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Foraging strategies and bioindicator potential of Black-winged Stilt *(Himantopus himantopus)* in an urban river ecosystem of Patna, Bihar, India

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Abstract Urban wetlands and modified riverine systems are vital yet vulnerable habitats for waterbirds. This study explores the feeding ecology of Black-winged Stilt *(Himantopus himantopus)*, a key bioindicator species, in a modified riverine wetland in Patna, India. A detailed observation on Black-winged Stilt (BWS) foraging behaviour was conducted across five sites during January–March 2025. We also assessed the microhabitat characteristics, water quality, and prey availability. The spatial and temporal variation in BWS abundance and feeding activity, prey selection, and their correlations with environmental parameters (nutrient concentration and water depth) and the impact of human disturbance was investigated. BWS showed a strong preference for shallow (5–10 cm), highly eutrophic sites (nitrate = 3.25±0.14 mg/L, phosphate = 2.63±0.16 mg/L), which correlated with high densities of *Chironomus* larvae, *Tubifex* and *Moina*. Pecking was the dominant foraging technique (72%), with activity peaking in the early morning. These findings highlight the BWS's adaptability and bioindicator potential in urban environments. Conservation efforts should prioritize maintaining critical microhabitats, regulating disturbances, and promoting community engagement for sustainable avifaunal conservation.

Keywords: Black-winged Stilt, urban wetlands, foraging ecology, bioindicator, habitat preference, prey availability, anthropogenic disturbance, waterbird conservation

Összefoglalás A városi vizes élőhelyek és a módosított folyami rendszerek létfontosságú, de sérülékeny élőhelyei a vízimadaraknak. Ez a tanulmány az egyik legfontosabb bioindikátor faj, a gólyatöcs *(Himantopus himantopus)* táplálkozás-ökológiáját vizsgálja az indiai Patna egyik módosított folyami vizes élőhelyén. A gólyatöcs táplálkozási viselkedésének részletes megfigyelésére 2025 januárja és márciusa között öt helyszínen került sor. Ugyancsak felmértük a mikrohabitat jellegzetességeit, a vízminőséget és a zsákmányállatok elérhetőségét is. Megvizsgáltuk a faj abundanciájának és táplálkozási aktivitásának térbeli és időbeli változásait, a zsákmány kiválasztását, valamint ezek összefüggéseit a környezeti paraméterekkel (tápanyagkoncentráció és vízmélység) és az emberi zavarás hatásával. A gólyatöcs a sekély (5–10 cm), erősen eutrofizált (nitrát = 3,25±0,14 mg/l, foszfát = 2,63±0,16 mg/l) helyeket részesítette előnyben, ami a *Chironomus* lárvák, *Tubifex* és *Moina* nagy sűrűségével korrelált. A csipegetés volt a domináns táplálkozási technika (72%), az aktivitás a kora reggeli órákban volt a legmagasabb. Ezek az eredmények rávilágítanak a gólyatöcs alkalmazkodóképességére és bioindikátor-potenciáljára városi környezetben. A madárvilág megőrzése érdekében a természetvédelmi erőfeszítéseknek prioritásként kell kezelniük a kritikus mikroélőhelyek fenntartását, a zavaró tényezők szabályozását és a közösségi szerepvállalás előmozdítását.

Kulcsszavak: gólyatöcs, városi vizes élőhelyek, táplálkozás-ökológia, bioindikátor, élőhelypreferencia, zsákmány elérhetősége, antropogén zavarás, vízimadár-védelem

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Introduction

The Black-winged Stilt *(Himantopus himantopus)* (hereinafter: BWS) is a widely distributed wader species found across Europe, Asia, Africa, and Australia (Birdlife International 2025). It is easily identifiable by its distinctive morphology, characterized by exceptionally long legs, a slender bill, and striking black-and-white plumage (Maleko *et al.* 2023). This species shows remarkable adaptability, thriving in diverse wetland habitats, including natural marshes, floodplains, rice paddies, and human-modified systems such as sewage ponds (Sandeep Kaur *et al.* 2022, Maleko *et al.* 2023).

BWS is known for its flexible foraging behavior, primarily consuming aquatic invertebrates (Nagarajan & Thiyagesan 1996, Maleko *et al.* 2023). Its ability to persist and even thrive in disturbed or polluted wetland systems, often by adapting to exploit new or marginal habitats, makes it a valuable subject for studying ecological responses to urban modification (Rehman *et al.* 2021).

