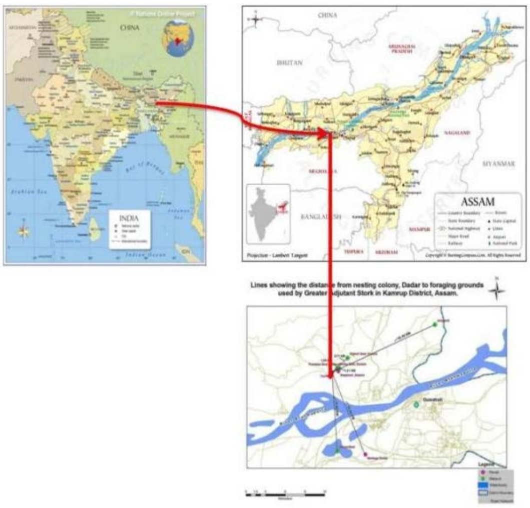
Habitat details and radial distances from nesting sites (Dadara, Pachariya, Singimari) are presented in Table 1. Site coordinates were recorded using Garmin GPS and Google Earth Pro (v7.0) and mapped using GIS to illustrate foraging-nesting site distances.

Field observations and data collection

The foraging behavior of GAS was recorded through direct observation and focal animal sampling over five years (Jan 2012–Dec 2017), covering both breeding (Sept–Feb) and non-breeding (Mar–Aug) seasons (Barman & Sharma, 2017). Observations were conducted twice weekly in wetlands and paddy fields, and thrice weekly at the garbage dump. Sites with a mean of > 50 birds were prioritized. Observations were made from 05:00–18:00 (non-breeding) and 06:00–17:00 (breeding), divided into four time blocks: 6:00–9:00, 9:00–12:00, 12:00–15:00, and 15:00–17:00 hours.

Foraging time and period

Foraging duration per individual was recorded in hours (Maheswaran, 1998). Loafing time was noted when a bird remained stationary away from water for >5 minutes (Clancy, 2011). Focal sampling followed after Altmann (1974).



a. Map of Kamrup District

b. Three habitat types

Figure 1. Study site locations and habitat types

Water Level

Water depth at foraging sites was estimated visually by leg submersion (Maheswaran & Rahmani, 2002; Clancy, 2011) and directly measured weekly with a calibrated tape. Depth categories: S1: 1–10 cm (lower leg joint), S2: 1–30 cm (full tarsometatarsus), S3: 1–40 cm (above tarsometatarsus), S4: 1–50 cm and S5: 1–70 cm (up to tibiotarsus).

Table 1. Description of foraging sites used by the Greater Adjutant Stork (*Leptoptilos dubius*) in Kamrup district, Assam. Aerial distance between the breeding colonies and foraging habitat (A) wetlands; (B) paddy fields and (C) the garbage dump

Habitat Type	Site No.	Location (GPS)	Prey Availability	Environmental Features	Radial Distance (km)
Wetland	A1	26°14’17.87”N, 91°39’17.92”E	Fish, amphibians, insects, snails	Shallow water, emergent vegetation, water hyacinth	1.2
Wetland	A2	26°14’18.03”N, 91°39’19.20”E	Fish, aquatic insects, snails	Permanent water, floating aquatic vegetation	1.3
Wetland	A3	26°13’50.89”N, 91°39’00.36”E	Fish, aquatic insects, snails	Seasonal wetland, marshy conditions	1.8
Wetland	A4	26°14’09.25”N, 91°39’13.68”E	Fish, crustaceans, insects	Floodplain wetland, variable depth	1.5
Wetland	A5	26°14’02.72”N, 91°39’01.74”E	Amphibians, insects, snails	Shallow pond, bordering vegetation	1.6
Wetland	A6	26°14’05.77”N, 91°39’08.10”E	Fish, amphibians, aquatic insects	Permanent wetland, some human disturbance	1.4
Paddy Field	B1	26°14’03.86”N, 91°39’12.31”E	Insects, small fish, frogs	Flooded during monsoon, proximity to wetland	1.6
Paddy Field	B2	26°14’07.03”N, 91°39’05.89”E	Aquatic insects, amphibians	Semi-permanent water, seasonal cultivation	1.7
Garbage Dump	C	26°12’36.30”N, 91°41’26.23”E	Offal, carrion, organic waste	High anthropogenic activity, dry and wet waste accumulation	4.2

Foraging behavior and strategies

Foraging behavior was observed using 10 × 50 binoculars and a 20× spotting scope, following Altmann (1974) and González (1997). Recorded behaviors included as: Foot stirring - leg movements to flush prey (Hancock et al., 1992), Steps - total steps taken by the focal bird (Frederick & Bildstein, 1992), Feeding attempts–number of bill jabs into water (Maheswaran & Rahmani, 2002), Feeding rate - prey captured per unit time (Frederick & Bildstein, 1992), Foraging success - prey caught per attempt (Dorfman et al., 2001), Peck rate - frequency of bill jabs while searching (Ishtiaq et al., 2010), Feeding success rate - fish caught per minute divided by total attempts (Ishtiaq et al., 2010), Foraging bout - 5-minute active foraging periods, timed with a stopwatch (Maheswaran & Rahmani, 2002). The term *foraging peck* refers to a quick beak strike to catch prey. A hand tally counter was used to count pecks and probes. Groping and lateral bill-swinging underwater were also noted (González, 1997).

Prey size and selection

Prey items were identified using standard zoological references at the University of Science and Technology, Meghalaya. In wetlands, prey size was visually estimated relative to the stork’s bill as one-fourth, half, or full bill length (Maheswaran & Rahmani, 2002). Actual size and weight were determined from regurgitated prey collected beneath nests during breeding, measuring length (head to tail) and weight with an electronic balance (Kalam & Urfi, 2007). Prey selection was evaluated following Chevailler et al. (2008).

