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FOREST LİTTER (LEAF AND BRANCH LİTTER) CONTRIBUTION TO AQUATIC ECOSYSTEMS

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Abstract: Forests significantly influence the quantity and quality of water within watersheds through the input of forest litter comprising leaves, branches, and other organic materials into aquatic ecosystems. This litter serves as a critical link between terrestrial and aquatic systems by supplying essential nutrients, such as carbon, nitrogen, and phosphorus, which drive microbial decomposition and form the base of detritus-based food webs. The decomposition process, governed by physical, chemical, and biological stages, is affected by environmental factors including temperature and oxygen levels. While moderate litter input supports aquatic biodiversity by providing habitat and nutrient resources, excessive accumulation can cause hypoxia, sedimentation, and eutrophication, degrading water quality. Forestry practices and land-use changes alter litter transport, sediment loads, flow regimes, and water temperature, impacting aquatic habitats and organisms. Riparian buffer zones play a vital role in regulating litter input and preserving water quality. Sustainable watershed management requires integrated approaches recognizing forest litter's ecological importance, protection of riparian areas, adaptive strategies for climate change, and enhanced public awareness. Continued research and monitoring are essential to support aquatic ecosystem health and sustainable fisheries.

Keywords: Forest litter, aquatic ecosystems, nutrient cycling, water quality, watershed management

Introduction

The quality and characteristics of the main river within a drainage basin are directly influenced by the ecological structure of the surrounding terrestrial ecosystem. Additionally, the diversity of tree species and structural changes within regional forests can indirectly play a significant role in determining water quality. Any intervention in the forest ecosystem not only alters the composition and structure of the stand itself but may also affect the surrounding environment. From this perspective, the water quality of a river within a watershed is indirectly impacted by forestry activities, particularly those related to timber production. These impacts can, in turn, significantly influence aquatic habitats. Due to the indirect nature of these effects and the complex, multilayered interactions between terrestrial and aquatic ecosystems, definitive conclusions on this subject remain elusive. Nevertheless, there has been a marked increase in long-term studies on this topic in recent years. Such developments are expected to offer valuable insights for environmental and natural scientists in understanding how water resources

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whose importance is steadily growing are shaped by environmental factors (Koralay et al., 2015).

There is a continuous exchange of matter and energy between terrestrial and aquatic ecosystems. One of the key components of this connection is forest litter, which consists of dead plant material such as leaves, small branches, flowers, and fruits (Gessner et al., 1999). This material, shed from forested areas, is transported, primarily via rainfall and surface runoff, into nearby streams, ponds, rivers, and lakes (Figure 1). The input of litter into aquatic systems directly influences the biological productivity and species diversity of these ecosystems (Tank et al., 2010).

Figure 1. Forest litter (Geziötesi, 2025).

The ecological functions of forest litter in aquatic environments are multifaceted. Primarily, it is decomposed by microorganisms, resulting in the release of essential nutrients such as carbon, nitrogen, and phosphorus, and thus initiating the aquatic food web (Wallace et al., 1997). Additionally, litter materials such as leaf debris provide shelter and spawning grounds for fish, aquatic insects, and benthic invertebrates (Cummins et al., 1989). This, in turn, positively influences survival rates, particularly for juvenile fish and macroinvertebrates.

When forestry practices are evaluated at the watershed scale particularly following timber harvesting and thinning operations near water bodies (i.e., within riparian zones), significant changes can occur in the flow regime of the main stream, water temperature may rise, and algal density often increases. Furthermore, the reduction in forest cover across the watershed leads to greater transport of sediment and organic matter into the stream. Collectively, these impacts contribute to a decline in water quality and exert adverse effects on invertebrates, fish species, and other aquatic organisms (Koralay et al., 2015).

From another perspective, forest litter can also influence the physical and chemical properties of water. For example, high litter input may increase dissolved oxygen consumption, and in some cases, excessive decomposition can lead to deteriorated water quality (Allan & Castillo, 2007). Nevertheless, controlled litter in put helps maintain the natural structure and productivity of aquatic ecosystems, which, in turn, supports sustainable fisheries and aquaculture development.

Forestry operations within forest ecosystems can exert a variety of ecological and environmental effects. This study specifically investigates how timber production and silvicultural practices influence water quality and aquatic ecosystems at the watershed scale.

The Transfer of Forest Litter to Aquatic Ecosystems

The transport of leaves, branches, and other organic materials shed from forests into aquatic ecosystems represents a fundamental example of matter and energy exchange between terrestrial and aquatic systems. This transfer generally occurs through physical processes and is strongly influenced by factors such as climatic conditions, topography, vegetation density, and the distance between forested areas and water bodies (Allan & Castillo, 2007). A significant proportion of water-producing watersheds is covered by forested land (Gülcü et al., 2008).

