

Waterfowl Diversity and Feeding Ecology in Panidihing Bird Sanctuary, Sivasagar District, Assam, India

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ABSTRACT

Wetlands of the Brahmaputra floodplain support rich waterfowl communities whose foraging ecology reflects the dynamic habitat conditions shaped by seasonal hydrology. This study investigated the dietary composition, foraging behaviour, and niche partitioning of eight duck and goose waterfowl species in Panidihing Bird Sanctuary, Assam, based on three years of field observations (2021-2023) across 13 sites. Direct behavioural sampling, videography, and coexisting habitat measurements were used to document feeding strategies, diet types, and habitat preferences. Waterfowl diversity showed a steady improvement over the study period, with the Shannon-Wiener index rising from $H' = 1.412$ (2021) to 1.543 (2022) and 1.745 (2023), indicating an increase in evenness and species balance. Shallow-water zones formed the most important feeding habitat (42% of records), followed by open water (32%) and grasslands (26%). Species exhibited clear trophic and spatial segregation: feeding activity ranged from 16% in Ruddy Shelduck to 37% in Indian Spot-billed Duck, while guild representation showed dominance of dabbling omnivores and aquatic-terrestrial herbivores (25% each). Foraging techniques were led by dabbling ($n=8$) and diving ($n=4$), with minor occurrences of surface skimming and kleptoparasitism. Dietary analysis revealed that benthic invertebrates and aquatic plants contributed the highest proportions (22.86% each), followed by fish (20%), while grasses and phytoplankton made up smaller shares (17.14% each). These patterns demonstrate strong niche partitioning determined by morphological traits, water depth preferences, and habitat heterogeneity. The findings highlight the importance of maintaining shallow wetland habitats and natural hydrological regimes to sustain diverse waterfowl assemblages in floodplain ecosystems.

Keywords: Waterfowl, foraging behaviour, wetlands, niche partitioning, ecosystem

Mathematics Subject Classification: 62H20, 62Q05

Journal of Economic Literature (JEL) Classification: Q57

1. INTRODUCTION

1.1 Importance of Wetlands and Waterfowl Ecology

Wetlands are among the most productive ecosystems worldwide, sustaining high biodiversity and delivering essential ecological functions such as nutrient retention, hydrological regulation, and carbon storage (Mitsch & Gosselink, 2000; Zedler & Kercher, 2005; Mitsch & Gosselink, 2015). Large floodplain wetlands of Northeast India support rich aquatic communities and serve as key habitats for resident and migratory waterbirds (Bassi *et al.*, 2014). Their seasonal hydrological fluctuations generate a range of habitat conditions, including deep open water, shallow littoral zones, and exposed grasslands, that shape the distribution and abundance of wintering waterfowl (Kingsford & Thomas, 2004; Ma *et al.*, 2010). Waterfowl play an important functional role in wetland ecosystems. Through grazing, sediment disturbance, and selective foraging, they influence nutrient cycling, vegetation structure, and the spatial distribution of invertebrates and macrophytes (Green & Elmberg, 2014). Waterfowl also serve as effective dispersal agents for wetland plants, transporting seeds across considerable distances and improving connectivity between isolated wetlands (Figuerola & Green, 2002; Brochet *et al.*, 2010). Understanding their feeding ecology and habitat preferences is therefore vital for designing conservation measures, particularly as wetlands in Assam face pressures from land-use change, siltation, hydrological modification, and climate variability (Davidson, 2014; Junk *et al.*, 2013).

1.2 Wetland Systems of the Brahmaputra Valley

The Brahmaputra Valley contains an extensive network of floodplain wetlands shaped by annual monsoon pulses and riverine geomorphology. These wetlands support exceptional biological diversity and form an important component of the Eastern Himalaya-Indo-Burma biodiversity hotspot. Each winter, large numbers of migratory waterbirds, including dabbling ducks, diving ducks, geese, and waders, depend on these habitats for feeding and survival (Islam & Rahmani, 2004; Choudhury, 2000; Rahmani *et al.*, 2016). Hydrological variability, particularly the seasonal expansion and contraction of waterbodies, plays a central role in structuring habitat availability and supporting high waterbird diversity (Kingsford, 2000; Ma *et al.*, 2010). Despite their ecological value, many wetlands in the region face degradation due to siltation, encroachment, pollution, and hydrological alteration. When water depth decreases and wetland margins shrink, waterbird abundance tends to decline in many floodplain systems. This finding emphasises the importance of focused conservation actions (Kingsford & Thomas, 2004).

1.3 Niche Partitioning in Waterfowl Communities

Niche partitioning allows ecologically similar waterfowl to coexist by exploiting different components of shared resources, thereby reducing interspecific competition (Schoener, 1974). Morphological traits such as bill morphology and body size influence the range of exploitable food items and foraging depths and therefore help structure assemblages into functionally distinct feeding guilds (Weller, 1999). Studies demonstrate that guild-level segregation (e.g., dabblers, grazers, divers) corresponds to habitat zones that vary in depth, vegetation, and prey accessibility, leading to predictable associations between foraging technique and microhabitat (Krapu & Reinecke, 1992; Baldassarre & Bolen, 2006). Seasonal variation in water level further increases habitat heterogeneity by creating a dynamic mosaic of foraging sites; these temporal shifts permit species with different morphological and behavioural attributes to occupy complementary trophic and spatial niches across the wintering period (Kingsford, 2000; Ma *et al.*, 2010). Studies from northeastern India likewise indicate that morphological and behavioural differences among waterbirds correspond with habitat-use patterns and guild structure, supporting the role of hydrological heterogeneity in sustaining species coexistence (Islam & Rahmani, 2004). Maintaining natural hydrological dynamics and structural complexity is therefore essential for preserving functional diversity and reducing competitive overlap in wetland waterfowl communities.

