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Nest-site selection and breeding ecology of the Wattled Crane (*Bugeranus carunculatus*) in the Afroalpine ecosystem of Bale Mountains National Park, Southeast Ethiopia

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The Wattled Crane (*Bugeranus carunculatus*), the largest and rarest crane species in Africa, is globally classified as Vulnerable and persists in small, fragmented populations, including one in Ethiopia. Despite its conservation significance, little was known about its breeding ecology in Ethiopia. Therefore, this study aims to address these urgent knowledge gaps by providing the first comprehensive investigation into the breeding ecology of the species including nest-site selection, clutch size, egg morphometry, and breeding success in the Afroalpine ecosystem of Bale Mountains National Park. Fieldwork was conducted over three consecutive breeding seasons (2015–2017), involving intensive ground surveys to locate and characterize nests, and detailed measurements and habitat features documented following established protocols. A total of nine nests were recorded, with six located on isolated islands in the Sanetti Plateau and three in wetlands at Sodota. Nests were constructed at elevations between 3,502 and 4,034 m, primarily with dominant grasses such as *Koeleria capensis* and *Luzula abyssinica*. Clutch initiation occurred between August and October, with clutch sizes ranging from one to two eggs (mean 1.78 ± 0.15). Egg length averaged 93.11 mm, width 65.07 mm, and weight 250.69 g. Hatching success was relatively low, with only six of the 10 eggs successfully hatching, with nest failures largely attributed to abandonment and predation by Thick-billed Ravens (*Corvus crassirostris*). However, fledging success was remarkably high, with all hatched chicks six surviving to independence, aided by strong parental defense and camouflage strategies. The study highlights the Wattled Crane's reliance on undisturbed wetlands with islands, abundant food, and minimal human disturbance has contributed to its remarkable fledging success. Therefore, strengthening collaboration with existing conservation programs, habitat restoration (including artificial islands), and continuous ecological monitoring are recommended to ensure the long-term survival of this threatened species in the Afroalpine habitat of the park.

KEYWORDS

Bale Mountains National Park, breeding ecology, fledging success, nest-site selection, Wattled Crane

1 Introduction

The Wattled Crane (*Bugeranus carunculatus*) is the largest, rarest, and most wetland-dependent of the six African crane species, and one of the four crane species found in Ethiopia (Meine and Archibald, 1996). Classified as *Vulnerable* by the IUCN Red List of Threatened Species (IUCN, 2017), its population is in decline, with three fragmented populations across Sub-Saharan Africa, with the largest in south-central Africa, and much smaller, isolated populations in Ethiopia and South Africa. Historically, Wattled Cranes were widespread and relatively abundant across southern and eastern Africa (Bento et al., 2007), but recent decades have seen significant declines due to extensive loss and degradation of wetland habitats (Konrad, 1981). The species is highly dependent on wetlands for foraging and breeding (Johnsgard, 1983; Harris and Mirande, 2013). Although other crane species such as the Blue Crane (*Anthropoides paradiseus*) and Demoiselle Crane (*Grus virgo*) are also affected by habitat changes, the Wattled Crane is especially vulnerable due to its narrower ecological requirements of pristine wetland ecosystems.

Globally, cranes have been the subject of extensive research, particularly in North America, Europe, and Asia, encompassing topics from behavioral ecology to satellite tracking (Harris, 1994; Harris and Mirande, 2013). However, research on Wattled Cranes in Africa, especially in Ethiopia remains limited, often fragmented, and lacking depth. While some studies have explored aspects of the species' distribution (Urban and Walkinshaw, 1967; Beilfuss et al., 2000), genetics (Jones et al., 2006), and behavior in captivity (Davenport and Urban, 2010), there remains a critical gap in understanding their breeding ecology in the wild, particularly in the Ethiopian highlands. In Ethiopia, Wattled Cranes are primarily distributed in upland wetlands at elevations between 2,134 and 3,999 meters above sea level (Johnsgard, 1983; Meine and Archibald, 1996), with historical records indicating a wider range and major wintering sites such as Boyo Wetland. Today, the Sanetti Plateau in Bale Mountains National Park (BMNP) is thought to be a key breeding ground, yet scientific knowledge about nesting behavior, reproductive success, and ecological drivers of habitat use is virtually absent.

Given that conservation efforts must be grounded in robust ecological knowledge (Liu et al., 2010), the lack of data on Ethiopia's Wattled Crane population represents a major barrier to effective conservation. This is particularly concerning given that wetlands, among the most productive ecosystems on Earth, are also among the most threatened, affected by agricultural encroachment, dam construction, water mismanagement, pollution, and climate change (Brinson and Malvárez, 2002; Mitsch and Hernandez, 2013). In Ethiopia, wetlands are vital for biodiversity and ecosystem services, yet remain undervalued and increasingly degraded due to unsustainable land use, buffer zone encroachment, deforestation, and invasive species (IBC, 2009). These pressures not only threaten crane habitats but also the many endemics and threatened species that share them.

Therefore, this study seeks to address these knowledge gaps by providing the first foundational investigation into the breeding ecology of Wattled Cranes in Ethiopia. It will explore the species'

reproductive performance, such as clutch size, hatching success, and fledgling survival in the Afroalpine wetlands of BMNP. The study will generate important baseline data that can inform national conservation planning, support international crane conservation efforts, and contribute to the long-term protection of high-altitude wetland ecosystems. Beyond its scientific value, this research will raise awareness about the ecological importance of the BMNP and strengthen the foundation for a biologically sound conservation strategy for one of Africa's most wetland dependent and threatened crane species.

2 Materials and methods

2.1 Study area

Bale Mountains National Park, located in the Southeastern part of the Ethiopian highlands within the Oromia National Regional State, covers an area of 2,150 km² and lies between the geographical coordinates of 6°29' - 7°10'N and 39° 28' - 39°57' E (Figure 1). Due to its unique topography, diverse climate, and exceptional levels of biodiversity and endemism, the Park forms part of the Eastern Afromontane biodiversity hotspot, one of the 36 globally recognized biodiversity hotspots in the world (Critical Ecosystem Partnership Fund, 2011). It contains the world's largest expanse of Afroalpine habitat (Marino, 2003; Ash and Atkins, 2009). The area was designated in the late 1970s to protect this unique ecosystem, along with the rare and endemic Mountain nyala (*Tragelaphus buxtoni*) and Ethiopian wolf (*Canis simensis*) (OARDB, 2007).