The riverine system around Patna, Bihar, India, serves as a compelling case study of urban-modified wetlands. Waterbirds, including the BWS, serve as important bioindicators of ecosystem changes and wetland health due to their sensitivity to habitat quality, their position within the food web and to the accumulation of pollutants (Joshi *et al.* 2021, Aarif *et al.* 2025). The unique morphological and behavioural traits of the BWS provide specific insights into microhabitat use and resource partitioning in disturbed environments. Monitoring the presence, abundance, and foraging success of this species can offer valuable information about the quality and availability of shallow-water habitats, which are often among the first to be impacted by urbanization and other anthropogenic pressures (Theodorou 2022).

This study integrates two complementary research perspectives within the same modified riverine system: a detailed examination of the foraging ecology of the BWS and the broad co-occurrence patterns of the general waterbird community with BWS.

Methods

The study was conducted along a 3.5-km urbanized stretch of a distributary channel of the Ganges River in Patna, Bihar, India. This river segment is located between Sabhyata Dwar (25.621935°N, 85.143886°E) and Anta Ghat (25.587126°N, 85.098380°E). The study area comprises of a mosaic of habitat types, including seasonal wetlands, areas impacted by agricultural runoff, shallow depressions, and zones influenced by religious activities. The river segment also features seasonal islands, embankments, sandbars, and partially vegetated banks, contributing to its ecological complexity.

For comprehensive data collection, five representative sites (Sites 1–5) were selected along this stretch *(Figure 1)*. Site selection was based on multiple criteria: accessibility, variation in water parameters, habitat diversity (e.g. presence and type of vegetation), and varying levels of human disturbance. The precise geographical coordinates for each of these five sites were recorded.

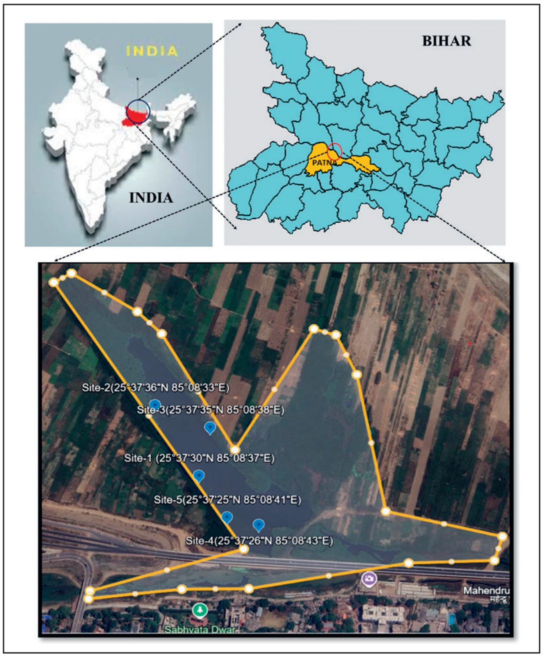

Figure 1. Map of the study area
1. ábra A vizsgálati terület térképe

Fixed vantage points were established at each of the five study sites for consistent scan sampling. We studied the behaviour of BWS by applying the focal animal sampling method (Altmann 1974). The overall waterbird community assessment was conducted over four months, from January to April 2025. More detailed observations, specifically targeting the foraging ecology of BWS, were carried out from January to March 2025. To account for diel variation in bird activity, observations were performed twice daily: early morning (7:00–10:00 AM) and late afternoon (3:30–5:30 PM).

To characterize microhabitat conditions at each site, several parameters were measured. Water depth was determined using a calibrated wading rod. Vegetation structure, a key component of wetland habitat, was evaluated using the line-intercept method along 10-meter transects, with dominant plant species recorded. Nitrate and phosphate concentrations were analysed using standard spectrophotometric methods, following protocols outlined by Trivedy and Goel (1986) and APHA (2017). Water clarity was assessed by measuring turbidity.

To assess the prey base available to the BWS, we sampled the benthic fauna and surface water organisms. Benthic macroinvertebrates were collected using an Ekman dredge, a tool effective for retrieving undisturbed sediment cores from soft-bottom habitats. Sediment samples were sieved through a 0.5 mm mesh to separate macroinvertebrates from fine sediments and preserved in 70% ethanol for laboratory analysis. In the laboratory, larvae were identified and counted under a stereomicroscope. Quantitative analysis of benthic abundance was performed using a fixed-area random subsampling technique, as described by Jones and Smol (2023), with a 10 × 10 cm plastic tray and 5 cm^2 random patches for subsampling. For surface water prey, specifically *Moina* spp., a Sedgewick-Rafter cell was used to count individuals in water samples.