Prey handling time (PHT)

PHT-the time from prey capture to swallowing (in seconds) was recorded across wetlands, paddy fields, and garbage dumps (Kushlan, 1979) using 10 × 50 binoculars from ~50 m. Stopwatches and tally counters were used during 5-minute foraging bouts, with a bout deemed successful if a fish was captured (Maheswaran & Rahmani, 2008). Prey size was estimated via bill length. To validate field estimates, PHT was also measured in captivity at the Assam State Zoo on six adult and six sub-adult storks using 50 known-size prey items per category. Observations occurred during 9:00–11:00 am and 3:00–4:00 pm over 12 days/month under varied water depths.

Prey profitability

Prey identified from regurgitates were matched with market specimens to determine length and weight. Major prey species included *Puntius puntius*, *Labeo rohita*, *Channa* spp., *Monopterus cuchia*, and *Heteropneustes fossilis*. These were offered to captive storks in 30 × 30 × 30 cm containers. PHT was recorded upon capture, and prey profitability calculated (Maheswaran & Rahmani, 2002) as: Prey Profitability = Prey weight (g)/PHT (s).

Foraging techniques

Ten distinct foraging techniques of the Greater Adjutant Stork were identified through pilot surveys and existing literature (Kushlan, 1977; Dorfman et al., 2001; Clancy, 2011), with acronyms adopted from Clancy (2011). Both visual and tactile methods, as well as combinations of the two (Sundar, 2004), were observed. These included: walking to water while visually scanning (WVS; Clancy, 2011); standing still and scanning the water surface (SVS; Maheswaran & Rahmani, 2002); continuous probing while walking in water (WP; Maheswaran & Rahmani, 2002); walking with visual attention and intermittent probing (WSP; Sundar, 2004; Clancy, 2011); running after visible prey (RDP; Dorfman et al., 2001); probing at a fixed point (PR; Clancy, 2011); standing and probing without movement (SP; Clancy, 2011); walking while probing and shaking the bill (WPS; Clancy, 2011); and groping through aquatic vegetation using the submerged bill (AG; this study).

Diet composition

During the breeding season, diet was assessed primarily from regurgitated prey at nesting sites. While exact identification was not always possible, dominant fish species observed at nearby wetland fish-landing sites were considered representative (Kalam & Urfi, 2007).

Body morphometry

Morphometric data were collected from 12 live (6 adults, 6 sub-adults) and 14 deceased storks at Assam State Zoo (Cwiertnia et al., 2006), assisted by a veterinarian. Measurements included: bill length (CULM), tibia, tarsus, wingspan, body length, depth, head length and breadth, tail length, and body mass (± 0.2 kg, spring balance).

Statistical analysis

Data were analyzed using PAST v4 and XLSTAT 21. One-way ANOVA (F-test) assessed variation in behavioral traits. Pearson's correlation (r; Zar, 1999) evaluated relationships among variables such as prey handling time (PHT), water depth, and prey size, helping to identify key drivers of foraging rate, prey choice, and energy efficiency.

RESULTS

Individual count

The GAS, which lacks sexual dimorphism, was most frequently observed during December (27%) and February (29%) at shallow water depths of 1–10 cm (Site S1). Few individuals were recorded at Sites S4 and S5. During summer, 20–25% of the birds were observed foraging in paddy fields and 30–40% at garbage dumps (Fig. 2).

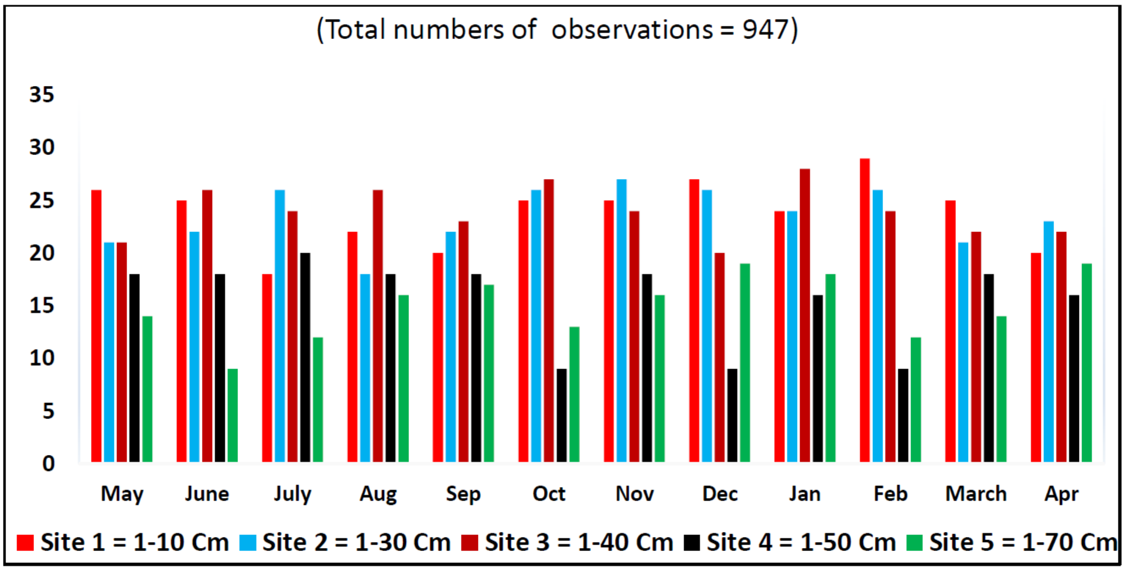


Figure 2. Greater Adjutant Stork at various water depths (S1 to S5) in wetlands during different months in a year

Foraging time

GAS showed peak foraging activity in the morning, particularly between 9:00–11:00 AM, with a secondary peak from 3:00–4:00 PM. In summer, the main foraging period shifted slightly earlier, between 8:00–11:00 AM. No nocturnal foraging behavior was observed.

Seasonal foraging success

Prey capture rates were significantly higher during the breeding season (~75–90%), coinciding with lower water levels and prey concentration in shallow pools. In contrast, during the non-breeding season, prey became more dispersed due to rising water levels, resulting in lower capture success (~30–50%).

Prey size by habitat

In wetlands, fish prey ranged from 5–20 cm, while eels and snakes measured 20–30 cm. In paddy fields, fish were smaller (5–10 cm), and eels/snakes ranged from 15–30 cm. At garbage dumps, prey size was not clearly defined (ND) but typically included various discarded animal materials.

