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# Nesting Ecology of Hornbill Species: A Review of Behavioral, Environmental, and Conservation Aspects

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## ABSTRACT

Hornbills (family, Bucerotidae) are one of the most ecologically important bird families in tropical and subtropical forests in Asia and Africa, playing a key role as long-distance seed dispersers, "farmers of the forest" and contributing significantly to forest regeneration, ecological connectivity and maintenance of biodiversity. India has nine species of hornbills in its forests, spread across different biogeographic regions, such as the Western Ghats, North-East forests, Himalayan foothills, Central Indian forests and Andaman & Nicobar Islands. They are well correlated with the availability of mature forests, fruiting tree phenology, breeding seasonality and climatic conditions at both spatial and temporal levels. This review brings together existing information on hornbill nesting ecology with a particular focus on behavioral adaptations, nest-site selection, cavity characteristics, breeding biology, chick development, diet and nesting ecology, and conservation issues. Hornbills have a highly specialized nesting mode where the female incubates and broods the chicks within the nest and is the sole provider of food and protection to the nestlings, while the male provides only food. Cavity size, tree species composition, canopy cover, food availability and microclimatic conditions all play a part in nest site selection. The review also notes that hornbills play an important role in promoting forest dynamics through their seed dispersal for larger size-seeded tree species, which contribute to natural forest succession and ecosystem resiliency. But habitat fragmentation, destruction of cavity bearing trees, poaching, climate change and growing human activities are really impacting hornbill breeding success and population persistence. Conservation measures such as habitat restoration, provision of artificial nest boxes, nesting tree protections, geo-tagging roosts, the Hornbill Nest Adoption Program, and community-based efforts have yielded positive results. The integrated habitat management, long-term ecological monitoring and community participation are crucial to sustain hornbills populations and conservation of tropical forest ecosystems in India, the review says.

**Keywords** Habitat fragmentation, Cavity-bearing trees, Forest regeneration, Nest-ecology, Ecosystem resilience, Habitat management, Community based conservation, Hornbills.

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## INTRODUCTION

The nesting ecology of hornbills is shaped by complex interactions among behavioral traits, habitat structure, and environmental variables. A defining feature of their reproduction is the sealing of the nest cavity by the female using a mixture of feces, mud, and fruit pulp, leaving only a narrow slit for food transfer, which ensures protection against predators but also increases dependency on the male for provisioning. Species-specific variations exist in nest site selection, cavity dimensions, clutch size, and breeding seasonality, influenced by local climatic conditions and forest composition (Naniwadekar *et al.* 2015). However, habitat fragmentation, loss of large trees, and poaching threaten hornbill populations, leading to reduced nesting opportunities and reproductive success (Utoyo *et al.* 2017). The conservation of hornbill nesting habitats is therefore essential for sustaining forest health and biodiversity.

This review synthesizes existing literature on the nesting ecology of hornbill species, with emphasis on behavioral strategies, nest site preferences, ecological requirements, and conservation challenges, aiming to inform targeted habitat protection and species management efforts.

### Objectives and scope

The review aims to provide a comprehensive synthesis of the current knowledge on the nesting ecology of hornbill species, addressing the following objectives:

1. Behavioral aspects of hornbill nesting are reviewed to examine site selection, nest preparation, parental roles during incubation and chick rearing.

2. The environmental factors that may influence success of nesting, including habitat quality, tree availability, and climatic conditions, are analyzed.

3. It helps us to show dangers to hornbill nesting (habitat loss, competition for nesting sites, climate change).

4. Conservation strategies and programs, including artificial nest boxes, habitat restoration, and community based programs are reviewed.

The review attempts to bridge knowledge gaps, informs conservation policies and sets the systematic agenda for maintaining hornbill species in the long term. The paper synthesizes results from this and other regions and habitat and presents a global view of the hornbill's nesting ecology, and emphasizes the need for local conservation.

### Spatial and temporal availability of hornbills in India

Hornbills are found in Indian forests in various ecological diversity zones from the tropical evergreen forests of the Northeast Indian states, the Western Ghats, dry deciduous forests to the urban areas of the Gangetic Plains, India hosts nine species of hornbills. They are well distributed in space and are heavily correlated with mature forest with large cavity bearing trees and fruiting species like Ficus, Syzygium and Terminalia. The Northeast India, especially Arunachal Pradesh, Assam and Nagaland, is one of the most significant regions for hornbill diversity, including the Great Hornbill, Rufous-necked Hornbill, Wreathed Hornbill and Oriental Pied Hornbill. The Western Ghats are home to endemic and regionally important species such as the Malabar Grey Hornbill, Malabar Pied Hornbill and the Indian Grey Hornbill, which is widely seen in the urban and semi-urban areas of northern and central India.

