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THE NESTING ECOLOGY OF VULTURES: A GLOBAL REVIEW OF BREEDING BIOLOGY AND SITE SELECTION

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ABSTRACT

Vultures are obligate scavengers, which are essential ecologically because they contribute important functions in the cycling of nutrients and in controlling diseases, but their population is experiencing unprecedented reductions worldwide. Their nesting ecology is important to successful conservation management. This review integrates existing information on the vulture breeding biology, nest site choice, and reproductive performance based on 35 studies involving Old World (*Accipitridae*) and New World (*Cathartidae*) species of vultures. We test the effect of environmental and anthropogenic variables on the selection of nest site, breeding phenology, and reproductive success in different geographic locations. Cliff-nesting birds (e.g., *Gyps spp., Neophron percnopterus, Gypaetus barbatus*) show considerable preferences to steep and remote locations that are undisturbed by human activity, whilst tree-nesting birds (*Aegypius monachus, Necrosyrtes monachus*) choose mature woodland patches with defined structural features. The success of breeding is significantly different between species and areas (0.34-1.20 fledglings per breeding attempt), and human disturbance, poisoning, loss of habitat and climate-related reasons were found to be the main threats. Human activities between 300 and 800 m of nests have a great impact on the productivity of the nests, and the forestry activity, recreational activities and construction of infrastructure lead to abandonment of nests and breeding failure. Critical knowledge gaps that we recognize are in the ecology of New World vulture nesting, the effects of climate change, and the density-dependent processes. The conservation strategies also focus on the creation of disturbance-free buffer strips, safeguarding prime nesting areas, reducing the risk of poisoning and the use of adaptive management techniques. This synthesis offers a basis of evidence-based conservation planning to protect the populations of vultures and the ecosystem services they offer.

Keywords: vultures, nesting ecology, breeding biology, nest site selection, reproductive success, conservation, anthropogenic disturbance, cliff-nesting, tree-nesting

INTRODUCTION

Vultures are a distinctive guild of obligate scavenging raptors distributed on six continents, including 23 extant species (Old World vultures, family *Accipitridae*, 16 species and New World vultures, family *Cathartidae*, 7 species). As the apex scavengers, vultures offer invaluable ecosystem services such as fast removal of carcasses, nutrient cycling, and control of diseases through prevention of transmission of pathogens in decomposing remains. Although vultures are crucial in the ecological context, the population of this group of birds has fallen drastically over the past decades, and several species were recently listed as Critically Endangered or Endangered by the International Union for Conservation of Nature (Arkumarev et al., 2018; Oruka et al., 2025).

The ecology of vulture nesting is the key element to successful conservation management, as the availability of breeding sites, their quality, and protection directly determine the viability of the population. Vultures are K-selected with life history traits of delayed sexual maturity, low reproductive success, high adult survival, and high fidelity to sites, which makes them especially sensitive to the loss of breeding habitats (Oppel et al., 2017). The choice of nest sites represents the complex interplay of topography, vegetation structure, food availability, and anthropogenic pressures, and species-specific needs are determined by evolutionary history and ecological limitations (Morán-López et al., 2006a).

The main risks of the vulture population are poisoning, habitat destruction, human interference, collisions with structures, and lack of food, which all overlap with nesting ecology. Disruption of important breeding zones can lead to nest desertion, decreased rates of provisioning, and breeding failure (Zuberogoitia et al., 2008, 2014). The development of infrastructure divides the nesting area and adds to the mortality due to collisions, whereas land use and sanitary regulations shift food sources around breeding places (Oppel et al., 2017). These pressures can be further intensified by climate change due to the change in phenology, extreme weather, and habitat change (Serebryakov, 2022).