Foraging behavior

The GAS exhibited seasonal variations in foraging behavior influenced by environmental conditions and prey availability (Table 2). The primary technique used was the standing position (60–80%), where the bird waited upright for 5–10 minutes before striking at prey, regardless of season. This was often followed by walking into the water, stirring vegetation (15–40 times per 5 minutes), and stepping deeper into the water. GAS also employed the walk-and-pick method, slowly moving through wetlands and agricultural fields while visually scanning for prey. During the breeding season, prey attempt and capture rates were highest in wetlands (60–80%). In contrast, capture rates in paddy fields during the non-breeding summer period were slightly lower (50–60%).

The GAS was observed to be a solitary forager, and prey capture data were recorded accordingly across different habitat sites. Bout duration, under similar foraging intensity (5 minutes), remained consistent in wetlands and paddy fields, while garbage dumps supported longer foraging bouts ranging from 8 to 20 minutes. The highest peck rate was observed in wetlands 20–50 pecks/minute during the non-breeding season and 30–75 during the breeding season compared to paddy fields and garbage dumps. Although the pecking rate in paddy fields was slower, feeding rates were highest at garbage dumps, indicating more frequent prey capture attempts (Table 2).

Table 2. Comparative foraging aspects of the Greater Adjutant Stork (*Leptoptilos dubius*) across three habitat types in Assam, India. N = Number of observations

Foraging aspect	Measurement description	Wetlands (N = 113)	Paddy fields (N = 66)	Garbage dump (N = 67)
Foot stirring	Number of times water disturbed per 5 minutes	2–50	1–5	Not detected
Step rate	Number of steps per minute during foraging	7–15	10–20	10–20
Feeding attempts	Number of bill jabs per 5 minutes (Non-breeding/Breeding)	2–8/2–15	2–5	2–5
Feeding rate	Prey captured per minute (Non-breeding/Breeding)	0.7–2.0/2.0–7.0	0.9–3.0	1.0–4.0/1.5–5.5
Feeding success	Percent of successful prey captures (Non-breeding/Breeding)	40–60%/50–80%	50–70%	60–80%
Peck rate	Number of pecks per minute (Non-breeding/Breeding)	20–50/30–75	20–50	5–15
Bout duration	Duration of uninterrupted foraging (minutes, NB/B)	5–15/5–30	5–15	8–20
Prey catch per bout	Number of prey captured per foraging bout (NB/B)	4–10/5–20	5–15	6–15
Prey composition	Estimated prey type proportions	Fish (70–80%), Eel (10–20%), Frog (5–10)		

Notes: NB = Non-breeding period, B= Breeding period

Prey handling time (PHT)

Foraging behavior data also included prey size, PHT, and water depth across various habitats - wetlands, paddy fields, garbage dumps, and captivity. Analysis of success rates per bout in these different conditions provided significant insights into the foraging efficiency of GAS in varied environments (Table 3).

Analysis of the Foraging success of the GAS based on the Correlation of matrix presented significant relationships as 1. PHT vs Feeding success (r = 0.478), a moderately positive correlation; 2. Feeding success vs Steps (r = 0.966), a strong positive correlation**;** 3**.** Peck vs water level (r = -0.522) a negative correlation**;** 4**.** PHT vs Foot length (r = 0.706**)** a strong positive correlation; 5. Water level vs Feeding success (r **=** -0.839**)** a strong inverse relations; 6. PHT vs Water level (r = 0.860**)** the strong positive correlation; 7. Foot length vs Steps (r = -0.632), an inverse relation.

Table 3. Prey size, water depth, foraging attempts and success of the Greater Adjutant Stork (*Leptoptilos dubius*) across different habitat strata and conditions

Habitat/Strata	≥ 5 cm < br > (1/4 beak)	≥ 8 cm < br > (1/3 beak)	≥ 15 cm < br > (1/2 beak)	Full beak length < br > or above	Foraging attempts (bouts) & < br > Success (%)
Wetland: S1	30–40 ± 4.0 (N = 80)	35–40 ± 2.0 (N = 20)	30–60 ± 4.0 (N = 80)	50–90 ± 4.0 (N = 22; Eel)	47.77 ± 9.33 (n = 41); 85.10%
S2	30–45 ± 5.0 (N = 85)	35–45 ± 2.0 (N = 65)	40–70 ± 5.0 (N = 85)	60–120 ± 5.0 (N = 15; Snake)	59.88 ± 7.89 (n = 49); 81.61%
S3	30–50 ± 3.0 (N = 350)	40–45 ± 3.0 (N = 120)	40–70 ± 5.0 (N = 48)	60–140 ± 6.0 (N = 15; Snake)	133.25 ± 9.58 (n = 97); 72.44%
S4	40–55 ± 4.0 (N = 320)	40–60 ± 4.0 (N = 200)	40–80 ± 4.0 (N = 125)	40–90 ± 5.0 (N = 35)	170.00 ± 11.39 (n = 83); 48.00%
S5	40–60 ± 5.0 (N = 22)	40–80 ± 5.0 (N = 80)	50–80 ± 5.0 (N = 100)	40–100 ± 5.0 (N = 25)	135.25 ± 9.47 (n = 59); 44.29%
Paddy Field (> 6 cm depth)	20–30 ± 2.0 (N = 90)	20–30 ± 4.0 (N = 150)	25–35 ± 6.0 (N = 121)	40–120 ± 6.0 (N = 23; 9 Eels + 15 Fish)	120.33 ± 9.61 (n = 87); 72.55%
Total Observations	32–47 ± 4.0 (N = 947)	35–50 ± 3.5 (N = 635)	31–66 ± 4.8 (N = 559)	48–95 ± 5.2 (N = 125)	666.5 ± 9.54 (n = 416); 62.46%
Captivity	10–30 ± 4.0 (N = 50)	20–40 ± 5.0 (N = 50)	20–60 ± 4.0 (N = 50)	30–90 ± 6.0 (N = 50; 12 Eels + 38 Fish)	50.00 (n = 29); 58.00%
Garbage Dump	15–70 ± 6.0 (N = 123)		Not applicable		

Note: PHT is implied through prey size and water depth: Sample sizes (N): indicate the number of observations within each size class: Values in parentheses (n) indicate the number of bouts to compute success rates. Captivity includes prey type as noted; wild data includes habitat-specific prey types such as fish, eel, and snakes.