Hornbills are generally only found and active during certain times of the year and are associated with fruiting phenology and breeding cycles. The breeding season of most hornbills in India starts with the pre-monsoon and early summer season (January – June) when food is abundant and climatic conditions are favorable. A number of species also migrate in response to seasonal changes, mostly due to food availability and habitat conditions. Hornbills are known to be seasonal in abundance, related to forest productivity, nesting cavity availability and anthropogenic disturbance (Naniwadekar *et al.* 2015). Their temporal distribution and breeding success are becoming impacted by climate variability and habitat fragmentation.

**Nesting behavior and ecology**

Hornbills have highly specialized nest site selection behavior, favoring specific locations, which offer best suitable conditions for reproductive success. These species nest in natural tree cavities or even in human made structures when natural sites are scarce (Patel, B. *et al.* 2022). And, these sites have been chosen due to a combination of factors including tree species, cavity dimensions, microclimatic conditions, and surrounding habitat.

**Hornbill nest preparation: behavioral and ecological insights**

**a. Male hornbills:** Play critical role in nest preparation by providing & collecting resources like mud, fruit pulp, leaves & bark, with which the female seals opening of the cavity to only a small slit for the male to pass food.

**b. Female hornbills:** Once the female hornbill enters a suitable cavity for nesting, she seals the entrance using a mix of mud, feces, fruit pulp, and regurgitated food- leaving only a narrow slit through which the male feeds her and later, the chicks. During this sealed nesting phase, the female remains confined inside the cavity for several weeks to months. One of the most extraordinary physiological changes observed is that the female sheds her flight and tail feathers, this molt is either partial or nearly complete, depending on the species.

**Nest-site selection**

**a. Habitat features:** Distance to detectable sources of food and amounts of dense undergrowth for cover are the other aspects that determine the selection of sites. Hornbills being frugivorous preferentially select nest sites in habitats with maximum fruit resources to minimize the distance to be covered by the male (Pradhan *et al.* 2024) Nesting on the surrounding habitat protects from the attack by the potential predators during the breeding season (Naniwadekar *et al.* 2021).

**b. Microclimatic Conditions:** Temperature, humidity and level of ventilation of the internal environment of the cavity are other important factors affecting nest-site selection. Desirable microclimate conditions help to hatch the eggs and the growth of chicks adding that they shield the eggs and chicks from volatile climate conditions and avail good thermal conditions always (Pule, O. 2025).

**c. Preferred nesting sites:** Hornbills are obligate secondary cavity nesters, meaning they do not excavate their own nest cavities but depend on pre-existing natural hollows or abandoned woodpecker or barbet holes in large, mature trees (Pawar *et al.* 2021). The availability, structure, and quality of these cavities significantly influence hornbill nesting success and population viability.

**d. Preferred tree species:** Larger mature trees are vital to hornbill nesting and roosting, and certain species may nest and roost in only certain types of trees (Aulia, E. F. *et al.* 2026) which can satisfy their needs with nest cavity space, canopy cover, and food sources (Table 1.). Hornbills do not select nest trees at random, they prefer trees that are taller, emergent with large natural holes, thick trunk and strong branches to hold the nest and the mass of the adult birds. Such trees are frequently members of species which grow slowly and are of hardwood having the endurance to survive decades of weathering and rotting to create natural hollows. Stander, M. C. *et.al.* (2021) quoted that sometimes, it has been observed that Hornbills in degraded forests have to nest in sub-optimal trees or completely give up breeding because of the absence of suitable cavity-bearing trees. Hence, Poonswad *et al.* (2013) mentioned that conservation strategies for the protection of old-growth and nesting trees with Community-based monitoring should be followed.

**e. Cavity dimensions:** In general, the size and form of the cavity have a great influence on the choice of a nest-site. These birds select holes that can at least accommodate the female and the young chick depending on the size and time the hornbills take to breed and hatch the eggs respectively so that it can also be well insulated and protected from predators. Size features, shape, depth of the entrance and internal volume of the cavities are one of the most important factors that affect selection of nest sites. Some of the observed features suggest that cavities with entrance diameter of 10-15 cm and depth over 30 cm (as

