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Influence of Nesting Habitat and Nest Emplacement on the Breeding Success of the Black Francolin (*Francolinus francolinus*, Phasianidae): A Case Study from Pakistan

Asad Ullah [1,*], Sumaira Shams [1,*], Sultan Ayaz [2], Eliana Ibáñez-Arancibia [3,4,5], Unays Siraj [6], Patricio R. De los Rios-Escalante [5,7,8] and Farhad Badshah [1,9,10]

1 Department of Zoology, Abdul Wali Khan University Mardan, Mardan 23200, Pakistan; farhadbadshah999@gmail.com
2 College of Veterinary Sciences and Animal Husbandry, Abdul Wali Khan University Mardan, Mardan 23200, Pakistan; sultanayaz64@awkum.edu.pk
3 PhD Program in Sciences Mentioning Applied Molecular and Cell Biology, La Frontera University, Temuco 4780000, Chile; e.ibanez05@ufromail.cl
4 Laboratory of Engineering, Biotechnology and Applied Biochemistry—LIBBA, Department of Chemical Engineering, Faculty of Engineering and Science, La Frontera University, Temuco 4780000, Chile
5 Departamento de Ciencias Biologicas y Químicas, Facultad de Recursos Naturales, Universidad Católica de Temuco, Casilla 15-D, Temuco 4780000, Chile; prios@uct.cl
6 Department of Biotechnology, Faculty of Science, Mahidol University, Bangkok 10400, Thailand; unayskhan@gmail.com
7 Núcleo de Estudios Ambientales UC Temuco, Casilla 15-D, Temuco 4780000, Chile
8 Estudiante Magister en Estadística, Instituto de Estadística, Facultad de Ciencias, Pontificia Universidad Católica de Valparaíso, Av. Brasil 2830, Valparaíso 2340025, Chile
9 Shenzhen Branch, Guangdong Laboratory of Lingnan Modern Agriculture, Key Laboratory of Livestock and Poultry Multi-Omics of MARA, Agricultural Genomics Institute at Shenzhen, Chinese Academy of Agricultural Sciences, Shenzhen 518000, China
10 A11 State Key Laboratory of Animal Biotech Breeding, Institute of Animal Sciences, Chinese Academy of Agricultural Sciences, Beijing 100193, China
* Correspondence: asadullah_zoology@awkum.edu.pk or asadsaysss@gmail.com (A.U.); sumairashams@awkum.edu.pk (S.S.)

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Simple Summary: The black francolin (*Francolinus francolinus*, Phasianidae) is a ground-dwelling bird found across Eurasia, including Pakistan. Understanding its breeding ecology is essential for conservation. This study explores how nesting habitat and site selection affect breeding success in the Totali Game Reserve. Results show that wetlands, particularly bush-covered areas, provide better protection for nests, leading to higher survival rates. These findings help us improve habitat management strategies for the species. Additionally, human activities including bird translocations may influence genetic diversity, highlighting the need for conservation efforts.

Abstract: Limited research exists on the breeding ecology of the black francolin (*Francolinus francolinus*) in northern Pakistan. This study assessed egg dimensions, clutch size, hatching, fledging, and overall breeding success across different habitats and nests (n = 25) at Totali Game Reserve, Buner. Generalized linear models (GLMs) were used to analyze the effects of nest site characteristics and nest traits on breeding parameters. Egg dimensions were consistent across sites whereas bush nests had slightly wider eggs. The average clutch size was 5.9 ± 1.7 eggs, with an average of 4.8 ± 1.0 hatchlings per nest. A total of 111 chicks fledged, averaging 4.4 ± 1.0 per nest, yielding an overall breeding success rate of 75.5%. Nests containing six eggs had higher hatching success (76.6%). GLMs results showed a significant positive relationship between clutch size and hatchling, while nest site and traits had no significant effects. However, fledgling success was positively influenced by hatchling numbers, with nests in wetland habitats yielding significantly more fledglings

(4.6 ± 0.9) than those from dryland habitats (4.0 ± 1.2). These findings suggest Black Francolins prefer nesting in wetland areas in bushes, likely due to better protection and favorable conditions.

Keywords: eggs; nests; morphometrics; Totali Game Reserve

1. Introduction

Ecological studies on francolins have gained significant attention because these birds serve as crucial indicators of environmental health [1,2]. Researchers have focused on these birds to explore the consequences of habitat changes and human-induced disturbances [3]. The black francolin (*Francolinus francolinus*) is distributed and breeds from Asia to the western Palearctic [4–6]. They have adapted to diverse habitats, and their breeding ecology [7,8], and their presence or absence provide significant information about the integrity of ecosystems [7,9]. The black francolin exhibits a broad geographical distribution throughout Eurasia, extending from Cyprus and southern Turkey through the Middle East to South Asia [5]. Research conducted in Iran and the Himalayan region has investigated its habitat preferences, population densities, and breeding ecology, using MaxEnt modeling, which identified optimal habitats within the Sistan region [9,10]. Black francolin species are taxonomically classified into six subspecies: *F.f francolinus*, found in Cyprus, Turkey, Iraq, and Iran; *F.f arabistanicus*, inhabiting southern Iran and western Iran; *F.f asiae*, native to northern India; *F.f. henrici*, occurring in north Pakistan and western India; *F.f.bogdanovi*, distributed across Iran, Afghanistan, and Pakistan; and *F.f melanonotus*, present in eastern India, Sikkim, and Bangladesh [5]. However, field observations and morphological characteristics have confirmed that the black francolin population in Totali Game Reserve belongs to the subspecies *F. f. henrici*. Therefore, it is essential to assess the influence of broader environmental factors, such as habitat degradation, human disturbance, and climate variability, on the success of black francolin breeding. Our study employs the Totali Game Reserve as a representative model and investigates the breeding ecology and generates broader insights into the habitat selection and success of black francolin breeding.

Successful breeding and survival depend on specific habitat conditions, such as vegetation cover and food availability [11]. In addition to Pakistan and India, successful breeding populations have been reported in Iran, Cyprus, and Bangladesh [12–14]. Their global distribution is influenced primarily by extrinsic factors, such as agricultural development, and habitat modification, and intrinsic factors, such as environmental adaptability and dietary flexibility [15]. Human activities, including hunting and poaching, worsen these challenges, resulting in higher mortality rates and lower breeding success during critical breeding periods [16]. Prior studies have indicated that habitat serves as a framework for reproductive strategies, impacting traits, i.e., clutch size and parental investment across various environments [15]. Avian research on breeding biology has shown that habitat loss significantly affects nesting success and parental investment, which, in turn, increases species vulnerability, with the black francolin being no exception [17].

Black francolins are typically monogamous birds with an extended breeding season ranging from March to July. They experience peak egg-laying periods between April and June, resulting in ground-nesting habits [9,18]. Ground nests depend on natural vegetation for cover, and proximity to such vegetation and wetland habitats enhances their breeding success [11]. Furthermore, effective nesting sites protect against predators, facilitate nest construction, and significantly influence hatching success [19,20], and thus the fledging success of black francolin [21]. Breeding seasonality and bird nesting provide

an understanding of broad patterns and their specific adaptations to the environmental conditions [22,23]. Primarily, these birds choose nest locations on the ground to establish scrape nests [16,24]. Their nests require minimal effort to construct and less extensive parental care during brooding, incubation, and hatching [25,26].