Detailed analysis of BWS foraging behaviours was a central component of the study. Observable actions were categorized and recorded to quantify foraging activity throughout the study period. The primary foraging techniques identified and monitored were:

(1) pecking: individuals used their beaks to tap or strike surfaces, such as the water's edge or exposed mud, to uncover or capture prey

(2) probing: this involved inserting the beak into the substrate, typically mud or sand, to locate and extract buried prey

(3) surface skimming (or surface filtering): this behaviour was characterized by moving the beak along the water's surface or sediment to capture prey, such as small invertebrates or floating detritus.

Results

Prominent plant species found in the study area included wild river creeper *(Ipomoea carnea)*, cattail *(Typha angustifolia)*, water hyacinth *(Eichhornia crassipes)*, doob grass *(Cynodon dactylon)*, kans grass *(Saccharum spontaneum)*, garden pea *(Pisum sativum)*, field cudweed *(Filago arvensis)*, dill *(Anethum graveolens)*, flax *(Linum usitatissimum)*, common milkwort *(Polygala vulgaris)*, and curly dock *(Rumex crispus)*.

Common birds found at the study sites included Common Moorhen *(Gallinula chloropus)*, Grey-headed Swamphen *(Porphyrio poliocephalus)*, Eurasian Coot *(Fulica atra)*, Little Grebe *(Tachybaptus ruficollis)*, BWS, Little Ringed Plover *(Charadrius dubius)*, Red-wattled Lapwing *(Vanellus indicus)*, Common Sandpiper *(Actitis hypoleucos)*, Green Sandpiper *(Tringa ochropus)*, Wood Sandpiper *(T. glareola)*, Temminck's Stint *(Calidris temminckii)*, Little Egret *(Egretta garzetta)*, Indian Pond Heron *(Ardeola grayii)*, Western Cattle Egret *(Ardea ibis)*, Shikra *(Tachyspiza badia)*, Black Kite *(Milvus migrans)* and House Crow *(Corvus splendens)*.

Table 1. Environmental parameters observed at each site
1. táblázat A vizsgálati helyekre jellemző környezeti paraméterek

Site	Average depth (cm)	Vegetation cover	Turbidity	Nitrate (mg/l)	Phosphate (mg/l)	Dominant plant species
1	122	low	low	2.8±0.26	2.16±0.15	cattail, water hyacinth, kans grass, pea, common milkwort, curly dock
2	61–91	Dense	Low	2.09±0.03	0.78±0.08	cattail, kans grass
3	20–25	Moderate	High	2.37±0.19	1.7±0.14	wild river creeper, pea, common milkwort, curly dock
4	5–10	Sparse	Very high	3.25±0.14	2.63±0.16	cattail, kans grass
5	25–31	Moderate	High	2.48±0.12	1.76±0.13	water hyacinth, wild river creeper, doob grass, kans grass, curly dock

Water depth varied considerably across the five study sites *(Table 1)*. Nutrient levels, specifically nitrate and phosphate concentrations, also varied significantly. Site 4, the shallowest, recorded the highest level of phosphate and nitrate *(Table 1)*. Nutrient concentrations decreased in the order of Sites 1, 5, 3, and 2. Turbidity levels also differed, with Sites 4 and 5 exhibiting high turbidity and poor water transparency, while Sites 1–3 maintained clearer water conditions *(Table 1)*.

A total of 520 BWS were recorded across the five study sites during the observation period. We found the highest abundance of BWS (280 individuals) at site 4. In contrast, we did not observe BWS at Site 1, characterized by deep water and concrete embankments. Juvenile BWSs were observed at sites 2 and 5. BWS primarily foraged in open, shallow water zones with depths ranging from 2 to 10 inches. Pecking was the most frequently observed technique, accounting for 72% of all instances, followed by probing at 15%, and surface skimming at 13% *(Table 2)*. We observed that feeding activity was more intense during the morning hours than in the afternoon.