The BMNP plays an important role in climatic control of the region, where it attracts a large amount of orographic rainfall. As in most Ethiopian highlands, the inter-tropical convergence zone, and altitudinal and topographic features influence the distribution of the precipitation in the Bale Mountains eco-region (Yoseph Assefa et al., 2011). Particularly, in the park, the amount of rainfall varies from 600–1000 mm to 1000–1400 mm annually at the lower altitudinal areas and in the higher altitudinal areas, respectively (OARDB, 2007). Data recorded for the year 2008 to 2017 from Ethiopian National Metrological Station Agency (ENMSA) revealed that rainfall at BMNP is widely spread during the whole year, although, peak rainfall occurs between March and October with the highest record in July (157.2 mm) followed by August (154.4 mm). Consequently, a total of 40 rivers rise from the Park area, contributing to five major rivers; the Web, Wabe Shebelle, Welmel, Dimal and Ganale. Due to this, the Bale Mountains eco-region are known as a “water tower” together with its capacity to hold water in swamps and lakes during the wet season and release it during the dry season. In addition to precipitation, the park exhibit strong seasonal temperature variation linked to altitude, cloud cover and rainfall regimes. Although mean monthly temperatures range between 11.6 °C and 15.2 °C, it experiences a coolest period between November and February, when clear skies and reduced humidity lead to pronounced night-time cooling and occasional frost in afro-alpine areas. However, warmer and more thermally stable conditions prevail during the main rainy season (June–September) due to persistent cloud cover that moderates daily temperature extremes.

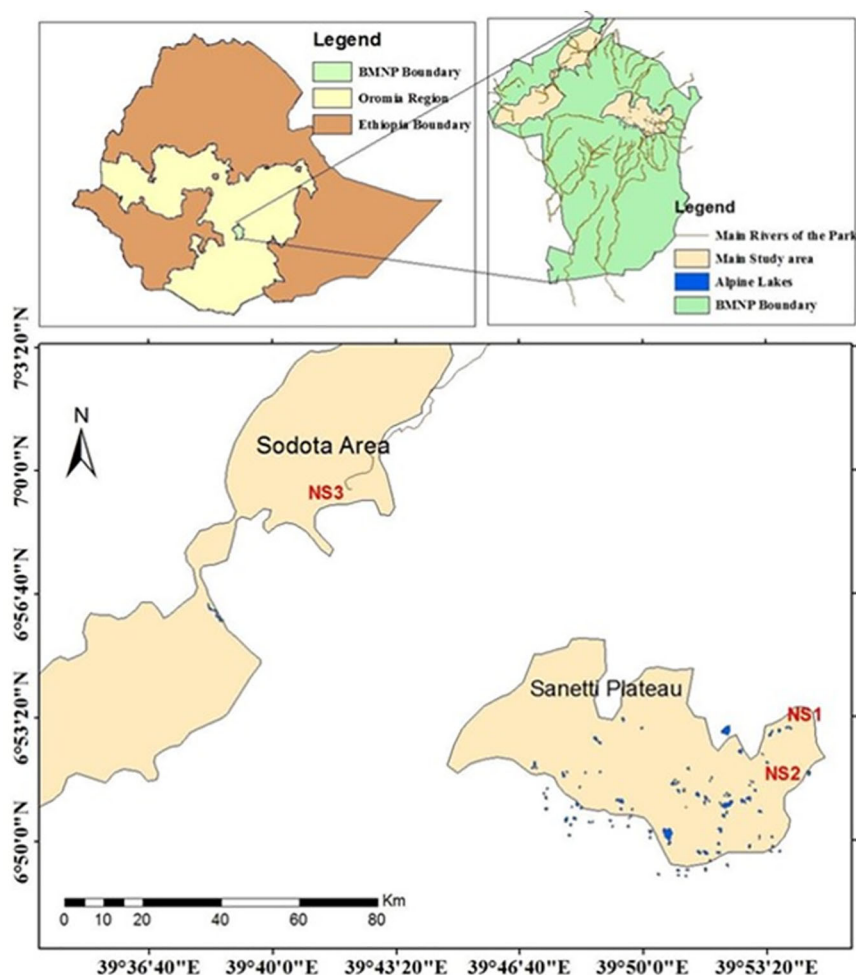


FIGURE 1
Location of different nests in different sites of the Afroalpine habitat.

This seasonal thermal pattern interacts with precipitation to influence primary productivity, insect abundance and vegetation growth, thereby affecting food availability and the timing of breeding in many highland species (Kidane et al., 2012).

The Afroalpine habitat of the BMNP covers approximately 1,000 km², accounting for about 17% of the total Afroalpine area on the African continent (OARDB, 2007). Typical Afroalpine steppe habitats include the Sanetti Plateau (3,800–4,000 m) and the upper Web Valley (3,450–3,550 m), characterized by short alpine grasses and herbs, scattered *Artemisia* sagebrush, *Helichrysum* bushes, and Giant lobelias (*Lobelia rhynchopetalum*) (Marino, 2003). Plant communities in these areas are specially adapted to harsh environmental conditions such as extreme temperatures, frost, and soil movement caused by high rodent activity.

This study is focused on the breeding ecology of Wattled Crane in Afroalpine steppe habitats, which hosts the only known breeding population outside southern Africa and the only protected breeding site in Ethiopia. Wattled Cranes prefer this habitat to breed due to the extraordinary habitat characteristics (vegetation and hydrology). The Afroalpine areas experience regular night frosts, diurnal temperature fluctuations far exceeding seasonal ones and intense irradiation. Rodents avoid extreme cold by going underground,

whereas larger mammals such as ungulates and birds like Wattled Cranes, must endure the harsh surface conditions (Marino, 2003). Despite these challenges, the Afroalpine habitat also serves as the only known breeding site for a number of Eurasian species, such as the Golden eagle (*Aquila chrysaetos*), the Ruddy shelduck (*Tadorna ferruginea*) and Red-bill chough (*Pyrrhocorax pyrrhocorax*).

Despite its rich biodiversity, a number of threats are facing the biodiversity of BMNP, such as forest clearing for firewood and timber production, habitat fragmentation, encroachment and degradation (OARDB, 2007).

2.2 Methods

To investigate and understand the breeding biology of Wattled Cranes, fieldwork was conducted for three consecutive breeding seasons (July through November 2015–2017) in the BMNP. During these three breeding seasons, intensive ground searches were conducted to locate Wattled Cranes nests in the Afroalpine habitat. Intensive ground searches took place from July to October of 2015 and were specific to Afroalpine habitats which were considered to be potential breeding sites based on the presence of Afroalpine lakes, lakes with islands, extensive marshes and swamps, and the availability

of food in the areas, which were considered basic requirements for nesting Wattled Cranes (Konrad, 1981; Johnsgard, 1983). The following two wet seasons searches were restricted to potential sites, based on the previous year's survey.

The searches for breeding pairs involved direct searches from vantage points and ground-level surveys using a 20-60x Swarovski telescope and 10x42 Bushnell binoculars, supplemented by first-hand information from local residents, including both seasonal and permanent nomads in the Afroalpine habitats, as well as Park experts.

2.2.1 Nest materials, vegetation height and nest morphometry

When nests were located, their positions were recorded using a portable Garmin GPS 72, and each nest platform was classified as active (if a breeding pair was observed with eggs incubating, or with at least one hatched egg) or attempted/inactive (if a breeding pair was present without eggs but with a nest) following Ivey and Dugger (2008). If nests contained cold, uncovered, intact eggs with no crane present, they were initially recorded as abandoned, with follow-up visits conducted to confirm abandonment, as recommended by Austin et al. (2007).

