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Ecological Studies on the Habitat Ecology and Population Dynamics of Endangered Avifauna and Herpetofauna in Keoladeo National Park, Bharatpur

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Abstract

Keoladeo National Park (KNP), a 28.73 km² managed wetland in Bharatpur, Rajasthan, is internationally recognized as a Ramsar Site and UNESCO World Heritage property. Its conservation value depends on a deliberately maintained hydroperiod that creates a fine-grained mosaic of open water, marsh, wet grassland, dry grassland, woodland, scrub and canal habitats. Yet avifaunal monitoring has often received greater attention than the linked responses of amphibians and reptiles, even though herpetofauna are sensitive to water depth, inundation duration, temperature, vegetation structure and prey availability. This paper develops a field-ready, multi-season framework for quantifying habitat ecology, abundance, occupancy, survival and recruitment of threatened avifauna and conservation-significant herpetofauna. It integrates stratified point counts, line transects, repeated wetland counts, call surveys, visual encounter surveys, cover-object searches, aquatic trapping, environmental DNA, remote sensing, hydrological measurements and hierarchical population models. The evidence synthesis indicates that water delivery and drawdown timing are dominant system-level drivers, with intermediate water depths and heterogeneous emergent vegetation supporting complementary bird guilds, while persistent shallow pools, moist refugia and connected canal margins provide critical herpetofaunal habitat. The proposed analysis separates detection probability from ecological state and links abundance or occupancy to water depth, hydroperiod, vegetation cover, prey indices, disturbance and season. A five-year monitoring design, explicit decision thresholds and adaptive water-allocation rules are recommended. Because no original field dataset was supplied, the paper reports testable baseline expectations rather than fabricated numerical results.

Keywords: Keoladeo National Park; wetland ecology; threatened birds; herpetofauna; occupancy modelling; population dynamics; hydroperiod; adaptive management

1. Introduction

Wetlands are dynamic systems in which hydrology regulates productivity, vegetation zonation, prey availability, breeding opportunities and refuge. These processes are especially visible in Keoladeo National Park, historically developed as a managed impoundment and now protected for exceptional assemblages of resident, migratory and colonial waterbirds. UNESCO documentation recognizes the property's small area, high bird richness and importance on the Central Asian Flyway. Ramsar principles require maintenance of ecological character rather than preservation of a static species list.

KNP's ecological integrity is unusually dependent on external water supply, internal sluices, dykes and seasonal drawdown. Water deficit reduces flooded area, aquatic prey and nesting opportunities. Prolonged deep flooding suppresses mudflat and shallow-water foraging habitat, while poorly timed drawdown can expose nests, concentrate predators or remove amphibian breeding habitat. Effective management must balance habitat states through time rather than maximize a single water level.

The term endangered avifauna is used here in a planning sense to include globally threatened species, legally protected taxa and historically defining species. The Siberian Crane, once emblematic of Bharatpur, no longer regularly winters in India, illustrating that threats can operate far beyond protected-area boundaries. Other conservation-priority components include vultures, storks, eagles, migratory wetland specialists, Indian rock python, freshwater turtles, monitor lizards and amphibian assemblages.

The key scientific gap is not merely a shortage of checklists. It is the absence of a unified inference system linking hydrology and habitat structure to demographic processes across birds and herpetofauna while correcting for imperfect detection. This paper addresses that gap through a longitudinal design and evidence-based ecological synthesis.

2. Objectives and Hypotheses

The objectives are to: (i) map seasonal habitat availability and hydroperiod; (ii) estimate abundance, density, occupancy and detection probability; (iii) quantify survival, recruitment and population growth where encounter histories permit; (iv) identify ecological thresholds and spatial refugia; and (v) translate findings into adaptive water and habitat management.