**Table 1.** Showing the Preferred Nesting Tree with Tree Characteristics.

| Hornbill Species | Preferred Nesting Tree Species | Cavity Height (m) | Entrance Diameter (cm) | Cavity Depth (cm) | Key Nest Tree Features |
|---|---|---|---|---|---|
| Great Hornbill (*Buceros bicornis*) | *Tetrameles nudiflora, Artocarpus chaplasha Toona ciliata, Ficus spp.* | 18-30 | 20-25 | 60-100 | Large girth (>150 cm), deep natural cavities, tall canopy, firm structure |
| Malabar Grey Hornbill (*Ocyceros griseus*) | *Terminalia paniculata Lagerstroemia microcarpa, Ficus benghalensis, Cullenia exarillata* | 15-25 | 15-20 | 50-70 | Moderate-sized trees, available cavities, secondary forests and plantations |
| Indian Grey Hornbill *(Ocyceros birostris)* | *Ficus religiosa, Albizia lebbeck, Mangifera indica, Azadirachta indica* | 6-15 | 10-15 | 30-60 | Medium-sized trees, cavities in dead branches or broken trunks, common in human modified landscapes |
| Oriental Pied Hornbill (*Anthracoceros albirostris*) | Terminalia myriocarpa, *Ficus* spp., *Bombax ceiba, Albizia procera* | 10-20 | 12-18 | 40-70 | Lowland forest, edge habitats; prefers trees with shallow to mid-depth cavities |
| Malabar Pied Hornbill (*Anthracoceros coronatus*) | *Sterculia villosa, Ficus* spp., *Bombax ceiba* | 8-18 | 12-17 | 40-70 | Prefers dry deciduous forest species medium height, softwood trees with accessible cavities |
| Wreathed Hornbill (*Rhyticeros undulatus*) | *Tetrameles nudiflora, Ficus* spp., *Chukrasia tabularis* | 15-25 | 18-23 | 50-80 | High canopy, riverine forests, large-trunk trees, deep nesting cavities |
| Rufous-necked Hornbill (*Aceros nipalensis*) | *Tetrameles nudiflora, Ficus* spp., *Artocarpus chaplasha, Duabanga grandiflora* | 20-35 | 18-22 | 60-90 | Very large emergent trees, minimal sway, deep cavity for nesting security |
| Narcondam Hornbill *(Rhyticeros narcondami)* | *Ficus rumphii*, *Pisonia grandis, Barringtonia asiatica* | 15-25 | 18-22 | 60-85 | Uses coastal forest species; highly site-specific due to island endemism |
| White-throated Brown Hornbill (*Anorrhinus austeni*) | *Canarium strictum, Tetrameles nudiflora, Ficus* spp | 18-30 | 20-24 | 70-100 | Moist evergreen forests, deep cavities, often in tall canopy trees |

mentioned in Table 1) are suitable for large hornbill species (Beastall *et al.* 2016).

## Materials required

Hornbills utilize a range of natural materials to construct and maintain their nests, showcasing remarkable in genuity and adaptability

**a. Mud:** The nest entrance is sealed by mud, which is one of the main sealing materials. The male Hornbill collects mud from near sources and passes it to the female inside the cavity. Mud used creates a secure barrier preventing disturbance and predators.

**b. Food remains:** Food debris such as fruit pulp are used to strengthen the seal besides mud. In addition it is adhesive; which helps the durability of the seal and also acts as insulation from environmental factors.

**c. Leaves and bark:** They are not just structural stuffers, they have crucial roles to play in thermoregulation and hygiene as well as parasite control and chick development.

Related ecological studies shows that the male and female hornbills, depending on the species, place plant materials, like fresh green leaves, strips of tree barks, and at times twigs into the nest cavity during

**Table 2.** Plant Species Used by Hornbills for Nesting and Their Known Bioactive Properties.

| Plant Species | Plant part Used | Region | Known Properties |
|---|---|---|---|
| *Terminalia bellirica* (Bahera) | Leaves and bark used in nest | Western Ghats, India | Antimicrobial, astringent |
| *Ficus racemosa* (Cluster fig) | Bark and leaves for lining | Arunachal Pradesh | Antibacterial, anti-inflammatory |
| *Syzygium cumini* (Jamun) | Leaf litter and bark pieces | Northeast & South India | Antioxidant, antifungal |
| *Tectona grandis* (Teak) | Dry leaves used | Central India | Aromatic wood, termite-resistant |
| *Vitex negundo* (Nirgundi) | Fresh aromatic leaves | Southeast Asia, Assam | Mosquito repellent, antifungal |

the pre-laying and incubation periods (Pasuwan, C.,*et al.* 2022). No random choice of these plant parts is taken, rather there are some specifications taken in consideration of the aromatic, insect-repellent or medicinal nature of the species of choice (as mentioned in Table 2).