The Panidihing Bird Sanctuary (PBS), situated in the Sivasagar District of Assam, India, is recognized as an Important Bird and Biodiversity Area and is also a regionally significant protected site (Rahmani *et al.*, 2016). A wide range of resident and migratory waterfowl utilise Indian wetlands (Sonal *et al.*, 2010). Seasonal hydrological fluctuations create dynamic habitat conditions (Murkin *et al.*, 1997), and these diverse wetland ecosystems support high shifting mosaics of aquatic and terrestrial habitats, which in turn enhance resource productivity and support diverse foraging opportunities (Mishra *et al.*, 2024; Space Applications Centre, ISRO. (2013). Despite their ecological importance, detailed quantitative studies on waterbird foraging ecology and on coexistence mechanisms such as habitat and trophic-niche segregation remain limited across most Indian wetlands (Mukherjee & Roy, 2021; Chatterjee *et al.*, 2020). This research aimed to thoroughly examine the dietary habits and foraging behaviours of waterfowl species within Panidihing Bird Sanctuary to address the recognized knowledge deficit. The purpose of this study was to analyse the dietary and foraging ecology of waterfowl species in Panidihing Bird Sanctuary in detail to close the identified knowledge gap.

2. METHODS

2.1 Study Area

Panidihing Bird Sanctuary (PBS) is situated in the Sivasagar district of Assam, India, approximately 22 km from Sivasagar town. The sanctuary, which covers 33.93 km² (Fig 1), was established in August 1996 and lies between 27°07'19"N and 94°35'47"E (Department of Environment & Forests, Government of Assam, 2013; BirdLife International, 2024). The sanctuary was created in 1996 and covers 33.93 km². It is distinguished by its intricate hydrological connections and is bounded by the rivers Brahmaputra, Desang, and Demow (Department of Environment & Forests, Government of Assam, 2013). The site is also characterised by a network of natural water channels, oxbow lakes (beels), and vegetation that undergoes seasonal flooding (Choudhury, 2000). The hydrology of the area is strongly influenced by monsoon rainfall (Incredible India, 2024; Key Biodiversity Area, 2024), producing a range of wetland types from permanent waterbodies to seasonally dry floodplain grasslands. During winter, many shallow beels recede and are used as grazing grounds. With yearly rainfall of 2,400-3,200 mm and temperatures varying from 7°C to 38°C, the region's humid tropical monsoon environment creates dynamic hydrological circumstances that influence the availability of waterbird habitat (Wikipedia, 2024; Abhipedia, 2024)



Fig 1: Map illustrating the sampling locations within the study

2.2 Data Collection

Field data were collected over three consecutive years from 2021 to 2024. The study focused on documenting the foraging and dietary behaviours of both resident and migratory duck species that utilise Panidihing Bird Sanctuary as a wintering ground. Bird species were collected from 2021 to 2023 by following the direct point count method found in and around the wetlands of the bird sanctuary (Bibby *et al.*, 2000; Rahayuningsih, M., & Priyono, B., 2016; and Ralph *et al.*, 1995). A total of 13 sampling sites were selected for the data collection, which are under both protected and fringe zones (Fig 1). The selected sites include Ujan tali, Balijan, Borbeel, Kandulijan, Tokia, Jarjariya, Phulai, Singarajan, Demowghat, Phokolai, Balikur, Dorou, and Dapani. Videographic documentation was also selectively employed to record foraging techniques and behavioural patterns. Behavioural observations were conducted following the direct observational method (Altmann, 1974; Martin & Bateson, 2007).

For each species, individual birds were observed continuously for 10 minutes, maintaining a minimum interval of 10 minutes before repeating observations on the same species to reduce temporal autocorrelation, following recommendations in behavioural sampling studies (Altmann, 1974). The actively foraging waterfowl species, involving their searching for prey or swallowing, were also recorded. Identification of waterfowl species was done based on visual observations as well as on their morphological features like shape, size, colour of bill, feathers, eyes, feet, legs and other parts of body by using Nikon D5600 cameras and 10×50 binoculars (Olympus) and by following Ali & Ripley (1987; Grimmer *et al.*, 1999). To link behaviour with habitat conditions, key environmental variables like water depth, temperature and habitat type were recorded concurrently at each observation point following standard limnological protocols (Wetzel, 2001). The study area map was prepared using QGIS software based on GPS coordinates of the sampling locations recorded with a Garmin eTrex 10x handheld GPS device.

2.3 Data Analysis

All behavioural and environmental data were compiled and organised using Microsoft Excel before statistical analysis (Zar, 2010). Species diversity across the three consecutive years of the study was quantified using the Shannon-Wiener diversity index (H') (Shannon, 1948; Jamakhandi & Kadadevaru, 2024). Several statistical tests were conducted using SPSS to examine the connection between species morphology and habitat utilisation (IBM Corp., 2022). To assess the association between waterfowl morphology and habitat use, Pearson's correlation analyses were performed between major morphological traits (bill length, tarsus length, and body mass) and habitat parameters (preferred and observed foraging depth), following Das *et al.*, (2020). A one-way ANOVA was applied to assess whether the studied

species differed significantly in these characteristics and in their patterns of habitat use (Sokal & Rohlf, 2012). When ANOVA results were significant, Tukey's HSD post hoc test was performed to identify which species pairs exhibited significant differences in their morphology and foraging behaviours.

3. RESULTS

3.1 Waterfowl Community Structure and Diversity

The structure of the waterfowl community in Panidihing Bird Sanctuary gradually improved over the three years (2021-2023), as indicated by the Shannon diversity index (H') (shown in Fig 2). In 2021, the community was strongly dominated by the Lesser Whistling Duck (*Dendrocygna javanica*), which contributed approximately 48.7% of all recorded individuals. Although species richness was moderate, with seven species present, the overall diversity remained relatively low ($H' = 1.412$). The dominance of a single species and reduced evenness suggested possible habitat stress or unequal access to resources, patterns commonly observed in wetlands experiencing ecological imbalance (Yan *et al.*, 2025).

