Chapter 3

Life on the Forest Floor: Litter Dynamics and Food Networks from Microfauna to Macrofauna

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Abstract

In forest ecosystems, the litter layer is not merely a passive organic waste layer but a dynamic component driving fundamental processes such as energy flow, nutrient cycling, and carbon transformation. This organic layer provides vital microhabitats for shelter, feeding, and reproduction across a wide spectrum, from micro- and macroinvertebrates to passerine birds, amphibians, and small mammals. At the same time, large mammals such as wild boar, brown bear, gray wolf, and ungulates act as 'ecosystem engineers' shaping decomposition processes and spatial heterogeneity on the forest floor from the top down through physical disturbances (bioturbation) and defecation. However, abiotic and anthropogenic factors such as traditional silvicultural practices, forest fires, and increasing drought stress due to global climate change seriously threaten the integrity of this sensitive layer and the food webs it supports. This study highlights data gaps in Turkish forests and recommends conserving litter to support sustainable forest and wildlife management.

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https://doi.org/10.58830/ozgur.pub1369.c5553

1. Introduction

In forest ecosystems, the litter layer is an organic layer formed by the accumulation of fallen leaves, twigs, bark, cones, and similar plant debris on the forest floor. Rather than being a passive by-product of the decomposition process, this layer is a dynamic component that actively participates in fundamental ecosystem processes, including energy flow, nutrient cycling, and carbon transformation (Swift et al., 1979; Prescott & Vesterdal, 2021). Litter forms a transition zone between mineral soil and the atmosphere, providing a fundamental interface where physical, chemical, and biological processes interact. This interface is regarded as a vital boundary layer where both material and energy flows are regulated in ecosystem functioning. In this respect, it constitutes an important microhabitat for soil formation and biodiversity (Prescott & Vesterdal, 2021).

Decomposition of dead organic matter is a key process in converting plant-produced organic matter into soil organic matter. This process forms the basis of the detrital food web, which governs the flow of energy derived from dead organic matter. This process transfers part of the carbon to the soil organic carbon pool, whilst releasing the remainder back into the atmosphere as CO_2 through microbial activity, thereby becoming an important part of the carbon cycle (Joly et al., 2020). In particular, the chemical composition of leaf litter (e.g., C/N ratio, lignin content) plays a decisive role in ecosystem processes and long-term carbon stability by influencing both the rate of microbial decomposition and the amount of humus formed (Melillo et al., 1982; Cornwell et al., 2008; Giweta, 2020). The rate and nature of decomposition processes are closely linked to the nutrient cycling and habitat structure created by the litter layer. In this context, litter decomposition is recognized as a fundamental mechanism that governs not only the residence time of carbon within the ecosystem but also plant productivity, soil fertility, and element cycling (Zhang et al., 2008; Prescott, 2010; Bradford et al., 2014).

The direction and rate of this fundamental process, which determines ecosystem dynamics, are shaped by the chemical composition of organic matter, environmental conditions such as temperature and humidity, and the structure of microbial communities (Krishna & Mohan, 2017). The nutrients released by this process are returned to the soil, thereby supporting plant growth and microfaunal activity. This situation forms the basis of 'bottom-up' control mechanisms in ecosystems, indirectly regulating the flow of energy from primary production to higher trophic levels. Litter is more than just a nutrient reservoir; thanks to its complex physical structure and its role in regulating microclimatic conditions, it provides a vital microhabitat for numerous organisms. In particular, while microarthropods such as Collembola and Acari, along with macroinvertebrates, complete their life cycles within this layer, these organisms constitute the primary food source for songbirds, reptiles, and insectivorous mammals (Wardle et al., 2004; Prescott and Grayston, 2013). These organisms form the lower levels of the detrital food web, acting as a bridge in the transfer of energy to higher trophic levels. The decomposition rate, chemical composition, and physical depth of the litter layer shape this interaction. Therefore, the litter layer should be considered an indirect driver of habitat suitability and trophic linkages for forest-floor fauna (deMaynadier & Hunter, 1995; Wardle et al., 2004).

These processes, which occur at the micro- and mesoscales, exert a decisive influence on the distribution and behavior of organisms at higher trophic levels, thereby shaping macroecological outcomes. Litter layers limit soil erosion by retaining minerals, regulating the microclimate, and slowing surface runoff, whilst also retaining moisture to support suitable habitats for microorganisms and other fauna (Prescott & Vesterdal, 2021). Furthermore, these layers host a bidirectional interaction network shaped at the macro-scale by the digging, chewing, and feeding activities of micro- and meso-scale invertebrates, as well as wild boar, bears, and large ungulates (Barrios-Garcia & Ballari, 2012; Tomita & Hiura, 2020). These species can be evaluated as ecosystem engineers because they physically alter habitat structure and redistribute organic material through digging, rooting, trampling, carrion deposition, and related bioturbation processes. Therefore, their effects should be framed as modifications of litter turnover, soil-litter mixing, and spatial heterogeneity rather than as complete top-down control of decomposition (Bump et al., 2009; Tuo et al., 2024).

