Review Article

Ant nesting behaviour in coastal environments: Structural patterns and adaptive ecological roles

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Abstract

Ants (Hymenoptera: Formicidae) are among the most ecologically influential terrestrial invertebrates, playing major roles in soil modification, nutrient cycling, and ecosystem regulation. In coastal ecosystems, where environmental conditions are highly dynamic, ant nesting behavior reflects strong adaptive responses to abiotic and biotic factors. This review synthesizes current knowledge on ant nest architecture, spatial distribution, ecological roles, and their significance as bioindicators in coastal habitats. Special attention is given to environmental drivers such as soil texture, salinity, moisture, vegetation cover, and tidal influence that shape nesting patterns. The review also integrates conceptual frameworks and discusses how ant colonies respond to anthropogenic disturbances. Overall, ants are highlighted as ecosystem engineers and reliable indicators of coastal ecosystem health.

Keywords: Ant nests, coastal ecosystem, bioindicator, soil ecology, spatial distribution, Formicidae.

Introduction

Coastal ecosystems represent transitional zones between terrestrial and marine environments, characterized by high spatial and temporal variability in environmental conditions. These ecosystems are influenced by multiple abiotic factors such as tidal action, salinity fluctuations, sediment dynamics, wind exposure, and periodic disturbances. Such variability creates a mosaic of microhabitats that support diverse biological communities.[1] Among terrestrial invertebrates, ants (Formicidae) are particularly successful colonizers of coastal landscapes due to their behavioral flexibility, social organization, and ecological adaptability.

Ants are widely recognized as ecosystem engineers, influencing soil structure nutrient redistribution, and organic matter decomposition through their nesting and foraging activities. Their nests are not merely shelters but complex systems that regulate temperature, humidity, gas exchange, and microbial activity in surrounding soils. In coastal environments, where soil conditions can vary from sandy dunes to clay-rich marshes, ants exhibit remarkable plasticity in nest construction and colony organization.[2]

Moreover, ants serve as effective bioindicators due to their sensitivity to environmental changes. Variations in nest density, distribution, and architecture often reflect underlying ecological disturbances such as pollution, habitat fragmentation, and climate-driven alterations in coastal systems. The study of ant nesting ecology, therefore, provides valuable insights into ecosystem functioning and resilience.[3]

This review focuses on the structural characteristics of ant nests, factors influencing their distribution, and their ecological importance in coastal ecosystems. It also integrates conceptual models and diagrammatic representations to enhance understanding of nesting dynamics and their environmental significance.

Ant nest structure and ecological function

Ant nests are complex subterranean systems composed of interconnected chambers and tunnels, each serving specialized functions such as brood development, food storage, and protection of the queen. Classic work by Hölldobler and Wilson (1998) demonstrated that nest architecture varies widely among species and is closely linked to environmental conditions and colony requirements.[4] For instance, studies on *Camponotus compressus* (Fabricius, 1787) have shown that nests in loose sandy soils tend to be deeper and vertically structured to maintain internal stability, whereas species such as *Solenopsis geminata* (Fabricius, 1804) construct relatively shallow and more horizontally spread nests in compact or clay-rich substrates. Similarly, a study by Tschinkel (1988), in his work on *Solenopsis invicta* (Buren, 1972), describes how nest architecture adapts to soil texture and moisture, influencing chamber arrangement and tunnel orientation.[5]

Beyond their structural complexity, ant nests function as dynamic microhabitats that significantly modify soil properties. According to Folgarait (1998), nesting activities lead to substantial bioturbation, improving soil aeration and enhancing water infiltration. Furthermore, in tropical and coastal systems, *Odontomachus* and *Pheidole* species have been observed to accumulate organic debris within their nests, which promotes microbial growth and accelerates decomposition processes. Dauber and Wolters (2005) further reported that such activities increase nutrient availability, particularly nitrogen and phosphorus, through the redistribution of organic matter within the soil profile.[6,7]

In coastal environments, where soils are often nutrient-poor and structurally unstable, these modifications are especially important. Studies on dune-inhabiting ants such as *Cataglyphis* sp. and *Anoplolepis gracilipes* (Smith, 1857) indicate that their nesting behavior enhances soil cohesion and facilitates plant establishment by creating nutrient-rich microsites. Thus, nest construction not only supports colony survival but also contributes to broader ecosystem processes, including soil stabilization and vegetation development in fragile coastal habitats.[8]

