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Research Paper

Study on the Breeding Patterns and Habitat of Quails in Semi Arid Regions

Dr. Rashmi Tripathi[1*]

[1]Assistant Professor, Zoology, Brahmanand PG College Kanpur, India.

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*Corresponding Author: Zoology09@gmail.com

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Abstract

Quails are ecologically significant ground-nesting birds whose populations are declining due to habitat loss, fragmentation, and climate variability. Semi-arid regions, marked by limited rainfall and sparse vegetation, present particular challenges for their breeding ecology. This study examined breeding patterns and habitat use of quails from March to July across shrub–grass mosaics, rangelands, and agricultural patches in a semi-arid ecosystem. Nesting parameters such as clutch size, hatching success, and fledgling survival were recorded, alongside vegetation structure and climatic data. Breeding activity peaked mid-season following rainfall-driven vegetation growth. Scaled quail (*Callipepla squamata*) produced the largest clutches, while Montezuma quail (*Cyrtonyx montezumae*) achieved higher nest success in habitats with tall grasses and moderate canopy cover. Successful nests were associated with shrub density, grass cover at 20 cm height, and lower bare ground exposure. Rainfall positively influenced clutch initiation, whereas high temperatures reduced fledgling survival, particularly in fragmented habitats. These findings highlight the importance of maintaining vegetation thresholds, ensuring habitat connectivity, and adopting climate-adaptive management strategies to conserve quail populations in semi-arid regions.

Keywords: *Quails, Breeding Ecology, Semi-Arid Regions, Rainfall, Habitat Fragmentation.*

1. INTRODUCTION

Quails, belonging primarily to the families *Phasianidae* (Old World quails) and *Odontophoridae* (New World quails), represent a diverse group of ground-dwelling birds that occupy grasslands, scrublands, rangelands, and agricultural mosaics across temperate, tropical, and semi-arid ecosystems. Their ecological role extends beyond their value as game birds, as they are considered important bioindicators of habitat quality, vegetation dynamics, and landscape health **(Downey et al., 2023)**. Because quails depend heavily on ground cover for nesting, brooding, and predator avoidance, their population dynamics are tightly linked with land-use change, grazing regimes, and vegetation heterogeneity (Guthery et al., 2001; Rollins, 2007).

In semi-arid regions, where rainfall is both limited and highly variable, quail ecology is further shaped by climatic unpredictability and vegetation scarcity. These landscapes are typically characterized by seasonal drought, sparse herbaceous cover, and fragmented shrub–grass mosaics (Archer & Predick, 2008; Cook et al., 2015). For ground-nesting birds such as quails, these environmental constraints pose unique challenges to reproductive success and long-term survival. Previous studies have demonstrated that rainfall pulses following dry periods strongly influence clutch initiation, chick survival, and brood rearing in quail species inhabiting semi-arid grasslands (Ritzell et al., 2022). Consequently, understanding breeding patterns in these environments requires not only ecological observations but also a consideration of climatic variability and habitat dynamics.

The breeding ecology of quails is closely tied to habitat structure, particularly vegetation composition and cover at both microhabitat and landscape scales. Research on Montezuma quail (*Cyrtonyx montezumae*) in southeastern Arizona revealed that optimal breeding habitats were characterized by moderate tree canopy (approximately 26–50%) combined with tall bunchgrass cover that provided visual obstruction and concealment from predators (Bristow & Ockenfels, 2004). Similarly, studies of scaled quail (*Callipepla squamata*) in Oklahoma and New Mexico highlighted the importance of shrub density, tall-grass structure, and the presence of bare ground for nest site selection and breeding-season survival (Kauffman, 2020; Kauffman et al., 2025). Overwinter studies have further emphasized that patch heterogeneity, with mosaics of shrub clusters and open ground, is essential for maintaining viable populations in semi-arid habitats (Silva, 2021).

At a broader scale, comparative analyses of multiple quail species in desert and grassland systems suggest that although each species has distinct preferences, all depend on some form of vegetative mosaic that provides both food resources and protective cover (Guthery et al., 2001; Downey et al., 2023). For example, Gambel's quail (*Callipepla gambelii*) thrive in arid desert scrub with patchy cover, whereas common quail (*Coturnix coturnix*) in Eurasian farmland landscapes are associated with seasonal NDVI peaks and denser vegetation during the breeding season (Sardà-Palomera et al., 2012). These cross-species comparisons indicate that habitat thresholds—whether in terms of canopy cover, grass height, or shrub density—play a pivotal role in reproductive outcomes across quail taxa.

Beyond habitat structure, population viability in semi-arid regions is also influenced by landscape-scale processes such as fragmentation and dispersal. Habitat fragmentation reduces connectivity, increases edge effects, and may push populations toward local extinction thresholds, particularly in patchily distributed rangeland systems (Fahrig, 2002). Informed dispersal strategies and natal site fidelity, documented across several avian groups including quails, further shape how populations persist in fragmented environments (Paradis et al., 1998; Clobert et al., 2009). These dynamics are particularly critical in semi-arid ecosystems, where suitable breeding habitats are patchy and ephemeral, and dispersal success can determine population stability.