Whilst studies on the effects of litter on wildlife in forest ecosystems worldwide are increasing, it is evident that research providing a comprehensive overview of long-term monitoring results, particularly regarding interactions at the species level, variations across different forest types, and differences associated with changing environmental conditions, remains limited (Müller & Bütler, 2010; Stokland et al., 2012). Indeed, studies on forest-floor structural elements show that deadwood and coarse woody debris play decisive roles in shaping microhabitat diversity, saproxylic food webs, and shelter opportunities, whereas leaf litter is more directly associated with detrital food-web dynamics, moisture buffering, and decomposition processes (Harmon et al., 1986; Siitonen, 2001; Lassauce et al., 2011; Prescott & Vesterdal, 2021). Studies examining the relationship between litter and wildlife in Türkiye are limited, and existing research has largely focused on soil properties, decomposition processes, and forestry practices (e.g., Tolunay, 2003; Çakır & Makineci, 2020). In this context, it is evident that the ecological interactions between changes in the forest floor (litter, canopy cover, etc.) and wildlife have not been examined using a sufficiently holistic and multi-purpose planning approach (Oğurlu, 2008).

This study aims to examine the multifaceted relationships between litter and wildlife from an ecosystem ecology perspective. Firstly, the direct and indirect effects of litter on invertebrate fauna will be discussed within the framework of decomposition processes and food web dynamics. Subsequently, the functional importance of this layer as a habitat for vertebrate shelter, feeding, and reproduction, along with the ecosystem engineering roles of large mammal species, is examined using examples from different habitat types. In this context, the study aims to evaluate litter layer dynamics within a holistic ecosystem framework where both bottom-up and top-down processes interact. Finally, in light of recent findings, particularly from Turkish forests, existing data gaps in the local literature have been analyzed. In this context, ecosystem-based management approaches aimed at integrating litter into sustainable forest management and biodiversity conservation strategies have been critically evaluated. The central role of litter in the forest ecosystem and its multi-layered interactions with wildlife, which form the conceptual framework of this study, are presented in Figure 1.

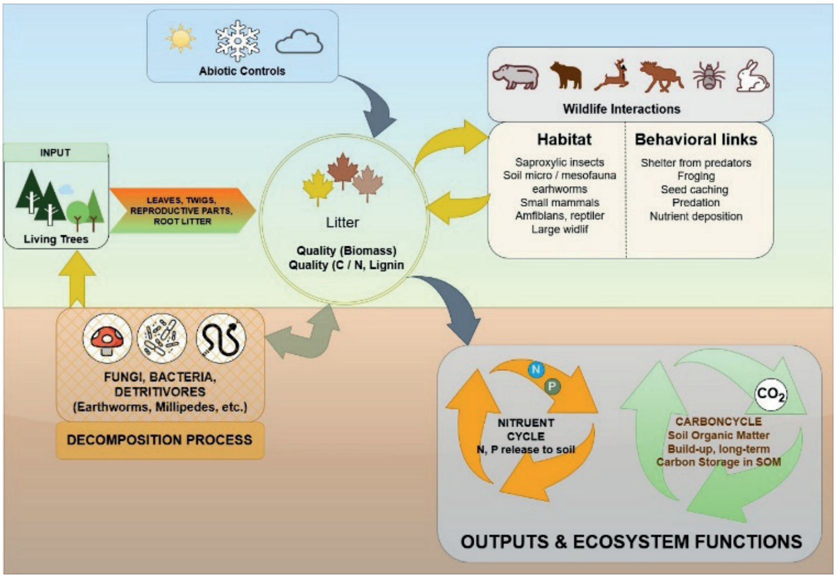

Fig. 1. A conceptual model illustrating the central role of litter in the forest ecosystem and its interaction with wildlife

2. The Ecological Importance of Litter

2.1. The Physical and Biogeochemical Functions of Litter

For many years, traditional forestry practices in Türkiye have focused on above-ground elements such as timber production, fire control, and timber resources. Consequently, the litter layer covering the forest floor has often been viewed as a 'fire hazard' or as combustible material (waste) that needs to be cleared (Bilgili, 1998; Orman Genel Müdürlüğü [OGM], 2022). In reality, however, the litter layer is central to the fundamental biological and physical mechanisms that sustain the forest ecosystem (Giweta, 2020; Li et al., 2023).