By 2022, the index increased to $H' = 1.543$, indicating an improvement in community balance and distribution. This shift corresponded with the regular winter arrival of migratory species such as the Bar-headed Goose (*Anser indicus*) and Greylag Goose (*Anser anser*), whose presence often enhances assemblage diversity through seasonal habitat use and expanded niche availability (Ling *et al.*, 2021; Naik & Sharma, 2022). The diversity index further increased to $H' = 1.745$ in 2023, reflecting higher species variety and a more even distribution among the eight species recorded. During this period, the Lesser Whistling Duck, Ruddy Shelduck (*Tadorna ferruginea*), and Bar-headed Goose (*Anser indicus*) were the most frequently encountered species.

The steady rise in H' across the three years ($R^2 = 0.981$) (shown in Fig 2) suggests progressive improvement in community structure and ecological stability. The Shannon index is widely applied in ecological studies to evaluate species diversity by incorporating both richness and evenness, and increasing values generally reflect greater community balance (Krebs, 1999). In wetland ecosystems, sustained habitat quality, stable hydrological regimes, and reduced anthropogenic disturbance are strongly associated with higher waterfowl diversity and more equitable species distribution (Weller, 1999; Krebs, 2014; Mitsch & Gosselink, 2015; Mukherjee *et al.*, 2021).

Waterfowl communities are known to respond sensitively to variations in habitat structure, water depth, and resource availability, particularly in seasonally dynamic floodplain wetlands (Baldassarre, 2014; Newton, 2008). The continuous increase in diversity over the study period

suggests that favourable habitat quality and stable water conditions supported the community. These findings emphasise the importance of long-term monitoring of waterfowl diversity, as such data provide a dependable measure of wetland ecological health, especially in areas where environmental conditions change seasonally (Mukherjee & Singha Roy, 2021; Mandal *et al.*, 2021).

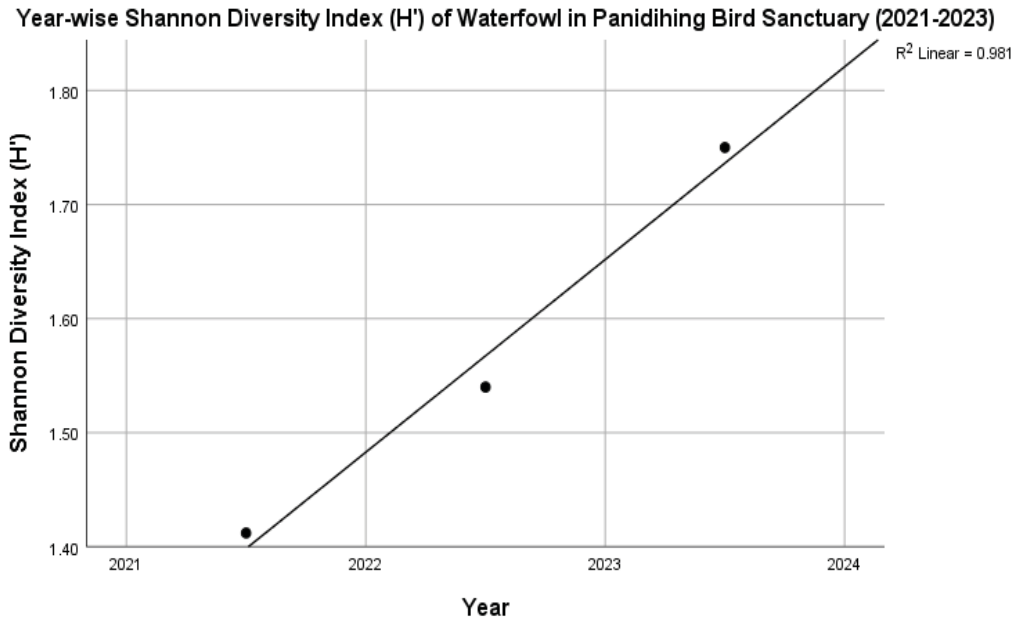


Fig 2: Line Graph illustrating the annual variation in waterfowl species diversity within the study area

Foraging Habitat of the Waterfowl Species in Panidihing Bird Sanctuary

Analysis of waterfowl foraging patterns in Panidihing Bird Sanctuary revealed strong habitat partitioning among species (shown in Fig 3). Shallow water habitats were the most frequently utilized (42%), possibly owing to the greater abundance of benthic invertebrates, submerged macrophytes, and aquatic plant seeds. Open water habitats accounted for 32% of foraging records and were primarily used by diving and dabbling ducks that depend on deeper water for fish, vegetation and plankton (Mukherjee *et al.*, 2021). Terrestrial grasslands, though less used (26%), remained important for grazing species such as geese that rely on grasses and agricultural residues (Fox *et al.*, 2017).

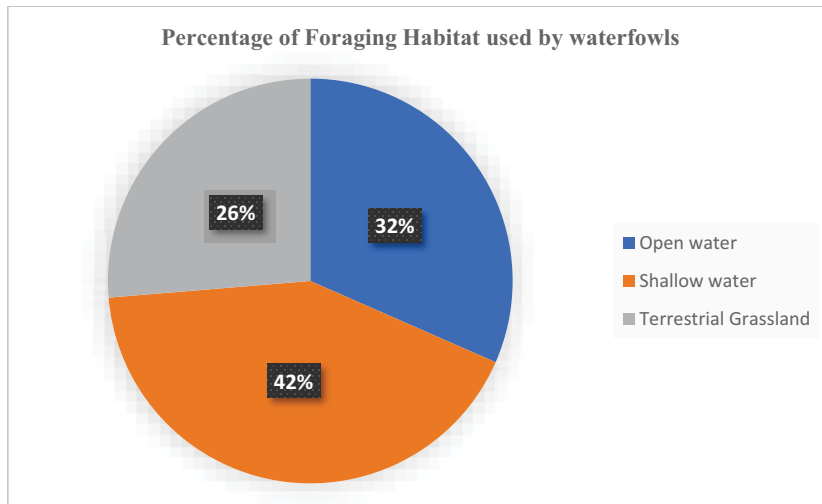


Fig 3: Pie Graph showing percentage of different types of Foraging Habitat used by Waterfowl species

The distribution of foraging activity across different habitats reflects the ability of waterfowl to utilise multiple feeding niches within the sanctuary. Such partitioning supports efficient resource use and reduces interspecific competition, as noted by Schoener (1974). The dominant use of shallow wetlands and marsh edges emphasises their role as essential feeding areas during both breeding and migratory periods (Baldassarre & Bolen, 2006).