Black Francolins are highly sensitive to human disturbances such as frequent visits to nests and egg handling during the breeding season, which lead to hatching failure [22,27]. Population fluctuations are influenced by various factors, including density-dependent competition for breeding sites and resources as well as environmental variables that influence their dynamics. In South Asia, limited research has been conducted on the breeding biology of black francolins, with studies predominantly carried out in countries such as India [9,13] and Bangladesh [14]. Most studies have focused on factors such as the clutch size, incubation period, and habitat preferences. However, significant research gaps remain in our understanding of their reproductive strategies and variations in breeding. Notably, no studies have been conducted on the breeding biology of black francolins in Pakistan. Therefore, comprehensive studies on nesting ecology are crucial for developing effective conservation strategies to sustain black francolin populations.

We have attempted to advance the knowledge of the breeding ecology of black francolin in Totali Game Reserve, Pakistan. Accordingly, in this study, we aimed to: (i) examine how nesting habitat and nest placement influence the breeding parameters of black francolins in Totali Game Reserve; (ii) assess the effect of nesting habitat on breeding success, hypothesizing that nests in wetlands exhibit a higher breeding success than those in dryland habitats due to the better cover and lower predation risks; (iii) evaluate the impact of nest placement on clutch size and hatching success, predicting that nests located in bushes will have larger clutch sizes and higher hatching success compared to those at field edges; and (iv) investigate the relationship between clutch size and fledgling success, predicting that a larger clutch size generally enhances fledgling success.

2. Materials and Methods

2.1. Study Area

The selection of the study sites was crucial to accurately representing francolin habitats and ensuring significant data collection. The key factors included species presence, site accessibility, and minimal human disturbance. We conducted our study in Totali Game Reserve, Pakistan (30,960 ha; 34°25′29.14″, 72°39′56.83″) (Figure 1) with elevations ranging from 500 m to 2100 m [28]. The Totali Game Reserve supports a population of black francolin; however, it faces threats from human activities, such as hunting, which is legally restricted, yet unauthorized poaching remains a significant concern, particularly during breeding season. Additionally, local communities engage in egg and chick collection, either for consumption or trade. Predators, including jackals *(Canis aureus)*, snakes, wild boars *(Sus scrofa)*, and stray dogs *(Canis lupus)*, pose additional risks to nesting success by preying on eggs and chicks. This region has mountainous terrain and an irregular low-rainfall regime. January and February record the lowest temperatures, (5.7 ± 2.3 °C and 9.4 ± 3.6 °C), whereas July and August are the warmest (25.7 ± 1.6 °C and 26 ± 1.5 °C). April experiences the highest precipitation (196.4 mm), while December receives the lowest (4.5 mm) [29] (Table S1). The study area comprises wetland and dryland habitats, including pure agricultural lands, shrubby *Dodonaea* (Hopbush) communities, mixed pine-grassland communities, *Eucalyptus* (forest gum) communities, and forest-agricultural transition zones. Deep forest regions were avoided due to the absence of the black francolin in these regions. Black Francolin nests in the study area were constructed using soft grass and dry unbaked twigs. Nesting sites were classified as either wetland or dryland habitats based on their loca-

tions. If a nest was built in a shrub, the nesting location was defined as 'Bushes'; otherwise, it was labeled 'Field edges' when they were located at the margins of agricultural fields.

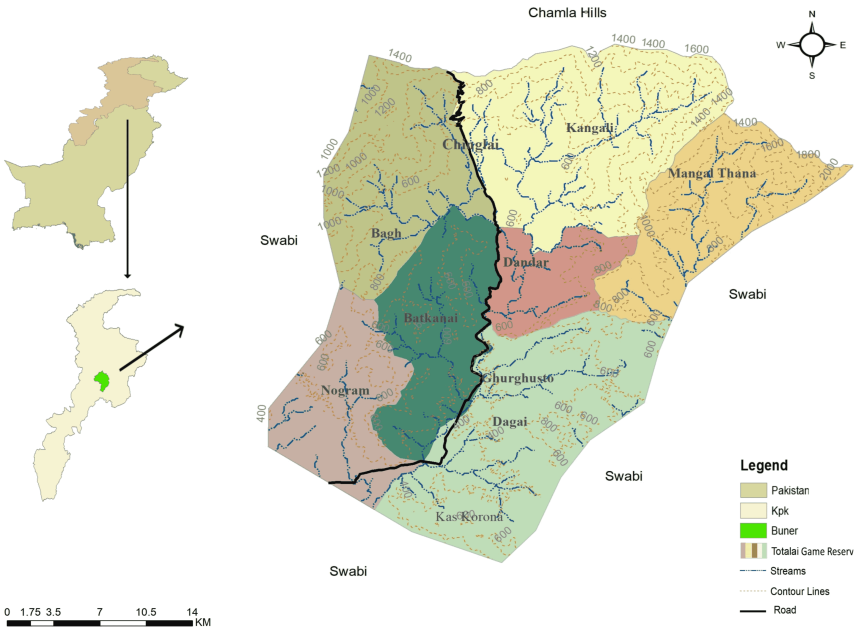

Figure 1. Map of the Totali Game Reserve located in Buner District of Khyber Pakhtunkhwa province, Pakistan.

2.2. Data Collection

2.2.1. Nesting Monitoring and Breeding Survey Methodology (BSM)

The primary aim of nest monitoring was to systematically assess the breeding ecology of black francolins by identifying nesting sites, evaluating breeding success, and analyzing key breeding parameters in 2023. Briefly, nests were searched from early March to late August 2023 based on parental behavioral cues, especially courtship displays by mating birds, along with the common bird census (CBC) methodology [30] involving acoustic calls surveys and visual observations, which is effective for estimating species abundance, identifying nesting sites, and tracking breeding success. No nests were observed until late March, with effective monitoring starting in early April when the first nest was found. Periodic surveys were conducted twice weekly from mid-April to August. We established nine fixed transects, each ranging in length from 1 to 2 km (mean $\pm$ SD: 1.2 $\pm$ 0.3), with a standardized width of 50 m (25 m on each side of the transect) in the survey area where black francolins were recorded in their breeding habitats, following a standardized line transect survey method [9,15]. Observers walked at a steady pace while recording the presence, abundance, and behavior of black francolins. To ensure spatial independence, a minimum separation of 100 m was maintained between adjacent transects, and their distribution was arranged as evenly as possible [9]. Surveys were carried out early in the morning (05.00–17.00), based on the nature of the habitat [30], and to track individual black francolins or their behavior assisted by wildlife watchers and trained locals. Nesting activity was assessed by noting sitting behavior, egg laying, clutch sizes, incubation periods, hatchling and fledglings numbers [31,32].

2.2.2. Nest Identification and Measurement Parameters

Nest identification and measurements involved analyzing the structural characteristics of black francolin nests, and their relationship with nesting success. Nest dimensions and associated environmental variables were measured systematically following [33]. Briefly,

a total of 43 active Black Francolin nests were identified, and a subset of 25 nests was selected based on their accessibility. The nest contents were carefully checked every 3–4 days throughout the survey. To quantify nest structure, three key parameters were measured using a measuring tape or a ruler with ±0.1 cm accuracy: outer diameter (cm), representing the overall size of the nest's structure; inner diameter (cm), indicating the available space for egg placement; and nest surface area (NSA) (cm^2), calculated using the formula:

$$\text{NSA} = \pi \times \left(\frac{D^2}{4}\right) \quad (1)$$

where $\pi = 3.1428$ and D is the inner/outer diameter average of the nest. These parameters indicated a nest's construction strength and cup volume, which determine the space availability for eggs and nestlings, potentially limiting clutch size [33].