Foraging techniques

The GAS exhibited varied foraging techniques across habitats, influenced by environmental conditions. In wetlands. Walking to water with visual search (WVS) and Standing and visual scanning (SVS) were the most frequent and time-consuming techniques, highlighting a strong reliance on visual cues in shallow waters. Walking with visual and intermittent probing (WSP) and Walking in water with constant probing (WP) followed in bout frequency but contributed less to total foraging time, suggesting these were brief, exploratory bouts. WSP often included bill-shaking to detect hidden prey, blending tactile and visual methods. Less common techniques- Running after detectable prey (RDP)**,** Probing at a fixed point (PR)**,** Standing and probing (SP)**,** and Walking, probing, and shaking the bill (WPS) **-** showed low bout and time percentages, often with bout frequency exceeding time, indicating short, possibly opportunistic use. RDP, for example, occurred in response to escaping prey. Active groping (AG)**,** mainly observed in paddy fields, involved tactile probing in low-visibility conditions and accounted for 7–10% of the foraging effort. Overall, visual strategies (WVS, SVS) dominated in both bout frequency and time, while tactile and mixed methods were used flexibly based on water depth, turbidity, and prey availability. The disparity between bout and time percentages across techniques (Fig. 3) reflects the GAS's adaptable foraging behavior in diverse habitats.

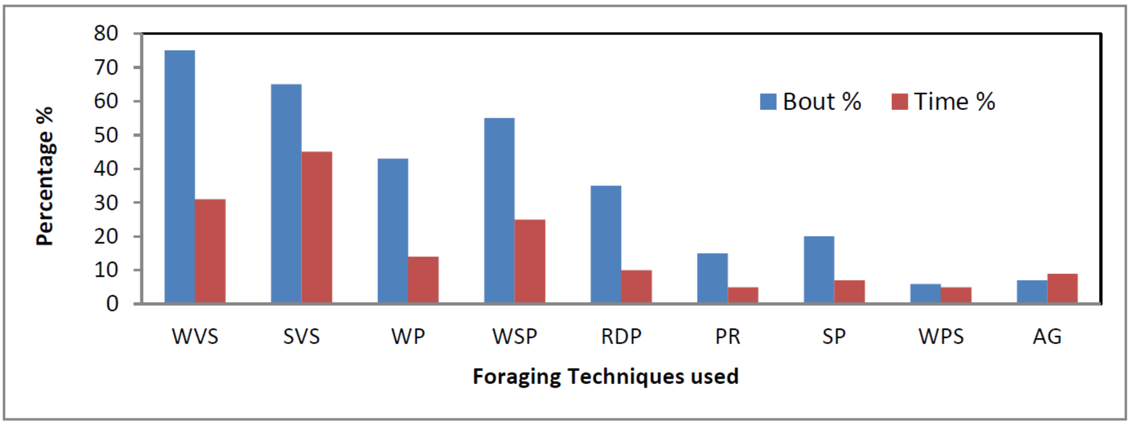


Figure 3. Different foraging techniques used represented by bout against time in the capture of prey in wetlands

Prey profitability

The highest prey profitability in chick (2.03 for *P. puntius*), sub-adult (2.76 for *C. punctatus*) and adult stork (3.09 for *M. cuchia*) was recorded in captivity (Fig. 4).

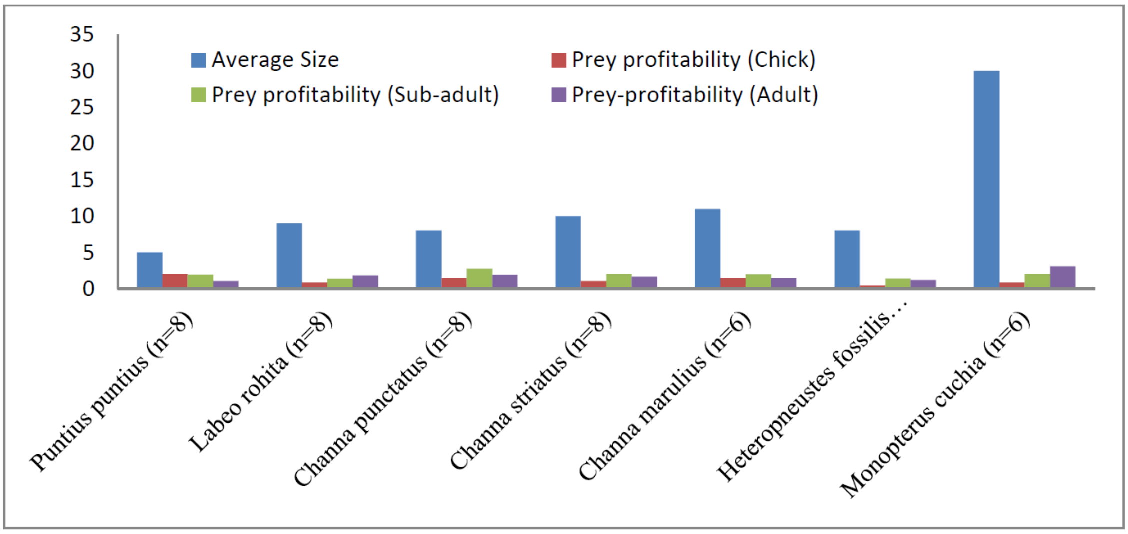


Figure 4. Prey profitability recorded for chick, sub-adult and adult Greater Adjutant Stork in captivity, the Assam State Zoo, Guwahati

DISCUSSION

The foraging ecology of the GAS is shaped by habitat type, prey availability, and seasonal dynamics. Colonial breeders along the Brahmaputra's north bank (Barman et al., 2020), GAS exhibit foraging behaviors influenced by prey density and energy optimization (Rose & Nol, 2010; Deboelpaep et al., 2020), consistent with optimal foraging theory (Krebs et al., 1983). These behaviors reflect trade-offs between efficiency and predation risk (Houston et al., 1993), as also seen in other storks (Alonso et al., 1994; Yurek et al., 2024).