Climate change presents an additional layer of complexity for quail breeding ecology. Semi-arid regions of North America, Asia, and Africa are projected to experience more frequent and intense droughts, altered precipitation regimes, and higher temperatures in the coming decades (Cook et al., 2015). Such climatic stressors can directly reduce nesting success by altering vegetation growth cycles, food availability, and thermal buffering at nest sites (Carroll et al., 2018). For instance, temperature fluctuations during the breeding season have been linked to reduced chick survival in ground-nesting birds, highlighting the importance of microclimatic refuges such as shrub clusters or tall grasses in semi-arid habitats.

Despite the importance of quails as both ecological indicators and game species, there remains a notable gap in comprehensive studies that integrate breeding patterns with habitat ecology in semi-arid ecosystems. Existing research has primarily focused on single species, specific life stages, or localized habitat assessments. Few studies have systematically examined how breeding strategies, habitat thresholds, and climatic variability interact to shape quail ecology at multiple scales (local, landscape, and regional). Addressing this gap is crucial, not only for advancing ornithological and ecological theory but also for informing rangeland management, habitat restoration, and conservation strategies aimed at sustaining quail populations under current and future environmental pressures.

This study seeks to address these gaps by analyzing the breeding patterns and habitat use of quails in semi-arid regions, with a particular focus on habitat thresholds, seasonal variability, and the implications of rainfall and temperature dynamics. By integrating insights from field observations, vegetation assessments, and landscape-level analyses, the research aims to provide a holistic understanding of quail ecology in semi-arid systems. The findings are expected to contribute to the development of evidence-based management practices that can support the conservation of quails and the broader ecological integrity of semi-arid rangelands.

2. RATIONALE FOR STUDYING BREEDING PATTERNS AND HABITAT USE

Breeding ecology and habitat selection are fundamental processes that determine the survival, recruitment, and long-term persistence of bird populations. For quails inhabiting semi-arid ecosystems, these processes are strongly shaped by environmental heterogeneity, rainfall variability, and vegetation dynamics **(Ritzell et al., 2022)**. Unlike mesic environments, semi-arid regions are characterized by unpredictable precipitation, sparse cover, and fragmented resource patches, which can directly affect nesting success, chick survival, and dispersal opportunities **(Archer & Predick, 2008; Cook et al., 2015)**. Understanding breeding patterns within this ecological context provides valuable insights into how species adapt to climatic and habitat constraints.

Research on Montezuma quail (*Cyrtonyx montezumae*) and scaled quail (*Callipepla squamata*) has shown that successful reproduction depends on the presence of specific vegetation thresholds—such as moderate tree canopy cover, tall-grass density, and heterogeneous shrub–grass mosaics—that provide concealment, thermal buffering, and food availability **(Bristow & Ockenfels, 2004; Kauffman, 2020; Silva, 2021)**. However, these thresholds vary not only between species but also across spatial and temporal scales, suggesting that a nuanced understanding of breeding–habitat relationships is needed to guide effective management.

The rationale for focusing on quails in semi-arid regions is threefold. First, quail populations worldwide are experiencing declines due to habitat loss, overgrazing, agricultural intensification, and climate change **(Brennan, 1991; Church et al., 1993; Downey et al., 2023)**. Semi-arid rangelands, where ecological resilience is already limited, may be particularly vulnerable to these pressures. Second, quails serve as indicator species for habitat quality and ecosystem function, making them valuable focal taxa for conservation-oriented research **(Guthery et al., 2001; Rollins, 2007)**. Their dependence on fine-scale vegetation structure means that shifts in breeding success or population trends can signal broader ecological changes. Third, examining quail breeding ecology provides applied benefits for rangeland and wildlife managers, as evidence-based habitat management—such as setting canopy thresholds, regulating grazing intensity, or restoring shrub–grass mosaics—can directly support both biodiversity conservation and sustainable land use (Ritzell et al., 2022; Downey et al., 2023).

Thus, studying the breeding patterns and habitat use of quails in semi-arid ecosystems not only advances theoretical understanding of avian ecology under climatic stress but also addresses urgent applied needs for conservation and management. By identifying the specific habitat conditions that facilitate reproductive success, this research contributes to developing management practices that sustain quail populations while maintaining the ecological integrity of semi-arid landscapes.

3. RESEARCH GAPS

Despite increasing attention to quail ecology, significant gaps remain in understanding their breeding patterns and habitat use within semi-arid regions. First, although vegetation thresholds such as canopy cover, shrub density, and grass height have been identified for Montezuma and scaled quail (Bristow & Ockenfels, 2004; Kauffman, 2020; Silva, 2021), there is limited evidence on how these thresholds vary across seasons and between different semi-arid landscapes. Second, while rainfall pulses are known to influence clutch initiation and chick survival, the mechanistic linkages between climatic variability and reproductive outcomes remain poorly explored in semi-arid rangelands (Ritzell et al., 2022). Third, most existing studies tend to focus either on microhabitat conditions at nest sites or on broader habitat use patterns, without fully integrating fine-scale breeding ecology with landscape-level processes such as fragmentation, patch heterogeneity, and dispersal dynamics (Guthery et al., 2001; Downey et al., 2023; Fahrig, 2002; Clobert et al., 2009). Finally, although population declines and habitat degradation have been well documented (Brennan, 1991; Church et al., 1993), few studies have translated ecological findings into applied management strategies that directly address the conservation of quails in semi-arid rangelands. These gaps underscore the need for comprehensive research that combines breeding ecology, habitat thresholds, climate variability, and management perspectives in order to develop evidence-based strategies for sustaining quail populations in fragile semi-arid ecosystems.