2.2.3. Measurement of Black Francolin Eggs

We accurately analyzed the eggs' morphometric characteristics to further understand their potential influence on breeding success following [34]. Briefly, morphometric measurements of eggs were taken in the morning using a digital caliper (0.1 mm) precision when the birds were involved in foraging activity. The utmost care was taken to avoid touching the eggs and disturbing the nests during the measurements [35]. Every week, marked nests were carefully checked during the early morning and late evenings until chicks fledged. Additionally, this study sought to determine the size of the clutch, which refers to the largest number of eggs found in a nest during the incubation period. The incubation period was defined as the time elapsed between the laying of the last egg to hatching [36]. Egg width (EW) and length (EL) were measured at their maximum dimensions, whereas egg volume (EV) [37] and the surface index (SI) [38] were calculated via the following formulas:

$$EV = (0.6057 - 0.0018W) \times LW^2 \quad (2)$$

$$SI = \frac{EW}{EL} \times 100 \quad (3)$$

where L is the egg's maximum length and where W is an egg's maximum width in millimeters.

2.2.4. Assessment of Breeding Success of Black Francolin

We assessed the breeding success of the black francolin species by documenting key breeding parameters as previously described method [33]. Briefly, we documented active nests, including clutch size, hatching numbers, and surviving fledglings at approximately 10 days old, when most of the chicks became mobile. Additionally, our study aimed to establish the duration of the incubation period for the eggs, which ranged from 16–21 days. Further, to quantify the hatching success [33], fledging success [39] and breeding success [40] were calculated as follows:

$$\text{Hatching Success} = \left(\frac{\text{Number of Eggs Hatched}}{\text{Clutch Size}}\right) \times 100 \quad (4)$$

$$\text{Fledging Success} = \left(\frac{\text{Fledglings}}{\text{Hatchlings}}\right) \times 100 \quad (5)$$

$$\text{Breeding Success} = \left(\frac{\text{Number of Fledglings Survived}}{\text{Clutch Size}}\right) \times 100 \quad (6)$$

2.3. Statistical Analysis of the Data

Statistical analysis was applied to each collected nest and summarized as the mean and standard deviation (mean ± sd) for nesting habitats and placement. Furthermore,

a two-way ANOVA was conducted to evaluate variation in nests based on eggs' morphometric parameters, including their outer and inner diameters and the nests' surface areas, and considering nesting habitat, placement, and their interactions as factors. A generalized linear mixed-effects model (GLMM) analyzed the relationships among egg traits (length, width, and volume), with the nest IDs as a random effect. A fixed effect was applied to the egg placement, eggs' dimensions, and nesting habitats. Generalized linear models (GLMs) were used to examine variations in clutch size, and hatchling and fledgling numbers, with likelihood ratio (LR) tests applied [33,41]. The explanatory variables included emplacement (bushes or field edges), nest habitat, and nest surface area, as well as nests' outer and inner diameters. The initial full model incorporated these variables and their interactions with clutch size to model hatchling and fledgling numbers. Each model was simplified based on the Akaike information criterion (AIC), using a forward and backward step selection procedure, and the final model with the lowest AIC value was selected. All statistical tests were applied via RStudio (2023).

3. Results

3.1. Breeding Chronology

Black francolins nests were not observed before late March, despite many individuals roosting in the area. Early gathering indicates pair formation and the onset of nest construction. The breeding period lasted from early March to late July, although some individuals laid eggs as late as August. However, nest predation and destruction extended breeding activity until September. The black francolins began pairing in the second week of March, lasting 10–15 days, followed by nest construction in early April. Egg-laying started in mid-April, with the first chick hatching in mid-May, and continued until late June. By the end of the breeding season, the first broods of black francolins were noted in June, after which the parents abandoned their nests, along with all fledglings.

3.2. Placement and Measurements of Black Francolin Nests

The average outer and inner diameters of the nests were 22.3 ± 1.6 cm (range: 18.9–25.5 cm) and 12.8 ± 1.2 cm (range: 10.7–15.6 cm), respectively. The nests' outer and inner diameters averaged 23.0 ± 1.4 cm and 13.4 ± 1.0 cm in wetland habitats, whereas, in dryland habitats, they averaged 21.1 ± 1.3 cm and 11.9 ± 0.9 cm, respectively. The average nest surface area was 2.4 ± 0.4 dm^2, with 2.6 ± 0.3 dm^2 in wetland and 2.1 ± 0.3 dm^2 in dryland habitat nests (Figure 2). Similarly, nests in bushes averaged 22.6 ± 1.7 cm (outer) and 13.0 ± 1.2 cm (inner), whereas those at the field edges measured 21.7 ± 1.5 cm (outer) and 12.5 ± 1.2 cm (inner). The average nest surface area was 2.5 ± 0.4 dm^2 in bushes and 2.3 ± 0.3 dm^2 for field edge nests (Figure 2). The ANOVA revealed significant differences across nesting habitats in terms of the outer diameter of nests (ANOVA: F (1, 21) = 10.2, $p = 0.004$), the inner diameter of nests (ANOVA: F (1, 21) = 10.7, $p = 0.003$), and the nests' surface area (ANOVA: F (1, 21) = 12.4, $p = 0.002$). However, nest emplacement and its interactions with habitat showed no significant differences.

3.3. Characteristics of Black Francolin Eggs

The black francolin eggs measured 42.0 ± 1.0 mm (range: 40–45) in length, 31.0 ± 1.6 mm (range: 27–34) in width, 20.6 ± 2.3 cm^3 (range: 15–25) in volume and 73.6 ± 3.2 cm^3 (range: 66–82) in shape index. In the wetland habitat nests, eggs were slightly larger (42.4 ± 1.1 mm length, 31.0 ± 1.6 mm width, and 20.7 ± 2.4 cm^3 volume), than those in dryland habitat nests (41.8 ± 0.9 mm length, 31.1 ± 1.5 mm width, and 20.6 ± 2.1 cm^3 volume). Egg morphometric parameters showed minimal variations across nest placement, with a slight increase in width in bush nests (Table 1). However, the egg volume significantly increased

with increasing egg length (GLMM: t = 13.4, $p < 0.001$) and width (GLMM: t = 40.3, $p < 0.001$). The GLMM results revealed a greater increase in volume with increasing egg width in the field edge nests than in the bush nests in wetland habitats (GLMM: t = 2.9, $p = 0.009$) (Figure 3, Table 2). Additionally, eggs from wetland habitat and field edges nests had greater volumes (GLMM: t = 2.5, $p = 0.02$) and (GLMM: t = 2.3, $p = 0.03$) respectively, but were significantly narrower and longer ($p < 0.05$) than those from dryland habitat bush nests (Table 2). The GLMM revealed a positive relationship between egg length and width in wetland habitat nests found at the field edges (Figure 3, Table 2).