The distribution and intensity of these foraging techniques varied considerably across the study sites. Site 4 exhibited the highest counts for all three techniques (*Table 2)*, indicating the highest overall feeding activity. Site 3 also showed significant foraging activity, whereas we recorded a moderate number of pecking instances but no probing or surface skimming at Site 4 *(Table 2)*. Site 2 showed only probing activity *(Table 2)*. Site 1 had no BWS.

Table 2. Black-winged Stilt abundance and foraging techniques across study sites
2. táblázat A gólyatöcsök abundanciája és táplálkozási technikái a vizsgálati helyeken

Site	Total number of Black-winged Stilts	Foraging techniques		
		Pecking (instances)	Probing (instances)	Surface skimming (instances)
1	0	0	0	0
2	4	0	16	0
3	170	57	33	40
4	280	72	50	61
5	3	60	0	0

Table 3. Prey abundance at different sites
3. táblázat A zsákmányállatok abundanciája a különböző vizsgálati helyeken

Site	*Chironomus* (per 5 cm²)	*Tubifex* (per 5 cm²)	Total benthic prey (per 5 cm²)	Estimated total benthic prey (per 100 cm²)	Total *Moina* (per 1 ml water)	Total *Moina* (per 250 ml water)
1	6	3	9	180	3	750
2	4	2	6	120	7	1750
3	10	2	12	240	15	3750
4	14	1	15	300	16	4000
5	8	3	11	220	14	3500

Primary prey included *Moina* spp. (abundant in surface water), *Chironomus* larvae (dominant benthic macroinvertebrates), and *Tubifex* spp. (less abundant benthic macroinvertebrates) *(Table 3)*.

Quantitative analysis of benthic macroinvertebrates revealed varying abundances across the study sites *(Table 3)*. *Chironomus* larvae were consistently the dominant macroinvertebrates, with higher densities in nutrient-enriched sediments. *Tubifex* spp. were most consistently present at sites 1 and 5, indicating mildly polluted, organically rich sediments. Site 4 exhibited the highest estimated total benthic macroinvertebrate abundance. The peak *Chironomus* abundance at Site 4 was likely due to stagnant water and high organic content, conditions ideal for this detritivore. The abundance of *Moina* spp. in surface water also varied across sites *(Table 3)*. Site 4 had the highest abundance, followed by Site 3, Site 5, Site 2, and Site 1.

The study documented interspecific associations as well as disturbances affecting BWS *(Table 4)*. Notably, no aggressive interactions between BWS and co-occurring species were documented. However, BWS faced threats from natural predators like Shikra, Black Kite, House Crow and Stray Dog *(Canis lupus familiaris)*, as well as pervasive anthropogenic disturbances.

Table 4. Interspecific associations and disturbances affecting BWS
4. táblázat Fajok közötti kapcsolatok és zavaró hatások a gólyatöcsökre

Site	Number of BWS	Co-occurring species	Disturbing species	Observed anthropogenic activities
1	0	0	0	–
2	4	Red-wattled Lapwing, Common Sandpiper, Green Sandpiper, Indian Pond Heron	Shikra, Black Kite	Agricultural runoff, waste dumping
3	170	Grey-headed Swamphen, Little Ringed Plover, Common Sandpiper, Wood Sandpiper, Green Sandpiper, Temminck's Stint	Black Kite	Minimal boat traffic, some waste dumping
4	280	Grey-headed Swamphen	Black Kite, House Crow	Fishing, water extraction for irrigation, waste dumping, noise pollution
5	3	Common Moorhen, Grey-headed Swamphen, Common Sandpiper, Wood Sandpiper	Shikra, House Crow, Street Dog	Fishing, water extraction for irrigation, waste dumping, noise pollution

Discussion

The abundance of BWS at Site 4 was primarily attributed to favourable characteristics, including shallow pools (5–10 cm deep), soft sediment, and minimal boat traffic. In contrast, site 1, characterized by deep water and concrete embankments, had no BWS sightings, highlighting the critical role of specific physical habitat features and low disturbance levels in BWS site selection. Juvenile BWS were more frequently observed at Sites 2 and 5, suggesting these locations may serve as safer foraging grounds or areas with less competition for younger birds. Cattail provided dense emergent cover at Sites 1 and 2, offering roosting and nesting sites while also supporting invertebrate prey for other birds coexisting with BWS.