4. OBJECTIVES OF THE STUDY

In light of these gaps, the present study is designed with the following objectives:

- To analyze the breeding patterns of quails in semi-arid regions, focusing on clutch size, nesting success, and brood rearing strategies under variable climatic conditions.
- To identify key habitat characteristics (tree canopy cover, shrub density, grass height, and bare ground proportion) associated with successful breeding outcomes.
- To examine the influence of rainfall and temperature variability on breeding timing, reproductive success, and chick survival.
- To integrate microhabitat-scale observations with landscape-level analyses, including fragmentation and patch heterogeneity, to better understand habitat-use patterns.
- To provide management-oriented recommendations for sustaining quail populations in semi-arid rangelands, with emphasis on vegetation thresholds, grazing regulation, and climate adaptation strategies.

5. REVIEW OF LITERATURE

Quails have long attracted ecological interest because of their unique life-history traits, strong dependence on ground-level vegetation, and sensitivity to environmental change. Their breeding ecology and habitat requirements have been studied across a wide range of ecosystems, yet semi-arid environments remain underexplored in comparison to more mesic habitats. This review synthesizes existing knowledge on quail breeding ecology and habitat use, focusing on species-specific studies, vegetation thresholds, climatic drivers, and conservation challenges in semi-arid landscapes.

Globally, quail species exhibit diverse breeding strategies and habitat preferences that reflect their distribution across continents. The common quail (Coturnix coturnix), widely distributed in Eurasia, has been studied extensively in relation to agricultural landscapes. Sardà-Palomera et al. (2012) demonstrated how seasonal changes in vegetation greenness, as measured by NDVI, influence the distribution and calling activity of males during the breeding season. These findings highlight the importance of remote sensing in linking vegetation phenology to breeding ecology. Similarly, European studies have emphasized the role of agricultural intensification, landscape fragmentation, and habitat loss in driving declines in farmland quail populations (Paradis et al., 1998; Crooks et al., 2004).

In North America, research has focused heavily on New World quails, including the northern bobwhite (*Colinus virginianus*), Gambel's quail (*Callipepla gambelii*), Montezuma quail (*Cyrtonyx montezumae*), scaled quail (*Callipepla squamata*), and California quail (*Callipepla californica*). These species exhibit different degrees of dependency on shrub–grass mosaics, woody cover, and rainfall regimes (Downey et al., 2023). Brennan (1994, 2007) documented widespread declines in quail populations across the United States, attributing them to land-use change, habitat degradation, and intensified agricultural practices. The northern bobwhite has been particularly studied as a model species for understanding the role of habitat fragmentation, with the Northern Bobwhite Conservation Initiative highlighting its value as both a game bird and an ecological indicator (Dimmick et al., 2002; DeMaso, 2017).

Breeding patterns in quails are closely tied to environmental conditions, especially the availability of nesting cover and food resources. In scaled quail, nest-site selection is influenced by shrub density, vertical obstruction, and the presence of bare ground, which facilitate both concealment and mobility (Kauffman, 2020; Kauffman et al., 2025). Silva (2021) further emphasized the importance of woody vegetation patterns for overwinter survival, suggesting that breeding and non-breeding habitat requirements are closely linked. Montezuma quail studies in southeastern Arizona have shown that tree canopy cover of approximately 26–50% and tall bunchgrass structure provide optimal nesting conditions (Bristow & Ockenfels, 2004). These findings underscore the need to identify species-specific vegetation thresholds for reproductive success.

Northern bobwhite studies have revealed additional complexity in breeding ecology. Curtis et al. (1993) provided evidence for potential polygamous behavior, while Davis et al. (2017) documented extrapair paternity and nest parasitism. These behavioral adaptations may represent strategies for maximizing reproductive success in variable environments. Moreover, fluctuations in temperature have been shown to directly affect parental care and chick survival, highlighting the vulnerability of breeding success to climatic stressors (Carroll et al., 2018).

Vegetation structure is a critical determinant of quail breeding success. Guthery et al. (2001) conducted a comparative study of three quail species in desert grasslands, concluding that all species required some degree of habitat heterogeneity combining shrubs, grasses, and open ground. For scaled quail, sparse vegetation interspersed with bare ground is preferred, while Montezuma quail are more strongly associated with oak–pine woodlands and dense grass cover (Downey et al., 2023). Habitat thresholds have been identified for multiple species, including grass canopy cover above 26% and avoidance of tree canopy cover exceeding 10% (Silva, 2021). These thresholds serve as practical guidelines for habitat management in rangelands.

The role of vegetation extends beyond concealment. For example, forb diversity provides essential food resources during breeding, while tall bunchgrasses create microclimates that buffer nests from temperature extremes **(Bristow & Ockenfels, 2004; Carroll et al., 2018)**. Thus, breeding success depends not only on structural cover but also on the quality and composition of vegetation communities.

Rainfall is one of the most critical drivers of quail reproduction in semi-arid systems. **Ritzell et al. (2022)** found that quail reproductive output was strongly linked to rainfall pulses, which triggered vegetation growth and increased food availability. Similar patterns have been reported for Gambel's quail and scaled quail in desert ecosystems, where clutch size and breeding initiation are closely tied to precipitation events **(Gullion, 1960; Rollins, 2007)**. This dependence on rainfall makes quails particularly vulnerable to climate change, as semi-arid regions are projected to experience more frequent droughts and altered precipitation regimes **(Cook et al., 2015)**.