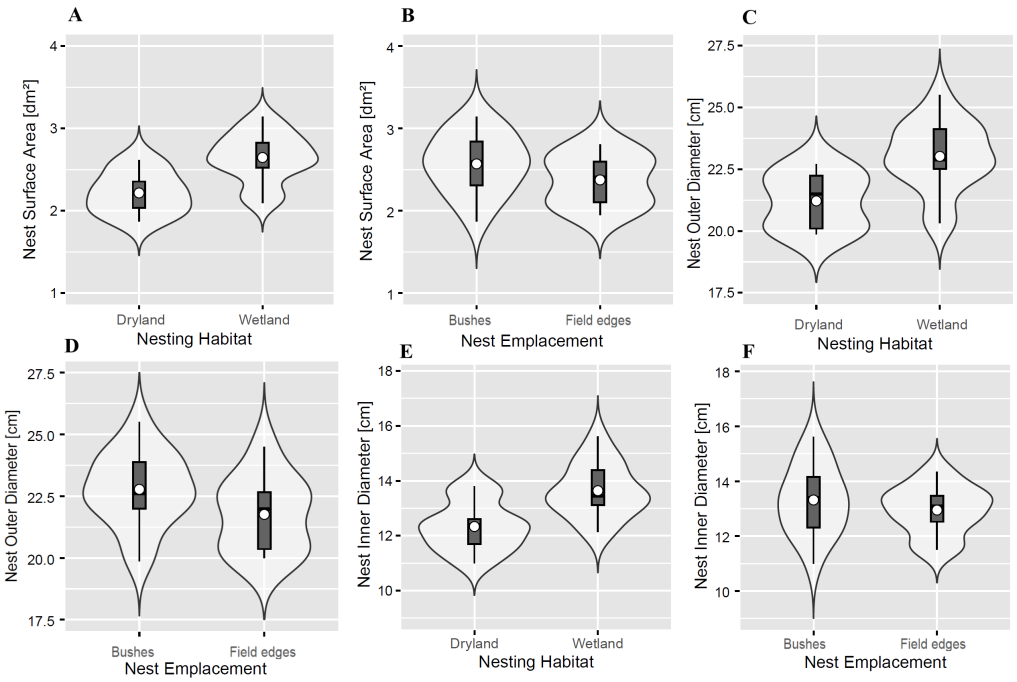

Figure 2. Violin plots with overlaid boxplots illustrate variations in black francolin nest measurements across habitats and emplacements in the Totali Game Reserve. (**A**,**B**) Nest surface area, (**C**,**D**) nest outer diameter, and (**E**,**F**) nest inner diameter, shown variation for different nesting habitats (dryland vs. wetland) and nest emplacements (bushes vs. field edges). Solid white circles indicate the mean values.

Table 1. Egg parameters of black francolin breeding at Totali Game Reserve. The data are presented as means ± standard deviation (SD), interquartile ranges (IQRs), and ranges [min–max].

Egg Parameters	Statistics	Nesting Habitat		Nest Emplacement		Overall
		Wetland (n = 20)	Dryland (n = 15)	Bushes (n = 24)	Field Edges (n = 11)	(n = 35)
Length [mm]	Mean ± SD	42.4 ± 1.0	41.8 ± 0.9	42.2 ± 0.9	42.0 ± 1.2	42.0 ± 1.0
	IQR	1.1	1.3	1.1	1.2	1.2
	Range	[40–45]	[40–44]	[40–44]	[40–45]	[40–45]
Width [mm]	Mean ± SD	30.9 ± 1.6	31.1 ± 1.5	31.4 ± 1.2	30.8 ± 1.7	31.3 ± 1.6
	IQR	1.0	2.5	1.2	2.4	1.8
	Range	[27–34]	[28–33]	[27–34]	[28–34]	[27–34]
Volume [cm^3]	Mean ± SD	20.7 ± 2.4	20.6 ± 2.1	20.9 ± 2.1	20.3 ± 2.7	20.6 ± 2.3
	IQR	2.0	2.7	1.9	3.5	2.5
	Range	[15–25]	[16–24]	[15–25]	[16–25]	[15–25]
Shape index [%]	Mean ± SD	73.1 ± 2.8	74.3 ± 3.6	73.6 ± 3.0	73.2 ± 3.6	73.6 ± 3.2
	IQR	2.5	4.2	3.1	2.1	3.2
	Range	[66–79]	[69–81]	[66–82]	[69–80]	[66–82]

Table 2. Gaussian GLMM assessed relationships among egg traits (length, width, and volume) across various nesting habitats (wetland vs. dryland) and placements (bushes vs. field edges) of black francolin breeding at Totali Game Reserve.

Variables	Estimate	Std. Error	df	*t*-Value	*p*-Value
Gaussian GLMM (Egg Volume)					
(Intercept)	−44.7	2.1	23	−20.9	0.001
Egg length	0.6	0.1	23	13.4	0.001
Egg width	1.4	0.04	23	40.3	0.001
Wetland habitat	6.1	2.5	23	2.5	0.02
Field edges	8.1	3.5	23	2.3	0.03
Wetland habitat × Field edges	−12.3	4.1	23	−3.0	0.006
Egg length × Field edges	−0.1	0.1	23	−1.6	0.1
Egg length × Wetland habitat	−0.1	0.1	23	−1.6	0.1
Egg width × Field edges	−0.1	0.1	23	−2.2	0.04
Egg width × Wetland habitat	−0.1	0.1	23	−1.7	0.1
Egg length × Wetland habitat × Field edges	0.2	0.1	23	1.7	0.1
Egg width × Wetland habitat × Field edges	0.2	0.1	23	2.9	0.009
Gaussian GLMM (Egg Length)					
(Intercept)	45.6	9.2	26	5.0	0.001
Egg width	−0.1	0.3	27	−0.4	0.7
Wetland habitat	−18.0	10.2	27	−1.8	0.09
Field edges	−3.9	11.8	26	−0.3	0.7
Wetland habitat × Field edges	6.9	15.0	27	0.5	0.7
Egg width × Wetland habitat	0.6	0.3	27	1.8	0.08
Egg width × Field edges	0.1	0.4	27	0.3	0.8
Egg width × Wetland habitat × Field edges	−0.2	0.5	27	−0.4	0.7
Gaussian GLMM (Egg Width)					
(Intercept)	38.3	21.7	26.7	1.8	0.09
Egg length	−0.2	0.5	27	−0.3	0.8
Wetland habitat	−56.6	26.1	27	−2.2	0.04
Field edges	−5.5	39.9	26.9	−0.1	0.9
Wetland habitat × Field edges	27.5	47.6	27	0.6	0.6
Egg length × Wetland habitat	1.3	0.6	27	2.1	0.04
Egg length × Field edges	0.09	1.0	27	0.1	0.9
Egg length × Wetland habitat × Field edges	−0.6	1.1	27	−0.5	0.6

3.4. Breeding Parameter Distributions Across Different Clutch Sizes

The clutch size of black francolins breeding ranged from four to eight eggs, with six being the most common, found in 10 out of 25 nests. The average clutch size was 5.9 ± 1.7 eggs. Wetland habitat nests had a higher average of clutch size 6.2 ± 1.2 eggs, with a total of 99 eggs than those in dryland habitat nests which had an average of 5.3 ± 1.0 eggs, with a total of 48 eggs. The clutches containing four or six eggs had the highest hatching success, while breeding success peaked in clutches of six eggs, but was lower in those containing seven eggs (Table 3). Fledging success was greater in five-egg nests compared to that in other common clutches (Table 3). The average number of hatched eggs was 4.9 ± 1.0 per nest (range: 2–7 hatchlings) (Figure 4), with 82 hatchlings recorded in wetland habitat, and 39 recorded in dryland habitat nests. Overall, 111 fledglings were recorded, averaging 4.4 ± 1.0 per nest (Figure 4), with the highest count (32 chicks) from wetland habitat nests with six egg clutches (Table 3). Hatching success was highest in four-egg clutches within wetland habitat bush nests (100%), followed by six-egg clutches (86.1%) in bushes and seven-egg clutches in dryland habitat nests (85.7%). Maximum fledging success (100%) was recorded in five egg nests in wetland habitats and at field edges, followed by seven egg nests in dryland habitats. The overall fledging success rate was 91.7% while breeding success was 75.5%. The breeding success rate for six egg nests was 76.7%, while nests containing five and eight eggs had a success rate of 75% (Table 3).