Nest dimensions including nest length, breadth (width), height from water surface (H1) and water depth from the nest edge or rim (H2) at each cardinal direction were measured using a measuring tape. In addition, nesting materials and their surrounding vegetation were carefully documented. Plants used as nesting materials were collected and identified using the Flora of Ethiopia (Hedberg and Edwards, 1989; Hedberg et al., 2003). If nests were located on an island, island length and width was also recorded to determine the island's size. Furthermore, nest concealment was assessed as horizontal concealment from ground level following Littlefield (2000). Because vegetation in the Afroalpine habitats including the wetlands is generally short and sparse (Muhammed and Elias, 2025), hence Wattled Crane nests were fully visible from above, indicating a high level of exposure to aerial predators. Therefore, concealment was evaluated only from a lateral perspective by estimating the distance at which a nest could be detected from the side categorized as: (1) poor- if visible from a distance greater than 50 m; (2) fair- if visible from 10–50 m; (3) good- if visible from 2–10 m; and (4) excellent- if visible only from less than 2 m.

In addition, when active nests were located, clutch size was recorded. For pairs observed before egg laying, laying dates were determined through intensive follow-up observations. Egg dimensions (length and maximum breadth) were measured using a digital vernier caliper, and egg weight was measured using a digital pocket scale.

Egg volume (V) and egg shape index (ESI) were calculated following Hoyt (1979) (Equation 1) and (Equation 2), respectively:

$$\text{Volume (V)} = 0.51 \times L \times B^2 \quad (1)$$

where V is egg volume, L is egg length, and B is egg breadth. The constant 0.51 is a species-general scaling factor proposed by

Hoyt (1979), which provides a reliable approximation of egg volume for most bird species.

$$\text{ESI} = \frac{B}{L} \times 100 \quad (2)$$

Where ESI= Egg shape index, B= egg breadth and L= Egg length.

Egg weight measurements were taken from freshly laid eggs or from eggs with known laying dates obtained through continuous nest monitoring, thereby minimizing the effect of weight loss during incubation. To correct for scale bias, all measurements were multiplied by a calibration factor of 0.9985 (199.7/200).

2.2.2 Breeding, nesting density, and nesting site fidelity

Active nests were monitored four to six times during the incubation and post-hatching period (August to December each year) to assess reproductive outcomes, including hatching and fledging success. Hatching success was determined by examining the fate of the eggs at the end of the incubation period or early hatching stage, with successful nests defined as those that hatched at least one egg (Littlefield and Paullin, 1990). Fledging success was calculated as the number of young birds that fledged divided by the total number of eggs hatched, multiplied by 100. Young birds that reached the height of their parents and begun to fly were considered as fledged (Mukherjee et al., 2002).

Nest or clutch initiation date was defined as the date the first egg was laid, determined through weekly nest checks (Holderby et al., 2012). For nests with incubating pairs, initiation dates were extrapolated by subtracting the incubation period from the hatching date. This information was used to determine the peak breeding season of Wattled Cranes (Mukherjee, 1999). The presence of predators, including mammals or birds of prey, during the incubation or post-hatching period was recorded through continuous monitoring throughout the study. Predators were identified if they frequently appeared near the nests where Wattled Cranes were incubating their eggs, attempted to flush the birds, or showed signs of feeding on the eggs. Similarly, any birds or mammals that tried to snatch chicks from the parents during the post-hatching period were also recorded as predators.

Throughout the study period, careful observations were conducted from a distance to minimize disturbance to the breeding pairs, as Wattled Cranes (Tarboton et al., 1987) and cranes in general are highly sensitive to disturbance and may abandon nests if repeatedly disturbed (Boise, 1975). Approximately 95% of the Afroalpine habitat was surveyed during the three breeding seasons.

For the purpose of estimating nesting density, potential nesting area was defined as habitat patches that met specific suitability criteria for Wattled Crane nesting, including the presence of Afroalpine wetlands, shallow lakes or marshes, and islands providing suitable nesting site and protection. Based on these criteria, a total of 2,305 ha in the Sanetti Plateau and 1,280 ha in the Sodota habitat were identified as suitable nesting areas (Figure 1). Nesting density was then calculated by dividing the total number of

breeding pairs by the extent (ha) of this defined suitable nesting habitat.

2.2.3 Statistical analyses

Quantitative data regarding nest characteristics, egg dimensions, and habitat variables were analyzed using SPSS statistical software (Version 25.0). Descriptive statistics (mean $\pm$ SE) were used to summarize breeding parameters. Given the small sample size ($n=9$) and non-normal distribution of the data, non-parametric tests were applied throughout the statistical analysis. The Independent Samples Mann-Whitney U test was used to compare egg dimensions and nest-site features between the Sanetti Plateau and Sodota Valley habitats. Differences in egg parameters across the three breeding seasons were assessed using Kruskal-Wallis test. In addition, a Spearman's rank correlation was employed to examine the relationships between specific habitat variables such as nest height and water depth. All statistical tests were two-tailed, and results were considered significant at $P < 0.05$.

3 Results

3.1 Population size, spatial distribution and nest characteristics

A total of nine breeding pairs of Wattled Cranes were recorded over three consecutive breeding seasons (2015–2017) in the Afroalpine habitats of BMNP, corresponding to nine active nests ($n = 9$) monitored during the study. Based on the defined suitable nesting habitat, estimated at 2,305 ha in the Sanetti Plateau and 1,280 ha in the Sodota habitat (totaling 3,585 ha), the overall nesting density was calculated at 0.0025 pairs per hectare (equivalent to 0.25 pairs per 100 ha, or 2.5 pairs per 1,000 ha).

The spatial distribution of breeding pairs was uneven between the two habitats, with six pairs recorded in the Sanetti Plateau and three in the Sodota habitat. Although more nests were found in the Sanetti Plateau, this difference likely reflects variation in habitat availability rather than a clear preference for Sanetti Plateau over the Sodota habitat.

Given that approximately 95% of the Afroalpine habitat was surveyed, the nests recorded are likely representative of most of the breeding population within the study area. Of the recorded nests, three were built in wetlands, whereas six were constructed on two islands during the three breeding seasons. The number of active nests varied among years, two nests were recorded in 2015, four in 2016, and three in 2017 across the Afroalpine habitats of the Park. The Sanetti Plateau, known for its numerous alpine lakes, provided nesting sites for Wattled Cranes on isolated islands with minimal vegetation, mostly short grasses dominated by *Koeleria capensis*. In contrast, the Sodota habitat, which contains only one large wetland, supported nests built within dense, tall grasses, primarily dominated by *Luzula abyssinica*. The distribution of Wattled Crane nests in the Afroalpine habitat remained consistent across the three breeding seasons, with nests located on the same two islands in the Sanetti

Plateau from 2015 to 2017 and within the same wetland in the Sodota habitat, though with slight variation in nest positions. Inter-nest distances varied between sites. In the Sanetti Plateau, where multiple nests were recorded within the same breeding seasons, the distance between neighboring nests was highly consistent, with a mean ($\pm$ SD) and median of 1.67 ± 0.00 km ($n = 3$ nest pairs). In contrast, no inter-nest distance could be calculated for the Sodota habitat, as only a single nest was recorded per breeding season. Distances between nests in different habitats reached up to 25.61 km but were not considered relevant for assessing within-habitat nest spacing (Table 1).