Ants as ecosystem engineers and bioindicators

Ants significantly influence soil systems through their role as ecosystem engineers, modifying both physical structure and chemical composition. Hölldobler and Wilson (1990) highlighted that nest construction involving extensive tunneling increases soil porosity and improves aeration and water movement.[4] Studies on species such as *Camponotus compressus* and *Pheidole* sp. show that their excavation activities loosen compact soils and enhance root penetration. Additionally, Folgarait (1998) reported that ants transport organic materials into their nests, leading to nutrient enrichment and increased microbial activity. In coastal environments, where soils are often sandy and nutrient-deficient, species like *Solenopsis geminata* contribute to the formation of nutrient-rich microsites, thereby

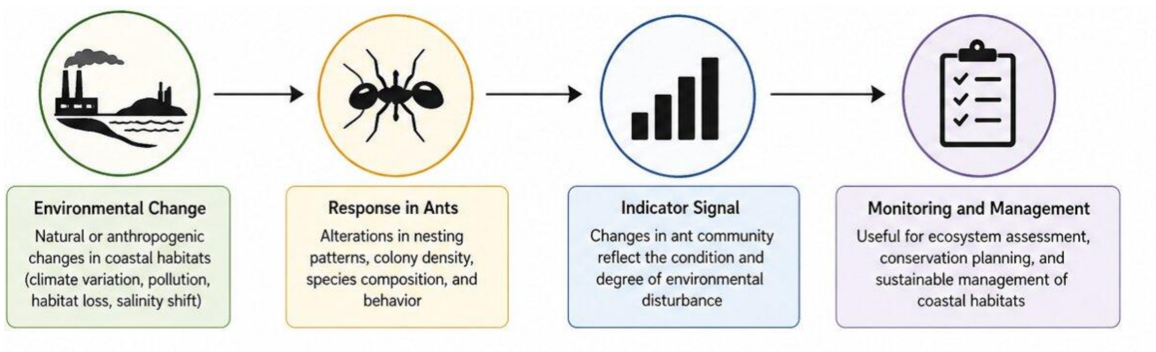

Figure 1: Schematic representation of the role of ants as bioindicators in coastal ecosystems, illustrating the pathway from environmental changes (natural and anthropogenic) to ant community responses, indicator signals, and their application in ecosystem monitoring and management.

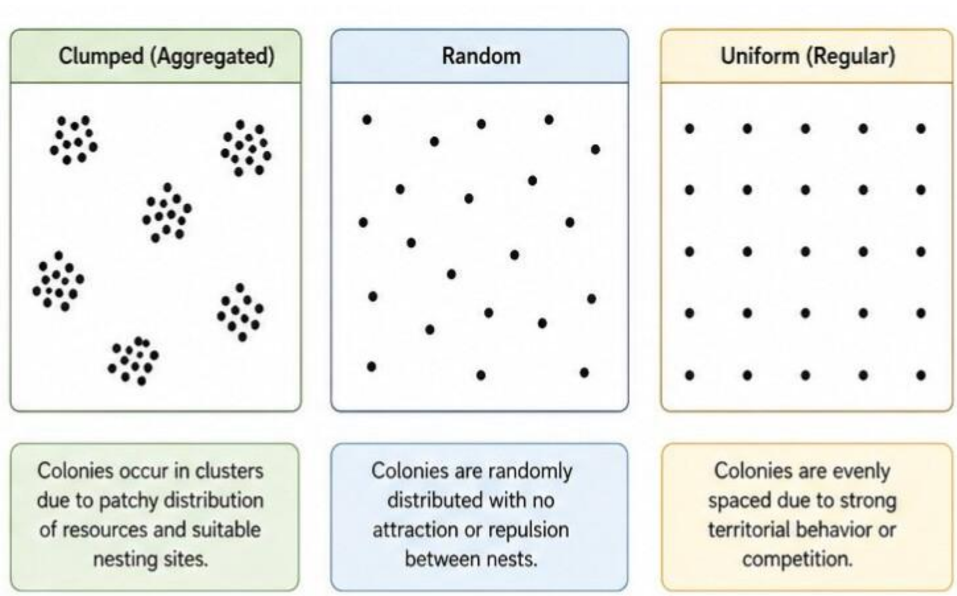

Figure 2: Schematic illustration of spatial distribution patterns of ant colonies, depicting clustered (aggregated), random, and uniform arrangements in relation to resource availability, habitat conditions, and interspecific interactions.

supporting plant establishment and improving soil stability.[6]