Wetlands were used year-round, while paddy fields were preferred during monsoon, consistent with Black-necked Stork patterns (Sundar, 2005). GAS typically foraged within

0.9–15 km of nesting sites, similar to related species (Sundar, 2005; Bryan & Coulter, 1987; Shao et al., 2015). Foraging peaked during 9–11 a.m. and 3–5 p.m., aligning with White Stork rhythms (Alonso et al., 1994), lasting up to 6–8 hours daily (Kaatz et al., 2002).

Prey's success varied by type, habitat, and season (Alonso et al., 1994; Olsson & Bolin, 2014; Janiszewski et al., 2014). The water level at wetlands (Site A) affected prey visibility and accessibility, mirroring Hooded Crane foraging (Zheng et al., 2015). GAS preferred prey-rich areas (Das et al., 2009; Rahman, 2020). Group foraging (4–15 individuals) occurred in wetlands and dumps; solitary foraging dominated paddy fields, paralleling *C. ciconia* and *L. javanicus* (Kaatz et al., 2002; Sundar, 2005). Techniques such as foot-stirring and walk-and-pick resembled Painted Stork behavior (Kalam & Urfi, 2007). Foraging effort intensified during the breeding season due to higher energetic demands (Kalam & Urfi, 2007).

Feeding success (50–80%) and peck rates (30–60/min) were highest in wetlands during breeding, reflecting adaptability to changing water levels (Ishtiaq et al., 2010). Although water depth was not the sole predictor of success, yet it influenced prey accessibility. Garbage dumps provided stable but potentially hazardous food sources (Dorfman et al., 2001). Diet primarily comprised fish, particularly *Monopterus cuchia* and *Heteropneustes fossilis*, similar to *Ciconia nigra* preferences (Chevallier et al., 2008). Feeding bouts lasted 5–15 minutes in wetlands/paddy fields and 8–20 minutes in dumps due to carcass processing. Higher prey catch per bout (5–15) was observed in paddy fields and dumps, correlating with prey density.

Shallow water enhanced prey detection (Collazo et al., 2002; Clancy, 2011). Tactile foraging improved capture of hidden prey (Kushlan, 1978), especially during seasonal paddy field flooding (Rezaeisabzevar et al., 2020). Feeding rates at dumps (1–5/min) exceeded those in live-prey habitats due to static food sources (Mandal et al., 2022; Raghuraman, 2024). Non-breeding individuals were more active in summer, possibly due to nutritional stress (Tryjanowski et al., 2006; Kruszyk & Ciach, 2010). GAS roosted in wetlands near dumps (López-Calderón et al., 2023), reflecting behavioral flexibility. However, scavenging decreased peck rates and increased ingestion risks (Henry et al., 2011).

PHT increased with prey size i.e.20–60 s for small fish; 50–140 s for eels/snakes. Site S4 recorded the highest PHT (170 ± 11.39 s), likely due to struggling prey (Maheswaran & Rahmani, 2008). In captivity, PHT was shorter (10–60 s); in dumps, it ranged from 15–70 s due to varied food types. PHT negatively correlated with success, while feeding success positively correlated with steps (r = 0.966) and peck rate (r = 0.842). High water depth reduced foraging efficiency (Jeschke et al., 2002). Technique selection shifted with water depth from probing to visual/tactile strategies. High peck/probe rates indicated habitat quality and energy gain (Rose & Nol, 2010; Mott et al., 2023). Despite consistent feeding, dumps present long-term ecological risks.

Nine foraging techniques (Fig. 4) varied by prey visibility and habitat. Walking visual search (70–75%) dominated in clear water, while Active groping (AG) was favored in turbid wetlands (Kahl, 1971; Gonzalez, 1997). GAS switched between visual and tactile methods depending on habitat and prey type (Kushlan, 1977; Kalam & Urfi, 2007). For elusive prey like *M. cuchia*, tactile strategies were more effective. Medium-sized prey such as *M. cuchia* and *H. fossilis* yielded the highest energy returns (Fig. 5). Cyprinidae and Channidae were dietary staples (Hunt et al., 2017), with *M. cuchia* being especially profitable for adults-similar to patterns in Black-necked Storks (Maheswaran & Rahmani, 2002). Regurgitate analyses confirmed these taxa as dietary cores. During non-breeding, increased dump use reflected adaptive foraging (Gilbert et al., 2016).

Morphological traits supported foraging success. The long, sensitive bill enabled both tactile and visual feeding (Hancock et al., 1992); elongated wings and legs reduced competition and aided habitat use (Kahl, 1972; Bryan et al., 1995). Long tibiotarsi allowed deep-water foraging (Fasola, 1994; Kushlan, 1978), and the 35 cm tail provided balance during strikes (Kahl, 1971). Body morphometry, especially bill, leg, wing, and head dimensions, was positively linked to foraging efficiency.

CONCLUSION

The GAS demonstrates significant behavioral and ecological adaptability, foraging successfully in wetlands, paddy fields, and garbage dumps. Its diverse techniques and selection of energy-rich prey reflect strategic responses to ecological variability. Morphological traits such as long legs and a strong bill enhance efficiency, especially in shallow wetlands. While garbage dumps provide reliable food, growing reliance on such habitats raises health and sustainability concerns. This study offers comprehensive insights into GAS foraging ecology, serving as critical baseline data for conservation planning. Identifying key habitat features and behaviors can inform targeted management, with an emphasis on wetland conservation. Continued monitoring of anthropogenic impacts is essential for long-term protection of this ‘Near Threatened species’.

Acknowledgements: The authors are grateful to the Gauhati University, University of Science and Technology Meghalaya, Aaranyak in Guwahati and TCRP Foundation. Also, profusely extend thanks to Dr. Ryan Bell, USA as well as Dr. Arup Nama Das, USTM for their constant support and encouragement.