Wattled Crane nests were recorded across an altitudinal range of 3502 to 4034 m asl, with an overall mean elevation of 3848.60 ± 76.09 m ($n = 9$). Although the total range spans over 500 m, nest elevations were strongly clustered by habitat type. Nests in the Sanetti Plateau were consistently located at higher elevations (3997.14 ± 12.19 m; range: 3962–4034 m), whereas all nests in the Sodota habitat occurred at a single lower elevation (3502 m). Consequently, altitudinal variation within each habitat was very limited, particularly in Sodota, while the overall variation reflects differences between the two habitats rather than a continuous altitudinal gradient. A significant difference in nest elevation between habitats was detected (Mann-Whitney $U = 22$, $P = 0.038$) (Table 2). The distance of nests from the mainland ranged from 8 to 800 m (mean $\pm$ SD: 250.2 ± 120 m; median: 25 m, $n = 9$). The relatively low median compared to the mean indicates a skewed distribution, with most nests located close to the mainland and a few nests occurring at much greater distances.

The active breeding season of Wattled Cranes in the Afroalpine habitat occurred between August and October, with peak clutch initiation in September and October. Across all three breeding seasons ($n = 9$ nests) clutch initiation was recorded in August one, September four and four in October.

When examined by year, slight variation in timing was observed. In 2015, clutch initiation occurred in late September and mid-October. In 2016, one clutch was initiated in mid-September, while the remaining clutches occurred in early October. In contrast, the 2017 breeding season began earlier, with one clutch initiated in late August and two in early to mid-September (Table 2).

Despite these differences, the small sample size limits robust inference regarding interannual variation in breeding timing. Overall, the results indicate a consistent concentration of breeding activity during the peak wet season, particularly in September and October. No nest construction or clutch initiation was recorded during July or November, indicating that the active breeding period was confined to late August through October.

3.2 Nesting materials and nest morphometry

Wattled cranes in the Afroalpine habitat built their nests on varying landforms, with six nests built on islands of Sanetti Plateau (Figure 2B) and three nests built on wetland in Sodota habitat (Figure 2A). In both habitats, nesting materials were primarily collected from the immediate surroundings of the nest sites. In the Sodota habitat, nests were constructed mainly from *Luzula abyssinica*

TABLE 1 Nest distribution, nearest neighboring nest pairs, and inter-nest distances (km) of Wattled Cranes in Sanetti and Sodota afroalpine habitats, across the 2015–2017 breeding seasons.

Nest No.	2015					2016					2017				
	Site name	Nest Id	Nearest distance to mainland (m)	The nearest nest pair	Inter distance between nests (km)	Site name	Nest Id	Nearest distance to mainland (m)	The nearest nest pair	Inter distance between nests (km)	Site name	Nest Id	Nearest distance to main land (m)	The nearest nest pair	Inter distance between nests (km)
1	Sanetti	Sa_N1	25	Sa_N2	1.67	Sanetti	Sa_N1	25	Sa_N2	1.67	Sanetti	Sa_N1	8	Sa_N2	1.67
2	Sodota	So_N1	800	Sa_N2	25.61	Sanetti	Sa_N2	8	Sa_N1	1.67	Sanetti	Sa_N2	25	Sa_N1	1.67
3						Sanetti	Sa_N3	8	Sa_N1	1.67	Sodota	So_N1	800	Sa_N1	25.62
4						Sodota	So_N1	800	Sa_N2 and Sa_N3	25.61					

*Inter-nest distance: straight-line distance between active nests (km).

TABLE 2 Nest site characteristics of Wattled Cranes recorded in Sanetti and Sodota sites showing nearest distance to the mainland, nest location type, water depth, and altitude during the 2015–2017 breeding seasons.

Nest No.	2015					2016					2017				
	Site name	Nearest distance to mainland (m)	Nest location	Water depth (cm)	Alt. (m asl)	Site name	Nearest distance to mainland (m)	Nest location	Water depth (cm)	Alt. (m asl)	Site name	Nearest distance to mainland (m)	Nest location	Water depth (cm)	Alt. (m asl)
1	Sanetti	25	Island	0.59	3962	Sanetti	25	Island	0.59	3972	Sanetti	8	Island	0.78	4034
2	Sodota	800	Wetland	1.28	3502	Sanetti	8	Island	0.86	4027	Sanetti	25	Island	0.59	3962
3						Sanetti	8	Island	0.87	4027	Sodota	800	Wetland	0.3	3502
4						Sodota	800	Wetland	1.28	3502					

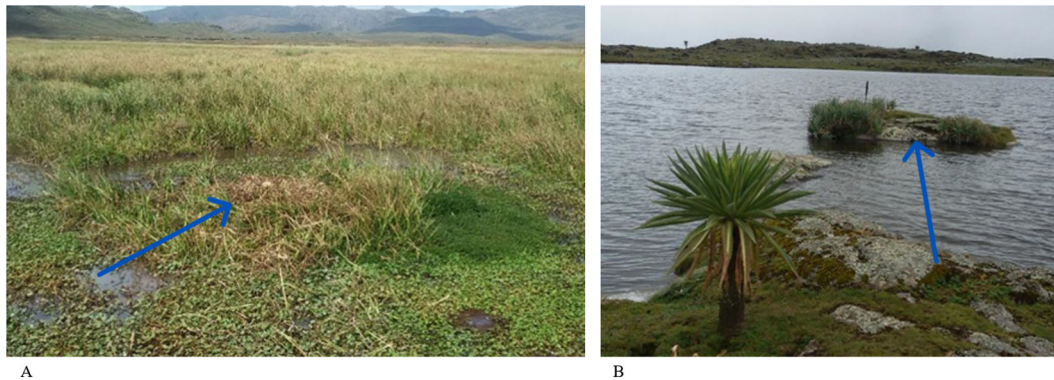


FIGURE 2

Panel (A) shows the Sodota wetland nesting habitat, characterized by a flat grassy wetland with shallow standing water. A blue arrow indicates the nesting site within the vegetation. Panel (B) shows the island nesting habitat on the Sanetti Plateau, with a small vegetated island surrounded by water in an Afroalpine landscape. A blue arrow indicates the nesting site on the island.

and *Koeleria capensis*, which were abundant in the surrounding marsh vegetation and were continuously added during the incubation period. Similarly, in the Sanetti Plateau, nests were composed predominantly of locally available plant species, including *Koeleria capensis*, *Kniphophia foliosa*, *Alchemilla pedata*, and *Cotula abyssinica*, all of which occurred in the vicinity of the nesting sites. On average, *Luzula abyssinica* accounted for 76% of the nest material in Sodota nests, while *Koeleria capensis* contributed around 24%. In contrast, nests in the Sanetti Plateau were constructed on isolated islands surrounded by shallow water, providing protection from terrestrial predators. These nests were composed predominantly of *Koeleria capensis*, which was present in all Sanetti nests and averaged 65.7% across the seasons. Other nesting materials used in Sanetti included *Kniphophia foliosa* (26.7% average), *Alchemilla pedata* (10%), and *Cotula abyssinica* (5%). One nest was uniquely built by creating a shallow depression and lining it with grass roots and feathers for comfort, while another was constructed using dry residual vegetation. Across all nine nests and over the three breeding seasons, *Koeleria capensis* was the most consistently and widely used material, occurring in every nest and forming the highest proportion of the overall nest composition.