Although there is increased awareness of the importance of conserving vultures, the synthesis of nesting ecology among species and geographies is scarce. The majority of studies have been done on European and Asian populations of cliff-dwelling birds, especially Egyptian Vultures (*Neophron percnopterus*), Griffon Vultures (*Gyps fulvus*), and Cinereous Vultures (*Aegypius monachus*), although African and New World species are relatively poorly studied (Bamford et al., 2009). This geographic and taxonomic bias restricts us in creating conservation strategies that can be used worldwide.

The present review provides a synthesis of current knowledge on the ecology of vulture nesting by exploring:

(1) patterns of nest site selection and habitat needs between cliff-nesting and tree-nesting species.

(2) parental care strategies, breeding biology and phenology.

(3) mating success and determinants of breeding success.

(4) human and natural hazards to nesting populations.

(5) conservation implications and priority research directions. With the results of 35 studies across several species and continents, we hope to supply a solid evidence basis of vulture conservation planning.

Nest Site Selection and Habitat Requirements

Cliff-Nesting Species

The most common nesting behaviour of Old-World vultures is cliff-nesting, especially in the genera *Gyps, Neophron* and *Gypaetus.* They are highly attracted to steep, inaccessible cliff faces that offer shelter against terrestrial predators and anthropogenic disturbance and have an appropriate microclimatic environment and closeness to foraging zones.

Egyptian Vulture (*Neophron percnopterus*) populations throughout their Palearctic distribution show congruent cliff-nesting choices with species-specific microhabitat necessities. Breeding pairs are found in upland areas in Sicily, where low cliffs are far away, and arboreal crops and Mediterranean vegetation are found (Sarà et al., 2003). Turkey Turks have distinct preferences in breeding, avoiding human settlements and roads, with nesting probability decreasing with higher altitude and south-facing cliffs; the territorial spacing of 1.5 km nearest-neighbour distance is evidence of territorial behaviour (Şen et al., 2017). Egyptian Vultures nest in cliffs of central-west Nepal at 523-1644 m above sea level, with 76% of nest sites in caves and 24% on open ledges: cliff height, proximity to anthropogenic trophic resources and altitude variation were the primary factors influencing nest site selection (Gurung et al., 2022). The Balkan people inhabit the land that is shaped by 48 environmental factors, and the factors of influence are highly geographically diverse, indicating that people are regionally adapted in their habitat choice (Oppel et al., 2017).

Griffon Vultures (*Gyps fulvus*) usually nest in colonies on the faces of cliffs, and the nature of nest sites greatly affects the breeding success. Nests in caves in Gamla, Israel, had a higher fledging success and attempted to breed more than exposed cliff nests, indicating that the microsite protection against weather and predators increases reproductive performance (Freund et al., 2017). Breeding sites of caucasian populations are also determined by the distribution of wild ungulates and the proximity to anthropogenic facilities, and it is best to breed within 5-10 km of human settlements (Pshegusov et al., 2023). Livestock as a food source has the greatest effect on the colony distribution, and its contribution is 45 percent, with the distance to settlements and agricultural facilities coming in second (Pshegusov et al., 2023).

White-rumped Vultures (*Gyps bengalensis*) in Himachal Pradesh, India, show flexibility in the substrate they nest in, using both trees and cliffs. Nevertheless, the close examination of 18 environmental variables showed certain preferences of the nest site features, and threats associated with human activities were found as the main issues related to the colony survival (Bhattacharya et al., 2024; Thakur, 2015).

Bearded Vultures (*Gypaetus barbatus*) have very picky cliff-nesting behaviour, favouring distant and lofty locations. In the Caucasus, highlands 5-10 km away from anthropogenic facilities are strongly correlated with nest site choice as pairs nest there (Pshegusov et al., 2023). Populations of Pyreneans

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have shown tolerance to certain human activities, with breeding success comparable in both restricted and non-restricted zones, but precipitation has adverse effects on reproductive output (Comor et al., 2019). The density of power lines and the proximity of human settlements to the territories of Southern African populations are associated with the territorial abandonment of anthropogenic infrastructure and their high sensitivity (Krueger et al., 2015).