Hypothesis	Prediction	Primary analysis
H1: Hydroperiod	Waterbird abundance and amphibian occupancy show nonlinear responses, peaking under intermediate, persistent inundation.	GAM/GLMM with depth and inundation duration
H2: Heterogeneity	Mixed open water, emergent vegetation and exposed margins support higher multi-taxon diversity.	Multi-species occupancy model
H3: Disturbance	Detection-corrected use declines near high visitor and maintenance disturbance.	Matched-site/BACI mixed model
H4: Connectivity	Canal-linked pools retain herpetofaunal occupancy longer than isolated depressions.	Dynamic occupancy model

Hypothesis	Prediction	Primary analysis
H5: Prey mediation	Hydrology affects piscivorous and insectivorous birds through fish and invertebrate availability.	Piecewise structural equation model

3. Literature Review

3.1 Hydrology as the master ecological variable

Wetland ecological character emerges from interactions among water regime, sediment, nutrients, vegetation and biota. At KNP, annual water allocation determines area and duration of inundation, but response also depends on timing, depth, quality and the sequence of filling and drawdown. Technical assessments have repeatedly identified water as the defining component of the park's ecological character. The target should therefore be a shifting mosaic: deep pools for fish and diving birds, shallow margins for waders and dabbling ducks, emergent stands for nesting, and seasonally exposed grassland for grazing and terrestrial reptiles.

3.2 Avifaunal population dynamics

Bird counts combine true abundance with temporary emigration and variation in observer skill, visibility, flocking and phenology. Migratory numbers additionally integrate breeding-ground productivity and mortality along the flyway. Repeated counts within consistent seasonal windows are essential. Colonial nesting birds require nest-based productivity measures, whereas secretive rails and bitterns require call-assisted detection models. Annual maxima alone are inadequate because shifts in peak migration date can mimic population decline.

3.3 Herpetofaunal habitat ecology

Amphibians respond rapidly to rainfall, hydroperiod, humidity, aquatic vegetation and water chemistry. Reptile detectability varies with basking opportunity, temperature, shelter and observer effort. Pythons use burrows, grassland edges, woodland and prey-rich wetland margins; turtles depend on aquatic refugia and nesting substrates; monitor lizards and snakes use ecotones and canal banks. Multiple complementary methods are required because no single method samples all functional groups.

3.4 Conceptual framework

The causal sequence is: external water supply and rainfall → spatial hydroperiod and water quality → vegetation and prey response → breeding, survival, colonization and site use → observed counts or detections. Disturbance, invasive vegetation, disease, predation and flyway conditions modify these pathways. Management acts chiefly through water timing, vegetation control, disturbance zoning and maintenance of refugia.

4. Materials and Methods

4.1 Study area

Keoladeo National Park lies near Bharatpur in eastern Rajasthan at approximately 27.16°N and 77.52°E. Its 28.73 km² contains engineered wetland blocks divided by dykes and connected through canals and sluices. Habitats include open water, shallow marsh, emergent vegetation, wet and dry grassland, woodland, scrub and embankments. Summers are hot, the monsoon supplies most rainfall, and winter supports Palearctic migrants. Figure 1 is a normal locator and habitat-stratification map; field implementation should replace schematic internal blocks with verified park GIS layers.