REFERENCES

Ali S., Ripley S. D., 1987. Compact handbook of the birds of India and Pakistan: together with those of Bangladesh, Nepal, Bhutan and Sri Lanka. Oxford University Press Delhi, New York, 2nd Ed, pp. 721.

Alonso J. A., Alonso J. C., Carrascal L. M., Muñoz-Pulido R., 1994. Flock size and foraging decisions in central place foraging white storks, Ciconia ciconia. *Behaviour*, 129(3): 279−292.

Altmann J., 1974. Observational study of behavior: sampling methods. *Behaviour*, 49: 227−267.

Barman P. D., Sharma D. K., 2017. Behavioural ethogram of the endangered Greater Adjutant Stork *Leptoptilos dubius* (Gmelin). *International Journal of Zoology Studies*, 2(6): 272–281.

Barman P. D., Sharma D. K., Cockrem J. F., Malakar M., Kakati B., Melvin, T., 2020. Saving the Greater Adjutant Stork by Changing Perceptions and Linking to Assamese Traditions in India. *Ethnobiology Letters*, 11(2): 20−29. https://doi.org/10.14237/ebl.11.2.2020.1648

Barman P. D., 2024. Species Fact sheet: *Leptotilus dubius*: Birdlife International. http://www.birdlife.org

BirdLife International., 2023. Leptoptilos dubius. The IUCN Red List of Threatened Species 2023: T22697721A229597779. https://dx.doi.org/10.2305/IUCN

BirdLife International., 2024. Species factsheet: Greater Adjutant *Leptoptilos dubius*. Downloaded from https://datazone.birdlife.org/species/factsheet/greater-adjutant-leptoptilos-dubius on 07/09/2024.

Bryan A. L. Jr., Coulter M. C., 1987. Foraging flight characteristics of Wood Storks in east-central Georgia, USA. *Colonial Waterbirds* 10:157–161.

Bryan Jr. A. L., Coulter M. C., Pennycuick C. J., 1995. Foraging strategies and energetic costs of foraging flights by breeding wood storks. *The Condor*, 97(1): 133−140.

Cairns D. K., 1987. Seabirds as indicators of marine food supplies. *Biolgical Oceanography*, 5: 261–271.

Chevallier D., Baillon F., Robin J-P., Maho Y. L., Massemin-Challet S., 2008. Prey selection of the black stork in the African wintering area. *Journal of Zoology*, 276(3): 276−284. https://doi.org/10.1111/j.1469-7998.2008.00488

Clancy G. P., 2011. The feeding behaviour and diet of the Black-necked Stork Ephippiorhynchus asiaticus australis in northern New South Wales. *Corella*, 36(1): 17–23.

Clements T., O'Kelly H., Sun V., 2007. Monitoring of Large Waterbirds at PrekToal, Tonle Sap Great Lake 2001–2007. Wildlife Conservation Society Cambodia Program, Phnom Penh, Cambodia. pp. 60.

Collazo J. A., Dawn A. O. H., Kelly C. A., 2002. Accessible habitat for shorebirds: Factors influencing its availability and conservation implications. *Waterbirds,* 25: 13−24. https://www.jstor.org/stable/i267776

Cook T. R., Lescroel A., Cherel Y., Kato A., Bost C. A., 2013. Can foraging ecology drive the evolution of body size in a diving endotherm? *PLoS ONE*, 8: e56297. doi: 10.1371/journal.pone.0056297

Coulter M. C., 1987. Foraging and breeding ecology of Wood Storks in east-central Georgia. Proceedings of the Third Southeastem Non-game and Endangered Wildlife Symposium. Georgia Department of Natural Resources, Atlanta, GA.: 21−27.

Coulter M. C., Bryan Jr A. L., 1993. Foraging ecology of wood storks (*Mycteria americana*) in East-central Georgia I. Characteristics of foraging Sites. *Colonial Waterbirds*, 16(1): 59−70.

Ćwiertnia P., Kwieciński Z., Kwiecińska H., Wysocki A., Tryjanowski P., Ollson O., 2006. Sexing of white storks Ciconia ciconia based on biometric measurements. White stork study in Poland: biology, ecology and conservation (Eds Tryjanowski, P, Sparks, T.H. & Jerzak, L.). Bogucki Wydawnictwo Naukowe, Poznań. pp. 123−129.

Das P., Behera B. K., Nagachan S. V., 2009. Beels of Assam An Overview. Wetlands of North East India: Ecology, Aquatic Bioresources and Conservation. Akansha Publishing House, New Delhi, India. pp. 29−40.

Das A. N., 2023. Studies on the Systematics and Ecology of Icthyofauna of Dheer Beel Assam. PhD Thesis. University of Science and Technology, Meghalaya, India. pp. 345.

Deboelpaep E., Coenegracht T., De Wlof L., Libert A, Vanschoenwinkel B., Koedam N., 2020. Bioenergetic data show weak spatial but strong seasonal differences in wetland quality for waders in a Mediterranean migration bottleneck. *Freshwater Biology*, 65: 1529−1542.

Dorfman E. J., Lamont A., Dickman C. R., 2001. Foraging behaviour and success of Black-necked Storks (*Ephippiorhynchus asiaticus*) in Australia: implications for management. *Emu-Austral Ornithology*, 101(2): 145−149.

Fairbairn D. J., 2010. Allometry for sexual size dimorphism: pattern and process in the co-evolution of body size in males and females. *Annual Review of Ecology and Systematics*, 28: 659–687.

Fasola M., 1994. Resource use of foraging herons in agricultural and non-agricultural wetlands in Italy.*Colonial Waterbirds*, 17(2): 156−161.

Frederick P. C., Bildstein K. L., 1992. Foraging Ecology of seven species of neotropical ibis Threskiornithidae) during the dry season in the Lanos of Venezuela. Wilson Bulletin 104: 1-21.

Gilbert N. I., Correia R. A., Silva J. P., Pacheco C., Catry I., Atkinson P. W., Franco A. M., 2016. Are white storks addicted to junk food? Impacts of landfill use on the movement and behaviour of resident white storks (Ciconia ciconia) from a partially migratory population. *Movement ecology*, 4(7): 1−13.