A large proportion of the primary production generated through photosynthesis in forest ecosystems returns to the forest floor over time as dead organic matter, rather than being consumed by herbivores. The litter layer provides a continuous input to forest soil by retaining elements such as carbon, nitrogen, and phosphorus from fallen leaves, twigs, and fruits. This accumulation serves as a vast carbon sink in the fight against global climate change. It also initiates the fundamental energy flow within the ecosystem, known as the 'brown food web' (Prescott, 2010; Giweta, 2020). The decomposition process is not limited to microorganisms; macrofaunal activities also support it. Recent global-scale syntheses indicate that vertebrates can accelerate litter mass loss mainly through physical fragmentation, bioturbation, and redistribution of organic material; their effects on nutrient cycling should therefore be interpreted as indirect and process-dependent (Li et al., 2023; Tuo et al., 2024). These decomposed materials provide a continuous supply of fresh nutrients essential for the continuity of ecosystem processes.

From a physical perspective, the litter layer acts as a protective cover over the mineral soil, dampening the kinetic energy of raindrops. This mechanism significantly reduces the risk of surface erosion by preventing soil fragmentation (Morgan, 2009). Research has shown that the layer of dead vegetation on the forest floor both reduces the kinetic impact of water and slows surface runoff. This process significantly reduces soil loss, particularly on sloping terrain (Zhu & Cheng, 2022). The stable soil surface resulting from erosion prevention has positive effects, such as preserving porosity and increasing water infiltration into the soil (Gomyo & Kuraji, 2016; Zhu & Cheng, 2022). This porous structure and moisture balance provide essential microhabitats for soil fauna, including larvae, earthworms, and small mammals.

The organic layer protects the soil surface from the drying effects of sunlight, wind, and sudden temperature fluctuations. Minimizing evaporation helps to retain moisture and ensures that the soil microclimate remains stable (Giweta, 2020). At the same time, this physical barrier plays a decisive role in shaping the understorey plant composition by filtering seed germination and seedling development (Facelli & Pickett, 1991). Global-scale research highlights the vital role of the litter layer in buffering moisture and temperature. Thanks to this insulation, the microbial biomass in the soil can remain active even during extreme heat or cold (Kara et al., 2014; De Frenne et al., 2021; Li et al., 2023).

2.2. The Integration of Litter, Wildlife, and Ecosystem Functions

The relationship between litter and wildlife is not limited to a passive nutrient cycle or microclimate regulation. This layer performs multi-level functions within the forest ecosystem, providing an indispensable infrastructure for both soil invertebrates and macrofauna. By providing essential nutrients for invertebrate detritivores, the litter layer supports the transfer of energy to higher trophic levels of the food chain (birds and mammals) (Giweta, 2020). It also contributes to the sustainability of forest population dynamics by providing shelter, hiding places, and breeding grounds for small mammals, amphibians, and reptiles (Hunter, 1990; deMaynadier & Hunter, 1995). This integrated structure demonstrates that the litter layer is an active ecosystem component that supports carbon sequestration. Consequently, the conservation of this layer is essential for the long-term persistence of wildlife populations (Lindenmayer & Franklin, 2013).

Traditional forest management plans in Türkiye generally focus on the development of the overstorey trees (Çepel, 1995; OGM, 2017). Wildlife management plans, however, largely exclude the habitat dynamics of the forest floor from their calculations, as they do not adequately account for ecosystem resources beyond animals (Oğurlu, 2008). Yet the litter matrix is not merely a food source for a wide spectrum of fauna, ranging from invertebrates to megafauna. It is also an indispensable microhabitat that fulfills functions such as shelter, concealment, thermoregulation, and reproduction (Wardle et al., 2004). The complete removal of the forest floor, under the guise of production or fire prevention, constitutes habitat destruction for these organisms (Kaynaş, 2017; Polat & Başkale, 2018).

Invertebrates form the base of the forest floor's food web. Decomposer groups such as springtails, mites, and millipedes physically break down the litter layer. This process accelerates the decomposition of organic matter by expanding the area for fungal and bacterial decomposition (Petersen & Luxton, 1982; Potapov et al., 2016). The abundance and diversity of these decomposer communities support ecosystem functions by providing an energy and food source for predatory insects and spiders at higher trophic levels (Bardgett & van der Putten, 2014). These insect communities, which are highly sensitive to environmental changes, increase in population as litter levels rise, and, with these characteristics, they become important biological indicators of forest health (Hopkin, 1997; Ponge et al., 2003). The responses of surface-active macrofauna to litter dynamics in Turkish ecosystems have been studied to a certain extent (Kaynaş, 2017). However, the trophic relationships of subsoil microarthropods (Acari and Collembola) in litter decomposition have not yet been the subject of comprehensive quantitative research (Potapov et al., 2016; Duyar, 2020).