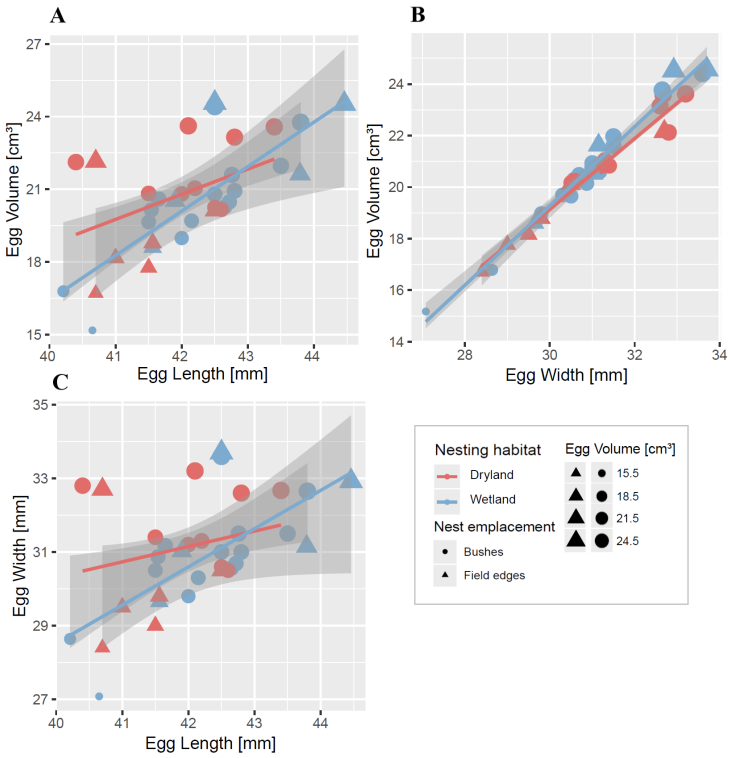

Figure 3. Scatterplots illustrate the relationships between egg dimensions (length, width, and volume) of the black francolin breeding in the Totali Game Reserve. (**A**) Relationship between egg length and volume. (**B**) relationship between egg width and volume (**C**) Relationship between egg length and width. Egg volume represents the values, with a color corresponding to the nesting habitat, and point shapes indicate nest placements. Linear regressions fitted via Gaussian GLM are shown as solid lines with light gray confidence regions.

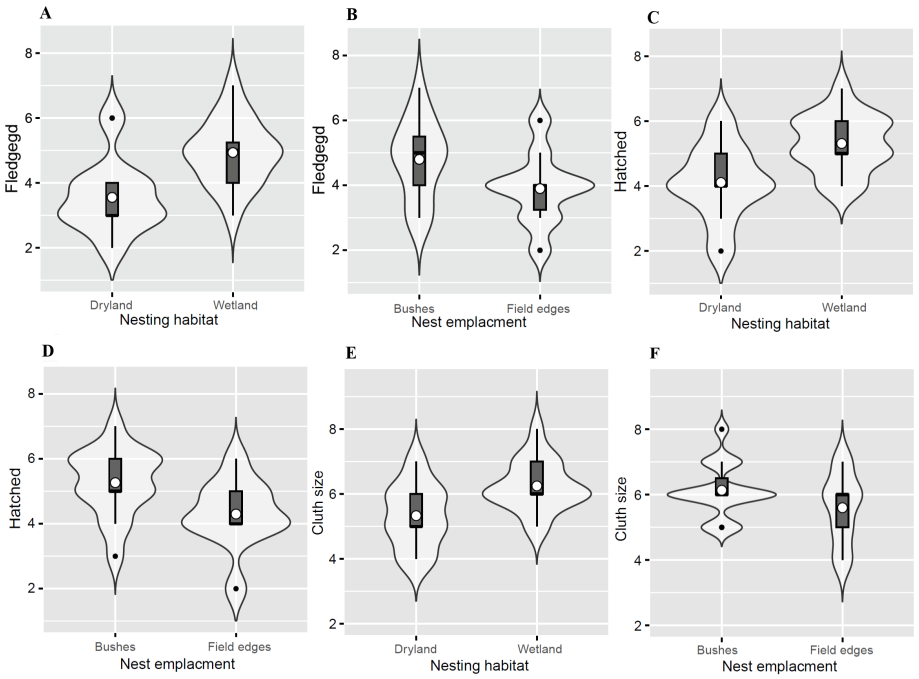

Figure 4. Violin plots with overlaid boxplots illustrate the distribution of the reproductive parameters of black francolin in the Totali Game Reserve. (**A**,**B**) number of fledglings, (**C**,**D**) number of hatchlings, (**E**,**F**) and clutch size, shown for different nesting habitats (wetland vs. dryland) and emplacements (bushes vs. field edges). Solid white circles indicate the mean values.

Table 3. Breeding characteristics of black francolin nesting at Totali Game Reserve. The reproductive data were categorized by the clutch size within the nesting habitat (wetland vs. dryland) and placement (field edges vs. bushes) in 2023.

Clutch Size	**4**	**5**	**6**	**7**	**8**	**Total**
Number of nests						
Wetland habitat	2	2	7	4	2	17
Dryland habitat	2	2	3	1	-	8
field edges	2	2	4	2	-	10
Bushes	2	2	6	3	2	15
Overall	4	4	10	5	2	25
Sum of clutches						
Wetland habitat	8	5	42	28	16	99
Dryland habitat	8	15	18	7	-	43
Field edges	8	10	24	14	-	56
Bushes	8	10	36	21	16	91
Overall	16	20	60	35	16	147
Number of hatchlings						
Wetland habitat	8	4	35	22	13	82
Dryland habitat	6	12	15	6	-	39
Field edges	6	8	19	11	-	44
Bushes	8	8	31	17	13	77
Overall	14	16	50	28	13	121
Number of fledglings						
Wetland habitat	7	4	32	20	12	79
Dryland habitat	5	11	14	6	-	32
Field edges	5	8	18	10	-	41
Bushes	7	7	28	16	12	84
Overall	12	15	46	26	12	111
Hatching success [%]						
Wetland habitat	100	80.0	83.3	78.6	81.3	82.9
Dryland habitat	75.0	80.0	83.3	85.7	-	82.0
Field edges	75.0	80.0	79.1	78.6	-	78.6
Bushes	100	80.0	86.1	80.9	81.3	84.6
Overall	87.5	80.0	83.3	80.0	81.3	82.3
Fledging success [%]						
Wetland habitat	87.5	100	91.4	90.9	92.3	96.3
Dryland habitat	83.3	91.7	93.3	100	-	82.1
Field edges	83.3	100	94.7	90.9	-	61.4
Bushes	87.5	87.5	90.3	94.1	92.3	91.8
Overall	85.7	93.8	92	92.8	92.3	91.7
Breeding success [%]						
Wetland habitat	87.5	80	76.2	71.4	75.0	80.0
Dryland habitat	62.5	73.3	77.8	85.7	-	74.4
Field edges	62.5	80	75.0	71.4	-	73.2
Bushes	87.5	70.0	77.8	76.2	75.0	92.3
Overall	75.0	75.0	76.7	74.4	75.0	75.5

3.5. Impact of Nest Traits on Clutch Size

The effects of the characteristics of the nest site, the traits of the nest, and the breeding parameters of the black francolin are summarized in Table 4. The GLM results revealed no significant effects ($p > 0.05$) of nest location, nesting habitat, or nest traits (e.g., nest surface) on clutch size. Consequently, the surface of the nest does not affect the number of eggs per nest, regardless of habitat or location (Table 4, Figure 5).