3.2 Foraging Guilds, Diets, and Techniques

The distinct feeding guilds of the waterfowl species in Panidihing Bird Sanctuary demonstrate the variety of their food preferences and foraging techniques (Baldassarre & Bolen, 2006; Middleton & Va der Valk, 1987; del Heyo *et al.*, 1992).

Bar-headed Goose (*Anser indicus*):

As a terrestrial grazer, this migratory species mostly consumed crops and water grasses. They spent about 34% of their time feeding. In early winter, they consumed almost half of their food in the form of grasses like *Paspalum distichum*; in late winter and spring, they began to eat more wheat, peas, and other crops. Their consumption of plankton was different from that of dabbling ducks (Middleton, 1987; Middleton & van der Valk, A. G., 1987).

Greylag Goose (*Anser anser*):

The Greylag Geese spent roughly 32% of their time feeding and were thus dedicated herbivores. Their diet changed with the seasons; in early winter, they ate water lily (*Nymphaea*

nouchali) leaves, and by March, *Paspalum distichum* had taken over. *Sagittaria* and *Ipomoea aquatica* were among the other plants that made modest contributions (Middleton & Van der Valk, 1987).

Indian Spot-billed Duck (*Anas poecilorhyncha*):

Over the course of the day, this resident dabbling duck fed consistently, with feeding making up around 37% of activity. Its food consisted of rice grains, tubers, snails, insect larvae, crabs, and occasionally fish, as well as the seeds of submerged plants and grasses. In shallow waters, anatids typically foraged by upending or dabbling (Parul & Kumar, 2024)

Gadwall (*Mareca strepera*):

Gadwalls, winter visitors, are fed for around 33% of their stay. They are herbivorous in winter season and forage in wetland areas with abundant submerged and floating vegetation along with algae (MCKnight & Hepp, 1998; Paulus, 1982) They also consumed fish, mollusks, large crustaceans, widgeon grass, and water milfoil which includes the leaves, stems, tubers, roots, and seeds (Paulus, 1982) They are among the few species that primarily consume filamentous algae for food, such as *Spirogyra*.

Lesser Whistling Duck (*Dendrocygna javanica*):

In contrast to other dabblers, this species exhibited relatively carnivorous feeding behaviour despite a high feeding activity (~35%). Besides submerged vegetation, its diet included molluscs, frogs, worms, snails, insect larvae, and small fish. Foraging behaviour involved upending and diving in shallow waters, with feeding activity occurring predominantly during early morning and nocturnal hours (Onwuka *et al.*, 2020). The presence of small, commonly occurring wetland fish species such as *Clarias batrachus*, *Channa punctatus*, *Heteropneustes fossilis*, and *Cyprinus carpio* in habitats occupied by Lesser Whistling Ducks suggests a potential predator–prey relationship (Ansari, 2016). The abundance of these fish in feeding grounds indicates their likely contribution to the species' diet (Ali *et al.*, 2020). Furthermore, previous studies have documented the consumption of aquatic vertebrates by this species, supporting its partial dependence on fish as a food resource (Gopi & Pandey, 2019).

Ruddy Shelduck (*Tadorna ferruginea*):

Ruddy Shelducks fed both on land and in shallow waters, with only ~16% of time devoted to feeding. Their diet included grasses, crops, seeds, algae, and small aquatic prey like molluscs, fish, and insects. They showed mainly crepuscular or nocturnal feeding activity, possibly to avoid daytime disturbance (Namgail & Fox, 2011).

Cotton Pygmy Goose (*Nettapus coromandelianus*):

These small resident ducks spent ~36% of their time feeding. They foraged by surface feeding and dipping among floating plants, consuming mainly seeds, fruits of aquatic plants like *Ipomoea*, *Hydrilla*, and *Ruppia*, water lilies, etc., and insect larvae. Unlike diving ducks, they relied on surface waters for food (Ali & Ripley, 1987).

Ferruginous Duck (*Aythya nyroca*):

This diving species is chiefly migratory and is a small contributor to the waterfowl population. During the entire study period, it was found in small numbers. They fed ~25% of the time, with peaks in late winter and spring. Their diet was omnivorous, consisting mainly of aquatic weeds, sedges, and hornworts (about 78%), along with insects, aquatic bugs, small fishes and molluscs (Kaur & Braich, 2021). They dived to reach submerged prey, differing from dabblers in feeding technique, and diving is recorded as the most frequent foraging technique opted by this species (Driadi *et al.*, 2019; Green, 1998b). While geese and most dabbling ducks foraged primarily during daylight, species like Ruddy Shelduck and Lesser Whistling Duck adopted nocturnal or crepuscular feeding, possibly to reduce competition and predation risks.

Composition of Feeding Guilds of Waterfowl Species

The composition of waterfowl feeding guilds in Panidihing Bird Sanctuary, as illustrated in the bar graph (shown in Fig 4), shows clear variation in foraging strategies among species. Dabbling omnivores (Indian Spot-billed duck & Lesser Whistling duck) and aquatic-terrestrial herbivores (Bar-headed Goose & Greylag Goose) were the most represented guilds, each comprising two species and together accounting for 25% of all species recorded. The majority suggests that shallow-water zones and emergent vegetation serve as important feeding habitats in the sanctuary. These areas are home to a large number of seeds, macrophytes, and small invertebrates (Weller, 1999; Baldassarre, 2014; Mukherjee & Singha Roy, 2021). Aquatic-terrestrial omnivores (Ruddy Shelduck) and diving omnivores (Ferruginous duck) were less prevalent, with only one species (12.5%) each. Due to their dependence on floating plants and easily accessible macrophyte layers, surface-feeding herbivores (Cotton Pygmy Goose) and dabbling herbivores (Gadwall) also made up one species (about 12.50%) (Krapu & Reinecke, 1992; Baldassarre, 2014). The comparatively large percentage of dabbling omnivores suggests significant dietary adaptability, allowing these birds to take advantage of a variety of food sources on marsh edges and shallow wetlands (Baldassarre, 2014; Fox *et al.*, 2017). The similar proportions of terrestrial and aquatic herbivores emphasise the ecological importance of surrounding grasslands and submerged vegetation in sustaining waterfowl assemblages in floodplain wetlands (Weller, 1999).