Golawski J. A., Kasprzykowski Z., 2021. Alternating foraging strategies in the white stork *Ciconia ciconia*: The effect of mowing meadows. *Agriculture, Ecosystems & Environment*, 319(1): 107563. doi: 10.1016/ J.AGEE.2021.107563

González J. A., 1997. Seasonal Variation in the Foraging Ecology of the Wood Stork in the Southern Llanos of Venezuela.*The Condor*, 99 (3): 671−680.

Goswami S. K., Patar P. J., 2007. Fall in the number of Greater Adjutant nests in Nagaon, Assam, India. CLP project ID: F03110012.

Grant P. R., Grant B. R., 2014. Natural Selection and Evolution:40 years of Evaluation: Darwin's Finches on Dophne Major Island. Princeton University Press pp. 55−76. doi: 10.2307/j.ctt5hhncc

Hancock J. A., Kushlan J. A., 1984. The herons handbook New York: Harper & Row. pp. 296.

Hancock J. A., Kushlan, J. A., Kahl M. P., 1992. 'Storks, Ibises and Spoonbills of the World'. Academic Press: London, pp. 385.

Henry P. Y., Wey G., Balanca G., 2011. Rubber band ingestion by a rubbish dump dweller, the white stork (Ciconia ciconia). Waterbirds, 34: 504−08. https://doi.org/10.1675/063.034.0414

Houston A I., McNamara J. M., Hutchinson J. M. C., 1993. General results concerning the trade-off between gaining energy and avoiding predation. *Philos Trans R SocBiol Sci*, 341: 375–397. https://doi.org/10.1098/rstb.1993.0123

Hunt K. L., Fraser J. D., Karpanty S. M., Catlin D. H., 2017. Body condition of Pipling Plovers (*Charadrius melodus*) and prey abundance on flood created habitat on the Missouri River, USA, *The Wilson Journal of Ornithology*, 129(11): 754−764.

Ishtiaq F., Javed S., Coulter M. C., Rahmani A. R., 2010. Resource Portioning in three Sympatric Species of Stork in Keoladeo National Park, India. *Waterbirds*, 33(1): 41−49. doi:10.1675/063.033.0105

IUCN, 2018. The IUCN Red List of Threatened Species. Version 2017-3: www.iucnredlist.org.

Janiszewski T., Minias P., Wojciechowski Z., Grys M., 2014. Habitat selection by the White Stork Ciconia ciconia during foraging in the non-breeding season. *Acta Ornithologica*, 48(2): 119–126.

Jeschke J. M., Kopp M., Tollrian R., 2002. Predator functional responses: discriminating between handling and digesting prey. *Ecol. Monograph* 72: 95-112. https://doi.10.1890/0012

Jetz W., Thomas G. H., Joy J. B., Redding D. W., Hartmann K., Mooers A. O., 2014. Global distribution and conservation of evolutionary distinctness in birds. *Current Biology*, 24(9): 919−930. https://doi.org/10.1016/j.cub.2014.03.011

Kaatz C., Engler S., Schmidt A., 2002. Comparative studies on the foraging ecology of the White Stork Ciconia ciconia in eastern Germany. *Vogelwelt*. 123: 109–118

Kahl M. P., 1964. Food ecology of the Wood Storks (Mycteria americana) in Florida. Ecol. II Monograph, 34: 97−117.

Kahl M. P., 1971. Food and Feeding Behavior of Openbill Storks. *Journal of Zoology*, 164(4): 491−539.

Kahl M. P., 1972. Comparative ethology of the Ciconiidae. *The Living Bird*,11: 39-51.

Kalam A., Urfi A. J., 2007. Foraging behaviour and prey size of the painted stork. *Journal of Zoology*, 274(2): 198−204. https://doi.org/10.1111/j.1469-7998.2007.00374.x

Krebs J. R., Stephens D. W., Sutherland W. J., 1983. Perspectives in optimal foraging. In Perspectives in Ornithology. Cambridge University Press, USA. pp. 165−221.

Kruszyk R., Ciach M., 2010. White Storks, Ciconia ciconia, forage on rubbish dumps in Poland- a novel behaviour in population. *European Journal of Wildlife Research*, 56: 83–87. https://doi.org/10.1007/s10344-009-0313

Kushlan J. A., 1977. Population energetics of the American white ibis. *The Auk*, 94(1): 114−122.

Kushlan J. A., 1978. Feeding ecology of wading birds. Wading Birds (Sprunt IV, A., Ogden, J. C., and Winckler, S. (Eds.), pp. 249−297. National Audubon Society Research Report No. 7.

Kushlan J.A., 1979. Feeding ecology and Prey selecti on in the white ibis. *Condor*, 81(4): 376−389.

López-Calderón C., Martín-Vélez V., Blas J., Höfle U., Sánchez M. I., Flack A., Fiedler W., Wikelski M., Green A. J., 2023. White stork movements reveal the ecological connectivity between landfills and different habitats. Mov Ecol. 11(1): 18. https://doi.org/10.1186/s40462-023-00380-7. PMID: 36978169; PMCID: PMC10045253.

Luthin C. S., 1987. Status of and conservation priorities for the world's stork species. *Colonial Waterbirds*, 10(2): 181−202. https://doi.org/10.2307/1521258

Maheswaran G., Rrahmani A. R. 2001. Effects of water level changes and wading bird abundance on the foraging behaviour of blacknecked storks Ephippiorhynchus asiaticus in Dudwa National Park, *India. Journal Bioscience*, 26(3): 373–382. https://doi.org/10.1007/BF02703747

Maheswaran G., Rahmani A. R., 2002. Foraging behaviour and feeding success of the black-necked stork (Ephippiorhynchus asiaticus) in Dudwa National Park, Uttar Pradesh, India. *Journal of Zoology*, 258(2): 189−195

Maheswaran G., Rahmani A. R., 2008. Foraging technique and prey-handling time in black-necked stork (Ephippiorhynchus asiaticus). *Integrative Zoology*, 3(4): 274−279. https://doi.org/10.1111/j.1749-4877.2008.00101.x

Mandal J., Bhaduri R., Sharma N., 2022. The Struggle of Existence for Scavenging Greater Adjutants Leptoptilos dubius. Imperiled: The Encyclopedia of Conservation, 1, pp. 77–87. doi: 10.1016/B978-0-12-821139-7.00229-4

Martin T. E., 1987. Food as a limit on breeding birds: a life-history perspective. *AnnualEcology and Systematics*, 18(1): 453−487.