**Functions of leaves and bark:**

**As a thermal regulator & nest bedding**

Leaves are used to produce a cushion of insulation within the cavity to eggs and chicks.

*Tectona grandis* and *Ficus racemosa* are favored for their long-lasting, slow-decaying nature to preserve temperature and minimize moisture in the cavity.

**Anti-insect/role and anti-parasitic role**

Plants containing aromatic and tannin such as *Vitex negundo* and *Terminalia bellirica* are naturally antimicrobial and antifungal agents, reducing the chances of fungal infections, lice and mites.

This kind of utilization could be seen to be the same as in case of self-medication behaviour (zoopharmacognosy) in birds whereby plants are selected on the basis of protective effects (Gysel 1961).

**Insect repellent**

*Vitex negundo* and *Syzygium cumini* leaves are preferred as they are mosquito repellents and may be utilized to protect the chicks during the protracted nesting period against bites and vector borne infections.

**Diet preferences by females and chicks during the nesting period**

Mukhtadin, M. R., Nurcahyani *et al.* 2023 wrote about the diet of hornbills during nesting adapted to provide the nutritional requirements of the nesting female and growing chicks and shifted toward higher-energy, protein rich, and easily digested food (As mentioned in Table 3.). Although fruit is the predominant component of their diet throughout the year, the breeding season can be followed by increased consumption of animal food (insects, reptiles, rodents, small mammals, and bird eggs) to help with chick growth and female confinement. The males take the role of the sole provider until the nest seal is broken mid-cycle and the male and female feed the chicks. The quality and quantity of food, its nutritional content and provisioning strength directly affect the mortality of chicks, and success of fledging (Poonswad *et al.* 2013).

**Breeding behavior**

Hornbills have a very specialized and synchronized breeding behavior that includes cavity nesting, female confinement and male provisioning. The female, during the breeding season (months of February-June in India), seals herself inside a tree cavity using a mixture of mud, droppings, and fruit pulp, leaving behind a slit hole for the male Hornbill to feed through (Hafeez, A *et al.* 2025). This confinement (lasting 3 to 4 months) includes the whole process from egg laying, hatching, incubation to first rearing of the

**Table 3.** Dietary Preferences by Females and Chicks during the Nesting Period.

| Species | Dominant Fruit Species (Botanical Name & Common Name) | Animal Prey Consumed | Diet Shift During Nesting |
|---|---|---|---|
| *Buceros bicornis* (Great Hornbill) | *Ficus spp.* (Figs), *Dysoxylum* (Rosewoods), *Elaeocarpus* (Rudraksha), *Litsea* (Indian laurel) | Lizards, small birds, insects | Fruit ~70%, Animal ~30%; ↑ protein during chick rearing |
| *Rhyticeros undulatus* (Wreathed Hornbill) | *Ficus* (Figs), *Polyalthia* (False Ashoka),*Knema* (Nutmeg family) | Frogs, lizards, snails, beetles | ↑ Animal prey during late nestling stage |
| *Anthracoceros albirostris* (Oriental Pied Hornbill) | *Artocarpus* (Jackfruit), *Ficus* (Figs), *Carica* (Papaya) | Caterpillars, crickets, grasshoppers | Fruit-dominant (~80%), moderate animal protein |
| *Ocyceros griseus* (Malabar Grey Hornbill) | *Symplocos* (Sweetleaf), *Ficus* (Figs), *Canarium* (Indian olive) | Occasional insects, ants | Highly frugivorous; <10% animal prey |
| *Ocyceros birostris (*Indian Grey Hornbill) | *Mangifera* (Mango), *Tamarindus* (Tamarind), *Ficus* (Figs) | Lizards, grasshoppers, ants, crickets (Fig. 1) | Fruit-heavy diet; moderate protein for chicks |
| *Aceros nipalensis* (Rufous-necked Hornbill) | *Castanopsis* (Chinkapin), *Schima* (Needlewood), *Quercus* (Oak) | Earthworms, insects, small rodents | Higher reliance on protein-rich prey in breeding |
| *Anorrhinus austeni (*White-throated Brown Hornbill) | *Canarium* (Indian olive), *Terminalia* (Arjun), *Sterculia* (Wild almond) | Rodents, bird eggs, insects | Increase animal prey delivery |
| *Rhyticeros narcondami* (Narcondam Hornbill) | *Ficus* (Figs), *Terminalia* (Arjun/Indian almond) | Insects, crabs | Seasonal diet change; more animal prey likely during nesting |
| *Anthracoceros coronatus* (Malabar Pied Hornbill) | *Ficus spp.* (Figs), *Caryota urens* (Fish-tail palm), *Syzygium cumini* (Jamun) | Beetles, grasshoppers, small reptiles | Moderate increase in animal prey during chick rearing |