The mean nest length was 78.2 ± 14.8 cm ($n = 9$), ranging from 40 to 140 cm, while the mean width was 74.0 ± 8.7 cm, with a range of 52–130 cm; the average height from the surrounding water surface was 41.9 ± 15.9 cm, ranging from 20 to 78 cm. In Sodota habitat, Wattle Crane nests were built on wetlands, with mean nest length, width and height from the surrounding water surface measuring 80.7 ± 24.8 cm, 76.7 ± 31.8 cm, and 30.0 ± 57.7 cm, respectively ($n=3$). In contrast, nests in the Sanetti Plateau were constructed on isolated islands surrounded by water, which likely provide protection from terrestrial predators and stable nesting conditions, with corresponding mean values of 79.0 ± 17.9 cm in length, 70.7 ± 7.3 cm in width, and 47.8 ± 6.1 cm in height ($n = 6$). The longest nest (140 cm) and the shortest (40 cm) were both recorded in Sodota in 2015 and 2016, respectively. Meanwhile, the maximum nest width (130 cm) and maximum height above water (78 cm) were recorded in the Sanetti Plateau in 2017 and Sodota in 2015, respectively, whereas the minimum width (52 cm) and minimum height (20 cm) were found in Sanetti in 2016 and Sodota in 2015.

Using an Independent Sample Mann-Whitney U test, nest morphometry parameters showed no significant variation in nest length ($U = 8$, $df = 1$, $P = 0.905$) and width ($U = 7.5$, $df = 1$, $P = 0.174$) between the two breeding habitats. However, there was significant difference in nest height from the surrounding water surface ($U = 8$, $df = 1$, $P = 0.048$), with island nests in the Sanetti Plateau having greater mean height (47.8 ± 6.1 cm) compared to wetland nests in the Sodota habitat (30.0 ± 5.8 cm). A Spearman's rank correlation analysis showed no significant relationship between nest height above the water surface and water depth ($R = -0.270$, $P = 0.483$), indicating that as water depth increased, nest height tended to decrease slightly, although the relationship was not associated with water depth.

Nest concealment among Wattle Cranes was categorized as poor in 4 nests (44.4%, $n = 9$), fair in 4 nests (44.4%, $n = 9$), and excellent in one nest (11.1%, $n = 9$) of observed nests. Notably, while horizontal visibility varied, all nests were 100% visible from above due to the short stature of Afroalpine wetland vegetation.

3.3 Clutch size and egg morphometrics

In the Afroalpine habitats, a total of nine nests were recorded across three consecutive breeding seasons. All nine nests contained eggs, with clutch sizes varying between one and two eggs per nest. Specifically, two nests contained a single egg, while the remaining seven nests contained two eggs. No instances of clutch sizes exceeding two eggs were observed during the study period. The overall mean clutch size was calculated at 1.7 ± 0.2 eggs per nest.

Overall, the eggs observed during the field survey were generally elongated and oval in shape, with minimal variation in size. Measurements were taken from 16 eggs across nine nests ($n = 9$ nests; $n = 16$ eggs). Overall, the mean egg length was 93.1 ± 1.3 mm (range: 87–101 mm) ($n = 16$ eggs), and the mean egg width was 65.1 ± 0.3 mm (range: 59–71 mm). The mean egg weight was 250.7 ± 4.7 g, (range 218 to 281 g) ($n = 16$ eggs). Statistical analysis indicated no significant difference in egg length ($\chi^2 = 0.826$, $df = 2$, $P = 0.688$) or egg weight ($\chi^2 = 0.575$, $df = 2$, $P = 0.771$) across the three breeding seasons. However, egg width showed a significant variation among seasons ($\chi^2 = 6.074$, $df = 2$, $P = 0.037$) (Table 3).

TABLE 3 Kruskal-Wallis test showing variation in egg dimensions of Wattled Cranes across the three breeding seasons (2015–2017).

Variables	Mean $\pm$ SE	df	χ^2	Sig
Egg length (mm)	93.1 $\pm$ 1.3	2	0.826	0.688
Egg width (mm)	65.1 $\pm$ 0.3	2	6.074	0.037
Egg weight (g)	250.7 $\pm$ 4.7	2	0.575	0.771

In the Sanetti plateau, the mean egg length was 93.3 ± 1.7 mm (range: 85–101 mm, $n = 11$), the mean egg width was 64.8 ± 1.0 mm (range: 59–70 mm), and the mean egg weight was 246.0 ± 6.1 g (range: 181–218 g). In contrast, eggs from the Sodota habitat had a mean length of 92.8 ± 2.2 mm (range: 87–99 mm, $n = 5$), mean width of 65.6 ± 1.7 mm (range: 61–71 mm), and mean weight of 261.0 ± 5.3 g (range: 248–280 g) (Table 4). Statistical comparisons between the two habitats revealed no significant differences in egg length ($U = 24$, $df = 1$, $P = 0.724$), egg width ($U = 24$, $df = 1$, $P = 0.762$) and egg weight ($U = 17$, $df = 1$, $P = 0.253$).

Egg Shape Index and Egg Volume was calculated from freshly laid eggs or from three clutches whose egg laying sequences was known through continuous follow-up. The egg sequence in the diametric data below (Table 5) shows that the first egg in the clutch was larger than the second egg in the same clutch. The mean difference in egg length, width and weight between the first and second eggs in the clutch was 5.67 ± 0.43 mm, 3.00 ± 1.15 mm and 7.00 ± 0.84 mm, respectively. In addition, the mean difference in egg volume and ESI between the first and second egg in the clutch was 30.97 ± 4.48 cm³ and -1.18 ± 2.59 , respectively.

3.4 Breeding performance

From a total of nine nests recorded, six nests successfully hatched one chick each. The remaining three nests were unsuccessful due to a number of nest failure causes. Notably, no evidence of re-nesting was observed following the destruction of any nest. The most commonly observed indicator of nest failure was the presence of unattended nests containing intact or partially damaged eggs without an incubating adult. Over the course of the study, the annual rate of nest failure showed a steady increase: no nests failed in 2015, followed by one failure in 2016, and two failures in 2017. In one case egg predation by Thick-billed Raven (*Corvus crassirostris*) was directly observed. In the remaining failed nests two no direct predation events were recorded; however, eggs were found abandoned, and the exact causes of failure could not be confirmed. These cases may be associated with either disturbance, predation attempts,

or other environmental factors, but no definitive evidence was obtained.