In addition to their engineering functions, ants are widely used as bioindicators due to their sensitivity to environmental changes (Figure 1). Andersen (1997) demonstrated that variations in ant diversity and colony structure reflect habitat disturbance and restoration status.[3] Similarly, Underwood and Fisher (2006) have observed that changes in species composition and nest density can indicate the effects of pollution and land-use change. Coastal species such as *Anoplolepis gracilipes* and *Odontomachus* species show measurable responses to environmental stress, including shifts in distribution and nesting behavior.[9] As noted by Alonso (2000), such responses make ant communities reliable tools for monitoring ecosystem health and assessing environmental quality over time.[10]

Spatial distribution of ant colonies

The spatial distribution of ant colonies in coastal ecosystems is governed by the combined effects of environmental heterogeneity, resource availability, and biotic interactions (Figure 2). Coastal habitats consist of diverse microenvironments that vary in soil type, moisture, salinity, and vegetation, leading to non-uniform patterns of colony establishment. Levings and Traniello (1981) have reported that ant colonies often exhibit clustered distributions in areas where resources and suitable nesting conditions are concentrated.[11] Similarly, Kaspari (2000) has observed that spatial patterns in ant communities are strongly linked to energy availability and habitat structure.[12] In some cases, uniform spacing develops due to competitive interactions and territorial behavior, as demonstrated by Levings and Traniello (1981) in studies of ground-nesting ant species. Species such as *Pheidole* sp. and *Camponotus* sp. commonly show aggregation in favorable microhabitats, reflecting localized environmental suitability.[11,13]

Environmental gradients further regulate colony distribution in coastal systems. Sanders *et al*. (2007) highlighted that factors such as salinity and moisture significantly influence ant diversity and spatial arrangement.[14] High salinity often restricts colony establishment, limiting species presence to less saline zones. Soil moisture also plays a key role, as excessively wet conditions can reduce nest stability and survival. In coastal dunes, Vandermeer *et al*. (2002) have observed that ant colonies are frequently concentrated in vegetated patches where microclimatic conditions are more stable and organic resources are available.[15] In contrast, areas exposed to frequent disturbance, like tidal inundation or human activity, tend to support fewer colonies and exhibit lower species diversity. Species like *Solenopsis geminata* may persist in disturbed zones, but the overall community structure becomes simplified. These spatial patterns provide important insights into habitat quality and ecosystem stability in coastal environments.[1]

Conceptual framework of ant nesting in soil

Ant nesting behavior can be understood as the outcome of interacting abiotic, biotic, and anthropogenic drivers that collectively determine where and how colonies establish (Figure 3). Abiotic conditions set the fundamental constraints on nest construction. Tschinkel (2005) showed that soil texture and compaction influence tunnel formation and chamber stability,[16] while Kaspari and Weiser (2000) emphasized the role of temperature and moisture in regulating colony activity and survival.[17] In coastal settings, salinity acts as an additional limiting factor, restricting many species to zones where salt concentrations are tolerable. Biotic factors further refine nesting patterns; vegetation cover provides microclimatic buffering and food resources, whereas competition and predation influence colony placement and persistence. Studies by Parr and Gibb (2010) indicate that competitive interactions among ant species can shape both nest spacing and habitat use.[18]

Anthropogenic influences increasingly modify these natural controls. Land-use change, soil disturbance, and pollution can alter substrate quality and resource availability, thereby affecting nesting success. Hoffmann and Andersen (2003) noted that disturbed habitats often exhibit simplified ant communities and altered nesting behavior.[19] In response to these combined pressures, ant colonies display considerable flexibility. They may adjust nest depth and structure, relocate to more suitable microhabitats, or modify foraging strategies