**Fig. 1.** Male of Indian Grey Hornbill catches cricket for feeding Female Grey Hornbill sealed inside the Nest Cavity (Pic credit: Asif A. Siddiqui).

chicks. The majority of the species lay between 1 to 3 eggs, clutch size is however dependent on the species and the body size. Male hornbills are extremely important as they end up spending much time foraging to feed the female and the chicks sometimes covering very long distances to find a wide variety of food in the form of fruits and small animals (Liang, H. *et al.* 2024). Cooperative breeding is recorded in certain species whereby the non-breeding members help raise provision of the chick as was in the case of the White-throated Brown Hornbill (*Anorrhinus austeni*) (Bora, B *et al.* 2023). When the juveniles

are part feathered, but can flee, the female and chicks come out.

**Pair-bonding & courtship behaviors**

Hornbills are predominantly monogamous, with several species forming long-term pair bonds that persist across multiple breeding seasons (Groot and Rose 2025). These bonds are reinforced through elaborate courtship rituals, which play a key role in mate selection, synchronization of reproductive timing, and strengthening pair cooperation for nesting.

**a. Courtship displays**

Courtship involves mutual preening, bill-clattering, head bobbing, and food exchange (courtship feeding), where the male offers fruits or small prey to the female.

In some species, the male performs aerial displays or chasing flights (Vikrant, A *et al.* 2021) particularly in open-canopy environments like that of the Great Hornbill (*Buceros bicornis*) and Wreathed Hornbill (*Rhyticeros undulatus*).

**b. Courtship feeding**

Male hornbills provide food to the female before and during the early nesting period, symbolizing their ability to provision the female while she is sealed inside the nest.

This behavior is especially pronounced and is considered crucial for pair bond reinforcement and female nutritional conditioning prior to egg-laying.

**c. Pair bond maintenance**

Pair interactions include vocal duets, close perching, and cooperative inspection of potential nest cavities.

These behaviors contribute to reproductive synchronization and help establish mutual trust, essential for the breeding strategy where the female becomes entirely dependent on the male during incubation and chick-rearing (Kannan and James 1999).

**Egg laying and incubation period**

**a. Egg-Laying:** After courtship and nest site preparation the female hornbill lays 1 to 2 eggs as clutch size varies with species (as mentioned in Table 3). The eggs most often are deposited in the deeper recesses of the cavity, away from predators and effects of the environment. Predators like snakes (as they are superb climbers), small mammals like squirrels, birds of prey and large corvids such as Serpent Eagle, Common Hawk Cuckoo, Jungle Crow, Drongo (as they have been seen to follow nesting hornbills or to wait on chances to steal the chicks at the cavity opening while they feed.), Reptiles like Monitor Lizard are capable of climbing tall trees and it is reported that they predate eggs and young hornbill chicks.

**Table 4.** Tabular representation of the Breeding Biology of Hornbill species.

| Species Name | Breeding Season | Clutch Size | Incubation Period | Nestling Period |
|---|---|---|---|---|
| Great Hornbill (*Buceros bicornis*) | Jan–Apr | 1–2 eggs | 38–40 days | 75–90 days |
| Wreathed Hornbill (*Rhyticeros undulatus*) | Jan–May | 1–2 eggs | 28–35 days | 75–85 days |
| Rufous-necked Hornbill (*Aceros nipalensis*) | Apr–Jun | 1–2 eggs | ~30–35 days | 65–80 days |
| Oriental Pied Hornbill (*Anthracoceros albirostris*) | Mar–Jul | 2–3 eggs | 26–30 days | 50–60 days |
| Malabar Pied Hornbill (*Anthracoceros coronatus*) | Feb–May | 1–2 eggs | 28–35 days | 60–70 days |
| Malabar Grey Hornbill (*Ocyceros griseus*) | Jan–Apr | 2–3 eggs | 25–28 days | 50–60 days |
| Indian Grey Hornbill (*Ocyceros birostris*) | Mar–Jun | 2–4 eggs | ~28 days | 45–50 days |
| Narcondam Hornbill (*Rhyticeros narcondami*) | Feb–Apr | 1–2 eggs | ~30 days | ~60 days |
| White-throated Brown Hornbill (*Anorrhinus austeni*) | Feb–May | 2–3 eggs | 25–30 days | 60–70 days |

**b. Incubation period:** The incubation period varies from 28 to 42 days, depending upon the species (as mentioned in Table 4). Most of the eggs were incubated by the female sitting on them and this helps to regulate temperature and humidity. The female remains in the nest during this period and the principal source of food is fed by the male, passing the food through the small slit in the nest entrance (Carstens, K. F *et al.* 2019). However, the energetic demands of incubation caused by the energetic need to remain with the male for nutrition while keeping the eggs warm and protected are energetically demanding.