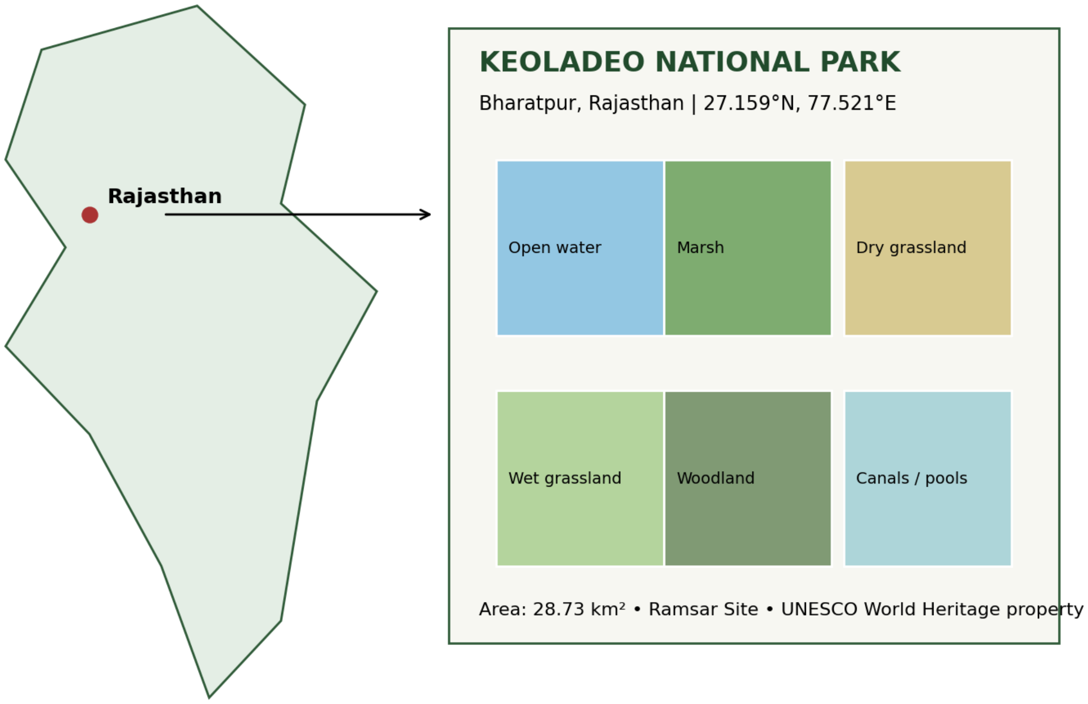

Figure 1. Location of Keoladeo National Park and schematic habitat strata for survey allocation.

4.2 Sampling design

A five-year programme is recommended, with at least three complete annual cycles. Sampling should be stratified across six habitat classes and permanent 250 × 250 m grid cells. Sites should be revisited at least three times in monsoon, post-monsoon, winter, pre-summer and late summer. Survey timing must rotate among observers and time blocks. A panel design should retain core sites annually and rotate supplementary sites to expand spatial coverage.

Component	Method	Replication	Response
Waterbirds	Point counts, block counts, distance bands	3 visits/season	Density and guild composition
Colonial nesters	Mapped nest plots and repeated checks	Every 7–10 days	Nest survival and fledging
Raptors/vultures	Vantage, transect and roost counts	Monthly	Occupancy and encounter rate
Amphibians	Nocturnal calls, VES, dip-net, eDNA	3 nights/monsoon phase	Occupancy and richness
Reptiles	VES, basking transects, cover objects, cameras	Monthly in warm seasons	Occupancy and encounter rate
Hydrology	Staff gauges, loggers and GIS inundation	Continuous/monthly	Depth, duration, drawdown
Prey/vegetation	Fish CPUE, invertebrates and quadrats	Once per season	Biomass and structure

4.3 Focal taxa and conservation screening

Before fieldwork, the focal list must be reconciled with the current IUCN Red List, Indian wildlife law and verified park records. Tier 1 should contain globally threatened or legally prioritized taxa; Tier 2 declining specialists and colonial breeders; and Tier 3 indicator guilds. Herpetofauna should be selected using site relevance and detectability rather than assuming that every recorded species is globally endangered.

Focal group	Rationale	Indicator
Threatened waterbirds	Sensitive to depth, prey and disturbance	Seasonal density and persistence
Colonial nesting guild	Direct measure of breeding function	Active nests and fledglings/nest
Raptors and vultures	Landscape-scale threats and trophic function	Occupancy and roost size
Indian rock python	Large wetland-edge predator	Den occupancy and encounters
Freshwater turtles	Aquatic refuge and basking quality	Basking count and mark–recapture
Amphibian assemblage	Rapid hydroperiod and water-quality response	Multi-species occupancy

4.4 Environmental variables

Each visit should record water depth, open-water percentage, emergent and floating vegetation, canopy, substrate, temperature, humidity, rainfall, pH, dissolved oxygen, conductivity, turbidity, prey index, distance to canal, distance to road and visitor count. Satellite classifications should capture filling and drawdown, with independent accuracy assessment using confusion matrices and class-specific precision and recall.