A notable predation event was observed in 2016 in the Sanetti plateau. When the incubating female left the nest briefly (approximately 20 meters away) for feeding, a Thick-billed Raven descended and began pecking at the eggs. The parent returned and drove away the predator before it could consume the egg, but subsequently fed on the yolk of the broken egg and discarded the shell in a nearby lake. Although it resumed incubation of the remaining egg, it abandoned the nest entirely after two days.

In general, egg mortality was high, with 10 out of 16 eggs failing to hatch due to a range of external factors. Six eggs failed to hatch as a result of abandonment, either of the second egg after the first chick hatched or of the entire nest. Two eggs were destroyed by Thick-billed Ravens in 2016. The remaining two were lost to unidentified causes, though raven predation was strongly suspected. Flooding was not observed as a cause of egg loss in either microhabitat. In one case, an abandoned egg was retrieved after its sibling had hatched and the parents had departed.

The incubation period could not be determined for six nests found late in the season and thus excluded from incubation analysis. For the remaining three nests, the mean incubation period was 34.3 ± 1.2 days, ranging from 32 to 36 days in 2016. Of the 16 eggs laid, only six hatched successfully. None of the hatched chicks were predated, although multiple predations attempt by Tawny Eagle (*Aquila rapax*) were observed in 2015 and 2016. These attempts were consistently prevented by vigilant parental defense. Mann-Whitney U test results indicated no significant difference in hatching success between the two breeding habitat ($U = 4.50$, $df = 1$, $P = 0.262$). Remarkably, all six chicks that hatched survived to fledging resulting in a fledging success rate of 100%. This high fledging success was consistent across breeding seasons. Overall, the breeding success of Wattled Cranes, as measured by chicks fledged per eggs laid was 37.5%.

3.5 Nest sight fidelity and chick defense strategies in wattled cranes

In the Sodota wetland habitat, pairs exhibited strong fidelity to general nesting areas, with nests constructed in the same wetland across breeding seasons, despite a slight variation in specific nest locations. In contrast, nesting behavior in the Sanetti area showed remarkably high site fidelity, with pairs consistently nesting on two small islands over three consecutive breeding seasons. On one of these islands, nesting occurred at precisely the same spot for three consecutive years, while on the second island, a similar pattern was observed in 2016 and 2017.

TABLE 4 Comparative egg diametric measurements of Wattled Cranes nesting in the distinct Afroalpine habitats of Sanetti ($n=11$) and Sodota ($n=5$) within BMNP.

Site name	Particulars	n	Egg length (mm)	Egg width (mm)	Egg weight (g)
Sanetti	Mean $\pm$ SE	11	93.3 ± 1.7	64.8 ± 1.0	246.0 ± 6.1
	Range		85-101	59-70	181-218
Sodota	Mean $\pm$ SE	5	92.8 ± 2.2	65.6 ± 1.7	261.0 ± 5.3
	Range		87-99	61-71	248-280

TABLE 5 Variations in Wattled Crane egg dimensions, volume, and Egg Shape Index (ESI) in relation to laying sequence.

Year	Egg length (mm)		Egg width (mm)		Egg weight (g)		Egg volume (cm ³)		ESI	
	1st egg	2nd egg	1st egg	2nd egg	1st egg	2nd egg	1st egg	2nd egg	1st egg	2nd egg
2016	96	89	64	66	234	221	200.5	197.7	66.7	74.2
2016	90	85	68	63	281	267	212.2	172.1	75.6	74.1
2017	94	89	71	65	255	261	241.7	191.8	75.5	73.0
Mean	93.3	87.7	67.7	64.7	256.7	249.7	218.2	187.2	72.6	73.8
SE	1.8	1.3	2.0	0.9	13.6	14.4	12.2	7.8	3.0	0.4

*ESI, Egg Shape Index.

Overall, the species demonstrated a high degree of nest site fidelity, estimated at 66.67%. However, individual breeding pairs were not ringed, so it was not possible to confirm whether the same pairs returned to the same sites each year.

Wattled Cranes use several defensive strategies in the Afroalpine habitats to protect their chicks from predators. One observed behavior was direct physical defense, notably recorded in 2015 on the Sanetti Plateau. During an attempted predation by a Tawny Eagle, one adult crane confronted the predator by flapping, leaping, and chasing it away, while the other parent guided the chick to safety by hiding it inside a dense shrub, *Helichrysum splendidum*. Camouflage was another critical strategy used, particularly during the first one to two weeks after hatching, when chicks could not travel long distances. During this vulnerable stage, parents concealed the chicks in patches of *Charex monostachya*, a grass with a brown hue closely matching the coloration of the chicks. As the chicks matured, their plumage color changed, and they began accompanying the parents more frequently, though they remained susceptible to threats due to limited mobility.

At this stage, when potential predators, including humans, approached, parents once again resorted to hiding the chicks in *Helichrysum splendidum*. The shrub's dense structure and color provided excellent camouflage. If the threat moved too close to the hidden chick, both adult cranes emitted loud, elongated alarm calls intended to distract or deter the intruder.

4 Discussion

4.1 Breeding phenology and timing

Wattled Cranes typically breed during the wet season, coinciding with increased water availability and the regeneration of sedge vegetation (Bento et al., 2007). While in some areas, such as Zambia, breeding may occur year-round with peaks in August (Konrad, 1981), our findings indicate that nesting in the Afroalpine habitats of BMNP occurs exclusively during the peak wet season from August to October. This pattern aligns with observations from other parts of Africa, where breeding temporally coincides with precipitation and seasonal flooding (Konrad, 1981; Meine and Archibald, 1996).

Previous studies in Ethiopia suggest that Wattled crane's nesting activity is closely associated with the long rainy season, particularly from late May to early September (Urban and Walkinshaw, 1967).

Similarly, Konrad (1981) observed that nesting in Wattled Cranes is directly influenced by the availability of food resources, which in turn depend on rainfall levels in a given area. Similar relationships have been documented in other crane species, such as the Whooping Crane (*Grus americana*), where precipitation and water levels positively influence nesting success (Spalding et al., 2009).

In BMNP, the wet season brings substantial orographic rainfall across the Afroalpine region, with annual precipitation ranging from 1,000 to 1,400 mm (OARDB, 2007). Wattled Cranes in this ecosystem exhibit a strong tendency nesting at high elevations (mean 3,848.60 ± 76.09 m a.s.l.) ranging from 3,502 to 4,034 m a.s.l., demonstrating remarkable tolerance to extreme elevations. This evolutionary adaptation makes the Wattled Crane the second-highest breeding crane among the world's 15 species, surpassed only by the Black-necked Crane, which nests at elevations of up to 4,328 meters above sea level in regions such as Ladakh (Johnsgard, 1983).