Rüppell's Vultures (*Gyps rueppellii*), a species of the Critically Endangered group, nest in cliff faces in small colonies. In the Luku Central Forest Reserve in Uganda, 57/14 nest attempts were successful, and cliff-nesting offered some protection against terrestrial threats (Oruka et al., 2025).

Tree-Nesting Species

Some species of tree-nesting vultures, such as the Cinereous Vulture (Aegypius monachus) and some African species, need to be found in mature forest stands with particular structural features. These species have unique conservation issues in terms of forestry management and habitat fragmentation.

Cinereous Vultures (*Aegypius monachus*) are arboreal nesting tree-nesters that nest in large stick nests in mature trees, mostly in Mediterranean woodland ecosystems. Hornachuelos Natural Park, Spain, nesting habitats were further away on bigger vegetation patches with a high cover of Cork Oak (*Quercus suber*) on steeper slopes with lower solar radiation; less than 8 percent of the study area was predicted to be suitable to nest (Guerrero-Casado et al., 2013). Vultures selectively nest in steep locations remote to human activity in seven colonies in Iberia with nesting substrate and climate conditions that are always of non-extreme climates and were associated with tree species of sufficient size (Moran-Lopez et al., 2006a). Suitability mapping in Portugal has indicated that although the areas of study are moderately to highly suitable as foraging sites, small areas are found to be suitable as nesting sites, which is an indication of habitat limitation (Lourenço et al., 2013).

Forestry activities have considerable effects on the nesting of Cinereous Vulture. The selection of breeding sites is always carried out by pairs in areas where forestry activities are low, meaning that they prefer undisturbed mature forest (Donázar et al., 2002). Cork exploitation within 500 m of nest, particularly intermediate and loud noise, is likely to lead to nest abandonment, and breeding success in pairs exposed to the intrusive anthropogenic activity was reduced by 20% (Margalida et al., 2011). This is because the habitat suitability is adversely affected by the presence of eucalyptus plantations rather than native oak and pine forests (Moran-Lopez et al., 2006a).

The nest site selection of Caucasian Cinereous Vulture populations is significantly affected by pine forests (*Scots Pine, Pinus sylvestris*) and distribution of wild ungulates, which indicates the significance of a nesting substrate and food supply (Pshegusov et al., 2023). The processes of density dependence act both at colony and nest site levels, and the productivity of breeding is best described by the interference competition; environmental limitations determined by physiography and human activity also affect the regulatory processes (Fernández-Bellon et al., 2016).

Hooded Vultures (*Necrosyrtes monachus*) in West Africa nest in trees in human-altered landscapes. The paradoxical effect of human settlements on nest success in Garango region, Burkina Faso, is that the closer the nests to human settlements, the higher the chances of nest success, indicating that there may be advantages of reduced predation or increased food availability around villages, but the nest trees are also threatened by egg and chick poaching or nest tree pruning or cutting (Dabone et al., 2019). More recent camera-trapping research has already started to reveal in-depth nesting ecology and infant mortality in this Critically Endangered species (Deikumah et al., 2025).

African White-backed Vultures (*Gyps africanus*) nest in trees in sub-Saharan Africa, but the ecological factors of nesting sites have not been well measured. Habitat models use the presence of a nest based on features such as the availability of trees, and the potential distribution is restricted by direct and indirect human disturbance (Bamford et al., 2009).

New World Vultures (*Cathartidae*) have varying nesting behaviours. In cities, Black Vultures (*Coragyps atratus*) and Turkey Vultures (*Cathartes aura*) exhibit nesting success, which depends on the land cover features around their nest sites (Partridge, n.d.). In Colombia, Andean Condors *(Vultur gryphus*) choose refuge sites attributable to the variability of temperature and humidity, distance to secondary roads, and housing units, and the heterogeneity of land cover, and anthropogenic variables and hierarchical behaviours affected selection at local scales (Serebryakov, 2022).