Misra A. M., Mandal J. N., 2009. Discovery of a breeding ground of the Greater Adjutant *Leptoptilos dubius* and their conservation in the floodplains of Bihar, India. *Journal of Bombay Natural History Society* 106(2): 190−197.

Mott R., Prowse T. A. A., Jackson M. V., Rogers D. J., O'Connor J. A., Brookes J. D., Cassey P., 2023. Measuring habitat quality for waterbirds: A Review. *Ecology and Evolution*, 13: e9905. https//doi.org/10.1002/ece3.9905

Navalón G., Bright J. A., Marugán-Lobón J., Rayfield E. J., 2019. The evolutionary relationship among beak shape, mechanical advantage, and feeding ecology in modern birds. *Evolution*, 73(3): 422–435. https//doi.org/10.1111/evo.13655

Newton I., 1998. Geographies, Population Limitation in Birds. Pergamon Oxford Academic Press, pp. 481−555.

Norberg R. A., 2021.To minimize foraging time, use high efficiency, energy expensive search and capture methods when food is abundant but low efficiency, low cost methods during food shortages. *Ecological Evolution*, 11(23): 16537−16546. https//doi.org/10.1002/ece3.8204

Norberg U. M., Norberg R. A., 2023. Evolutionary divergence of body size and wing and leg structure in relation to foraging mode in Darwin's Galapagos finches. *Biological Journal of the Linnean Society*, 2023, 140(2): 240–260. https//doi.org/10.1093/biolinnean/blad053

Odum W. E., Odum E. P., Odum H. T., 1995. Nature's pulsing paradigm. *Estuaries*, 18: 547–555. https://doi.org/10.2307/1352375

Olsson O., Bolin A., 2014. A model for habitat selection and species distribution derived from central place foraging theory. *Oecologia*, 175(2): 537–548. https//doi.org/10.1007/s00442-014-2931-9

Raghuraman A., 2024. Ghouls among the Garbage – The Greater Adjutants of Guwahati, July 7. https://www.greeno-greindia.org/category/birds-2/bird-behaviour

Rahman M., 2020. Ornamental fish and certain phytoplankton diversity in Digholi Beel of Kamrup district of Assam, India. *International Journal of Applied Research*, 6(12): 323-327

Rahmani A. R., Narayan G., Rosalind L., 1990. Status of the Greater Adjutant (Leptoptilosdubius) in the Indian subcontinent. *Colonial Waterbirds*, 13: 139–142

Rezaeisabzevar Y., Bazargan A., Zohourian B., 2020. Landfll site selection using multi criteria decision making: Infuential factors for comparing locations. *J Environ Sci*, 93: 170–84. https://doi.org/10.1016/j.jes.2020.02.030

Rose M., Nol E., 2010. Foraging behavior of non-breeding Semipalmated Plovers. Waterbirds, 33(1): 59−69. https//doi.org/10.1675/063.033.0107

Saikia P. K., Bhattacharjee P. C., 1989. A preliminary survey of adjutant storks in Assam. *Asian Wetland News*, 2(2): 14−15.

Schmidt-Nielsen K., 1984. Scaling: why is animal size so important? Cambridge University Press, pp. 241.

Shao M., Guo H., Cui P., Hu B., 2015. Preliminary study on time budget and foraging strategy of wintering Oriental white stork at Poyang Lake, Jiangxi Province, China. *Pakistan Journal of Zoology*, 47(1): 71−78.

Sharma D. K., Baruah C., Barman P. D., 2021. Perfect and Imperfect Microsatellite Markers in Determination of Genetic Status of Greater Adjutant Stork (*Leptoptilos dubius* Gmelin). *Bioinform Proteom Opn Acc J*, 5(1): 000137. https//doi.org/10.23880/bpoj-16000137

Sundar K. S. G., 2004. Group size and habitat use by Black-necked Storks Ephippiorhynchus asiaticus in an agriculture-dominated landscape in Uttar Pradesh, India. *Bird Conserv. Int.*, 14(4): 323–334. https://doi.org/10.1017/S0959270904000358

Sundar K. S. G., 2005. Effectiveness of road transects and wetland visits for surveying Black- necked Storks Ephippiorhynchus asiaticus and Sarus Cranes Grus antigone in India. *Forktail*, 21: 27–32.

Tryjanowski P., Sparks T. H., Jerzak L. 2006. The white stork in Poland: studies in biology, ecology and conservation. Poznan, Bogucki Wydawnictwo Naukowe. https://nora.nerc.ac.uk/id/eprint/3133

Urfi A., 2011. Foraging ecology of the painted stork (*Mycteria leucocephala*): a review. *Waterbirds,* 34(4): 448–456. https://doi.org/10.1675/063.034.0407

Whitfield A. K., Blaber S. J. M., 1979. Feeding ecology of piscivorous birds at Lake St Lucia, Part 3: swimming birds. *Ostrich*, 50(1): 10−20.

Yurek S., DeAngelis D. L., Lee H. W., Tennenbaum S., 2024. Visualizing wading bird optimal foraging decisions with aggregation behaviors using individual-based modeling. *Ecological Modelling*, 493: 110702. https://doi.org/10.1016/j.ecolmodel.2024.110702

Zar J. H., 1999. Biostatistical Analysis (4th ed.). Upper Saddle River, NJ: Prentice Hall.

Zheng M., Zhou L., Zhao N., Xu W., 2015. Effects of variation in food resources on foraging habitat use by wintering Hooded Cranes (*Grus monacha*). *Avian Res*, 6: 11. https://doi.org/10.1186/s40657-015-0020-3