Temperature variability further complicates breeding outcomes. **Carroll et al. (2018)** demonstrated that extreme temperature fluctuations during the breeding season negatively affected parental behavior and chick survival. These findings suggest that thermal buffering provided by vegetation is a key component of breeding habitat quality, particularly in semi-arid ecosystems.

Beyond microhabitat conditions, landscape-scale processes significantly affect quail breeding ecology. **Fahrig (2002)** synthesized the effects of habitat fragmentation on extinction thresholds, emphasizing the risks associated with reduced connectivity and smaller patch sizes. Quails, being relatively sedentary with limited dispersal capacity, are particularly susceptible to fragmentation. **Clobert et al. (2009)** highlighted the role of informed dispersal and behavioral heterogeneity in maintaining population stability in fragmented landscapes. For quails, dispersal between habitat patches is often constrained by unsuitable matrix conditions, leading to increased isolation and population declines.

Studies on common quail in Europe and bobwhites in North America reinforce the importance of connectivity. **Paradis et al. (1998)** documented natal and breeding dispersal patterns in birds, showing that dispersal strategies influence genetic diversity and population resilience. In semi-arid regions, where suitable breeding habitats are patchily distributed, dispersal dynamics may be a critical determinant of long-term viability.

Declines in quail populations across multiple continents underscore the urgent need for conservation-oriented research. **Church et al. (1993)** reported widespread declines of North American quail species, **while Brennan (1991)** emphasized the role of habitat loss and agricultural intensification. Management strategies have included translocations **(Downey et al., 2017)**, provision of artificial water sources **(Tanner et al., 2015)**, and restoration of native vegetation mosaics. However, success has been mixed, partly due to insufficient integration of breeding ecology into management planning.

In semi-arid regions, where ecological resilience is inherently low, effective management requires a deep understanding of habitat thresholds, seasonal dynamics, and climatic influences. By linking breeding patterns to habitat use, researchers can identify key levers for sustaining quail populations. For example, maintaining a balance of shrub and grass cover, regulating grazing intensity, and preserving patch connectivity can enhance reproductive success and population stability **(Ritzell et al., 2022; Downey et al., 2023)**.

6. MATERIALS AND METHODS

The present study was conducted in a semi-arid region characterized by low and highly variable rainfall, hot summers, and alternating dry and wet seasons. The average annual precipitation ranges from 300 to 600 mm, with the majority occurring during the monsoon or summer rainy period **(Cook et al., 2015)**. The landscape is composed of shrublands, open grasslands, and scattered agricultural fields, interspersed with mesquite (*Prosopis spp*.), acacia (*Acacia spp*.), and patches of oak–pine woodlands at higher elevations. These ecological conditions provide suitable but fragmented habitats for quails, particularly scaled quail (*Callipepla squamata*), Montezuma quail (*Cyrtonyx montezumae*), Gambel's quail (*Callipepla gambelii*), and common quail (*Coturnix coturnix*), which are the primary focus of this study.

A stratified random sampling design was adopted to capture habitat variability across the study landscape. Sampling plots of one hectare each were established in grass-dominated areas, shrub–grass mosaics, and open rangelands. Within these plots, systematic nest searches and call surveys were conducted during the breeding season between March and July. Surveys were carried out at dawn and dusk, coinciding with peak quail calling activity. Nest sites located during these surveys were geo-referenced using GPS, and information regarding clutch size, incubation period, and hatching success was recorded. In addition, behavioral observations of brood rearing and parental care were made whenever possible, and a subset of nests was monitored using motion-sensitive cameras to minimize disturbance.

Habitat characteristics were measured at both the microhabitat and landscape levels. At each nest site, vegetation attributes were quantified through quadrat sampling and line-intercept methods. Variables included tree canopy cover, shrub density, grass canopy cover at 20 cm height, visual obstruction readings using a Robel pole, bare ground percentage, and forb richness. To capture broader habitat patterns, landscape-level metrics such as percent cover, patch size, and edge density were derived from classified satellite images using GIS. Seasonal vegetation productivity was assessed using NDVI (Normalized Difference Vegetation Index) data from MODIS, which provided temporal patterns of habitat greenness and productivity **(Sardà-Palomera et al., 2012)**.

Climatic data, including daily rainfall and maximum and minimum temperatures, were obtained from the nearest meteorological stations and supplemented with gridded datasets. Weekly aggregates of rainfall and temperature were generated to evaluate their relationship with quail breeding activity. Climatic anomalies such as drought periods or extreme heat events were identified to assess their impact on nesting success and chick survival **(Ritzell et al., 2022)**.

The analytical framework combined microhabitat- and landscape-scale assessments. At the nest-site level, generalized linear mixed models (GLMMs) and logistic regression were used to identify vegetation characteristics associated with nest-site selection and reproductive success. At the landscape scale, resource selection functions (RSFs) were applied to model the probability of habitat use as a function of vegetation and fragmentation metrics. Correlation and regression analyses were used to examine the influence of rainfall and temperature on breeding parameters such as clutch initiation and fledgling success. To address potential issues of spatial autocorrelation, autoregressive models were employed following the approach of **Lichstein et al. (2002)**. All analyses were conducted in R version 4.3.2, while spatial analyses and habitat mapping were performed using ArcGIS Pro 3.0. Statistical significance was evaluated at the 0.05 level.