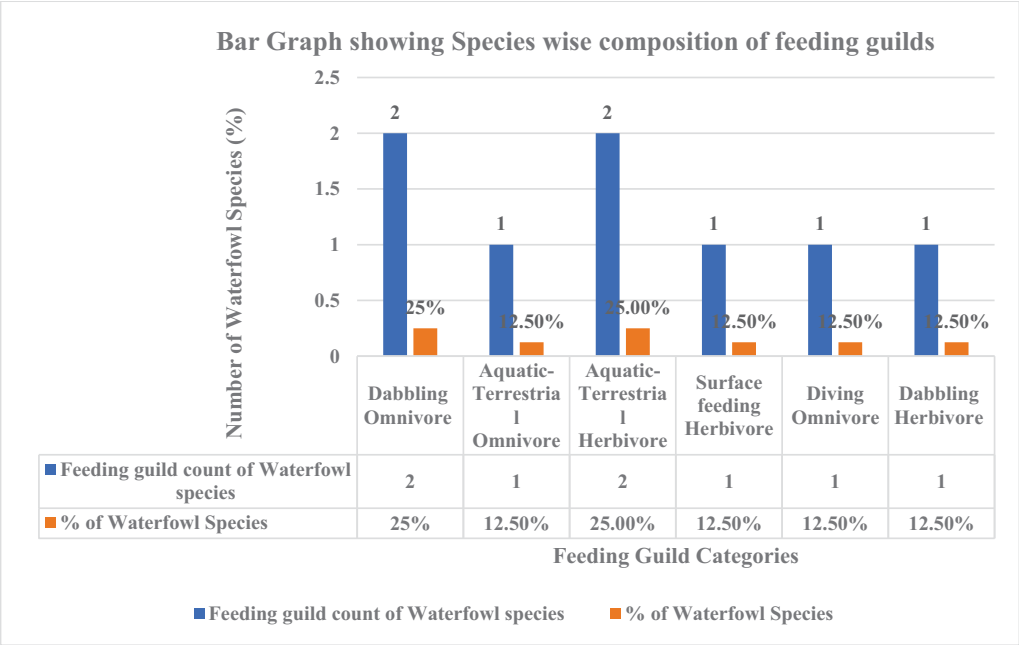


Fig 4: Bar Graph showing percentage of different feeding guilds found in the study area

Geese and other grazing waterfowl commonly utilise both marsh margins and adjacent agricultural fields, reflecting a dual habitat dependence that has been widely documented in floodplain wetland systems (Owen, 1980; Fox et al., 2017). Such habitat flexibility allows herbivorous species to exploit seasonal food availability across naturally modified landscapes. Conversely, the limited presence of diving omnivores suggests reduced use of deeper-water habitats, likely linked to seasonal water depth fluctuations or lower availability of submerged vegetation and benthic prey (Krapu & Reinecke, 1992; Colwell & Taft, 2000; Baldassarre, 2014).

The bar graph represents the distribution of feeding strategies observed among the waterfowl species in the study area (shown in Fig 5). Dabbling was the most frequently recorded method (n = 8), indicating its prominence as the primary foraging strategy. Filtering and grazing were moderately represented (n = 3 each), followed by upending, head-neck dipping, and diving (n = 4), which together reflect the use of both surface and subsurface feeding opportunities. Surface skimming (n = 2) and kleptoparasitism (n = 1) were the least common behaviours.

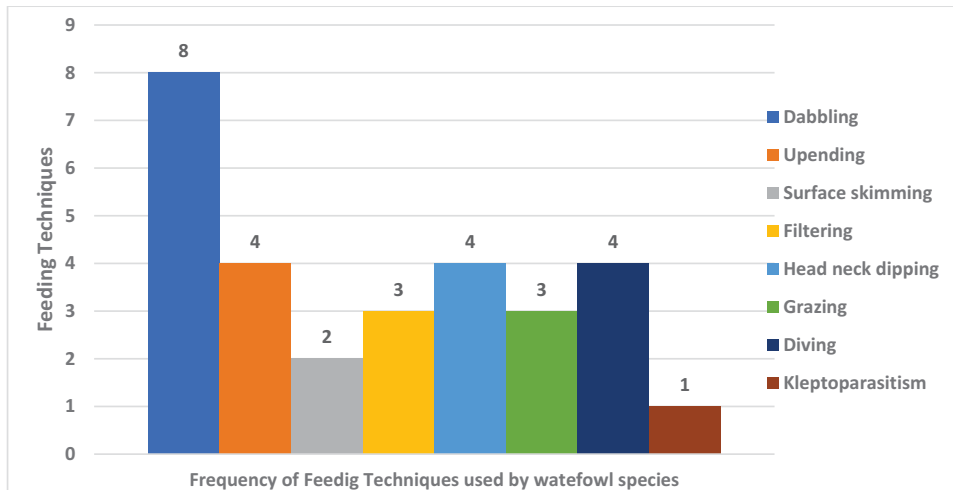


Fig 5: Bar Graph showing the number of different types of Feeding techniques employed by waterfowl species in the study area

The dominance of dabbling and diving is consistent with previous studies indicating that these foraging strategies facilitate access to a wide array of food items, including aquatic vegetation, seeds, algae, small invertebrates, and benthic prey (Baldassarre & Bolen, 2006; Arzel *et al.*, 2006; Weller, 1999). Dabbling ducks generally forage in shallow waters where submerged vegetation and invertebrates are easily accessible. Diving species, in contrast, typically utilise deeper sections of wetlands and tend to occupy distinct microhabitats that reduce dietary and spatial overlap with dabbling guilds (Poysa, 1983; Nilsson, 1972; Baldassarre & Bolen, 2006). The low frequency of kleptoparasitism suggests that it functions primarily as an opportunistic behaviour rather than a regular feeding strategy, which aligns with broader observations that such behaviour typically occurs when direct foraging yields lower returns (Brockmann & Barnard, 1979).