4.2 Nest site selection and habitat use

Most nests recorded in this study were located on isolated islands, while fewer occurred in wetlands. However, habitat availability was not quantified, and therefore preference cannot be conclusively determined. These high-altitude wetlands provide suitable nesting and foraging conditions. Comparable patterns have been reported in other crane species inhabiting high-altitude wetlands, where nesting sites are closely associated with water bodies and vegetation structure (Zhang and Luo, 1991; Kuang et al., 2010; Liu et al., 2010; Li et al., 2022; Chen and Wang, 2025).

Another likely reason for the Wattled Crane's to breed in the Afroalpine habitat may also be linked to minimal human disturbance in the area, as the park is legally protected. McCann et al. (2001) reported that Wattled Cranes prefer to nest in wetlands with minimal human activity. Although Wattled Cranes were historically reported from a wider range of wetland habitats in Ethiopia (e.g., Urban and Walkinshaw, 1967), there is currently insufficient site-specific historical evidence to determine whether the present Afroalpine breeding distribution represents a shift from former lowland breeding areas or reflects long-standing habitat use. Similarly, Black-necked Cranes usually prefer to breed in wetlands far from human interference, which is a safer environment for foraging, nesting, and raising their young (Kuang et al., 2010).

The nesting habitat of Wattled Cranes ranges from smaller wetland habitats to larger wetlands shallow waters remain as

floodwaters recede (Konrad, 1981) or in sites characterized with abundant natural grasslands and wetland vegetation (Johnsgard, 1983; Wojtaszekova, 2008). In the Afroalpine, Wattled Cranes did not clear vegetation around the nest, unlike Sarus Crane (*Grus antigone*) (Mukherjee et al., 2000) and Black Crowned Crane (Shimelis Aynalem, 2017), which tend to remove surrounding vegetation to improve visibility and detect approaching predators. Contrary to this observation, Johnsgard (1983) reported that Wattled Cranes nesting in marshes stripped of plants for a distance of up to four meters from the nest. In the Afroalpine habitat, such vegetation-clearing behavior was not observed. This may be attributed to the specific nest locations, such as islands with sparse vegetation or open wetlands where visibility was not obstructed. This observation is further supported by nest concealment data, where horizontal visibility varied while all nests were 100% visible from above. This likely reflects the open nature of Afroalpine habitats, where vegetation cover is limited.

The primary nest materials used by Wattled Cranes in the study area were *Koeleria capensis* and *Luzula abyssinica*, both of which were locally dominant plant species. Nest height above the water surface ranged from 40 to 140 cm, which is slightly higher than that reported for Black Crowned Cranes (30–130 cm) (Shimelis Aynalem, 2017) and Sarus Cranes (41–95.67 cm) (Mukherjee et al., 2000). This difference may reflect species-specific nesting behaviors (Shimelis Aynalem, 2017) and habitat characteristics. In the Afroalpine habitat, Wattled Cranes predominantly (66.67%) nested on islands that naturally rise above the surrounding wetlands due to local topography and water levels. Similarly, Mukherjee et al. (2000) noted that nest height and material selection are often influenced by the prevailing water levels in a given habitat.

4.3 Breeding behavior

Courtship and display behaviors were rarely observed during the study period. This may be due to the timing of observations, which were primarily focused on nesting stages, or the relatively inconspicuous behavior of breeding pairs. A similar display behavior has also been documented in Wattled Crane pairs in South Africa (McCann et al., 2001).

Although the nests were relatively close- only 1.67 km apart on the Sanetti Plateau, no territorial conflicts were observed among the breeding pairs. This absence of conflict may be attributed to the low nesting density and availability of sufficient foraging territory in the area. Additionally, no overlap in feeding areas was observed between different pairs, possibly contributing to the lack of boundary disputes. In contrast, the breeding territories of Wattled Cranes in south-central Africa are reported to be smaller, often less than 1 km² (Konrad, 1981), suggesting more spatial flexibility in the BMNP population.

4.4 Reproductive characteristics

The clutch size of Wattled Crane was only either one or two with an average clutch size of 1.78 with the majority of nests having a clutch size of two. Wattled Crane's clutch size in the study area was one to two eggs, with an average of 1.78 eggs per nest. This corresponds with reports from South Africa, where the majority of

breeding Wattled Crane in the KwaZulu-Natal also lay two eggs (McCann et al., 2001). On the other hand, Konrad (1981) reported a somewhat lower average clutch size of 1.6 eggs based on 91 nests. This difference may be attributed to variation in breeding altitude, as Pomeroy (1980) reported that crane populations breeding at higher altitude have slightly larger clutch sizes than to those at lower altitudes. Nevertheless, compared to other crane species, Wattled Cranes showed relatively small clutch sizes. For instance, Black-crowned Cranes, Sarus Cranes, Greater Sandhill Cranes, and Common Cranes have reported average clutch sizes of 2.0 (Shimelis Aynalem, 2017), 1.99 (Mukherjee et al., 2002), 1.92 (Maxson et al., 2008), and 1.83 eggs, respectively. These comparisons reveal that Wattled Cranes have one of the smallest clutch sizes among crane species. Similarly, Konrad (1981); Johnsgard (1983) reported that the Wattled Crane has the smallest clutch size of all cranes worldwide.

This study revealed that Wattled Crane's peak egg-laying months were September and October, occurring coinciding with the peak rainy season in the area (OARDB, 2007). This seasonal pattern reveals the crucial role rainfall in shaping the timing of reproduction, as it influences habitat conditions and the availability of abundant food resources essential for breeding. As noted by Perrins (1970), the actual date at which bird species lay eggs is closely related to the availability of food at the time of laying, further supporting the link between resource abundance and breeding phenology. On the contrary, a 13-year study of captive breeding of Wattled Cranes at the New York Zoological Park reported peak egg-laying periods in April (11 eggs), March (10 eggs), February (9 eggs) and with no eggs laid in August, September, or October (Conway and Allegra, 1977). This variation is likely attributable to differences in seasonal climatic conditions between the two regions, particularly in rainfall patterns, which directly affect breeding performance and food availability for chicks. Comparable results have been reported in Florida Sandhill Cranes (*Grus canadensis pratensis*), where increased rainfall triggered reproductive behavior in January and March (Layne, 1983). Similarly, Wattled Cranes in the KwaZulu-Natal region of South Africa also show a breeding season aligned with high rainfall, occurring from May to August (McCann et al., 2001).

According to Meine and Archibald (1996), Wattled Cranes have the longest incubation period of any cranes with incubation period of 32–40 days. The incubation period from this study shows a similar result where average incubation period of the three nests was 34.33 ± 1.20 days with maximum incubation period of 36 days and minimum incubation period 32 days.

4.5 Breeding performance

Hatching success in Wattled Crane was 37.5% which seems very low compared to Greater Sandhill Cranes (69.2%) (Provost et al., 1992) and Black Crowned Cranes (91.3%) (Shimelis Aynalem, 2017). This suggests that reproductive output in this population may be limited. Konrad (1981) has also reported that Wattled Cranes have the lowest reproductive rate of all crane species.