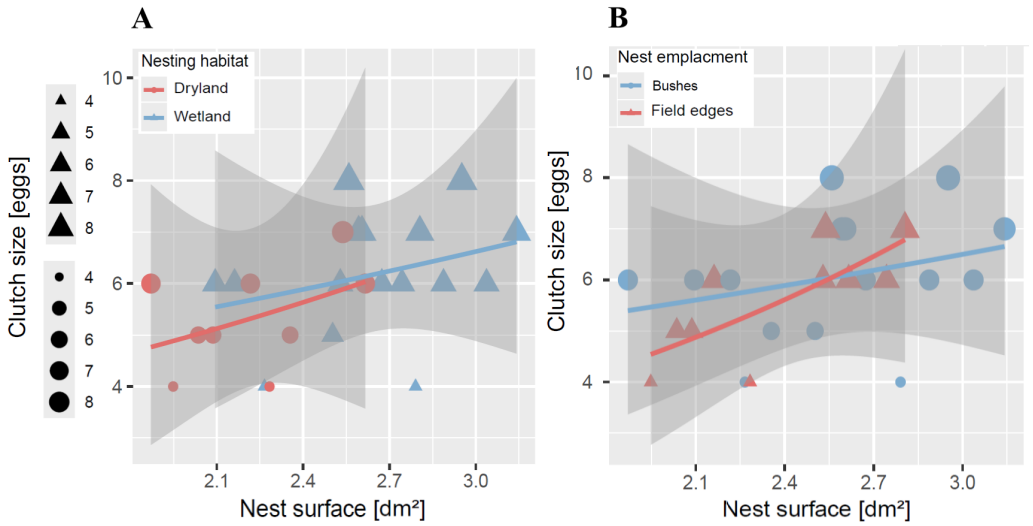

Figure 5. The relationship between nest surface and clutch size of black francolin breeding at Totali Game Reserve. Observations are grouped by (**A**) nesting habitats and (**B**) nest emplacements. Linear regressions fitted via Poisson GLM are shown as solid lines with light gray confidence regions.

Table 4. GLMs analyzed the impacts of nest site and characteristics on clutch size (GLM 1), nest characteristics and clutch size on hatchling numbers (GLM 2), and nest characteristics, clutch size, and hatchling numbers on fledgling variation (GLM 3) in black francolin breeding at the Totali Game Reserve. Model parameters were selected through a 'backward/forward' stepwise method based on the minimal AIC.

Variables	LR χ^2	*p*-Value	Sig.
GLM 1: Clutch size (AIC = 83.4, ΔAIC = 6.1)			
Nesting habitat	4.2	0.06	N.S
Nest placement	0.1	0.8	N.S
Nest surface area	3.3	0.1	N.S
Nesting habitat × Nest surface area	0.1	0.8	N.S
Nest placement × Nest surface area	1.4	0.3	N.S
GLM 2: Hatchling numbers (AIC = 49.3, ΔAIC = 4.7)			
Clutch size	18.4	0.001	**
Nesting habitat	0.2	0.5	N.S
Nest placement	0.8	0.1	N.S
Nest surface area	0.1	0.6	N.S
Nesting habitat × Nest placement	0.30	0.3	N.S
Clutch size × Nest placement	0.7	0.1	N.S
Clutch size × Nesting habitat	0.2	0.4	N.S
Clutch size × Nesting habitat × Nest placement	0.05	0.7	N.S
GLM 3: Fledgling numbers (AIC = 39.0, ΔAIC = 0.3)			
Hatchlings	18.7	0.001	**
Clutch size	1.2	0.01	*
Nesting habitat	0.01	0.9	N.S
Nest placement	0.01	0.8	N.S
Nest surface area	0.8	0.05	*
Clutch size × Nest placement	0.1	0.5	N.S
Clutch size × Nesting habitat	2.0	0.002	**

Notes: N.S = not significant, * = significant at $p < 0.05$, ** = highly significant at $p < 0.01$.

3.6. Variation in Hatchling Numbers

The general linear model (GLM) revealed a significant increase in hatchling number with increasing clutch size (LR: $\chi^2 = 18.4$, $p = 0.001$). However, nest surface area had no significant effect on hatchling variation, regardless of nest location or habitat. However, hatchling numbers were slightly greater in dryland habitat nests, particularly at field edges (4.9 ± 1.0 hatchlings) compared to in bushes (4.8 ± 1.0 hatchlings). GLMs results revealed no significant influence of nesting habitats or their interactions with nest surfaces (Table 4, Figure 6).

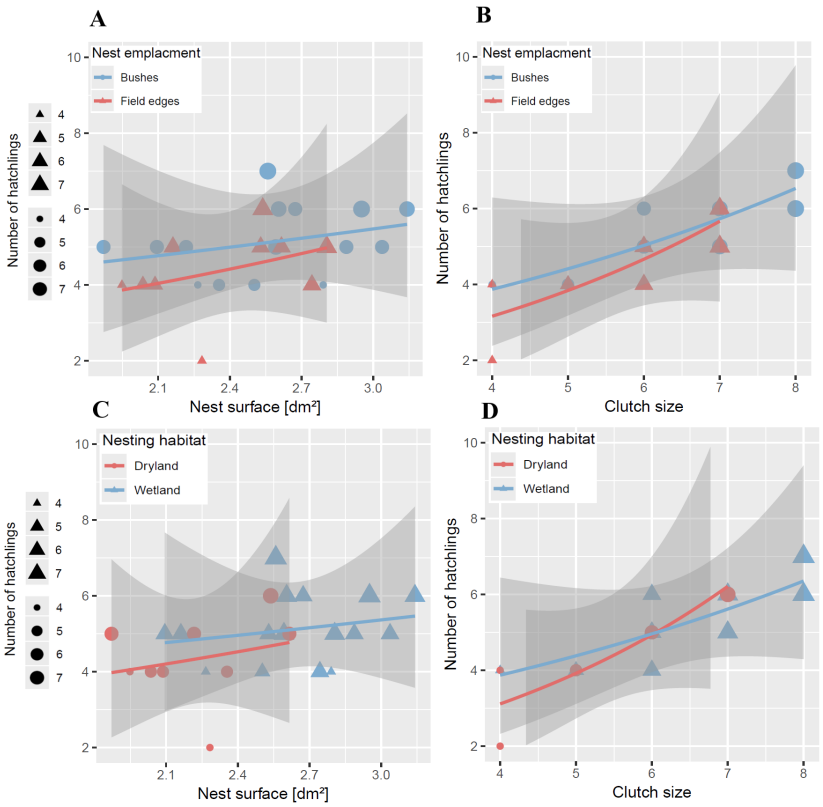

Figure 6. Scatterplots illustrating the relationships between hatching success, nest surface, and clutch size in black francolin breeding at Totali Game Reserve. Data are categorized by nest placements in the upper plots (**A**) nest surface vs. hatchling, (**B**) clutch size vs. hatchling, and by habitats in the lower plots (**C**) nest surface vs. fledglings, (**D**) clutch size vs. fledglings. Linear regressions fitted via Poisson GLM are shown as solid lines with light-gray confidence regions.

3.7. The Influence of Clutch Size, Hatching Success, and Nest Surface on the Number of Fledglings

The simplified GLM revealed that fledgling numbers significantly increased with the number of hatchlings (LR: $\chi^2 = 18.7$, $p = 0.001$) and larger clutch sizes (LR: $\chi^2 = 1.2$, $p = 0.01$). Additionally, the number of fledglings increased significantly with increasing nest surface area (LR: $\chi^2 = 0.8$, $p = 0.05$). Clutch size also had a significant effect on fledgling variations, with differences between Wetland and dryland habitats (LR: $\chi^2 = 2.0$, $p = 0.002$) (Table 4). Regardless of nesting site or placement, the selected GLM confirmed that fledgling numbers increased significantly with the increasing number of hatchlings (Table 4, Figure 7).