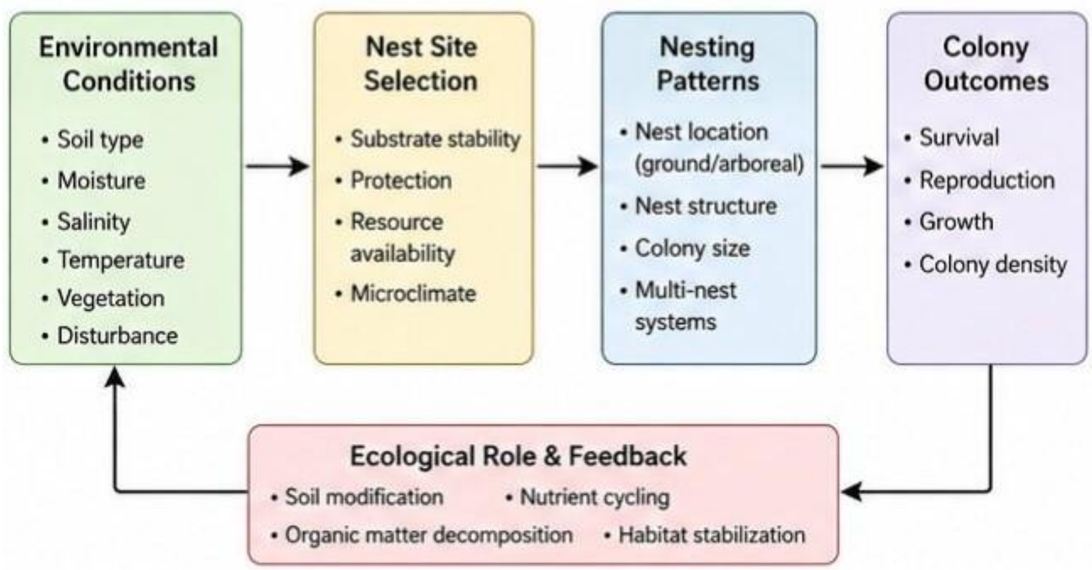

Figure 3: Schematic framework of ant nesting in soil, showing the interaction between environmental conditions, nest site selection, nesting patterns, and colony outcomes, along with feedback mechanisms influencing ecosystem processes.

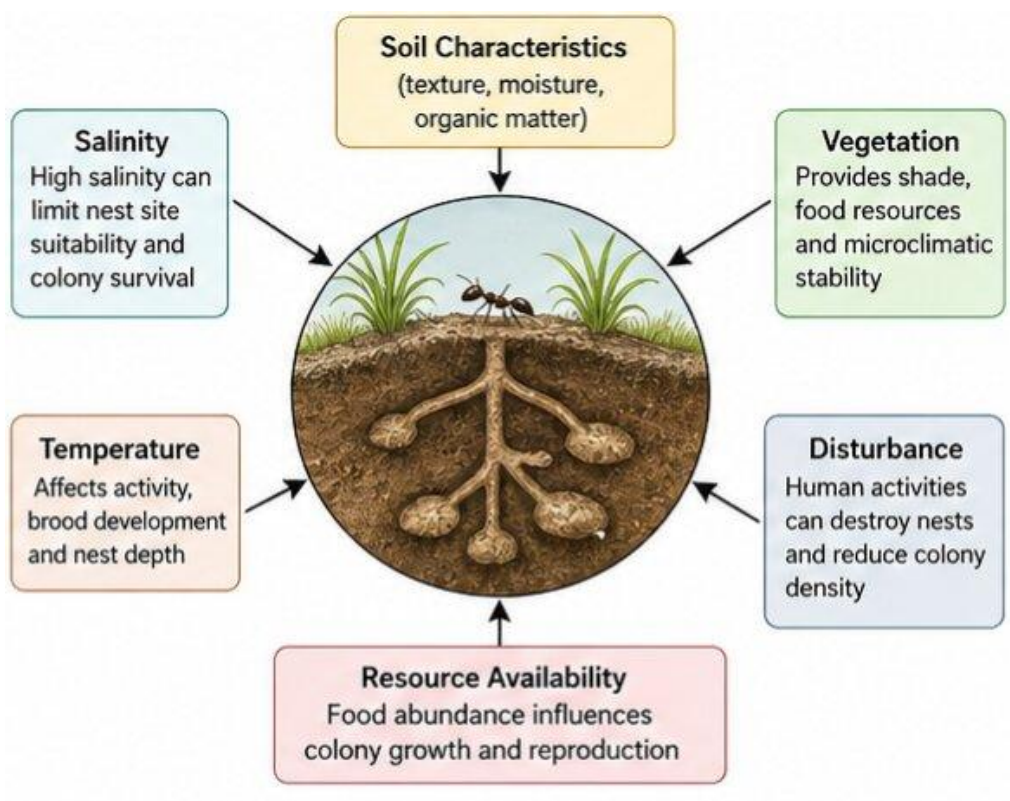

Figure 4: Schematic representation of factors affecting ant nesting, including soil characteristics, salinity, temperature, vegetation, resource availability, and disturbance. These abiotic and biotic factors influence nest structure, colony survival, and distribution patterns. Their combined effects determine the stability and persistence of ant colonies in coastal ecosystems

to cope with changing conditions. Observations on species such as *Solenopsis invicta* and *Camponotus* spp. demonstrate this capacity for adaptive response under environmental stress. Such behavioral and structural adjustments enable ants to persist in variable coastal environments while continuing to perform essential ecological functions.[20]