Environmental Correlates of Site Selection

The choice of nest site across species is an optimization of a combination of environmental factors such as topography, microclimate, food availability and predation risk. Physical barriers include steep slopes and cliff faces that make it harder to access terrestrial predators and human disturbance (Morán-López et al., 2006a; Şen et al., 2017). Microclimate is affected by aspect and solar radiation, and cliffs facing south in temperate areas have thermal benefits (Şen et al., 2017).

Proximity to human infrastructure becomes an important variable in practically all populations that are observed. Egyptian Vultures, Cinereous Vultures and Bearded Vultures always nest in places that are more distant to roads, settlements and places that experience high human activity (Sarà et al., 2003; Guerrero-Casado et al., 2013; Krueger et al., 2015). Nevertheless, the best distances differ according to species and area, with certain populations demonstrating tolerance limits of 3 to 10 km around settlements (Pshegusov et al., 2023).

The availability of food, especially the distribution of wild ungulates and livestock, has a strong effect on nest site selection on landscape scales. The distribution of Griffon Vulture colonies indicates that 45% of the distance to livestock facilities contributes to the distribution, and Bearded Vulture models are closely associated with the distributions of wild ungulates (Pshegusov et al., 2023). This nesting habitat-foraging habitat relationship emphasizes the value of landscape-scale conservation planning.

The structure and composition of vegetation influence tree-nesting species, where mature trees must be large enough and structurally stable to support large nests (Moran-Lopez et al., 2006a; Thakur, 2015). Species-specific substrate preferences. White-rumped Vultures nesting in India selected only pine trees (*Pinus roxburghii*) at an average height of 15.4 m (Thakur, 2015). Niche partitioning enables the coexistence of many species of vultures, although they have similar habitat requirements. The threatened vulture species in the Caucasus exhibit overlapping yet different nesting needs, and niche sharing minimises direct competition (Pshegusov et al., 2023). This implies that conservation efforts need to take into consideration multi-species assemblages and no single-species approaches.

Breeding Biology and Phenology

Vultures have K-selected reproductive behaviours that are typified by long breeding periods, high parental investment, and one (occasionally two) offspring. The knowledge of breeding phenology and parental investment patterns is vital towards identifying sensitive periods that need to be guarded against disruption.

Laying Seasons and Phenology: Latitude, altitude and regional climate patterns are all affected in breeding phenology. Mediterranean Egyptian Vultures normally begin breeding during late winter to early spring and lay their eggs between March and April. Breeding phenology of Bulgarian populations followed between 2005 and 2016 revealed a stable adaptive breeding to the local environment (Arkumarev et al., 2018). Species found in the tropics of Africa might have longer or more fluctuating breeding periods based on rainfall and food supply.

Incubation Period: The incubation of vultures takes more time than larger raptors of a similar size, with an average of 38-58 days depending on species. Incubation is done by both parents, and frequent nest changes. The long incubation is due to the large size of the egg in relation to adult body mass and the necessity of low and high temperatures.

Chick Development and Nestling Period: Vulture chicks are semi-altricial and hatch with down and open eyes, but need much parental care. The nestling stage is unusually prolonged, 90-150 days according to the size of the species. Griffon Vultures and Cinereous Vultures take around 110-130 days to nest, whereas smaller Egyptian Vultures have a fledge period of 90-100 days. In this long duration, weather extremes, food shortages, and disturbance are threats to the chicks.

Parental Care and Provisioning: Parents both take part in the provisioning of chicks, and adults make foraging trips, which can extend to hundreds of kilometres. The rate of growth of chicks and survival depend on provisioning rates and food delivery frequency. Provisioning behaviour may be interrupted by human disturbance; Egyptian Vulture adults in northern Spain were unable to feed chicks when humans were within a range of 307 m, but were able to feed on nests at an altitude of 837.5 m, with a range of highest alert of 605 m (Zuberogoitia et al., 2008). This indicates species-specific disturbance sensitivity thresholds that should be used in the setting of buffer zones.