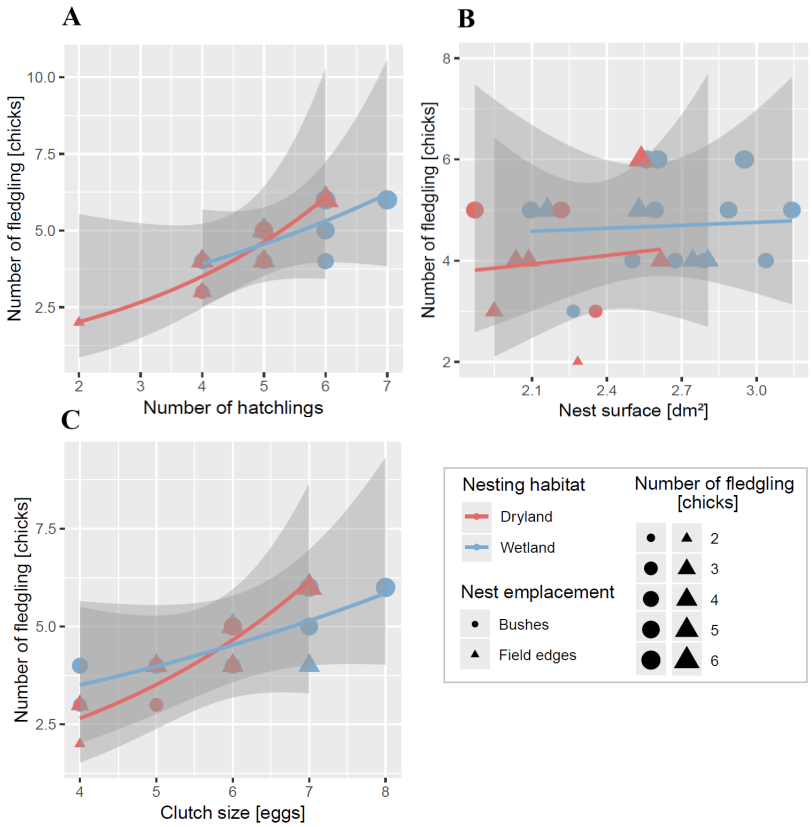

Figure 7. Scatterplots show correlations among the fledgling number, nest surface, clutch size, and hatchling numbers in black francolin breeding at Totali Game Reserve. Observations are categorized by nesting habitats and emplacements. (**A**) hatchling vs. fledgling, (**B**) nest surface vs. fledgling, (**C**) clutch size vs. fledgling. Linear regressions fitted via Poisson GLM are shown as solid lines with light-gray confidence regions.

4. Discussion

We investigated the influence of nesting habitats and nest emplacements on the breeding success of black francolins. Our study was conducted in the Totali Game Reserve, Pakistan, with the aim of evaluating site selection, clutch size, hatching success, and fledglings. Our findings indicated a strong preference for wetland habitats, particularly within bushes, which provide enhanced protection against environmental stressors and predation. Utilizing the Totali Game Reserve as a model system, we demonstrate using Generalized Linear Models (GLMs) that nest placement significantly affects the success of the black francolin's breeding.

Our investigation enhances the understanding of black francolin breeding ecology and contributes to a broader framework for evaluating these species' reproductive strategies. These species exhibit remarkable ecological plasticity across Eurasia; however, despite extensive research on breeding populations in various regions, significant knowledge gaps persist regarding the role of habitat features in influencing breeding success under diverse ecological conditions. The relationship between nest characteristics and breeding performance in birds is complex and varies by species. Although factors such as nest location and structural composition can significantly influence breeding outcomes, others, such as nest size, material composition, and height, do not consistently correlate with breeding success [42–44]. Research indicates that nest dimensions and material flexibility often have minimal impact on offspring survival [45,46], whereas the ecological importance of nest height is shaped by environmental conditions and predation risks [47]. Similarly, the effectiveness of nest concealment does not universally enhance breeding success [48].

These complex associations are largely influenced by species-specific nesting behaviors, climate influences, and predation pressure [23,49].

Black francolins may rely on breeding patterns that vary significantly across regions. In the Totali Game Reserve, black francolins breed from April to August. In the northwestern Himalayas [9] and Bangladesh [14] the breeding season lasts from March to July, peaking in May to June. Bump & Bump [50] documented a longer breeding period extending from March to September, while in the Sistan Plain (Iran) the breeding season was shorter spanning from mid-March to mid-May [10]. In another study Khan [51] reported breeding from February to May with reduced activity continuing until July. Similarly, Negi & Lakhera [11] observed that black francolin breeding calls started in April–May, whereas, Ali and Ripley [52] recorded breeding from March to May across regions. Pomeroy [53] noted that black francolin mostly breeds between mid-April and late May. Furthermore, they may rear a second brood within a year, as observed in multiple cases worldwide [50,54–56]. Importantly, variations in breeding timing and duration across regions highlight the dependence of the black rancolin on seasonal climatic conditions, which affect food availability [57,58].

Additionally, this dependence of the black francolin aligns its breeding cycle with the optimal climatic conditions, ensuring sufficient food for raising young [11]. The global distribution of black francolin is largely influenced by both its ecological adaptability and human interventions. In Pakistan, previous studies have documented translocation and restocking programs, which have influenced population dynamics and genetic diversity [12]. These efforts, while aimed at conservation and game hunting, may have also introduced competition among individuals originating from different regions. Research has shown that translocated populations can exhibit variations in breeding success and their call frequency due to local adaptation processes [59]. However, a previous study indicates that their distribution worldwide is driven not only by intrinsic species traits such as large clutch sizes, high breeding success with short incubation periods, and early sexual maturity [6,33], but also by thriving in diverse habitats. Specifically, their preference for scrub habitats with sparse shrubs and tall grasses supports their nonmigratory behavior and short-distance movement [15]. Unlike migratory birds that move in response to seasonal fluctuations, black francolins exhibit strong site fidelity, selecting habitats that ensure year-round availability of food, nesting cover, and protection from predators [9]. Such sedentary behavior is further supported by their ability to make short-distance movements between adjacent habitat patches, such as wetlands and agricultural fields, to optimize their resource use without engaging in large-scale migrations [7].

Moreover, recent studies highlighted significant genetic diversity within black francolin populations with the Himalayan population exhibiting distinct genetic traits compared to those at lower altitudes [13]. Genetic diversity increases their resilience to environmental changes and pressures. Previous genetic analyses of black francolins in Pakistan utilizing mitochondrial DNA (mtDNA), and microsatellites revealed distinct lineages, but extensive genetic mixing due to human-mediated translocations for chirping competitions [5,60]. Further, cross-species microsatellite implications provide molecular tools for assessing the population structure and informing conservation strategies.

Nest site selection is crucial for bird reproduction and is influenced by predation risk, resource availability, and microclimate [61]. Research indicates that black francolin prefer to nest in areas with dense vegetation, especially perennial grasses, and shrubs, to protect against predators and harsh weather [9,16]. Nesting success is supported by diverse plant species, including *Acacia modesta, Saccharum* spp., *Tamrix* spp., and *Cynodon dactylon* [16,62]. Mostly, black francolin prefer diverse habitats, ranging from subtropical to lower-temperate regions [9], typically building nests on the ground by creating shallow scrapes concealed by

vegetation [7,14]. Moreover, nesting behavior is an adaptive strategy to reduce predation risk and other disturbances, especially anthropogenic disturbances, which are significantly less common in dense vegetation [22].