Factors affecting ant nesting

Ant nesting patterns are influenced by a combination of physical, biological, and environmental constraints that determine colony establishment and persistence.[21] Soil characteristics play a primary role in shaping nest structure (Figure 4). Studies on Indian ant species such as *Diacamma indicum* have demonstrated that soil texture and compaction directly influence tunnel formation and chamber organization, with loose soils allowing deeper excavation while compact soils restrict nest expansion.[22] Similarly, research from the Darjeeling Himalaya by Saha *et al.* (2018) showed that nest soils exhibit altered physico-chemical properties and higher microbial activity compared to surrounding soils, highlighting the importance of substrate conditions in nest development.[23]

Moisture and salinity further regulate nesting success, particularly in coastal environments where fluctuating water levels and salt concentrations can limit colony survival. Temperature also plays a key role, as nest architecture is often adjusted to maintain suitable internal conditions for brood development. Vegetation cover enhances nesting success by stabilizing soil, moderating microclimate, and providing food resources. For example, studies on *Camponotus compressus* indicate strong associations between nesting activity and plant interactions, which support nutrient cycling and habitat stability.[24]

Anthropogenic disturbances such as land-use change, pollution, and habitat fragmentation further influence nesting patterns. These disturbances alter soil properties and resource availability, often leading to reduced colony density and shifts towards disturbance-tolerant species. Overall, the interaction of abiotic, biotic, and human-induced factors determines the distribution, structure, and stability of ant populations in coastal ecosystems. [25]

Ecological importance in coastal ecosystems

Within coastal ecosystems, soil-dwelling invertebrates play a crucial role in maintaining ecosystem functioning, particularly under conditions of high environmental stress and limited nutrient availability. The ecological significance of ants as soil modifiers has been widely documented, with Folgarait (1998) describing ants as key agents of soil transformation through bioturbation and nutrient redistribution.[6] Similarly, Lavelle *et al*. (2001) emphasized that soil fauna, including ants, contribute to the development of soil structure by enhancing aggregation and facilitating the incorporation of organic matter into deeper layers.[26]

In tropical environments, including parts of India, Bagyaraj *et al*. (2016) highlighted the importance of soil invertebrates in nutrient cycling and ecosystem productivity, particularly in fragile ecosystems. The movement of soil particles and organic materials within nest systems promotes localized nutrient enrichment, especially of nitrogen and phosphorus, which supports plant establishment. In coastal regions, where sandy soils are inherently low in nutrients, such processes become critical for maintaining primary productivity.[27]

The role of ants in improving soil permeability and reducing erosion has also been recognized in ecological studies.

According to Calle *et al*. (2013), ant nesting enhances water infiltration and reduces surface runoff, thereby stabilizing soil in erosion-prone habitats.[28] This is particularly relevant in coastal zones along Kerala, where monsoon-driven erosion and tidal disturbances significantly affect landscape stability. By indirectly promoting vegetation growth, ants contribute to dune stabilization and long-term habitat persistence.[29]

Beyond physical and chemical modifications, ants also influence biological processes within soil systems. Wardle (2006) noted that soil organisms regulate microbial activity and decomposition processes, and ant nests often act as hotspots for microbial diversity due to accumulated organic residues. This interaction accelerates decomposition and strengthens nutrient cycling within the ecosystem.[30]

Furthermore, in disturbance-prone environments, ants play an important role in ecological recovery. Hoffmann and Andersen (2003) reported that ants respond rapidly to environmental changes and contribute to ecosystem resilience by facilitating soil restoration and supporting recolonization processes. Such contributions are particularly significant in coastal habitats where environmental constraints limit natural regeneration and long-term stability.[19, 29]

Conclusion

Ants are key ecological components of coastal ecosystems due to their nesting behavior, soil-modifying activities, and sensitivity to environmental change. Their nests function as complex ecological systems that influence soil properties and nutrient dynamics. The spatial distribution and structural diversity of ant colonies provide valuable indicators of habitat condition and ecosystem health. As bioindicators, ants offer an efficient means of monitoring coastal environmental changes. Understanding their nesting ecology is, therefore, valuable for conservation and sustainable management of coastal habitats.

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Conflict of interest
There are no conflicts of interest.

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