Fledging and Post-Fledging Dependency: Young vultures also live at varying levels of dependency after fledging, acquiring skills in foraging and social behaviours. The post-fledging death rate may be high, and the young ones are prone to starvation, poisoning and road accidents during their initial year of independence.

Breeding Frequency and Site Fidelity: The vast majority of vulture species breed once each year,

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assuming favourable conditions, but can skip breeding in years of poor food or after breeding failure. It has a strong site fidelity so that successful pairs reuse the nest site or territory for several years. More attempts to breed in Griffon Vultures were made in cave nests than in exposed nests, implying that high-quality nest sites are selectively maintained (Freund et al., 2017). Nevertheless, White-rumped Vultures in India exhibited high intra-colony mobility, with about 65% of nests being newly constructed in 20112012, indicating the flexibility with which nests were placed during the colony areas (Thakur, 2015).

Reproductive Performance and Productivity

There is a large variation in reproductive performance in populations of the vultures across and within species, with both intrinsic (age, experience, genetic quality) and extrinsic (food availability, weather, disturbance) factors playing a role. This variation is important to understand population viability and set conservation priorities.

Breeding Success Metrics: Breeding success is normally considered as the number of fledglings per breeding attempt, number of fledglings per occupied territory, or number of fledglings per successful pair. These measures complement each other in terms of information on reproductive performance at various points of the breeding cycle.

High-Performing Populations: The breeding performance of Bulgarian Egyptian Vultures is very high, having breeding success of 1.11 ± 0.13 fledglings per laying pair, productivity of 0.88 ± 0.1 fledglings per occupied territory, and fledgling success of 1.2 ± 0.1 fledglings per successful pair (Arkumarev et al., 2018). Territories that had high occupancy rates had a pair output of 88% of fledglings, which revealed the value of conserving core breeding areas.

The mean productivity of Balkan Egyptian Vulture populations was 0.80 fledglings per occupied area (Oppel et al., 2017). In Himachal Pradesh, India, there was an increasing nest success of White-rumped Vultures, with positively changing nest success rates of 56.1% in 2009- 2010 to 79.4% in 2011- 2012, and 81 nesting pairs in 2012 compared to 102 nesting pairs in 2010 (This increase could be indicative of the remediation of the effects of diclofenac poisoning or of increased safety precautions.

Moderate-Performing Populations: Annual breeding success of Hooded Vultures in Burkina Faso ranged between 0.68 and 0.71 chicks per breeding pair per year and was determined as 0.57 chicks per territorial pair in 2014/15 (Dabone et al., 2019). Vultures in Uganda by Rüppell recorded a nest success of 57% (8 out of 14 nests), which is moderate for a Critically Endangered species that is experiencing numerous threats (Oruka et al., 2025).

Low-Performing Populations: In Gamla, Israel, there were very low fledging success rates among Griffon Vultures, with just 34 percent of all breeding events yielding fledged young (Freund et al., 2017). Poisoning, hunting, and lack of right nesting sites all contributed to such low productivity, and this example demonstrates how various stressors can reduce reproductive output to unsustainable levels.

Factors Influencing Breeding Success: Breeding success is influenced by many factors. Breeding habitat quality, such as nest site and food. Griffon Vultures had greater success with cave nests than open nests (microsite effects; Freund et al., 2017). Cinereous Vultures have density-dependent productivity at colony and microsite scales, with interference competition causing success declines at high densities (Fernández-Bellon et al., 2016).

Success is influenced by the weather during key periods. Egyptian Vultures in northern Spain exhibited a negative effect of rainfall and the number of rainy days in June during the small nestling stage on breeding success (Zuberogoitia et al., 2014). In the French Pyrenees, precipitation had a negative effect on the breeding success of Bearded Vultures (Comor et al., 2019).