Nest failures are common in birds in general and cranes in particular, often caused by predators such as mammals, birds of

prey, or other unknown factors. In Sarus Cranes, mammals including Jackal (*Canis aureus*) and Feral dogs (*Canis domesticus*), as well as birds such as House crows (*Corvus splendense*) have been documented preying on eggs (Mukherjee et al., 2002). Similarly, Greater Sandhill Cranes (*Grus canadensis tabida*) lose 20% of their eggs to Coyotes (*Canis latrans*), 9% to Raccoons (*Procyon latrans*), and 15% to Common ravens (*Corvus corax*) (Littlefield, 1995). In the present study, two nest failures were attributed to unknown causes; however, egg predation in the Afroalpine habitat was confirmed only for Thick-billed Ravens. The open Afroalpine nesting environment, characterized by very limited vegetation cover above nests, likely increases their visibility to aerial predators and may therefore elevate the risk of avian predation. Supporting this, Wattled Cranes were observed feeding on broken eggs after chasing the predator, a behavior previously reported for the species (Burke, 1993).

Despite the presence of Ethiopian Wolves- the ecological equivalent of Coyotes, which cause 20% of egg loss in breeding Greater Sandhill Cranes (Littlefield, 1995), no predation on eggs or chicks was recorded. This may be because nests were located on deeply situated islands surrounded by cold alpine waters, which likely limit access by Ethiopian wolves.

Fledging success can be increased if nesters or breeders are very experienced, which helps them to nest early and selection of wetlands with bigger size (Nesbitt et al., 2008; Ivey and Dugger, 2008) or availability of food (Holderby et al., 2012). On the other hand, Coverdale and McCann (2009) have also reported that pair formation of Wattled Crane with older and with more experience, allows a pair to successfully fledge a chick. This factor might have helped Wattled Cranes in BMNP to have 100% fledging success with 0% of chick mortality in the study area. On the other hand, it could be either due to the defensive ability of the species against predators or the advantages of the Afroalpine habitat for camouflage strategy. Cooperative defense, in which both parents coordinate anti-predator behavior by confronting or distracting predators while protecting or concealing chicks, was observed against predators such as Tawny Eagles. In addition, the use of alarm or guard calls may further enhance chick survival by warning offspring and deterring potential threats. Reports from Johnsgard (1983), indicated that in Sandhill Crane and all other species of cranes, pairs and flock mates respond to the approach of intruding conspecifics and some other disturbances by performing loud, guttural squawks (often in series) which is considered as guard-call. Likewise, low density of predating mammals in the Afroalpine habitat might have also contributed to the higher fledging success of Wattled Crane in the area. On the contrary, Greater Sandhill Cranes which lived in an area of high predating mammal density like Coyotes in their breeding area, cause loss of eggs (Littlefield et al., 2001).

Breeding inside the Park which is legally protected from human disturbance might have also helped for the higher percentage of fledging success. On the contrary, human related deaths of chicks in Sarus Cranes as a result of crop harvesting (Mukherjee et al., 2002) and Black Crowned Crane due to deliberate killings of chicks by local communities (Shimelis Aynalem, 2017) have decreased the fledgling success. For instance, in Florida Sandhill Cranes (Nesbitt

et al., 2008) and Sarus Crane (Mukherjee et al., 2002), chick mortality was 44.74%, 8.7%, respectively. Johnsgard (1983) and Cooper (2006) have also reported that breeding success of Sandhill Cranes was influenced by human related impacts such as overstocking and development of wind farms, respectively.

Re-nesting was not detected; however, this cannot be ruled out because individuals were not marked and pairs may have re-nested outside monitored areas. This might be due to lack of favorable environment in the area as the breeding season progresses either related to available food or nesting habitat. Similarly, Florida Sandhill Crane re-nesting chance was very dependent on the prevailing favorable environmental conditions. Shimelis Aynalem (2017) has also reported that late nesters had lower breeding performance than those which nests early.

4.6 Conservation implications

The Afroalpine wetlands of BMNP represent critical breeding habitat for Wattled Cranes in Ethiopia. However, the results suggest that multiple factors may influence breeding success, including habitat conditions, disturbance, and predation.

The relatively low reproductive success, combined with the limited number of nesting sites, highlights the vulnerability of this population. Conservation efforts should therefore focus on protecting key wetlands, maintaining hydrological integrity, and minimizing disturbance during the breeding season.

Future studies should aim to quantify habitat availability, identify foraging areas, and assess the role of disturbance and predation more rigorously. Long-term monitoring, including individual marking, would also improve understanding of site fidelity, re-nesting behavior, and population dynamics.

5 Conclusion and recommendations

Wattled Cranes are the largest and rarest of the African cranes that show discontinuous distribution across many African countries. Its population is declining, due to various factors from wetland degradation to illegal trade. This particular study provides the first detailed account of the breeding ecology, nesting characteristics, and reproductive performance of the Wattled Crane in the Afroalpine habitats of the BMNP or the northern population of the species. The result of this study revealed that most Wattled Cranes nests were located on isolated islands or within marshy wetlands, suggesting that these habitats may offer favorable nesting conditions. For breeding, they prefer an area with elongated rainfall (August–October), abundant food resource as well as alpine lakes and marshy wetlands to build their nests underscoring the strong influence of seasonal hydrology on breeding phenology and success. Availability of hiding spots or presence of vegetation for their young and less disturbance were the main determining factors for Wattled Cranes' breeding performance in BMNP. Clutch size was typically one to two eggs, and egg-laying patterns showed that the first eggs were generally larger and heavier than the second. Despite a low hatching rate (37.5%), fledging success reached 100%, suggesting

strong parental defense and effective chick-rearing behaviors. Nest-site fidelity across successive years was observed at the level of breeding locations, with nests repeatedly recorded on the same islands and wetlands. However, because individual birds were not marked, it was not possible to confirm whether the same pairs consistently returned to these sites. Overall, the findings indicate that Afroalpine wetlands in BMNP represent one of the most important breeding habitats for Wattled Cranes in Ethiopia. Nevertheless, the relatively low hatching success and limited number of nesting sites highlight the vulnerability of this population. Conservation efforts should focus on maintaining the integrity of these wetlands, minimizing disturbance during the breeding season, and supporting long-term monitoring. Future studies should aim to quantify habitat availability, evaluate nesting success in relation to environmental variables, and assess movement patterns and site fidelity through individual marking. Indeed, it is essential to establish and maintain long-term monitoring efforts aimed at minimizing disturbances in critical breeding areas.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was approved by Ethiopian Wildlife Conservation Authority. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

HT: Formal analysis, Supervision, Validation, Writing – review & editing, Methodology, Data curation, Investigation, Software, Writing – original draft, Conceptualization. AB: Validation, Methodology, Visualization, Supervision, Conceptualization, Writing – review & editing, Resources. GA: Visualization, Funding acquisition, Resources, Project administration, Conceptualization, Methodology,

Supervision, Validation, Writing – review & editing. MN: Project administration, Supervision, Writing – review & editing, Resources.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. ChatGPT (OpenAI) was used for language editing, grammar correction, and copy editing of the manuscript. All scientific content, analyses, interpretations, and conclusions were developed and verified by the authors.

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