The dimensions of the nests of the black francolins investigated in our study are closely aligned with those reported in previous studies. The average outer diameter of the nests was approximately 22.4 cm, similar to the values reported in India [9,11]. However, the diameters recorded in the present study were greater than reported for other francolin species. For instance, Little & Crowe [31] reported an average nest diameter of 16.9 cm for greywing francolin, and Van Niekerk [63] reported a much smaller average diameter of 13.76 cm for crested francolin in South Africa. Moreover, Khalil et al. [64] reported that the outer and inner diameters of grey francolin in the Salt Range, Pakistan, were 17.5 cm (15.2–21.2 cm) and 13.1 cm (10.1–17.8 cm) respectively, which were lower compared to those in our study. The clutch size significantly influenced the hatching and fledgling rates, with six-egg nests having the highest breeding success, which highlights the critical role of habitat and clutch size in optimizing the breeding success of black francolin.

Wetland habitats are more suitable than dryland habitats as breeding grounds because of a variety of favorable factors. These include (i) nearby agricultural fields that provide valuable foraging opportunities, particularly during chick-rearing; (ii) access to water sources in the surrounding areas; and (iii) abundant vegetation with trees, shrubs, herbs, and grasses, creating high-capacity habitat [6,51]. These favorable conditions provide protection from predators, ensure nest stability, and offer abundant materials for nest construction. Additionally, these sites provide convenient access to rich foraging habitats that fulfill their nutritional needs throughout the breeding season [7,9]. Environmental conditions drive phenotypic responses affecting clutch size [65,66] and genetic variations [67,68]. Individual optimization of clutch size (e.g., as postulated by Pettifor et al.) [69] assumes that the clutch size is adaptively adjusted to the individual bird's abilities to produce hatchlings and rear nestlings, i.e., a female breeder with larger clutches will be able to produce more hatchlings and rear more fledglings than a female breeder with smaller clutches. Individual optimization of clutch size also assumes that individual breeders adaptively adjust the clutch size so that the success of hatching/fledging/breeding is always maximized (e.g., on average 90%) across the different clutch size classes. Consequently, clutch size should be positively associated with brood size at hatching/fledging, but not associated with the success of hatching/fledging/breeding.

The clutch sizes vary among black francolin species and regions, ranging from 4 to 12 eggs [55,64]. The largest clutch size recorded for black francolin was 11 eggs [10], whereas prior studies have reported 6 to 10 eggs [70], and 5 to 7 eggs [11], closely aligned with our results. Nonetheless, the recorded mean clutch size was 5.9 eggs per nest, similar to that in the Himalayan regions [9] but slightly lower than the value reported by [11,51]. Seven-egg clutches were predominant in India, whereas clutches with five and six eggs were relatively uncommon [11]. Our findings from the Totali Game Reserve, indicate that the most common clutch was seven eggs, while clutches of five and six eggs were less frequent and those ranging from two to four eggs were occasionally observed. During the study period, hatching success was recorded at 82.3%, with an average of 4.8 $\pm$ 1.0 hatchlings per nest, which was lower than the findings of previous studies [9], but higher than the values recorded for grey francolins at 74.8–76.2% [64,71].

Fledgling success (91.7%) does not convey the same adaptive significance as that of the mean clutch size, as it is related only to hatching success. Additionally, the vegetation structure at the nesting site has no impact, despite it being crucial in nest site selection for black francolins [62,71]. However, the fledging success rate in the present study was higher than reported previously [9]. In our study area, hatching success was positively

associated with clutch size, particularly in the nests located in wetland habitats, especially within bushes. Kumar et al. [9] justified the preference for wetland habitats using several factors, such as areas with a mix of grasslands, scrub vegetation, the availability of cover, and food resources that facilitate both foraging and nesting, whereas Negi & Lakhera [11] reported nests specifically at the field edges of Uttarakhand, India, indicating adaptability to diverse habitats.

Several studies have reported the significant impact of nesting habitats, i.e., wetlands and drylands, on hatching success [51]. Owing to their location within vegetation, bush nests provide better protection than field edge nests against strong winds and predation. We found that hatching success was positively associated with the number of bush nests. Nest site selection has been linked to reproductive characteristics in various bird species, including the black francolin [40,72]. Parental age significantly influences clutch size in black francolins, with both younger and older parents generally producing smaller clutches [73,74]. Inexperienced younger breeders typically have lower productivity [75,76], with low breeding success frequently linked to poor nesting site selection and occupancy patterns [33]. Environmental factors also play a significant role in the interaction between age and breeding success. A previous study on collared flycatchers *Tyrannidae* spp.) revealed that both young and old females laid smaller clutches under poor environmental conditions, whereas middle-aged females maintained consistent clutch sizes regardless of environmental quality [74]. Furthermore, physiological changes associated with aging contribute to variations in clutch size. Older female birds, including black francolins, may have higher yolk deposition rates, leading to larger eggs and potentially larger clutches, as they reach their reproductive peak [77].

Young black francolin (first-time breeders) often lay their eggs later in the season than older pairs because experienced older francolins are better at selecting the optimal nest sites compared to other bird species [73,78]. These less favorable sites increase the vulnerability to harsh weather conditions and predation [76,79], which can significantly reduce brood survival rates and breeding success. Black Francolin nest site selection and high chick productivity are influenced by key ecological factors, such as cultivated fields with abandoned land, forest edges, relatively high altitudes, and access to water and food resources [11,51].

Our research limitations include a dataset focusing on a single year and a single breeding season, which limits its broad applicability. Further, key environmental factors such as predation, food availability, and climate variation were not extensively analyzed. Additionally, human disturbance and its effects on nesting behavior were not fully assessed.

Future research should focus on and incorporate multiyear and seasonal data, larger sample sizes, and ecological modeling to understand the long-term breeding trends and habitat dynamics, improving the conservation strategies for black francolin species.

5. Conclusions

In the Totali Game Reserve, this study of the breeding ecology of black francolins highlighted their ecological success, particularly, range expansion, breeding, and adaptation. Our findings indicated a preference for wetland habitats with nests being placed in bushes because these habitats offer more secure features for nest sites and placement. The vegetation structure appears to be a key factor in the selection of nesting sites among black francolins. To gain deeper insights into the nest-site selection process for the black francolin, ongoing monitoring of their nesting ecology and reproduction biology across this protected region is highly recommended. We identified factors influencing their spatial expansion and predicting habitat use patterns and trends in population dynamics.

The current research can ultimately contribute to developing conservation strategies and mitigating the ecological impacts of habitat alterations.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/birds6020016/s1, Table S1: Long-term climate data for Totali Game Reserve, Buner district of Khyber Pakhtunkhwa, Pakistan (January–December 2023). Coordinates: (34°25′29.14″; 72°39′56.83″; altitude: 2100 m asl).

Author Contributions: A.U.: Formal analysis; investigation; methodology; visualization; writing—original draft. S.S. and E.I.-A.: Conceptualization; supervision; methodology; funding acquisition; project administration; writing—review and editing. S.A. and U.S.: Data curation; formal analysis; investigation; visualization; writing—review and editing. P.R.D.l.R.-E. and F.B.: Resources; funding acquisition; formal analysis; validation; writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: All of the research procedures were approved by the Institutional Ethics Committee of the Animal Ethics and Welfare Committee of the Department of Zoology, Abdul Wali Khan University, Mardan, Pakistan (PK) (approval no. AWK-ZOO24906), and all of the methods were carried out according to the Code of Practice for the Care and Handling of Animal Guidelines.

Data Availability Statement: The data from this study are available from the corresponding authors upon reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

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