These biological decomposition processes on the forest floor are not limited to micro-scale arthropods but are also strongly driven by macrofauna (Hättenschwiler et al., 2005; Joly et al., 2020). In this context, earthworms (Lumbricidae) are among the detritivores that play a key role in litter decomposition. In particular, earthworm diversity and biomass are higher in soils rich in organic matter that contain mull and moder-type humus. Conversely, these values decrease significantly under acidic and mor-type litter conditions (Ghilarov, 1979). Although litter from coniferous species generally has low digestibility, earthworm activity supports its decomposition, thereby contributing to the regeneration of forest ecosystems (Bernier & Ponge, 1994). Fresh litter from deciduous species is generally not in a digestible form. These litter materials become digestible by earthworms only after undergoing preliminary decomposition by fungi and bacteria. This is due to earthworms' inability to digest complex components such as lignin and their reliance on symbiotic microflora for their feeding strategies (Neuhauser et al., 1978; Edwards & Bohlen, 1996). With these characteristics, earthworms are recognized as important biological regulators that accelerate the decomposition of organic matter during the transition from litter to soil and facilitate the return of nutrients to the cycle (Paoletti, 1999).

As decomposition processes at lower trophic levels progress to the middle and upper trophic levels, the litter layer's moisture- and thermal-buffering functions transform into a physiological refuge for small vertebrates. Amphibians and reptiles are the vertebrate groups most dependent on the quality and depth of the litter layer due to their physiological constraints (deMaynadier & Hunter, 1995). The permeable skin through which amphibians exchange gases leaves them vulnerable to water loss. Consequently, during their terrestrial phases, they must remain hidden beneath moist litter layers throughout the day. For example, research on the endemic Lycian newt, native to Türkiye, demonstrates that population density increases significantly in areas with deep litter layers possessing high moisture-retention capacity (Polat & Başkale, 2018). Reptiles, on the other hand, use deep layers of litter as hibernacula to regulate their body temperature (thermoregulation) and protect themselves from freezing (Vitt & Caldwell, 2013).

Litter plays a decisive role in the distribution of small mammals. Rodents and insectivorous mammals are both the most active consumers of the forest floor and a primary food source for predatory birds and mammals (Orrock et al., 2000). These animals are protected from predators by the tunnel systems they create within the litter. Particularly in regions with heavy snowfall, the sub-snow zone, the area between the snowpack and the mineral soil, serves as a vital thermal refuge. This zone enables small mammals to remain active throughout the winter in an insulated environment and to be protected from deadly freezing temperatures (Pauli et al., 2013). Furthermore, by storing the seeds they collect beneath the litter layer, they facilitate the natural regeneration of the forest and the dispersal of plant species (Vander Wall, 2001). These complex relationships between small mammals and the litter layer, along with their seed-storing behaviors, have been modeled in detail in North American and European forests (Orrock et al., 2000; Vander Wall, 2001). However, the ecosystem engineering roles of small mammals (*Apodemus* spp.) in Turkish forests have not yet been adequately investigated. Existing studies have focused primarily on species distribution and population structure (e.g., Keten et al., 2016).

A large proportion of forest birds depend on the forest floor for feeding, nesting, or shelter. Various bird species feed on the invertebrate fauna beneath the litter by rummaging through it. A reduction in litter depth decreases arthropod biomass. This negatively affects the birds' foraging success during the breeding season and the survival rates of their young (Burke & Nol, 1998). In addition to feeding, the color and texture of dried leaves provide excellent camouflage for the eggs of ground-nesting birds and enhance nest success against visual predators (Martin, 1993). Birds' constant scratching and turning over of the litter layer to forage not only ensures the survival of their own populations. These activities may contribute to the physical turnover and fragmentation of litter, thereby indirectly influencing decomposition processes at the forest-floor scale (Tuo et al., 2024).

Another complementary process driven by these vertebrate groups utilizing the forest floor is the strengthening of the symbiotic relationship between litter and subterranean fungi. When discussing litter decomposition processes, one must not overlook the mycorrhizal fungal networks that form a vast bridge between the subterranean invertebrate fauna and the tree roots in the upper soil layer. The breakdown of complex organic matter, particularly high-carbon lignin and cellulose, is not merely a bacterial process but is primarily the work of fungi that secrete ligninolytic enzymes (Prescott & Vesterdal, 2021). Furthermore, the digging of the forest floor by wild animals is not merely a physical mixing process. Many mammal species locate and consume underground fungi, the reproductive structures of mycorrhizal fungi, using their sense of smell. As a result of this process, known in ecology as 'mycophagy' (fungus-eating behavior), animals transport fungal spores over long distances and deposit them back onto the forest floor via their feces. This situation elevates wild animals to an essential vector for establishing root-fungus symbiosis in the forest's natural regeneration areas (Maser et al., 1978; Johnson, 1996).

Micro- and meso-scale bioturbation in the forest floor represents only one component of ecosystem engineering. At higher trophic levels, the activities of large mammals, which induce substantial physical changes in the forest floor, become increasingly important (Bump et al., 2009; Tuo et al., 2024). From a global ecological perspective, massive megaherbivores such as elephants function as 'mega-gardeners' within forest ecosystems. By consuming vegetation and breaking branches and trees, these species control the amount and spatial distribution of fresh organic material added to the litter layer on a macro-scale (Campos-Arceiz & Blake, 2011). Furthermore, according to a global meta-analysis by Tuo and colleagues (2024), vertebrate herbivores and carnivores accelerate litter decomposition by an average of 6.7 percent, whilst the physical fragmentation caused by these animals can lead to dramatic increases in decomposition rates of up to 34.4 percent. The relevant study notes that invertebrates generally influence leaf chemistry. In contrast, it is emphasized that large vertebrate herbivores increase the overall decomposition rate within the system by stimulating soil microbial activity through their feces and physical interventions.