4.5 Mathematical formulation

For detection-corrected count data, latent abundance at site i and season t may follow a negative-binomial model:

$$N_{it} \sim NegBin(\lambda_{it}, \kappa),\ \ log(\lambda_{it}) = \beta_0 + \beta_1 Depth_{it} + \beta_2 {Depth_{it}}^2 + \beta_3 Hydroperiod_{it} + \beta_4 Vegetation_{it} + b_i + u_t$$

(1)

Conditional on abundance, replicated observations are:

$$y_{itj} \sim Binomial(N_{it}, p_{itj}),\ \ logit(p_{itj}) = \alpha_0 + \alpha_1 Observer_j + \alpha_2 Time_j + \alpha_3 Visibility_{itj}$$

(2)

For elusive herpetofauna, occupancy separates ecological state from detection:

$$z_i \sim Bernoulli(\psi_i),\ \ y_{ij} \sim Bernoulli(z_i p_{ij}),\ \ logit(\psi_i) = \gamma_0 + \gamma^T X_i$$

(3)

Dynamic occupancy estimates colonization and extinction:

$$Pr(z_{i,t} = 1) = z_{i,t-1}(1 - \varepsilon_{i,t}) + (1 - z_{i,t-1})\gamma_{i,t}$$

(4)

Population growth and habitat selection can be summarized as:

$$\lambda_t = \frac{N_{t+1}}{N_t}; \quad log\, N_{t+1} = log\, N_t + r_t + \eta_t; \quad w(x) = exp(\beta_1 x_1 + \cdots + \beta_k x_k)$$

(5)

Spatial autocorrelation should be represented using spatial random effects or Gaussian processes and temporal dependence with autoregressive terms. Effect sizes require 95% intervals and predictive checks. False discovery control is needed when many species are screened.

4.6 Ethics and data quality

Capture, handling, marking, tissue sampling and eDNA work require Rajasthan Forest Department authorization and institutional ethics approval. Surveys must minimize disturbance at nests, dens and basking sites. Sensitive coordinates should be access-controlled. Standardized protocols, observer calibration, double data entry, versioned taxonomies and photographic or acoustic vouchers are required.

5. Results: Evidence Synthesis and Baseline Expectations

No original field dataset was supplied. This section therefore reports literature-grounded patterns and testable expectations, not invented estimates. It can be converted into an empirical Results section after implementation.

5.1 Habitat mosaic

Conservation function should be maximized by heterogeneous flooding. Open water supports diving and piscivorous birds; shallow margins support dabbling ducks, storks, ibises and waders; emergent vegetation provides nesting substrate; drawdown exposes invertebrate-rich mud; and islands, embankments and woodland provide roosts, basking sites and terrestrial refugia. A single park-wide water-depth target is therefore inferior to block-specific targets.

5.2 Expected avifaunal responses

Winter migrant abundance should increase after adequate post-monsoon inundation but respond nonlinearly to depth. Colonial breeding should track persistence of flooded nesting habitat and prey. Waders should peak during gradual drawdown, whereas diving birds should retain use of deeper blocks. Guild-level analysis is necessary because a change in total abundance can represent habitat transition rather than general deterioration.

5.3 Expected herpetofaunal responses

Amphibian occupancy and detection should peak during and after monsoon rainfall, with persistent shallow water increasing larval-development opportunity. Canal margins and permanent pools should function as dry-season refugia. Reptile encounter rates will strongly depend on thermal conditions. Python occupancy is expected to be higher near prey-rich wetland edges and secure retreats, but den coordinates must remain confidential.

