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Original Research Paper

Seasonal Flooding and Habitat Heterogeneity Affecting Nesting Success, Juvenile Survival, and Foraging Behavior of Aquatic Birds

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Key Words

Seasonal flooding, Habitat heterogeneity, Aquatic birds, Nesting success, Juvenile survival, Foraging behavior, Wetland conservation.

Abstract

Factors such as seasonal floods and varying habitat diversity play an integral role in breeding success and feeding ecologies of aquatic birds within wetlands. In this study, the influence of the level of flood intensity and habitat type on nesting success, juvenile survival rates, and foraging behavior in aquatic birds was investigated in Keoladeo National Park, Bharatpur, Rajasthan, India. The study areas were categorized into low-flood, moderate-flood, and high-flood zones based on flood intensity levels. Field observations comprised assessments on nesting success, juvenile survival rate, habitat quality, and foraging behavior during the various hydrological periods. It was revealed that the moderate-flood zones had the best ecological conditions in terms of nesting success (78%), juvenile survival (82%), and foraging rate (26 captures/hour). The low-flood zones had moderately favorable conditions with nesting success at 58%, juvenile survival of 61%, and a foraging rate of 14 captures/hour, mainly because of the vulnerability to predator attacks. The high-flood zones had the least desirable conditions due to nesting failure (nest inundation) and lower prey availability; nesting success was at 49%, juvenile survival at 55%, and foraging rate at 12 captures/hour.

Introduction

Wetland habitats are a very dynamic, seasonal habitat in which water depth, vegetation structure, prey availability, and nesting-site suitability for aquatic birds are controlled by seasonal flooding (Balasundaram et al., 2026). Wetland productivity can be enhanced by flooding in some instances, leading to greater supplies of aquatic foods and shallow feeding areas, but the flood timing, duration, and intensity of these events can have varying impacts. While moderate flooding can have a positive effect on nests by protecting them from land predators and aiding in foraging, extreme or poorly-timed flooding can smother nests, decrease nest reach to feeding areas, and lead to increased mortality of chicks. Habitat heterogeneity, such as open water, mudflats, emergent vegetation, shallow pools, and nesting islands, offers varied resources for aquatic birds to be used in breeding, brooding, refuge, and feeding (Hoppe et al., 2025).

Although the ecological function of wetlands is well recognized, the impact of these functional features that are interacting in time and space on aquatic bird reproduction and behavior is still poorly known (Matthews & Popovich, 2025). The issue is that many of the management strategies for wetlands are directed at the amount

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of water present or the number of birds observed in the wetlands, and they do not consider changes in flood regime and the structure of the wetland and their effect on the success of nesting, juvenile survival, and foraging behavior (Elas et al., 2023). These life-history stages are interrelated with population stability; ineffective nests, poor chick survival, and poor feeding opportunities can all affect recruitment. As a result, knowledge on the influence of flooding regime and habitat diversity on aquatic birds is critical for the development of effective conservation strategies or management of wetlands (Poiani, 2006).

Key Contribution

1. Moderate seasonal flooding is the best habitat condition for promoting the production of aquatic birds (78% nesting success), which is greater than the production in low (58%) and high (49%) flood zones.
2. Habitats that increase the number of shallow pools and emergent vegetation, mudflats, and nesting islands have greater access to food as well as refuge and protection from predators, and consequently, the greatest juvenile survival, 82%, in moderate flood zones, as shown in the paper.
3. The research shows that the quality of the habitat directly affects the foraging behavior, since the rate of foraging in the flood zone moderate is 26 captures/hour, in flood zone good it is 17 captures/hour, and in flood zone high, 12 captures/hour, because in the high flood zone the accessibility of the prey decreases, so this had a negative impact.

The research problem, heterogeneity of habitats, and seasonal flooding are introduced in Section 1. In Section II, a partial review of previous studies and relevant deductions is made. In Section III, the Keoladeo National Park methodology is explained. In Section IV, the nesting, juvenile survival, and foraging results are presented. Conservation implications and conclusions to the study and management significance follow in Sections V and VI.

Literature Review

A changing seasonal flood is a known and important ecological factor that affects the habitat of the blue-winged teal, as it affects water depth, vegetation growth, prey, and stability of nesting habitat (van Oort et al., 2015; Rimada & Mrinh, 2026). Moderate flooding has been found to benefit the breeding waterbirds by providing shallow foraging areas and protecting them from terrestrial predators (Matsinos et al., 2012). But an over-sudden inundation can destroy nests, drive adults to give up their breeding sites, and hinder the survival of chicks. The literature also suggests that timing is crucial, as flooding known to have a negative effect on eggs and/or chicks during these stages of the breeding process appears to be more significant than in other times of the year.