Wild boars are among the leading mammals that alter the physical structure of the forest floor. As noted in the study by Barrios-Garcia and Ballari (2012), wild boars use their powerful snouts to root through the litter matrix and the underlying mineral soil to reach underground plant roots, tubers, and soil invertebrates. This bioturbation activity accelerates humification by mechanically mixing litter with mineral soil. At the same time, the physical voids created within the compacted litter layer provide ideal beds for the germination of early-succession plants, thereby supporting spatial heterogeneity. However, this engineering activity also has negative effects on trophic levels. Indeed, it has been found that excessive wild boar activity causes habitat destruction and local population declines in snake and amphibian populations that use this layer as a refuge (Massei & Genov, 2004).

Bears' foraging strategies on the forest floor constitute a powerful ecological mechanism that can influence the development of forest flora. Research conducted in Japanese forests has revealed that, during the summer months, bears dig deep into the litter layer and surface soil in search of cicada nymphs. It has been established that this intense digging causes damage by severing fine root biomass, reducing the soil's water-holding capacity, and slowing the increase in inorganic nitrogen concentrations (Tomita & Hiura, 2022). Together with the removal of cicada nymphs and disturbance of fine roots, these changes show that bear digging can modify soil-water conditions, organic matter dynamics, and inorganic nitrogen availability at the predator-plant interface (Tomita & Hiura, 2022). This demonstrates that the litter layer is not merely a static area where carbon decomposes, but a dynamic interface between predators, soil organisms, and plants.

Hoofed animals, particularly wild horses and wild sheep, influence litter ecology through both physical browsing and defecation. The browsing trails created by these animals on the forest floor break down the vegetation and litter layer, forming a complex landscape mosaic. On the other hand, intense hoof pressure can fragment the litter layer excessively, increasing the risk of surface erosion and soil compaction (Eldridge et al., 2020). In addition to physical effects, hoofed animals may influence the forest floor through grazing pressure, trampling, and trail formation. In the case of Anatolian wild sheep, the available local literature supports discussion of habitat use, restoration planning, and carrying-capacity considerations rather than dung-mediated nutrient enrichment. Therefore, the influence of this species on the forest/steppe floor should be framed mainly through grazing pressure, trail formation, and trampling-related spatial heterogeneity (Ünal et al., 2016). Deer, which are key herbivores in North American and European forests, also compact and break down litter through their intensive grazing and the physical pressure of their hooves. These physical effects indirectly control ecosystem processes by altering the composition of the forest floor flora (Rooney & Waller, 2003).

The relationship between large mammals and the forest/steppe floor does not always manifest as physical alteration of the soil; sometimes, soil conditions shape the animal's physiology and adaptive capacity. Recent research by Zhao et al. (2026) on arid-region herbivores such as gazelles (*Gazella* spp.) indicates that soil-associated microorganisms and soil properties can influence the gut microbiome through a pathway linking soil, plants, food, and gut microbiota. When gazelles graze or lick the ground, they may ingest environmental microorganisms associated with soil and plants. Soil organic carbon and phosphorus may shape the diversity of cellulose-digesting bacteria in the gut. This demonstrates that the soil component of the forest/steppe floor can function as a reservoir of microbial adaptation for herbivores (Zhao et al., 2026).

Top predators, often overlooked in current ecological thinking, are extraordinary engineers who govern the dynamics of the litter layer by shaping the distribution of carrion. This is demonstrated by the massive 50-year study conducted by Bump and colleagues (2009) in Isle Royale National Park. According to the research, massive 'biogeochemical hotspots' form in forest floor areas where Gray wolves bring down their prey. As the carcass biomass decomposes on the forest floor, the litter layer undergoes a sudden nutrient shock; at these sites, the soil and litter become 100% to 600% richer in inorganic nitrogen, phosphorus, and potassium than in control areas. This flood of nutrients flowing into the litter layer triggers an explosion in microbial biomass (bacteria and fungi) and dramatically increases the nitrogen content in the leaf tissues of surrounding plants. These plants, now of higher nutritional quality, become a magnet for other herbivores, creating a massive feedback loop together with the droppings left in the area. The multifaceted physical and biogeochemical mechanisms by which large mammals affect litter dynamics on the forest floor are systematically summarised in Table 1.