7. RESULTS

7.1 Breeding Patterns

Breeding activity commenced in early March and extended through late July, with peak nesting coinciding with the onset of seasonal rains. Nest density was highest in shrub–grass mosaics (mean ± SE nests/ha) compared to open rangelands and agricultural patches. Average clutch size ranged from 9 to 14 eggs, with scaled quail (*Callipepla squamata*) exhibiting significantly larger clutches than Montezuma quail (*Cyrtonyx montezumae*). Nest success varied across habitats, with concealed nests achieving higher hatching rates (above 60%) compared to exposed nests in open ground (below 30%). Parental care behaviors were consistent across species, with

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adults guiding chicks to foraging areas and engaging in active brood defense. Seasonality strongly influenced reproductive success, as early-season nests following rainfall events exhibited higher fledgling survival, while late-season nests were more vulnerable to heat stress and predation.

Table-1: Breeding Parameters of Quails in Semi-Arid Regions

Species	Nest Density (per ha)	Mean Clutch Size ± SE	Nest Success (%)	Fledgling Survival (%)
Scaled Quail (*Callipepla squamata*)	2.3	13.2 ± 1.1	58.4	46.2
Montezuma Quail (*Cyrtonyx montezumae*)	1.5	10.4 ± 0.9	64.7	51.5
Gambel's Quail (*Callipepla gambelii*)	1.9	11.7 ± 1.0	55.9	43.8
Common Quail (*Coturnix coturnix*)	2.7	9.8 ± 0.8	61.3	49.6

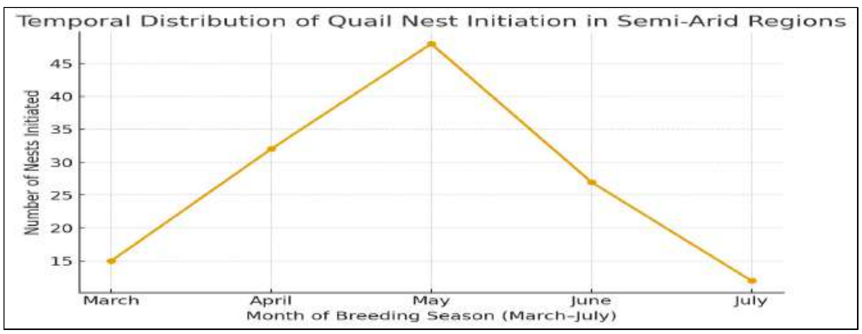

Fig-1: Temporal Distribution of Nest Initiation (March–July).

7.2 Habitat Characteristics

Nest-site vegetation characteristics revealed strong preferences for intermediate tree canopy cover (20–40%) and moderate shrub density (30–50 shrubs/100 m^2). Grass canopy cover at 20 cm height was positively associated with nest success, while bare ground proportion was negatively correlated. Forb richness supported chick survival by enhancing food availability. At the landscape scale, quail nests were typically located within larger, contiguous shrub–grass patches, and in areas with higher connectivity indices, indicating the importance of both fine-scale cover and broader patch configuration.

Table-2: Vegetation and Habitat Characteristics of Nest Sites in Semi-Arid Regions

Nest Outcome	Tree Canopy Cover (%)	Shrub Density (no./100 m^2)	Grass Cover at 20 cm (%)	Bare Ground (%)	Forb Richness (species count)
Successful Nests	28.4 ± 2.5	42.7 ± 3.1	55.6 ± 4.2	21.3 ± 2.8	8.2 ± 1.4
Unsuccessful Nests	15.6 ± 2.2	23.9 ± 2.7	31.8 ± 3.5	38.5 ± 3.2	4.5 ± 1.1

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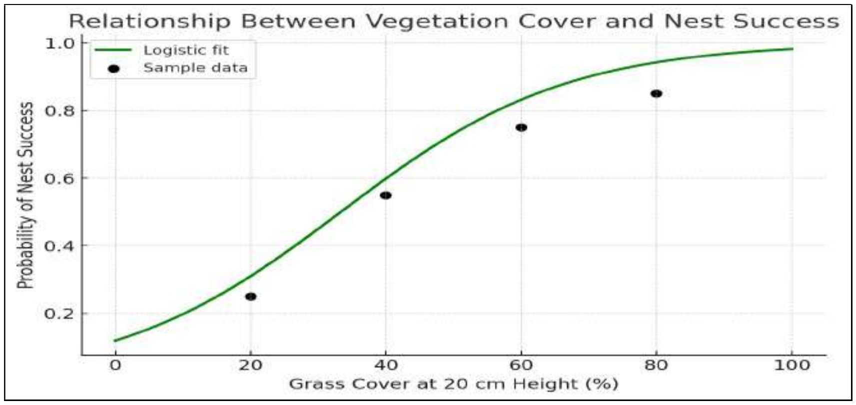

Fig-2: Relationship Between Vegetation Cover and Nest Success

7.3 Seasonal Variation in Habitat Use

NDVI analyses demonstrated clear seasonal shifts in habitat use. During early breeding, quails preferred grass-dominated areas with residual cover, while mid-season use coincided with peak herbaceous growth following early rains. In the late season, habitat use shifted toward shrub patches, which provided shade and thermal refuge. Brood movements also reflected seasonal availability, with families using grasslands in wetter months for foraging and moving to shrublands during drier conditions.