These weather impacts could be exacerbated by climate change. Human disturbance is a key factor decreasing breeding success across species and geographic areas (see Section 5.1). Hunting and poisoning lead to direct mortality of chicks and adults, with consequent impacts on population dynamics (Freund et al., 2017; Oruka et al., 2025).

Regional Variation: Spatial variation in breeding success exists within species, and is related to habitat quality, food availability and the level of threat. Balkan Peninsula Egyptian Vultures demonstrate that key environmental factors differ among regions, implying that management should be region-specific (Oppel et al., 2017). Cinereous Vultures in the SW Iberian Peninsula show geographical differences in anthropic and natural factors influencing their breeding success (Morán-López et al., 2006b).

Population-Level Implications: Poor productivity, late age of maturity and high adult survival requirements imply that small decreases in breeding success can lead to population decline. Populations with reproductive rates lower than 0.5-0.6 fledglings per territory occupied may not be able to maintain their numbers in the absence of immigration or increases in adult survival. The extremely low reproductive success observed in some populations (e.g., 34% in Israeli Griffon Vultures) suggests populations in peril and in need of emergency action (Freund et al., 2017).

Anthropogenic and Environmental Influences

Human Disturbance

Human disturbance during the breeding season is one of the most common and preventable factors affecting vulture breeding success. Impacts depend on disturbance type, time, intensity and species-specific responses, but generally decrease productivity.

Types and Impacts of Disturbance: Northern Spain's Egyptian Vulture population suffered human disturbance during 42 of 100 breeding attempts over eight years. Forestry activities resulted in 100% breeding failure in 13 attempts, and disturbance from free-time activities (walking, climbing, photography) resulted in 44% failure in 25 attempts (Zuberogoitia et al., 2008). Reproduction was reduced in territories with human disturbance, but some pairs improved their success by nesting away from disturbance. In Biscay, northern Spain, 59 nests (30.9%) in 17 of 22 study territories were highly disturbed, fledging only three birds from 2000-2012; management initiatives from 2010-2012 led to increased success to similar levels as undisturbed territories (Zuberogoitia et al., 2014).

Bearded Vultures demonstrate variable responses to human activities. In the French Pyrenees, breeding success was similar in restricted and non-restricted areas, with no evidence that hunting was perceived as a threat, suggesting some adaptation to human presence (Comor et al., 2019). However, this tolerance may not extend to all activity types or populations.

Cinereous Vultures are highly sensitive to forestry. There is a likely risk of nest abandonment from cork exploitation (within 500 m) and intermediate and high noise, with a 20% reduction in breeding success in pairs exposed to "intrusive" human activity (Margalida et al., 2011). In lowland breeding sites, high rainfall during the nestling stage and human disturbance had a negative effect on breeding success (Donázar et al., 2002).

The records of Bearded Vultures' tolerance towards human activities are mixed. In the French Pyrenees, lay date and breeding success did not differ between restricted and non-restricted zones, and there was no evidence that hunting is perceived as a threat, highlighting the bearded vultures' tolerance of human activities (Comor et al., 2019). But this might not apply to all activities or populations.

Disturbance Thresholds and Buffer Zones: Buffer zone set-up at species-specific disturbance distances. In Spain, Egyptian Vultures' flight distance to prevent access by parents to nestlings, due to human presence, was 307 m; whereas they could access the nest at 837.5 m, maximum alert distance was 605 m and could be protected by a buffer zone of 57 ha (Zuberogoitia et al., 2008). These observed distances inform conservation buffer zones.

Human avoidance in nest site selection. Egyptian Vultures in Sicily, Turkey and Nepal consistently avoid roads and villages (Sarà et al., 2003; Şen et al., 2017; Gurung et al., 2022). Cinereous Vultures select sites away from roads, villages, and patch edges (Guerrero-Casado et al., 2013). This could indicate that large spaces free of human disturbance are important at minimal distances for suitable habitat.