The pie chart (shown in Fig 6) summarises the percentage distribution of principal food categories consumed by waterfowl within the study area. Aquatic plants and benthic invertebrates represented the dominant dietary components (22.86% each), followed by fish (20.00%), whereas grasses and phytoplankton constituted comparatively lower proportions (17.14% each). This dietary composition indicates that the waterfowl community relies on both plant- and animal-derived resources, reflecting a diversified feeding pattern. The high proportion of submerged vegetation and benthic invertebrates further highlights the ecological importance of wetland habitats in providing a range of trophic resources essential for sustaining waterbird populations (Arzel, 2006; Ntiamoa-Baidu *et al.*, 1998).

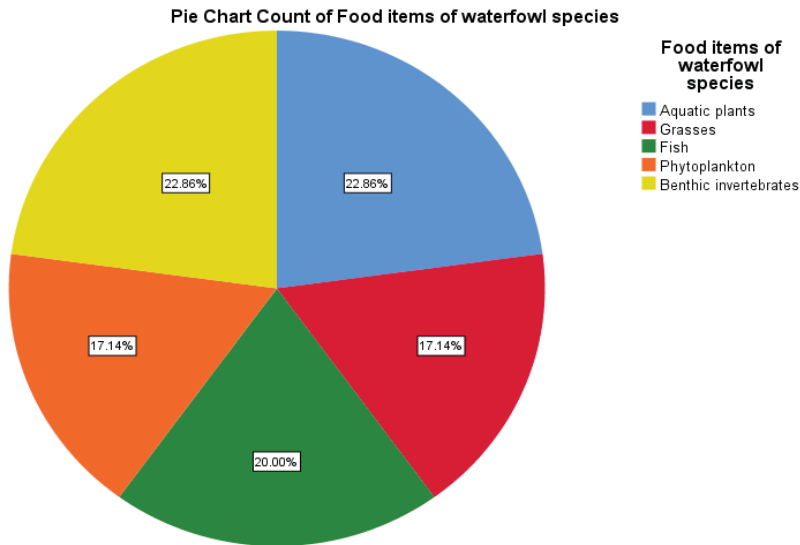


Fig 6: Pie chart showing the percentage of different food items found in the diet of Waterfowl species

Fish consumption indicates the existence of species that include opportunistic carnivores or piscivores in their diet, especially in shallow and moderately deep wetland zones where small fish and related aquatic fauna are accessible (Ntiamoa-Baidu *et al.*, 1998). Meanwhile, the intake of grasses and phytoplankton supports the requirements of herbivorous guilds, including grazing geese and dabbling ducks that forage along wetland margins and adjacent terrestrial patches (Arzel *et al.*, 2006; Fox & Abraham, 2017). The way waterfowl use many different types of food shows that they are quite flexible in what they eat. This ability to adjust their diet helps them get through seasonal changes in water levels, plant cover, and the availability of prey (Baldassarre & Bolen, 2006; Arzel *et al.*, 2006; Newton, 2008). Such flexibility has become even more important as wetlands continue to change due to shifting water conditions and growing human pressures.

The pie chart (shown in Fig 7) illustrates the dietary makeup of eight species of waterfowl found in Panidihing Bird Sanctuary, emphasising their reliance on five main food groups: fish, aquatic plants, grasses, phytoplankton, and benthic invertebrates. The findings show that the Ruddy shelduck and Indian spot-billed duck contributed 25% of the total, showing similar preference for each of the four main food sources. The rather consistent diets of the cotton pygmy goose, ferruginous duck, bar-headed geese, and lesser whistling duck, which contributed about 20%, indicate their feeding habits. While the Gadwall had a modest preference for aquatic plants, fish, and benthic invertebrates (33.33% each), the Greylag

geese showed equal consumption (25% each) of all food categories, suggesting dietary specialisation towards plant and invertebrate-based resources.

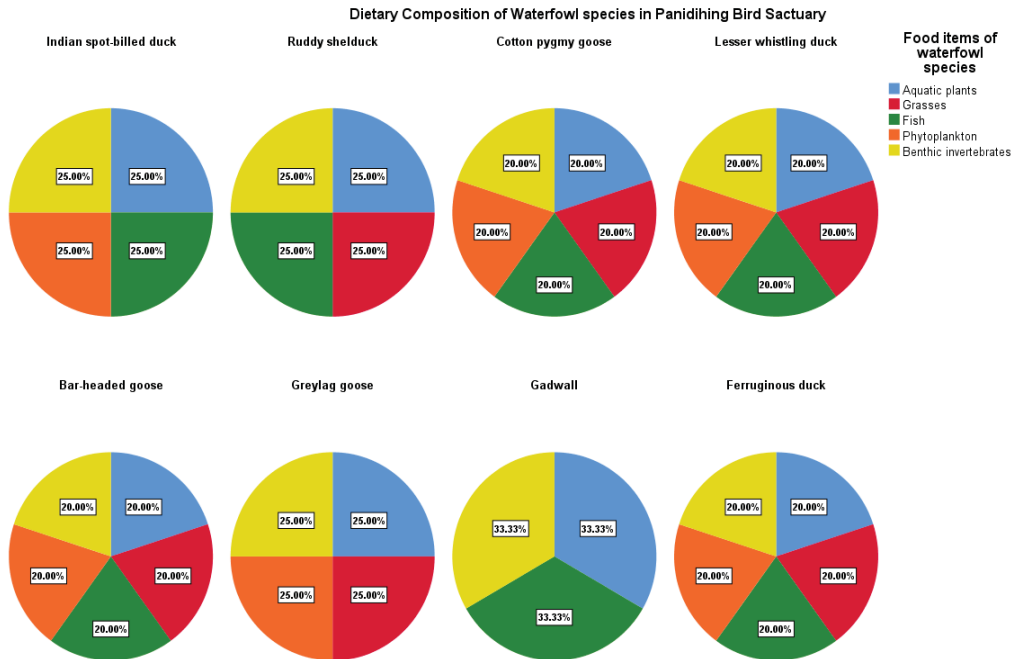


Fig 7: Pie chart showing the percentage of dietary composition of food items consumed by Waterfowl species