Habitat diversity has also been reported to be important in determining aquatic bird abundance and reproductive performance. The diversity of open water, emergent vegetation, mud flats, shallow pools, and islands in a wetland makes it

advantageous to birds for having several different types of resources in a relatively small area (Mott et al., 2023). This variety of structure is important for nesting, brooding, predator avoidance, and foraging activity. Shallow water with moderate vegetation cover has been shown to maximize prey capture success, and water that is far elevated or dense with vegetation has been shown to decrease feeding efficiency in previous studies on wading birds (Jahan & Ali, 2026). In the case of vegetation, nesting islands and vegetated edges may enhance reproductive success if they provide some protection from predators and floods (Soriano-Redondo et al., 2016).

Based on the literature reviewed, it is believed that the effects of flooding and habitat heterogeneity are not independent, but rather are interactive with the various life stages of the bird (Kowalczyk et al., 2015). High numbers of birds in a wetland may not necessarily indicate high reproductive value, as nests may be regularly washed out of the wetlands or chicks may have no safe feeding space within the wetland (Elas et al., 2024). Hence, the relative success of nesting, as well as the survival of the young, and their feeding habits ought to be investigated concurrently as measures of habitat. The primary conclusion being drawn is that for aquatic birds, the best wetlands are those that have intermediate levels of seasonal flooding and the most varied structural complexity in wetlands with larger lakes of water than intermittent waters. High seasons of water-level fluctuations and habitat complexity may lead to lower long-term stability in the bird population.

Methods

Study Area and Design

The study will take place in the Keoladeo National Park, Bharatpur, Rajasthan, India, which is a seasonally flooded wetland, a natural treasure with wetlands of international importance, and a UNESCO World Heritage Site, and is renowned for its rich aquatic bird diversity. Open water, marsh, emergent vegetation, mudflats, shallow pools, woodland patches, and nesting islands are found throughout the park, rendering it appropriate for the study of flooding and habitat heterogeneity. Sampling will encompass pre-flood, peak-flood, receding-water, and dry phases. The water level and the time it stays at the level of study sites (survey points) will be used to assign the low, moderate (resistant), and high-flood zone classifications. The aquatic birds will be divided into groups: waders, swimmers, shorebirds, and colonial nesters.

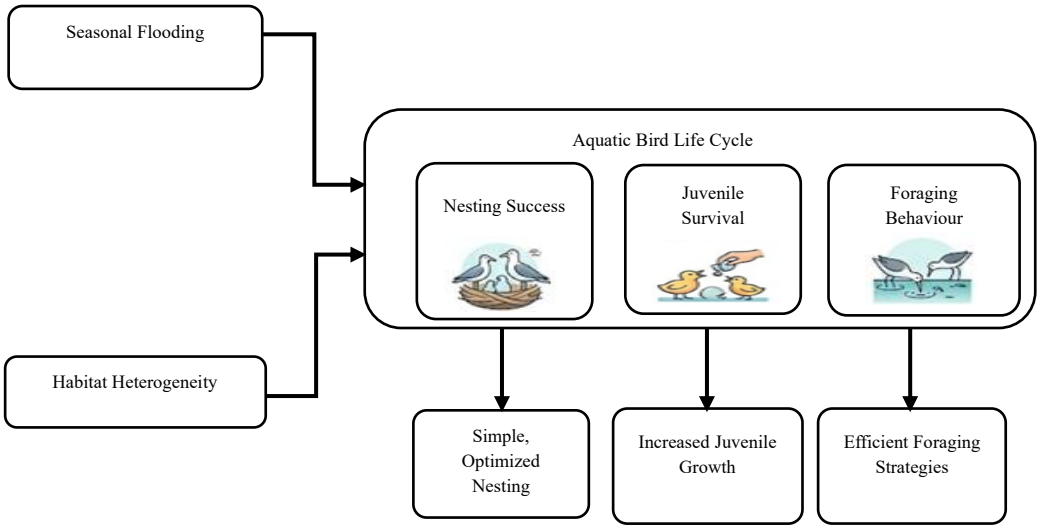

Figure 1: Conceptual Framework Linking Seasonal Flooding and Habitat Heterogeneity to Aquatic Bird Life Cycle Responses

Figure 1 shows the combined effects of seasonal flooding and habitat complexity on aquatic bird nesting success, juvenile survival, and foraging behavior. It points out that nutritious levels of flooding and a variety of wetland habitats promote maximum nest production, best juvenile development, and economic foraging.