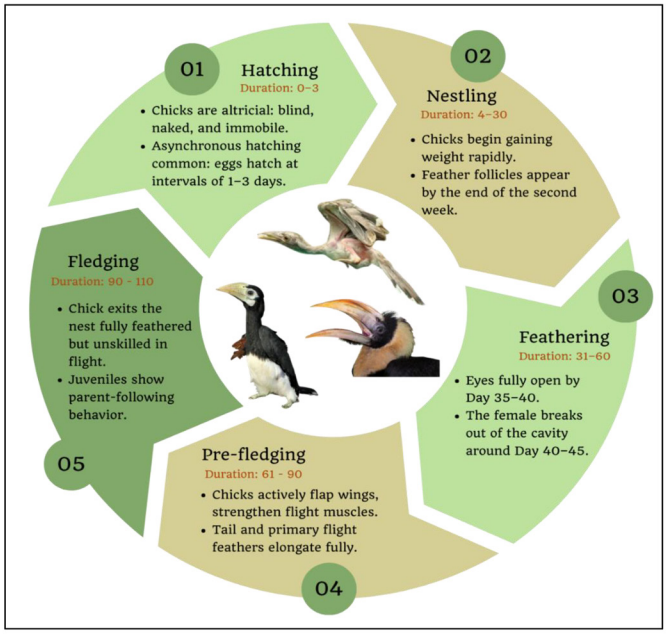


**Fig. 2.** Pictorial representation of the developmental process in hornbill chicks.

**Table 5.** Tabular representation of fledging success and survival rates in hornbills.

| Aspect | Details | Key Findings/Examples |
|---|---|---|
| Fledging Success Range | Percentage of hatched chicks that successfully fledge | Great Hornbill: 65–75% in undisturbed forests Oriental Pied Hornbill: Up to 80% in secondary forests |
| | | Rufous-necked Hornbill: Often <50% |
| Cavity Quality | Deep, secure, insulated cavities reduce chick mortality | Poor cavities lead to exposure, predation, and lower success |
| Parental Provisioning | Frequency and quality of food delivered to chicks | High fruit diversity + animal protein improve chick growth |
| Female Emergence Timing | Female exits cavity mid-cycle to help in chick care | Earlier emergence enhances late-stage chick survival |
| Predation & Competition | Natural enemies and cavity intruders | Predation by snakes, lizards; competition with bees/squirrels |
| Human Disturbance | Logging, hunting, and disturbance near nest sites | Causes nest abandonment or poor provisioning, esp. in large species |
| Post-Fledging Survival | Period after chicks leave the cavity (2–4 weeks) | High mortality; survival improves with continued parental care |
| Cooperative Breeding | Involvement of helpers in chick care | Observed in *Anorrhinus austeni*, improves chick survival |
| Conservation Measures | Actions to enhance nesting success | Artificial nest boxes, nest tree protection, community monitoring |

**Chick development phases**

The growth of hornbill chicks is highly dependent with the long developmental period characterized by physiological and behavioral shifts in the nest-holes. As altricial, they are born blind, naked, and without the ability to regulate body temperatures; hence, to an overwhelming extent, they are brooded and nourished by the female during the initial phase. Their development is staged in a series of specific processes-hatching, nestling, feathering, pre-fledging, and fledging (Fig. 2), which are also characterized by significant milestones e.g. opening of the eyes, development of the feathers, and coordination of muscles (Carstens, K. F. *et al.* 2019). These stages occur slightly later or earlier between species but in general are also timed to coincide with high levels of parental investment (particularly the male) in the offspring. This gradual growth approach has resulted in a perfect fit when it comes to survival in enclosed cavities and it is directly associated with ecological specialization and reproductive success.

**Fledging success and survival rates**

Fledgling success, or the rate of survival of chicks at the time of leaving the nest, is a major indicator of the reproductive outcomes and maintenance of the population of Hornbills. This success can range greatly between species and habitats (as mentioned below in Table. 5) and can depend upon the quality of nest cavity, parental rates of feeding, the effect of predators and human disturbance. The cavity-dependent species and larger-bodied species are most responsive to the degradation of the habitat as well as food shortages during the breeding season (Pattinson, N. B. 2022).