Overall, the findings show that the species under study exhibit a pattern of opportunistic feeding tactics and nutritional adaptability. In wetlands, this feeding flexibility enables waterfowl to adjust to anthropogenic stresses and seasonal changes in food availability. Similar patterns have been documented in dabbling ducks, which consume a broad range of food items, including aquatic invertebrates, seeds, small fish, and submerged macrophytes, depending on availability (Swanson *et al.*, 2013; Ntiama-Baidu *et al.*, 1998). This determines the ecological significance of preserving a variety of trophic supplies in wetlands in order to support both resident and migratory duck populations.

3.3 Morphometric and Habitat Correlations

The present morphometric analysis reveals a strong functional link between anatomical traits and foraging ecology among the waterfowl guild under study (shown in Table 1). Our statistical results demonstrate a significant positive correlation between culmen (bill) length and foraging water depth ($r = 0.735$, $p = 0.002$), indicating that interspecific variation in bill morphology enables access to different habitats. Species with longer bills tended to forage in deeper water, suggesting morphological adaptations that facilitated the exploitation of benthic and deeper-water food sources (Aarif *et al.*, 2024).

Table 1: Pearson’s correlation matrix illustrating relationships between morphological characteristics (bill length, tarsus length, body mass) and foraging water depth variables in Lesser Whistling Duck (N = 15).

Correlations

		Bill Length (mm)	Tarsus Length (mm)	Body mass (g)	Preferred Foraging Water Depth (m)	Water Depth of the foraging habitat (m)
Bill Length (mm)	Pearson Correlation	1	-.108	.542*	.373	.735**
	Sig. (2-tailed)		.701	.037	.171	.002
	N	15	15	15	15	15
Tarsus Length (mm)	Pearson Correlation	-.108	1	.377	.231	.063
	Sig. (2-tailed)	.701		.166	.407	.824
	N	15	15	15	15	15
Body mass (g)	Pearson Correlation	.542*	.377	1	.818**	.395
	Sig. (2-tailed)	.037	.166		.000	.145
	N	15	15	15	15	15
Preferred Foraging Water Depth (m)	Pearson Correlation	.373	.231	.818**	1	.074
	Sig. (2-tailed)	.171	.407	.000		.794
	N	15	15	15	15	15
Water Depth of the foraging habitat (m)	Pearson Correlation	.735**	.063	.395	.074	1
	Sig. (2-tailed)	.002	.824	.145	.794	
	N	15	15	15	15	15

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Furthermore, a strong positive correlation was observed between species body mass and foraging depth ($r = 0.818$, $p < 0.001$) (Table 1). This finding indicates that larger-bodied taxa predominantly exploit deeper aquatic habitats, supporting the premise that allometric scaling

influences habitat selection and foraging strategy, thereby structuring avian assemblages along physical gradients (Ntiemoa-Baidu *et al.*, 1998).

Statistical analysis of morphometric and habitat data revealed clear functional relationships supporting niche differentiation within the waterfowl assemblage. A strong positive Pearson correlation was observed between bill length and preferred foraging water depth ($r = 0.735$, $p = 0.002$), indicating that species with longer bills forage in deeper water where they can access submerged vegetation and benthic prey. Likewise, body mass was strongly and positively correlated with foraging depth ($r = 0.818$, $p < 0.001$), implying that larger species tend to exploit deeper foraging zones. In this study, body mass explained approximately 67% of the variation in preferred foraging depth ($R^2 = 0.669$), while bill length alone accounted for roughly 54% ($R^2 = 0.540$), consistent with the expectation that increases in overall body size and culmen length improve access to deeper resources. A moderate positive allometric relationship between body mass and bill length ($r = 0.542$, $p = 0.037$) further indicates that larger taxa typically possess proportionally longer bills, a trait that facilitates probing or reaching prey in more structurally complex or deeper substrates. Tarsus length showed no significant associations with other measured traits, suggesting that leg dimensions were not a principal determinant of foraging depth in the present guild. These results corroborate findings from Indian and regional studies linking bill morphology and leg length to water-depth preferences (Aarif *et al.*, 2024; Meitei *et al.*, 2024) and align with broader syntheses that identify morphology as a key predictor of habitat use and foraging strategy in waterbirds.

The one-way ANOVA indicated clear morphological differentiation among the five species examined, with significant interspecific variation in body mass ($F(4,10) = 6.22$, $p = 0.009$), tarsus length ($F(4,10) = 24.37$, $p < 0.001$), and bill length ($F(4,10) = 12.17$, $p = 0.001$). Although preferred foraging depth did not differ significantly among species ($F(4,10) = 2.71$, $p = 0.092$), the depth actually used during foraging varied significantly ($F(4,10) = 6.08$, $p = 0.010$), indicating partial overlap in habitat use. Patterns of interspecific morphological divergence observed here are consistent with findings that bill and leg morphology influence access to prey and microhabitat depth gradients in waterbirds (Cezilly & Boy, 1988; Zwarts & Blomert, 1992; Elphick & Oring, 1998). These relationships highlight the functional role of species-specific morphometrics in structuring foraging niches within wetland communities.

Post-hoc Tukey HSD tests indicated that Gadwall foraged in deeper water than Ferruginous Duck (Mean difference = -0.50 m, $p = 0.009$) and Ruddy Shelduck (Mean difference = -0.41 m, $p = 0.030$), whereas depths used by the remaining species did not differ significantly. These results imply that species-specific morphological traits (bill length, body mass) translate into differences in realised foraging depth and thereby contribute to niche partitioning and reduced

interspecific competition in the wetland assemblages (Schoener, 1974; Zwarts & Blomert, 1992; Ntiamoa-Baidu *et al.*, 1998).