Table 1. Physical and biogeochemical impact mechanisms of large mammals on the litter layer

Animal Group/Species	**Physical Impact Mechanism**	**Biogeochemical Impact and Consequences**	**References**
Wild boar (*Sus scrofa*)	Rooting	Mixes mineral soil with dead vegetation, initiating humification. However, it destroys reptile burrows.	Barrios-Garcia & Ballari, 2012
Brown bear (*Ursus arctos*)	Deep Digging (Searching for Insects/Roots)	Disturbs surface soil and litter, reduces fine-root biomass, and may alter soil water conditions and inorganic nitrogen availability.	Tomita & Hiura, 2020; 2022
Wild horse (*Equus ferus*)	Trampling and Compaction	Thins the litter layer, increasing the risk of erosion. However, it deposits large amounts of C and N on the surface through its droppings.	Eldridge et al., 2020
Anatolian wild sheep (*Ovis gmelini anatolica*)	Creation of Trampling Trails	Creates local spatial heterogeneity through grazing, trampling, and trail formation; should be evaluated mainly in terms of habitat use, restoration planning, and carrying capacity.	Ünal et al., 2016

Gray Wolf (*Canis lupus*)	Managing Carcass Distribution	Creates massive biogeochemical hotspots by introducing a shock of inorganic N, P, and K into the forest floor.	Bump et al., 2009
Gazelle (*Gazella spp.*)	Soil Licking	May facilitate microbial adaptation by transferring soil-associated environmental microbiota to the gut through grazing and soil licking.	Zhao et al., 2026
Elephant (*Loxodonta* and *Elephas* spp.)	Branch/Tree Breaking and Chewing	Modifies macro-level litter biomass input and disperses seeds.	Campos-Arceiz & Blake, 2011
Deer (Cervidae)	Grazing and Hoof Pressure	Controls the input of organic matter into the litter and shapes the flora by compacting its structure.	Rooney & Waller, 2003

3. Factors Affecting Litter Dynamics

3.1. Factors Affecting Litter Dynamics

In traditional forestry approaches, dead litter and understorey vegetation have often been regarded as a potential fire risk, and there has been a tendency to remove them from production areas (Çepel, 1995; Lindenmayer & Franklin, 2013). Interventions involving heavy machinery during live litter clearing leave the soil exposed to atmospheric conditions. This situation weakens the dead litter's functions of erosion control, moisture retention, and insulation (Binkley & Fisher, 2019; Zhu & Cheng, 2022). Furthermore, heavy machinery causes soil compaction. This compaction disrupts gas exchange between the mineral soil and the litter layer, thereby hindering aerobic decomposition processes and the mobility of the soil-dwelling invertebrate fauna (Cambi et al., 2015). All this physical damage fundamentally disrupts the energy flow occurring from the forest floor upwards. This situation also indirectly threatens organisms at higher trophic levels. Recent studies have shown that the complete removal of litter leads to significant reductions in soil organic carbon stocks and a decline in microbial diversity (Sayer, 2006; Jandl et al., 2007; Nave et al., 2010).

Today, the concept of sustainable forest management regards the conservation of deadwood as a fundamental requirement within the framework of ecosystem-based approaches (Bauhus et al., 2009; Palik et al., 2020). Furthermore, there are retention forestry approaches that aim to leave a certain proportion of coarse woody material and branches on the site within production areas. These practices increase the structural complexity of the dead wood matrix, thereby creating vital microhabitats for saproxylic (dead wood-dependent) organisms and small vertebrates (Lindenmayer et al., 2012).

Forest ecosystems are not sealed-off environments impervious to external influences. Consequently, anthropogenic pressures are not limited to mechanical interventions alone. In conjunction with globalization and climate shifts, invasive alien species infiltrating the forest floor can disrupt the dynamics of the litter layer. For example, invasive insect species cause stress on plants and lead to sudden, out-of-season mass defoliation. This situation can disrupt the carbon-nitrogen balance by subjecting the soil to a sudden shock of fresh organic matter, and may pave the way for the collapse of the native microfauna (Gandhi & Herms, 2010).

3.2. Forest Fires and Soil Reactions

In addition to anthropogenic mechanical interventions, forest fires whose frequency and intensity can also vary due to human influence are another major factor that suddenly transforms the litter matrix. Forest fires, particularly ground fires, cause sudden and significant changes to the soil surface by rapidly mineralizing accumulated organic material over many years (Certini, 2005). This situation results in habitat loss for many organisms that depend on the litter layer (Neary et al., 1999).

However, ecosystems possess a degree of resilience and the capacity to recover after the fire. As vegetation regrows, the layer of dead organic matter reforms over time, and ecosystem functions are gradually restored (Certini, 2005; Pausas & Keeley, 2019). In particular, following low- and medium-intensity fires, partially burnt organic material and pyrogenic carbon (black carbon) remain on the ground. These structures improve the soil's water holding capacity whilst creating new micro-niches that ensure carbon remains stable for centuries (Santín et al., 2016). Consequently, modern fire management approaches recommend strategies that preserve heterogeneous and mosaic structures rather than homogeneous clearing practices. Patches of unburned or partially burned dead vegetation left in the field will serve as strategic refugia, enabling wildlife populations to recolonize burned areas (Meddens et al., 2018).