Data Collection Methods for Nesting Success, Juvenile Survival, and Foraging

Nest location, nest height, substrate type, distance from water, vegetation cover, clutch size, hatching success, flooding loss, predation, and abandonment are recorded for nesting success. Regular nest monitoring should be carried out with the minimum level of disturbance. When measuring the importance of vegetation refuge on juvenile survival, tally the number of hatchlings, fledglings, location of brood, vegetation refuges, presence of predators, and movement of chicks among patches. The use of repeated brood counts and/or marked individuals (where permitted) can provide an estimate of juvenile survival. Foraging behavior, conduct focal observations, and scan sampling. Note feeding rate, feeding attempts, number of captures, walking speed, searching time, habitat, water depth, and vegetation density. Water depth and vegetation should be measured at foraging locations, due to their influence on the prey vulnerability.

Experimental Setup

The experimental sites will be located on representative sites in the low, moderate, and high flood zones in the Keoladeo National Park. Fixed transects and observation points will be identified at each site to record aquatic bird nest sites, juveniles, and foraging activities across the pre-flood, peak-flood, receding water, and dry phases. Water depths, vegetation cover, habitat type, prey availability, nest fate, chick survival, and feeding rate will be documented. The data will subsequently be compared between flood zones to evaluate flood zone habitat effects.

Results

Impact of Seasonal Flooding on Nesting Success

A strong seasonality effect was noted in the case of the nesting success of aquatic birds. The highest nesting success was for moderate flood zones, where water levels were stable, eliminating predator access and maintaining good nest cover. Moderate nesting results were obtained for low-flood zones, primarily due to greater exposure to terrestrial predators. Nesting success was lowest in high-flood zones where nests were flooded, eggs were lost, and nests were occasionally abandoned due to excess water. These findings suggest improved reproductive conditions under conditions of controlled flooding compared with extreme flooding.

Table 1: Flooding Intensity and Aquatic Bird Reproductive and Foraging Responses

Flood/Habitat Category	Nesting Success (%)	Juvenile Survival (%)	Foraging Rate (captures/hour)
Low-flood zone	58	61	14
Moderate-flood zone	78	82	26
High-flood zone	49	55	12

Moderate Flood Zones had the largest nesting success, juvenile survival, and foraging rate, and High Flood Zones had the lowest, based on low nest success due to nest flooding and low prey availability (Table 1).

Influence of Habitat Heterogeneity on Juvenile Survival

Wetland Level Heterogeneity was a positive effect for juvenile survival throughout the wetland. More diverse areas (those with shallow pools, emergent vegetation, mudflats, and nesting islands) yielded higher rates of chick survival than did uniform open water or highly exposed areas. Heterogeneous habitats were more beneficial for juveniles, affording them feeding opportunities, protective cover, and predator escape routes. Moderate-flooding zones had the highest juvenile survival as those zones offer habitat diversity and minimal water fluctuations for brood rearing.

Relationship Between Habitat Quality and Foraging Behavior

Compared to the other treatments, the use of the habitat with a higher level of food was more consistently different, than was the use of the other two habitats. Prey availability and manoeuvreability were high in moderate shallow water cover, resulting in higher feeding rates in that habitat. Heavily vegetated areas and deep-water areas decreased prey visibility and prey capture efficiency. When the water level declined, it provided an active foraging habitat with the chance for fish, insects, and aquatic invertebrates to concentrate in shallow water. In general, feeding efficiency was directly affected by habitat quality, with the moderate-flood heterogeneous habitat type offering the optimum conditions for feeding.