The observed inverse relationship between water depth and nutrient concentration, with the shallowest site (Site 4) exhibiting the highest nutrient levels, suggests that these shallower areas, potentially subject to reduced water flow or increased accumulation of agricultural runoff, act as nutrient traps. This condition promotes eutrophication, which directly supports a rich prey base for waterbirds. The abundance of BWS in shallow, soft-sediment, nutrient-rich habitats (Site 4) underscores their specific niche requirements, which differ from those of other co-occurring waterbirds. Other species such as egrets and Grey-headed Swamphens showed a preference for areas that were either more vegetated or slightly deeper. This highlights that, even within a modified riverine system, specific microhabitat features are critical drivers of species distribution and facilitate coexistence through resource partitioning (Zhu *et al.* 2023).

The observed dominance of pecking, probing, and surface skimming as primary foraging techniques directly corresponds to the types of prey available and the microhabitat conditions across the sites (Nagarajan & Thiyagesan 1996, Ueng *et al.* 2009). Pecking and probing are effective for capturing benthic invertebrates like *Chironomus* and *Tubifex* in soft sediments, while surface skimming is employed for organisms like *Moina* found in surface water.

The high pecking activity of BWS at Sites 3 and 4 may be attributed to greater prey availability and higher nutrient concentrations, which likely promote increased abundance of benthic invertebrates. Flock sizes of BWS were larger at Sites 3 and 4. Birds in larger flocks exhibit lower vigilance and greater foraging efficiency compared to those in smaller groups (Yasmin & Yahya 2000, Beauchamp 2008). This suggests a potential social buffering mechanism against disturbances, where individuals in larger groups can allocate less time to vigilance (due to more eyes available for threat detection) and more time to foraging. The absence of probing and surface skimming by BWS at Site 5, despite their presence, could be attributed to natural predators such as Stray Dogs, Shikras, Black Kites, and House Crows, which may deter foraging behaviours. Furthermore, the waterbody faced constant pressure from various human activities, including fishing, water extraction for irrigation, vehicular emissions and associated vibrations from nearby infrastructure, indiscriminate waste dumping, and chronic noise pollution.

The feeding frequency of BWS consistently peaked during early morning hours. This temporal pattern is likely influenced by factors such as increased prey mobility during cooler morning temperatures and reduced human disturbance at these times. This observation aligns with optimal foraging theory, which predicts that early morning peaks in avian foraging activity help replenish energy reserves depleted during overnight fasting, thereby reducing the risk of starvation (Elgar 1989, Beauchamp 2008). Adaptive strategies enable BWS to optimize energy intake while minimizing exposure to threats. Understanding these temporal foraging patterns is crucial for effective conservation planning, facilitating the implementation of targeted disturbance management strategies during critical foraging periods for the species.

The dominance of *Chironomus* (a pollution-tolerant species) and *Tubifex* (indicative of organically rich sediments) in the benthic community, particularly at sites with high nutrient loads, suggests that the modified riverine habitat, despite its degraded state, provides a substantial food source for BWS (Li *et al.* 2010). This highlights how BWS can thrive in anthropogenically altered environments by exploiting abundant, pollution-tolerant invertebrate prey that flourish in eutrophic conditions. This adaptability underscores their role as indicators of modified wetland health rather than pristine conditions. Consequently, conservation efforts for BWS in urban settings may paradoxically involve managing nutrient levels to sustain these specific invertebrate populations, rather than aiming for pristine conditions that may be unachievable or favour different prey species.

The findings of this study strongly reinforce the established role of BWS as valuable bioindicators of modified riverine ecosystem. Waders are important ecological wetland health indicators since these species are sensitive to a complex set of environmental factors (Aarif *et al.* 2025, Yang *et al.* 2025). Their preferential use of shallow, moderately eutrophic habitats, coupled with their observable sensitivity to disturbance, makes them excellent indicators of specific microhabitat conditions and the pervasive impacts of anthropogenic activities within urban riverine systems (Nagarajan & Thiyagesan 1996, Sandeep Kaur *et al.* 2022).

The study's findings provide clear, actionable recommendations for the conservation of BWS and, by extension, the health of urban riverine wetlands. Conservation planning must prioritize the maintenance and protection of critical shallow, soft-sediment habitats, as these are demonstrably preferred by the stilts and support high prey availability (Rehman *et al.* 2021). Furthermore, it is imperative to regulate anthropogenic disturbances near wetland zones.

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