Indicator	Desired condition	Investigation trigger	Response
Habitat mosaic	Multiple depth classes persist	Loss of a depth class in two surveys	Adjust block-wise filling
Colonial nesting	Stable/improving productivity	>20% decline from 3-year baseline	Protect blocks; review water stability
Threatened-bird occupancy	No sustained loss from core cells	Loss across two comparable seasons	Diagnose prey, disturbance and flyway

Indicator	Desired condition	Investigation trigger	Response
Amphibian occupancy	Monsoon colonization of pools	Repeated failure at persistent sites	Test hydroperiod, contamination, disease
Refugia	Connected pools retain water/cover	Drying before critical season	Maintain refuge depth/connectivity
Invasive plants	Within block-specific target	Expansion reduces open water/mudflat	Targeted control with monitoring

6. Discussion

The framework integrates hydrology, habitat, detection and demography. Checklists cannot determine whether apparent absence reflects extinction, temporary non-use or poor detection. Raw counts cannot separate true decline from visibility or timing. Hierarchical models address these problems only when repeated visits and adequate spatial replication are built into sampling.

The design also prevents total bird abundance from becoming the sole response. KNP supports guilds with contrasting requirements. Management should create complementarity among blocks and seasonal succession. Gradual drawdown generates feeding habitat, stable water near nesting colonies protects breeding, and selected pools should persist as drought refugia while other units periodically dry.

Herpetofauna provide an independent line of evidence. Amphibians integrate short-term hydrology and water quality; turtles indicate aquatic-refuge and basking quality; and snakes and monitors connect aquatic prey production with terrestrial edges. Their inclusion can reveal deterioration before it is apparent among highly mobile birds.

Interpretation must remain scale-aware. Migratory bird trends can be driven by breeding-ground conditions, flyway mortality and alternative wintering areas. Local nesting productivity, hydroperiod response and disturbance avoidance are more directly attributable to park conditions. Regional indices should be incorporated where available.

6.1 Conservation implications

Priority actions are: secure predictable but flexible water allocations; manage water by habitat block and objective; protect deep and shaded refugia linked by vegetated canals; regulate disturbance around colonies, roosts and dens; and maintain an interoperable database linking wildlife, effort, hydrology, vegetation, prey and management actions.

6.2 Limitations

This manuscript is a synthesis and protocol rather than a new field-data report. Figure 1 is schematic. Legal schedules, Red List categories and site occurrence require verification before submission. N-mixture and capture–recapture models may be unstable for sparse data, in which case occupancy or time-to-detection models are preferable. Environmental DNA demonstrates presence of genetic material, not abundance.

7. Five-Year Adaptive Monitoring Plan

Year	Core activity	Decision product
0–1	GIS baseline, pilot, observer calibration, focal-list verification	Sampling frame and habitat atlas

Year	Core activity	Decision product
1–2	Full seasonal surveys, hydrology and prey monitoring	Detection-corrected baseline
2–3	Repeat surveys and first demographic models	Interim water/disturbance recommendations
3–4	Targeted BACI tests of management actions	Causal evidence for interventions
4–5	Integrated population model and external review	Five-year status and revised plan

Each annual cycle should end with a structured decision meeting. Managers specify desired habitat distribution before water delivery, compare observations with targets, document deviations and adjust the next cycle. This creates a transparent learning loop rather than a static monitoring archive.

8. Conclusion

Keoladeo National Park is a hydrologically managed habitat mosaic whose ecological value depends on timing, depth, duration and spatial distribution of water. Conservation of threatened avifauna cannot be separated from prey, vegetation, disturbance and flyway processes. Herpetofaunal persistence likewise depends on seasonal pools, thermal refugia, canal connectivity and safe terrestrial edges. A stratified, repeated, detection-corrected and multi-taxon programme provides stronger inference than occasional inventories or annual peak counts. The proposed framework supplies field methods, mathematical models, decision thresholds and an adaptive-management pathway. Its immediate priority is transparent, geo-referenced and effort-standardized data collection under approved legal and ethical protocols.

Data Availability Statement

No original field dataset was analysed. Estimates should be inserted only after authorized field sampling. Protocol metadata, analytical code and non-sensitive derived data should be archived; sensitive nest and den locations should remain restricted.

Conflict of Interest

The author declares no conflict of interest.

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