**Ecological role of hornbills in forest ecosystems**

Considered as "keystone mutualists" and "farmers of the forest" due to their critical contribution to tropical forest ecosystems (Naniwadekar *et al.* 2021). Hornbills are highly efficient long-distance seed dispersers and eat a wide range of fruits, carrying seeds long distances within the forest, promoting natural regeneration and genetic swamping of plant populations. *Ficus, Dysoxylum, Canarium* and *Myristica* are examples of large seeded tree species that rely heavily on hornbills for dispersal as the smaller frugivorous birds cannot eat and disperse the large fruits.

Apart from the dispersal of seeds, hornbills play other roles in the ecology. They impact forest composition and succession, and play a major role in carbon sequestration, habitat complexity and ecosystem resilience. They are also important indicators of the health of old-growth forests because they are cavity-dependent and require older trees to nest. Reductions in hornbills are commonly associated with reduction in forest structural diversity and degradation of forest ecosystem (Aulia, E. F *et al.* 2026).

Trophic interactions also play a role in the impact of the hornbills on the fruiting dynamics and food-web stability in tropical forests. Because of their sensitivity to habitat disturbance, they are also considered as flagship and umbrella species for the conservation of biodiversity. Conservation of the habitats of the hornbills also indirectly aids the conservation of other associated flora and fauna species that inhabit the same habitat.

**Threats to hornbill nesting success**

Hornbills are very specialized Cavity nesting Birds and they have to respond to various types of anthropogenic/ ecological threats which may limit their nesting success.

**Logging and destruction of nesting trees:** Hornbills require big and old trees where they nest. The Eastern Himalayas has witnessed selective logging of hardwood trees, monoculture plantations, shifting agriculture (jhum) practices thus resulting in the drastic reduction of suitable nest sites, thus increasing the lack of availability of cavities, which indirectly causes competition in a nest-site among species and even disruption of breeding cycles (Ferreira, G. B. *et al.* 2023).

**Poaching and hunting adults at the time of breeding:** Hornbills in some indigenous societies in Northeast India are hunted in their breeding season because of their casques, feathers and meat having a direct implication to nesting success and their population recovery due to the loss of their breeding pairs

when they nest abandon or do not perform a complete nesting process. Ruchira *et al.* (2025) mentioned that the Nyishi tribe were original wearers of Great Hornbill casques as head gear. Even after awareness campaigns which have minimized this practice, hunting continues to take place in isolated places (Rana, K *et al.* 2025).

**Human activity and nest disturbance:** The rising human settlement, tourist activities, and development projects around the protection zones bring about disturbances like noise, vibration, and light pollution to the nesting hornbills such that they fail to sustain their nest because females abdicate the nest during incubation or early stages of rearing young ones. Nesting by hornbills is shown to have been avoided in the prospect of human modified land in the Western Ghats, according to the studies by Pawar *et al.* 2018 hence causing fragmentation.

**Normal attack by natural predators:** In spite of the fact that hornbills seal their nests, their eggs or chicks can be predated by monitor lizards (*Varanus spp*.), macaques (*Macaca spp.*), snakes and even the honey badger, particularly where the sealing is incomplete or the nest slit is wide.

**Climate change and extreme weather conditions:** More frequent storms, heatwaves, and unseasonable rains have been noted to harm nest cavities, food sources during breeding season and even the nesting cycle. According to Naniwadekar *et al.* (2015), heavy rainfalls during the months of March and April in North-Eastern India have been intertwined with nesting failures in the Oriental Pied and Wreathed Hornbills.

**Non-native species, competition:** Inserts of foreign bees, wasps and pigeons into empty cavities may hinder the breeding cycles or it may minimize the available cavities where they can nest.

The ecological disturbances combined with the anthropogenic pressures and climatic variability caused a complex interconnection that is threatening the nesting success of hornbills in India (Gupta, M. 2025). As far as conservation is concerned, there is a need to conserve the mature forests, encourage the community-based protection of the nesting trees, minimize poaching and establish artificial nest boxes in the degraded habitats.

**Conservation efforts for hornbills**

Hornbills being charismatic seed dispersers have a key ecological role which is the regeneration of the forests and the maintenance of biodiversity (Kemp, A.C. 2001). Nevertheless, the populations of hornbills in India have been threatened by the loss of their habitat, poaching activities, as well as diminishing nesting habitats. The concern for hornbill conservation should thus be addressed in a multifaceted manner incorporating conservation and protection of their habitat, by laws or the involvement of the community and research as well.