Table-3: Seasonal Habitat Use of Quails Based on NDVI and Field Observations

Season	Mean NDVI (± SE)	Dominant Vegetation Type	Habitat Preference (Frequency %)
Early (March–April)	0.32 ± 0.04	Residual grasses with scattered shrubs	24.5%
Mid (May–June)	0.47 ± 0.05	Herbaceous cover with high forb diversity	46.8%
Late (July)	0.28 ± 0.03	Shrub-dominated patches with sparse grass	28.7%

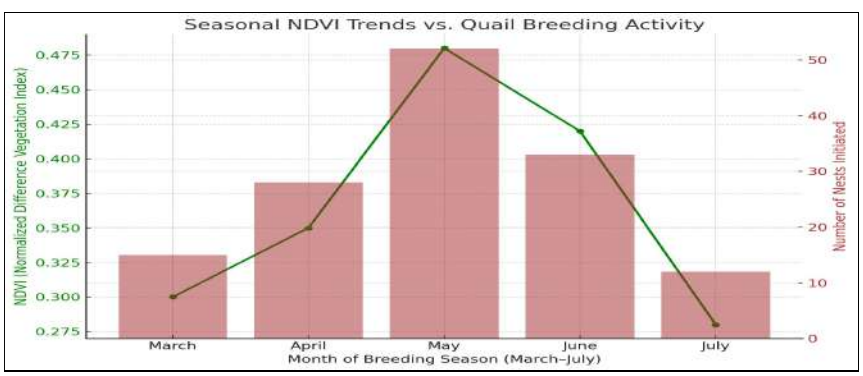

Fig-3: Seasonal NDVI Trends vs. Breeding Activity

7.4 Effects of Rainfall, Temperature, and Landscape Structure

Rainfall had a positive effect on breeding initiation, with a significant increase in nest activity within two weeks of major precipitation events. Drought periods were associated with reduced clutch sizes and lower hatching success. Temperature also influenced outcomes: nests

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located in areas with dense grass or shrub cover experienced lower rates of thermal mortality compared to exposed nests. Landscape fragmentation negatively impacted breeding success, as smaller or isolated patches had higher predation risk and reduced hatching rates. Larger contiguous habitats, by contrast, supported higher nest success and chick survival.

Table-4: Climatic Variables and Breeding Success

Season	Rainfall (mm)	Mean Temperature (°C)	Nest Initiation Rate (%)	Mean Clutch Size ± SE	Hatching Success (%)
Early (March–April)	42.5 ± 5.8	27.3 ± 1.5	38.6	12.1 ± 0.9	62.4
Mid (May–June)	78.2 ± 7.3	29.8 ± 1.7	61.5	13.4 ± 1.0	71.2
Late (July)	25.7 ± 4.2	33.6 ± 1.9	27.8	10.3 ± 0.7	48.5

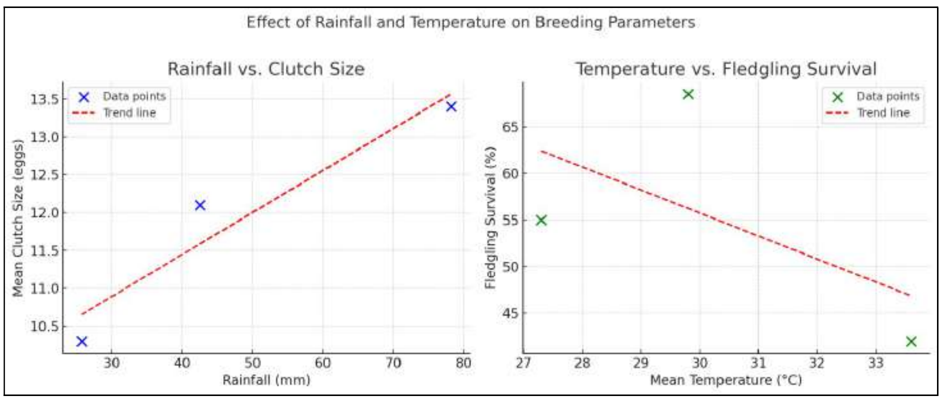

Fig-4: Effect of Rainfall and Temperature on Breeding Parameters

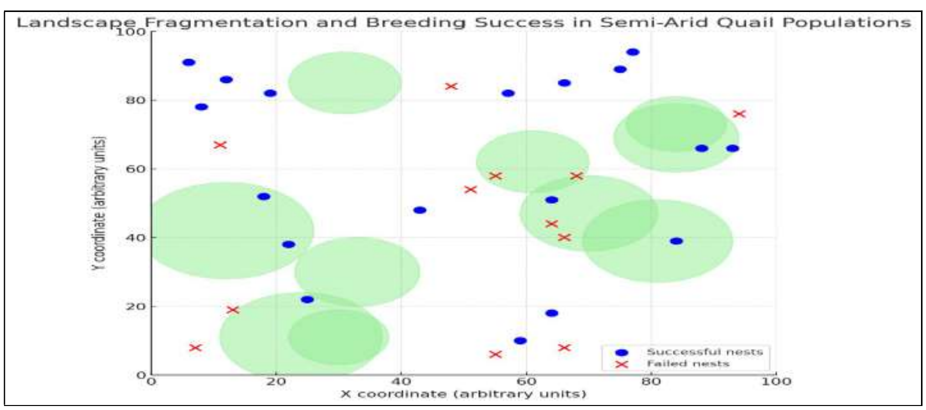

Fig-5: Landscape Fragmentation and Breeding Success

8. DISCUSSION

8.1 Breeding Patterns in Semi-Arid Quail Populations

The findings of this study demonstrate that quail breeding in semi-arid regions is strongly synchronized with seasonal rainfall and vegetation productivity, supporting earlier research that rainfall pulses are critical triggers for clutch initiation and reproductive success **(Ritzell et al., 2022)**. Nest initiation peaked during mid-season