Temporal Sensitivity: The effect of disturbance depends on the stage of breeding, with incubation and early nestling periods being the most vulnerable. Human activities during these periods may lead to abandonment or mortality of chicks through chilling or starvation. Managers need to plan activities close to breeding areas considering seasonal avoidance and sensitivity to vulture presence.

Infrastructure and Habitat Loss

Power lines and other human activities can directly and indirectly impact nesting vultures through collision and electrocution, habitat fragmentation, and displacement from nesting habitat.

Power Lines and Electrocution: For Bearded Vultures in southern Africa, abandonment of known territories is associated with proximity to infrastructure and human settlement, with almost 50% of territories abandoned (Krüger et al., 2015). Power lines are both a mortality and a barrier to vultures, and may negatively impact habitat quality by preventing sightings of prey and providing a refuge for vultures' prey. The combined effect of increasing power lines in the vultures' range poses an emerging threat.

Habitat Loss and Fragmentation: Sicily has high-density forests (without cliffs) unsuitable for nesting, high human density and intense agricultural activity, making up roughly 60% of the island (Sarà et al., 2003). This provides an example of land-use change removing nesting habitat at a landscape level. Cinereous Vultures need large areas of undisturbed forests, with less than 8% of some study areas predicted to be suitable for nesting (Guerrero-Casado et al., 2013).

Fragmentation decreases patch sizes and increases edge effects, contributing to decreased habitat quality. Tree-nesting species are affected by forestry. Eucalyptus plantations at the expense of native oak and pine forests for Cinereous Vultures decrease habitat quality (Morán-López et al., 2006a). Intensive forest exploitation and clear-cuts destroy nesting substrate and cause nest disturbance (Donázar et al., 2002). For Hooded Vultures, pruning and cutting of trees led to direct nest failure (Dabone et al., 2019).

Food Availability and Sanitary Regulations: Shifts in agricultural practices and sanitary standards that limit carcass availability influence vultures through greater travel distances to food and impacts on breeding performance. Poisoning, electrocution, collision with man-made objects and direct persecution, mixed with agriculture changes, interact with the landscape structure to affect territory occupation and breeding performance (Oppel et al., 2017). Proximity of nesting and foraging habitats affects breeding success, as suitable nesting habitat includes proximity to foraging sites to ensure adequate food (Pshegusov et al., 2023).

Climate and Weather Effects

Weather and climate affect vulture breeding directly through nest and chicks' microclimate and indirectly on food availability, and may be exacerbated by climate change.

Weather Impacts on Breeding Success: Effect of rainfall during key breeding periods on breeding success Egyptian Vultures in northern Spain experienced breeding success negatively impacted by rainfall and rainy days in June, the period of small nesting (Zuberogoitia et al., 2014). Bearded Vultures in the French Pyrenees had breeding success negatively affected by rainfall (Comor et al., 2019). Cinereous Vultures with lowland nesting sites had breeding success negatively impacted by rainfall during the nestling period (Donázar et al., 2002). This probably works via thermoregulation problems for chicks, lower foraging success and mortality of nestlings during storms.

Microclimate and Nest Site Selection: Nests are located to optimise microclimate. In temperate climates south-facing cliffs are warmer (Şen et al., 2017) and cave nesting protects against climatic extremes (Freund et al., 2017). Climatic variability affects Andean Condor refuges in Colombia (Serebryakov, 2022).

Climate Change Projections: Vulture distributions and breeding habitat are predicted to be strongly affected by climate change scenarios. The distribution of the Andean Condor in Colombia is expected to shrink by 18-32% under climate change (Serebryakov, 2022). Projected impacts of global warming pose a threat for Cinereous Vulture (Morán-López et al., 2006a). These forecasts indicate climate-adapted conservation approaches which should consider future range shifts and habitat suitability.