3.3. Global Climate Change and Microclimatic Changes

Both silvicultural interventions and fires have an impact at local and regional scales. Global climate change, however, is the most comprehensive abiotic stressor transforming litter dynamics across entire ecosystems.

Rising temperatures and prolonged drought reduce litter moisture content, thereby slowing decomposition and limiting microbial activity (Allison & Treseder, 2008; Classen et al., 2015). The effect of temperature increases on decomposition rates is not linear. Whilst rising temperatures may temporarily accelerate decomposition in some regions, this effect may reverse in the long term due to moisture limitation (Prescott, 2010). Furthermore, climate-driven changes in precipitation regimes and moisture availability can modify the biochemical and physical pathways through which litter-derived carbon is transformed into soil organic matter, thereby influencing soil organic matter formation and stabilization processes (Cotrufo et al., 2015). Climate change also affects litter quality by altering plant species composition, and this in turn reshapes the direction of decomposition (Zhang et al., 2008).

In addition to these global-scale processes, comprehensive quantitative studies conducted in Turkish forests clearly demonstrate the carbon storage potential of litter and how this potential varies with environmental variables (Tolunay & Çömez, 2008; Tolunay, 2011). These findings indicate that carbon accumulation in forest ecosystems may vary considerably depending on forest type, stand structure, and environmental conditions (Sarıyıldız et al., 2005; Kahveci & Kara, 2026). These results not only quantitatively demonstrate the role of litter in the terrestrial carbon budget but also contribute to understanding its potential for biodiversity and wildlife (Kahveci et al., 2025).

As Türkiye's forests lie within the Mediterranean climate zone, it is important to consider not only global models but also region-specific projections for the Mediterranean Basin (Giorgi & Lionello, 2008). The severe summer drought and high evaporation characteristic of the Mediterranean climate render the dead litter a biologically inactive environment during the summer months, transforming it into a fuel layer highly susceptible to burning (Keeley et al., 2011). As Bilgili (1998) also noted within the framework of combustible material management, this loss of moisture does more than merely increase the risk of fire. It also causes moisture-dependent groups, such as earthworms, to retreat to very deep soil layers, amphibians, such as the Lycian newt, to enter summer dormancy, and insectivorous birds feeding on the surface to be unable to find food (Ficetola & De Bernardi, 2004; Rutigliano et al., 2004).

Beyond these abiotic processes, for amphibians and many soil organisms sensitive to moisture conditions, a drying litter layer can cease to be a suitable habitat and instead become a lethal physiological stressor (Blaustein et al., 2010; Blankinship et al., 2011). In this context, it is stated that climate change affects ecosystem functions indirectly yet powerfully, not only through rising temperatures but also via the disruption of the litter microhabitat (Shoo et al., 2011).

Consequently, these three key factors, anthropogenic interventions, fire regimes, and global climate change, shape litter dynamics at different scales, yet in an interactive manner. This interaction emerges as a fundamental driving force determining the structural and functional integrity of forest ecosystems.

4. Ecological and Conservation Significance

The most fundamental way to enhance the resilience of forest ecosystems against severe abiotic stresses, such as climate change and drought, as detailed in the previous section, is to preserve the spatial heterogeneity provided by litter decomposition stages. In this context, litter is a key component of biodiversity in global ecosystems. Organic residues at different stages of decomposition create specific micro-niches for thousands of species of microorganisms and invertebrates (Bardgett & van der Putten, 2014). This diversity at the lowest level of the food chain supports a broad network extending up to higher trophic levels. Furthermore, the temporal and spatial heterogeneity created by the decomposition stages maximizes species accumulation within the ecosystem. Consequently, competitive exclusion between species is limited (Barton et al., 2013).

Forests with an intact litter layer and deep, moist organic layers possess greater ecological resilience against environmental stressors and severe climatic fluctuations (Johnstone et al., 2016). This enables species to survive in micro-refuges, particularly in the face of increasing drought and heat stress associated with climate change (Frey et al., 2016). Furthermore, increased litter heterogeneity supports functional diversity, thereby ensuring the continuity of ecosystem processes (Hättenschwiler et al., 2005).

From a conservation biology perspective, habitat management should encompass not only the tree canopy but also the forest floor (Lindenmayer & Franklin, 2013). In this context, the concept of litter should not be limited to fallen leaves and needles. Coarse woody materials that fall to the forest floor as a result of wind, snow breakage, or natural felling are the fundamental building blocks of this biological matrix. Dead wood acts like a sponge, retaining moisture within it and creating vital micro-oases for wildlife, particularly during dry periods. These fallen logs provide an essential habitat for saproxylic insect species and xylophagous (wood-eating) larvae. At the same time, carnivorous mammals such as woodpeckers, which feed on these larvae, and the pine marten, which uses hollowed-out logs as nests, are dependent on this matrix (Siitonen, 2001; Stokland et al., 2012). In Turkish forestry, ‘emergency harvesting’ (the rapid removal of fallen trees from the site) is often carried out after storms or snow damage. These interventions may provide short-term economic gains. However, by collapsing the saproxylic food chain on the forest floor, they cause long-term habitat loss for wildlife (Thorn et al., 2018).