**Protection and restoration of habitat:** Hornbills are quite specific in their reliance on old-growth forests as nesting and foraging sites, especially ones that have large emergent trees which offer good natural cavities (Suttidate, N. 2022). Hornbill vital areas like Pakke Tiger Reserve (Arunachal Pradesh), Dandeli-Anshi Tiger Reserve (Karnataka), and Silent Valley National Park (Kerala) have been marked as the sites of special concern. Improvement in the quality of the degraded habitat has also been encouraged through reforestation of *Ficus* species as one of the main food plants of the species (Pradhan *et al.* 2024).

**Hornbill Nest Adoption Program (HNAP):** Hornbill Nest Adoption Program (HNAP) in Pakke Tiger reserve is the best community based conservation activity where the local tribes, Nyishi people, are involved in conservation of hornbill nests. The villagers are provided financial incentive in exchange for their voluntary protection of trees with active nest colonies (Vishwakarma, A *et al.* 2022). The model has greatly boosted the success of nesting and resulted in the local stewardship of the conservation.

**Artificial nest boxes installation:** In the countries where there are limited trees to nest such as those in the Terai area and some in the Northeast region, nest boxes have also been erected especially on species such as the Oriental Pied Hornbill and Indian Grey Hornbill. Studies indicate that hornbills will adopt

such structures provided that the location of the structures is ecologically suitable with sufficient dietary resources and minimal disturbance.

**Connection between culture and traditional knowledge:** The Nyishi people of Arunachal Pradesh replaced the use of real beaks on ceremonial headgear to a fibreglass substitute, thus keeping their tradition and conservation both in practice (Kumar and Riba 2015). These programs unite the time-old knowledge with contemporary conservation morality, which renders them efficient and culture-sensitive (Amin and Ripot 2018).

**Public engagement & citizen engagement science:** Hornbill Watch programs and Hornbill Festival in Nagaland create awareness and encourage people to report Hornbill sightings that can be useful for population monitoring. Photography contests at school levels, eco-clubs and school-level campaigns have also been employed in establishing a bond between young people and hornbill conservation. Sivasankaran *et al.* 2025 concluded that Hornbill Festivals (such as celebrated in Nagaland since the year 2000) (and now celebrated in Protected Areas of Uttar Pradesh Terai Region since 2023) combine information about preserving nature with cultural traditions and help to sensitize by creating awareness for the Hornbill Species. In a study by Naniwadekar *et al.* (2015), The NCF and the Arunachal Pradesh Forest Department organized village workshops and displayed posters in the area to inform people about the ecological role of Hornbills and the need to protect their habitats.

**Eco-development and alternatives of livelihood:** Livelihood programs which include eco-tourism, handicraft manufacturing, and organic farming are the conservation-related initiatives that have been introduced to curtail circumstances of reliance on hunting and logging in hornbill habitats. In north-eastern India, participatory conservation funds and payment to ecosystem services are also being tried. Responsible ecotourism could encourage people to care for wildlife habitats in the Western Ghats and Northeast India as mentioned by Bajagain *et al.* 2025.

**Nesting and Roosting trees to be Protected:** Geo-tagging and Roost tree mapping is essential for the habitat conservation especially in human modified landscapes where hornbills are living alongside humans (Rana, K. *et al.* 2025).

## CONCLUSION

Hornbills with their essential role of seed dispersing and flagship species of tropical and subtropical forests are the important elements of the ecological network, which connects the avian behavior with the forest. Their nesting ecology have evolved through the availability of cavities, preference of tree species, breeding behaviors, role of the parents, and chick development, indicating a sensitive attachment to mature forest habitats and a steady environmental situation. Nevertheless, habitat fragmentation, clear-cutting of cavity-bearing trees, hunting, and low density of fruiting trees are deadly to their nesting achievement and long-term populace efficiency.

The conservation efforts should then focus on preserving old-growth trees, restoring of damaged habitats, and conservation of important fruiting and nesting trees. Through the application of traditional ecological knowledge and contemporary monitoring tools as well as community-based nest protection initiatives, there can be an improvement in local stewardship. Moreover, long-term research on the phenology of nesting, chick survival, and habitat selection is also necessary to enhance the management interventions in the changing climatic conditions.

Finally, it should be noted that the ecology of hornbill nesting is not only important in the survival of these charismatic species but also to the survival of the ecological integrity of tropical forest ecosystems (Naniwadekar *et al.* 2021). The answer to the survival of hornbills and forests that it represents is the comprehensive, multidisciplinary approach which involves behavioral ecology of hornbills and the forests it represents, the habitat management, and conservation policy.

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