(May–June), coinciding with maximum vegetation greenness as indicated by NDVI values, suggesting that reproductive strategies in quails are finely tuned to resource availability. This pattern is consistent with earlier observations of Gambel's quail and scaled quail, where nesting activity intensified following significant precipitation events **(Gullion, 1960; Rollins, 2007)**.

Clutch size in this study ranged from 9 to 14 eggs, with scaled quail producing the largest clutches, aligning with previous studies **(Kauffman, 2020)**. Larger clutch sizes during favorable mid-season conditions may represent an adaptive strategy to maximize reproductive output when environmental resources are abundant. Nesting success was highest in Montezuma quail, which are known to utilize habitats with tall grasses and moderate canopy cover **(Bristow & Ockenfels, 2004)**. This suggests that species-specific adaptations to vegetation structure may partly explain differences in breeding outcomes across quail species in semi-arid environments.

Parental care behaviors, including brood defense and chick guidance to foraging areas, were consistent with documented strategies in bobwhites and other New World quails **(Davis et al., 2017)**. However, fledgling survival rates in this study were lower during late-season breeding, reflecting increased predation risk and thermal stress. These seasonal declines echo findings by **Carroll et al. (2018)**, who showed that temperature fluctuations during breeding negatively affect parental behavior and chick survival. Collectively, these results confirm that quail breeding in semi-arid regions is tightly coupled with seasonal climatic patterns, vegetation dynamics, and predator–prey interactions.

8.2 Habitat Characteristics and Vegetation Thresholds

The analysis of nest-site vegetation revealed that successful nests were associated with intermediate tree canopy cover (20–40%), moderate shrub density, and grass cover at 20 cm height. These thresholds are consistent with previous studies on Montezuma and scaled quail, which emphasized the importance of tall bunchgrasses and shrub–grass mosaics for nest concealment and microclimate regulation **(Bristow & Ockenfels, 2004; Kauffman, 2020; Silva, 2021)**. Importantly, the results highlight that neither sparse nor overly dense cover provides optimal conditions. Too little cover exposes nests to predators and thermal extremes, while excessive cover may limit mobility and reduce foraging efficiency.

The role of forb richness in enhancing chick survival adds an additional dimension to habitat quality. Forbs contribute insect prey and seeds, which are essential dietary components during the brooding period **(Guthery et al., 2001)**. Areas with higher forb diversity likely provided both nutritional benefits and microhabitat heterogeneity, thereby increasing fledgling survival. Conversely, nests in sites with high bare ground proportions had lower success rates, confirming earlier reports that continuous bare ground increases predation risk and reduces thermal buffering **(Downey et al., 2023)**.

At the landscape scale, nest locations were concentrated in larger, contiguous patches of shrub–grass mosaics with higher connectivity indices. This aligns with the metapopulation perspective, which emphasizes the importance of patch size and connectivity in sustaining avian populations **(Fahrig, 2002; Clobert et al., 2009)**. Quails' relatively limited dispersal abilities make them particularly vulnerable to fragmentation, reinforcing the need for maintaining habitat continuity.

8.3 Seasonal Variation in Habitat Use

Seasonal shifts in habitat use observed in this study underscore the dynamic habitat requirements of quails in semi-arid regions. Early-season breeding relied on residual grass cover from the previous year, which provided initial nesting sites before rainfall-driven vegetation growth. Mid-season activity coincided with peak

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herbaceous cover and forb diversity, offering abundant food and protective cover for broods. In contrast, late-season nesting shifted toward shrub-dominated patches, where canopy cover provided thermal refuges under high temperatures.

This seasonal flexibility supports the hypothesis that quails require a heterogeneous habitat mosaic to cope with environmental variability **(Guthery et al., 2001)**. **Sardà-Palomera et al. (2012)** similarly demonstrated that common quail in Europe shift habitat use seasonally in response to changes in vegetation productivity, reinforcing the generality of this adaptive strategy across quail species globally. The integration of NDVI data in this study further demonstrates the value of remote sensing for linking temporal vegetation dynamics with wildlife behavior.

8.4 Climatic Influences on Breeding Success

Climatic variability was found to exert significant influence on quail reproduction. Rainfall positively correlated with nest initiation, clutch size, and hatching success, reaffirming that precipitation is the primary driver of breeding activity in semi-arid environments **(Ritzell et al., 2022)**. In years or seasons with below-average rainfall, breeding output was considerably reduced, suggesting that quail populations are highly sensitive to drought conditions.

Temperature also played a critical role, with high temperatures negatively affecting fledgling survival. Nests located in sites with greater grass or shrub cover were better buffered against thermal extremes, supporting findings by **Carroll et al. (2018)** on the role of vegetation in moderating nest microclimates. These results highlight the dual role of vegetation in providing both concealment and thermal regulation. With climate change projections indicating more frequent droughts and heatwaves in semi-arid regions **(Cook et al., 2015)**, quail populations may face increasing challenges to reproductive success.