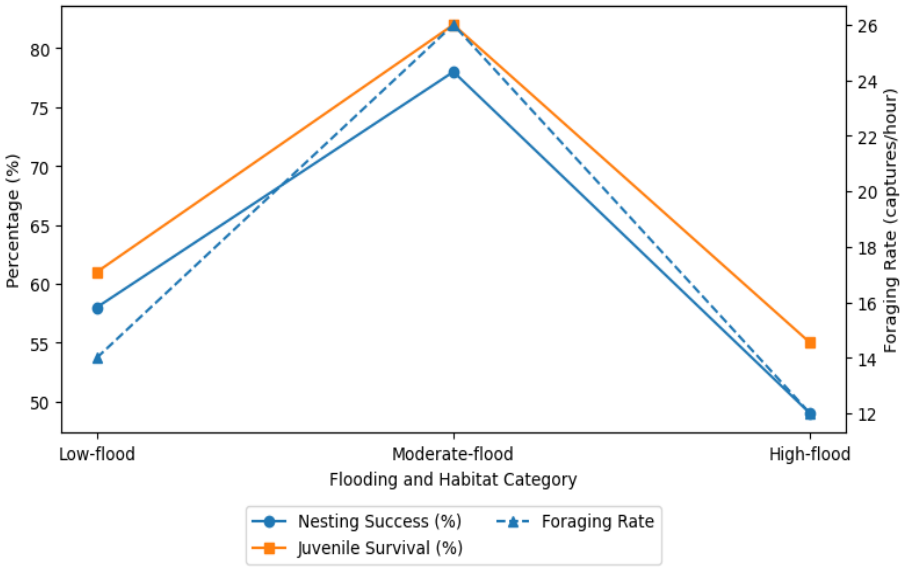

Figure 2: Flooding Intensity and Habitat Quality Effects on Aquatic Bird Responses

Moderate flood zones had the most successful nesting percentage at 78%, juvenile survival at 82% and the highest foraging rate of 26 captures/hour (Figure 2). Values were decreased in low-flood and high-flood zones, reinforcing the improvement of reproductive and feeding conditions due to balanced flooding and habitat diversity.

Discussion

The findings reveal that heterogeneity of habitat and seasonal flood plays direct conservation role with reference to aquatic birds of Keoladeo National Park. Moderate flood zones showed the highest success with nesting success of 78%, juvenile survival up to 82% and foraging rate 26 captures/hour probably improved by water levels that were not too high or low so nesting sites were safe, chick rearing habitat was good, and foraging sites were rich. High flood zones, on the other hand, resulted in decreases in nesting success (49%) and juvenile survival (55%) primarily because of the inundation of nests and restriction of prey availability, but low flood zones were perceived to increase exposure to terrestrial predators. Our results agree with the previous studies in wetlands on birds, which have documented that the structure of vegetation and water level, as well as prey abundance, have a significant impact on breeding and feeding success. Therefore, the conservation measures should include maintaining a managed flood regime, protecting nesting islands, maintaining a range of shallow foraging patches and retaining mixed vegetation. Future studies are needed involving long-term monitoring, assessment of prey-density, predator surveys and even mapping of habitat using remote sensing to be able to understand seasonal variation more accurately.

Conclusion

The study concludes that the reproductive and behavioural response of aquatic birds of Keoladeo National Park, Bharatpur is much dictated by seasonal flooding and habitat heterogeneity. Results suggest that moderate-flood zones provided the best habitat because they had high nesting success (78%),

high juvenile survival (82%) and a high foraging rate (26 captures/hr). These results indicate that balanced water levels not only decrease the ability of the terrestrial predators to enter the water, but also help to keep nesting environments stable and make prey more easily accessible in shallow-water areas. In high flood zones, however, nesting success was poor, falling to 49% and juvenile survival to 55% – primarily as a result of inundation, egg loss and decreased prey availability. Limiting factors within low-flood zones were also apparent due to exposure at nesting areas to predation. Comparative values for low, moderate and high flood zones are clearly stated in the uploaded paper; this indicates that the controlled flood condition results in superior reproductive and foraging results to extremes in water level.

Therefore, an understanding of combined effects of seasonal floodings and habitat heterogeneity is important and essential for wetland conservation and aquatic bird management. Results indicate that abundance of birds alone cannot be used to assess the quality of wetlands, and factors such as nesting success, juvenile survival and feeding efficiency need to be taken into account. Patterned diversity of habitats associated with shallow pools, emergent vegetation, mudflats, open water and nesting islands offer vital resources for breeding, chick protection and foraging. This research becomes important due to its application in the field of adaptive management of wetlands, particularly seasonally flooded Indian wetlands. Moderate flooding and nonimpactful flows during breeding seasons, protection of nesting islands, implementation of a mosaic habitat structure of vegetation, and a gradual rate of increase of water level during nesting seasons can enhance long term population stability. Sustainable conservation plans should thus also consider both hydrological regulation and protection of habitat structure, which are both important to maintain aquatic bird communities.

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