4. DISCUSSION

The waterfowl assemblage at Panidihing Bird Sanctuary exhibits clear mechanisms of niche partitioning, reflected in both morphological differentiation and species-specific foraging strategies. Morphometric traits, particularly bill length and body size, were strongly associated with observed foraging behaviours, a pattern consistent with functional relationships documented in empirical studies of waterbirds (Aarif *et al.*, 2024; Barman *et al.*, 2020; Cezilly & Boy, 1988; Zwarts & Blomert, 1992). The positive association between bill length and realised foraging depth suggests adaptive specialisation among species capable of exploiting deeper microhabitats. The studies on inland wetland ecosystems also show that diverse feeding guilds and niche partitioning enable species to coexist for long periods by reducing direct competition for prey and microhabitats (Chatterjee *et al.*, 2020). This relationship mirrors findings from multispecies shorebird and waterbird assemblages, where culmen length predicts the depth and type of prey substrates accessed during foraging (Aarif *et al.*, 2024; Zwarts & Blomert, 1992).

Dabbling species, including Gadwall, predominantly utilised shallow vegetated zones, whereas species with greater body mass and longer bills accessed deeper feeding strata. Such differentiation among species occupying the same wetland matrix supports established principles of resource partitioning, whereby morphological constraints and behavioural adaptations reduce direct competition (Schoener, 1974). The divergence between the relatively narrow range of preferred foraging depths and the significant interspecific variation in actual foraging depth indicates that species partition available resources through fine-scale behavioural adjustments, closely aligning with classical niche differentiation theory (Schoener, 1974). Feeding guild classification further clarifies the coexistence of multiple species within the wetland system. Distinct guilds such as grazers, dabblers and deep-foraging species utilise different components of the habitat, reinforcing the role of trophic and spatial partitioning in sustaining community structure. Similar guild-based patterns have been observed in other South Asian wetland bird communities, where morphological and behavioural differentiation underpin stable coexistence (Ntiamoa-Baidu *et al.*, 1998; Zwarts & Blomert, 1992). The sanctuary's hydrological and habitat heterogeneity plays a central role in sustaining waterfowl diversity.

Seasonal variation in water depth creates a mosaic of foraging environments, from deep, open waters to shallow, vegetation-enabling habitats, with distinct ecological niches for species with

differing morphological attributes to exploit. Such habitat complexity is widely recognised as a key factor of waterbird diversity in dynamic wetland ecosystems (Ma *et al.*, 2010). Declining water levels during certain periods enhance prey accessibility by aggregating macroinvertebrates and small fish, and simultaneously reveal marginal vegetation that supports herbivorous guilds. Such hydrological influences have been observed in floodplain wetlands, where depth variability governs foraging-resource distribution and promotes community stability (Ma *et al.*, 2010). The observed increase in Shannon diversity in the study area across sampling periods suggests that heterogeneous wetland systems can safeguard against temporal variability in resource availability. This aligns with broader assessments indicating that wetlands with intact hydrological regimes sustain more resilient and diverse waterbird communities (Ramsar Convention Secretariat, 2016). Maintaining natural hydrological processes, therefore, remains essential for the long-term conservation of migratory and resident waterfowl within major riverine wetlands.

5. CONCLUSION

This research indicates that the Panidihing Bird Sanctuary maintains a stable and increasingly thriving waterfowl population, highlighting its ecological significance in the Brahmaputra floodplain. The steady rise in the Shannon-Wiener diversity index from $H' = 1.412$ in 2021 to 1.745 in 2023 showcases a positive change in species diversity, evenness, and the overall structure of the community. Improvements in diversity over time are commonly viewed as signs of favourable habitat conditions and ecological stability within wetland ecosystems (Keddy, 2010). The frequent presence of migratory species alongside resident waterfowl underscores the sanctuary's significance as a seasonal refuge of regional importance, aligning with trends observed in other floodplain wetlands (Ntiama-Baidu *et al.*, 1998; Gatto *et al.*, 2008). A major finding of this research is the distinct evidence of multi-dimensional niche partitioning among the species examined, which aids their coexistence in a common habitat. Spatial separation was noticeable, with species utilising shallow wetlands, open-water areas, and grassland regions in different ways. This type of habitat partitioning minimises direct competition and is a widespread strategy that fosters species coexistence within waterbird groups (Wiens, 1989; Weller, 1999). Trophic differentiation further reinforced this trend, as species accessed a broad array of food sources, which included benthic invertebrates, aquatic macrophytes, fish, grasses, and phytoplankton.

The partitioning of resources based on dietary differences has been recognised as a key factor influencing community structure among wetland birds (Krebs, 2009; Ntiama-Baidu *et al.*, 1998). Additionally, adaptations in morphology and behaviour were closely associated with foraging techniques. Differences in bill shape, body dimensions, and feeding depths allowed

species to effectively access various food sources, reducing interspecific competition. For instance, dabbling species like the Indian Spot-billed Duck demonstrated increased foraging behaviour in shallow waters, while diving species took advantage of deeper areas. These observations align with previous research highlighting strong connections between morphology and feeding habits in waterbirds (Cezilly & Boy, 1988). Similar patterns have also been documented in other tropical and subtropical wetlands, indicating that such adaptive differentiation is a widespread ecological phenomenon (Gatto *et al.*, 2008). Seasonal fluctuations in water level influence waterbird communities, with some species increasing and others declining, while contributing to habitat heterogeneity and trophic diversity in floodplain wetlands (Boukrouma *et al.*, 2018; Junk *et al.*, 1989; and Keddy, 2010). Regular monitoring is necessary to detect ecological changes and inform management, with emphasis on conserving natural hydrological regimes and vegetation structure. Long-term assessment of species diversity, habitat conditions, and ecological interactions remains essential for developing adaptive conservation strategies and sustaining both resident and migratory waterfowl populations (Ma *et al.*, 2010)

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