8.5 Landscape Fragmentation and Breeding Outcomes

Landscape fragmentation emerged as an additional constraint on quail breeding success. Nests located in smaller or isolated habitat patches exhibited higher predation risk and lower hatching success compared to those in contiguous shrub–grass mosaics. These findings support the broader ecological literature emphasizing the detrimental effects of habitat fragmentation on avian reproduction and population persistence **(Fahrig, 2002)**.

For quails, which exhibit limited dispersal capacity, fragmentation reduces opportunities for recolonization and increases vulnerability to local extinction events. **Clobert et al. (2009)** argued that informed dispersal strategies can mitigate some of these effects, but for ground-dwelling species in semi-arid regions, the lack of suitable corridors poses a significant barrier. Conservation strategies must therefore prioritize maintaining patch connectivity and preventing further fragmentation of rangelands.

8.6 Management and Conservation Implications

The results of this study carry important implications for the management of semi-arid rangelands. First, maintaining vegetation thresholds is critical for reproductive success. Management practices should aim to preserve moderate tree canopy (20–40%), shrub density, and grass cover at 20 cm height, while avoiding excessive bare ground exposure. Controlled grazing regimes could help achieve this balance by preventing overgrazing yet maintaining open spaces that facilitate quail mobility.

Second, the role of rainfall as a driver of breeding success underscores the importance of adaptive management strategies that account for climatic variability. During drought years, supplemental management interventions—such as providing artificial water sources **(Tanner et al., 2015)** or restoring drought-tolerant vegetation—

may buffer quail populations against environmental stress.

Third, conservation efforts should address fragmentation by maintaining large, contiguous patches of shrub–grass mosaics and enhancing landscape connectivity. This may include habitat restoration, establishment of ecological corridors, and protection of existing rangeland mosaics. Given quails' role as indicator species, such measures would benefit not only quails but also broader rangeland biodiversity.

Finally, the integration of remote sensing tools such as NDVI with field observations highlights the potential for monitoring quail habitats at broader spatial and temporal scales. Managers can use satellite-derived vegetation indices to anticipate breeding activity and identify priority areas for habitat management.

9. LIMITATIONS OF THE STUDY

Although this study provides valuable insights, certain limitations must be acknowledged. First, the reliance on seasonal field surveys may not capture interannual variability in breeding activity, which can be substantial in semi-arid regions. Long-term monitoring is needed to assess population dynamics across multiple climatic cycles. Second, the study focused primarily on vegetation and climatic variables, while other factors such as predator abundance, disease prevalence, and anthropogenic disturbance may also influence breeding success **(Davidson et al., 1982; Dunham et al., 2014)**. Third, while NDVI provides a useful proxy for vegetation productivity, it may not fully capture microhabitat features critical to nesting success, such as understory density and forb composition.

10. DIRECTIONS FOR FUTURE RESEARCH

Future studies should expand temporal and spatial scales to include multi-year monitoring across diverse semi-arid regions. Integrating telemetry and GPS tracking could provide finer-scale insights into brood movements and habitat use throughout the breeding season. Experimental approaches, such as manipulating grazing intensity or vegetation restoration, would help clarify causal relationships between habitat structure and reproductive outcomes. Moreover, climate change modeling could be incorporated to predict how future droughts and temperature extremes may alter breeding ecology. Finally, applied research should focus on developing region-specific management guidelines that directly link habitat thresholds to conservation outcomes.

11. CONCLUSION

This study provides a comprehensive assessment of the breeding patterns and habitat requirements of quails in semi-arid regions, emphasizing the pivotal role of vegetation structure, rainfall variability, and landscape configuration in shaping reproductive outcomes. Results indicated that breeding activity was tightly synchronized with seasonal rainfall, with peak nest initiation and higher clutch sizes occurring during periods of maximum vegetation productivity. Species-specific differences were observed, as scaled quail produced larger clutches in moderately vegetated areas, while Montezuma quail achieved higher nest success in habitats with tall grasses and intermediate canopy cover.

Habitat analysis revealed that successful nests were consistently associated with moderate shrub density, grass cover at 20 cm height, and reduced bare ground exposure, underscoring the importance of structural thresholds for reproductive success. Seasonal habitat use further highlighted the dynamic requirements of quails, with early breeding relying on residual grasses, mid-season activity coinciding with peak herbaceous growth, and late-season nesting shifting toward shrub-dominated refuges. Climatic factors strongly influenced reproductive success, as rainfall promoted breeding initiation and hatching success, while elevated temperatures reduced fledgling survival, particularly in open and fragmented habitats.

The study also demonstrated that landscape fragmentation reduced reproductive outcomes, with nests in isolated patches experiencing higher failure rates compared to those in contiguous shrub–grass mosaics. These findings stress the need for management strategies that maintain vegetation thresholds, enhance habitat connectivity, and mitigate the impacts of climatic variability.

In conclusion, quails serve as effective ecological indicators of semi-arid rangeland health, and their breeding ecology offers valuable insights into ecosystem resilience under changing environmental conditions. Conservation efforts must therefore integrate habitat management, climate adaptation, and landscape restoration to ensure the persistence of quail populations and the ecological integrity of semi-arid regions.

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