Interactions with Other Stressors: Climate impacts interact with other factors to affect breeding populations. Drought-induced shifts in food abundances may compound habitat loss and disturbance. Exposure to extreme weather events may result in greater mortality in populations that have been affected by poisoning and persecution. We need to understand these interactions to forecast population responses to global change.

Conservation Implications

Litterature on nesting ecology of vultures highlights several conservation needs. First, it is important to define and maintain disturbance-free areas around nests. Minimum recommended distances (300-800 m) determined empirically should be used to establish protective zones, with modification for different species and human activities (Zuberogoitia et al., 2008; Margalida et al., 2011). Time-of-year constraints on forestry, recreation and urban development during the nesting period (February to August in temperate zones) can also significantly limit disturbance.

Second, safeguarding and managing breeding habitat at landscape scales is critical. For cliff-nesters, finding and protecting cliff systems with appropriate attributes (cliff height, orientation, weather shelter) is vital. For forest-nesting species, ensuring adequate amounts of mature forest with suitable structure (tree species composition and density) is critical, requiring incorporation of vulture conservation in forestry management strategies (Donázar et al., 2002; Margalida et al., 2011). Habitat suitability models can be used to prioritise areas for conservation and management (Guerrero-Casado et al., 2013; Pshegusov et al., 2023).

Third, reducing poisoning by education, enforcement, and offering alternative pest control solutions is essential. Poisoning is a leading cause of mortality in many areas (Freund et al., 2017; Oruka et al., 2025), impacting not only the target species, but cascading through the entire scavenger community. Feeding stations can also mitigate risks from poisoning and boost breeding, with monitoring in Azerbaijan revealing that supplementary feeding during the breeding season led to 1.2-1.6 times greater engagement in breeding (Karimov, 2015).

Fourth, infrastructure impacts can be mitigated by planning. Overhead power lines should be avoided where possible and existing lines retrofitted with bird-safe options to minimise electrocution and collision deaths (Krüger et al., 2015). Renewable energy initiatives should consider protecting vultures, using suitable site selection and modifications during operation.

Fifth, connect nesting and foraging habitat to meet nutritional demands Food plays a critical role in nesting and breeding performance (Pshegusov et al., 2023), and demonstrates the need for large-scale conservation involving nesting and foraging habitats. Ample livestock carcasses through policies promoting extensive livestock production benefit vultures without disrupting local land use.

Conclusion

Nest site selection is a key point where a range of environmental pressures met vultures, which are facing conservation threats like never before. This meta-analysis of 35 studies shows nest site selection, reproductive biology, and breeding success is influenced by intricate interactions of topography, vegetation structure, food supply, human activities and climate. Cliff-nesting species are highly selective of steep, distant, humanoid-free habitats, whereas tree-nesting species are selective of specific forest characteristics in mature forest stands. Breeding performance is highly variable (0.34-1.20 fledglings per breeding pair), with human impacts, poisoning, habitat alteration and climate as key bottlenecks.

Our evidence lays out a plan for conservation: avoiding disturbance around active nests (300-800 m), ensuring conservation of key nesting habitat at landscape scales, preventing pollution via education and enforcement, and dealing with infrastructure impacts via proactive conservation planning, in addition to managing nesting and foraging habitat. But there are research gaps for New World and African vultures, climate change, and effectiveness of conservation interventions.

Vultures render a unique ecosystem service; their protection demands sound management based on knowledge of their nesting ecology. Vultures' site-fidelity, low productivity, and vulnerability to disturbance highlight the need to conserve breeding populations. With increasing human impacts and rapid climate change, flexible conservation efforts based on rigorous science, and delivered through partnerships, hold the key to ensuring future vulture populations and the services they provide. Policies and conservation measures can halt vulture declines and support these remarkable species to continue providing crucial ecosystem services if future research addresses key knowledge gaps and evidence-based conservation strategies are implemented.

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