An intact litter layer for wildlife supports gene flow between isolated populations by creating safe ecological corridors within the forest. A thick litter layer in buffer strips near water sources improves water quality, supports erosion control, and provides suitable habitats for moisture-dependent species (Naiman et al., 2010). In this context, litter depth and structure should not be treated merely as a static ground cover in habitat suitability models developed for wildlife. Rather, this layer should be assessed as a key environmental variable determining species distribution (Zellweger et al., 2019)

In recent years, remote sensing techniques and high-resolution environmental data have advanced rapidly. As a result, litter and structural habitat metrics can now be integrated into species distribution models. This technological integration enables the development of far more precise conservation plans (He et al., 2015; Zellweger et al., 2019). Furthermore, ensuring the continuity of deadwood is a fundamental management tool that strengthens ecological connectivity at the landscape scale by mitigating the effects of habitat fragmentation (Bennett, 2003; Lindenmayer and Franklin, 2013).

5. Conclusions and Recommendations

The litter layer covering the forest floor is not merely a pile of organic waste; it is an invaluable biological asset that stores carbon, protects soil health, prevents erosion, and provides essential habitats for wildlife. The global vision for forestry is currently evolving towards ecosystem-based and multi-purpose planning. In line with this, it is essential that the concept of ‘litter management’ be elevated to a priority within our country’s forestry and wildlife policies. There are numerous studies in the international literature examining litter-wildlife dynamics. However, the lack of sufficient research into this ecological interaction in Turkish forests represents a serious academic shortfall that must be addressed at the national level. This shortfall must be rectified, and the sustainability of litter dynamics must be made an integral part of national wildlife conservation strategies.

In this context, to guide the planning of future ecosystem inventories, we must move beyond traditional observation methods and integrate advanced technological methods into the process. In this context, using airborne or terrestrial LiDAR technologies, forest floor litter depth, coarse woody debris volume, and ground-level spatial heterogeneity can be mapped and overlaid with data from camera trap networks. In this way, activities of large mammals on the forest floor, such as digging or carcass deposition, can be monitored with high precision. Additionally, Environmental DNA (eDNA) technology can be used to assess the hidden biodiversity of microhabitats on the forest floor. This method allows for the molecular analysis of hair, feces, or saliva residues left by animals in the area. Consequently, wildlife abundance can be quantitatively determined without disturbing the animals.

In line with this vision, several key strategies aimed at protecting the health of forest ecosystems and wildlife populations must be implemented in Türkiye as a matter of urgency:

- Absolute protection zones: In ecosystems hosting species sensitive to endemic and microhabitat characteristics, all mechanical interventions affecting the litter layer must be halted, and these areas must be designated as absolute protection zones. These areas must be designed on a large scale to mitigate the risks of climate change and habitat fragmentation. When defining boundaries, the process must take into account not only trees but also the migration routes of megafauna and large animals that interact with the microbial pool in the forest floor.
- Retention of coarse woody material: Coarse woody material, such as fallen tree trunks and logs, which serve as shelter for wildlife in forest production areas, should be left on-site to a certain extent. This practice will enhance the litter matrix's water and air retention capacity.
- Biological corridors in firebreaks: When establishing firebreaks, the practice of completely stripping the forest floor over distances of several kilometers, which triggers erosion, should be abandoned. Instead, natural biological corridors should be left in place to allow wildlife to cross.
- Updating inventory parameters: To ensure that all these processes can be monitored at an organizational level, new ecological criteria must be incorporated into forest management plans and wildlife management plans. Data such as 'litter depth', 'carbon accumulation', and 'degree of decomposition' must be recorded as official inventory parameters.
- Ecosystem-based dynamic forest and wildlife management: When preparing ecosystem-based forest and wildlife management plans, the conservation of carbon stocks in dead organic matter and the continuity of the nutrient cycle must be taken as a fundamental principle. The conservation of large mammal populations, which are the most

important driving force behind this cycle (the predator-prey balance), must be recognized as a mandatory criterion in management plans.

Consequently, the strategic objectives presented in this study align with the United Nations Sustainable Development Goals (SDGs) goal on 'Life on Land' (SDG 15). Within the framework of this global consensus, which aims to protect and restore terrestrial ecosystems and halt biodiversity loss, the litter layer should not be viewed merely as organic waste or as a soil cover. Rather, this irreplaceable layer should be recognized as the 'biological insurance' of the entire forest ecosystem.

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