In regions where forest and pasture lands have been converted to agricultural use, soil becomes more susceptible to external disturbances, and the risk of erosion increases markedly. As a result, the volume of sediment transported into streams and rivers rises substantially. In addition, chemical waste, domestic pollution, and sewage leakage from industrial and residential areas can severely degrade water quality. Similarly, the use of agrochemicals such as fertilizers, pesticides, and herbicides in agricultural zones has negative impacts on aquatic systems.

Even small-scale interventions within a watershed can, over time, affect the entire basin, altering both the quantity and quality of water. Moreover, various activities carried out along river systems such as vegetation removal, application of agricultural chemicals, or the construction of structures in streambeds can disrupt the physical, chemical, and biological characteristics of aquatic environments. These disturbances negatively affect not only the macro and microfauna inhabiting the system but also the surrounding vegetation, wildlife, and nearby human settlements (Li & Migliaccio, 2011).

Although open lands devoid of vegetation may initially yield higher water volumes, the quality of this water is generally low due to degradation caused by sediment transport, flooding, and rainfall-induced surface runoff. Over time, this can accelerate the siltation of reservoir basins and reduce their overall functionality.

Forest litter reaches the water through various pathways (Figure 2). These pathways include:

- **Gravity (Direct Fall):** Leaves and branches from overhanging vegetation contribute to the aquatic environment by falling directly into nearby streams or ponds (Gessner et al., 1999).
- **Surface Runoff:** During rainfall events, water flowing over the soil surface mobilizes forest litter accumulated on the forest floor and transports it into adjacent aquatic environments (Tank et al., 2010).
- **Wind Dispersal:** Especially during dry periods, lightweight leaves and small branch fragments can be transported into aquatic systems by wind
- **Flood Events:** During seasonal or sudden flood events, large amounts of forest litter can be transported into aquatic systems within a short period of time, significantly altering the physical and chemical properties of the water.

Figure 2. Light leaves and small branch fragments (Geziötesi, 2025).

The transport of forest litter is closely linked to seasonal cycles. In temperate climate zones, leaf fall peaks in autumn, leading to an increased input of litter into aquatic ecosystems during this period (Wallace et al., 1997). Although transport slows during winter, snowmelt in spring can trigger a renewed influx. In arid and semi-arid regions, litter transport typically occurs in late summer and autumn, coinciding with rainfall events. These seasonal patterns play a key role in determining the timing of litter delivery and associated nutrient inputs to aquatic systems.

The amount of litter transported into aquatic systems is also influenced by several site-specific factors, including the proximity of the water body to the forest, slope gradient, soil permeability, and vegetation type. In sloped areas, surface runoff occurs more rapidly, increasing the likelihood of litter reaching the water (Figure 2). Riparian buffer zones help regulate the controlled entry of litter into water bodies and can also act as filters, reducing excessive transport (Allan & Castillo, 2007). Plant species further influence both the quantity of litterfall and its decomposition rate. For instance, leaves from hard-leaved species decompose more slowly and may persist in the aquatic system for extended periods (Gessner et al., 1999).

Figure 3. Probability of forest litter reaching the water (Haber61, 2017)

Ecological Functions and Decomposition Process of Forest Litter

Forests have significant effects on both the quantity and quality of water (Gülcü et al., 2008). Water originating from forested areas is generally abundant and of high quality. Trees contribute to soil protection and enhance its structural properties by forming a protective litter layer composed of dead organic material on the soil surface. This layer improves soil aggregation, increases organic matter content, and enhances physical characteristics such as infiltration capacity, permeability, and porosity (Koralay et al., 2015). Forest litter, including fallen leaves and branches, also plays vital ecological roles in aquatic ecosystems. It serves both as a nutrient source and as habitat, contributing significantly to the energy and matter cycles within these systems. However, the ecological effects of litter in aquatic environments are closely linked to the rate and mode of its decomposition.

The decomposition of forest litter generally occurs in three main stages:

- **Physical Decomposition:** This involves the fragmentation and mechanical breakdown of litter through external forces such as wind, water flow, and physical disturbances. This stage increases the surface area of the litter, facilitating subsequent biological activity.
- **Chemical Decomposition:** In this stage, the organic components of litter—such as lignin, cellulose, and hemicellulose—are broken down by water and enzymatic action. Complex compounds like lignin degrade more slowly, whereas cellulose decomposes at a faster rate.
- **Biological Decomposition:** This stage is driven by microorganisms (e.g., fungi and bacteria) and detritivores (e.g., macroinvertebrates), which utilize the litter as a source of energy and nutrients. Through this process, organic matter is mineralized and incorporated into the ecosystem's food web (Gessner & Chauvet, 1994).

Microorganisms play a central role in the decomposition of leaf litter in aquatic environments. Fungi, in particular, are highly specialized in breaking down complex organic compounds such as lignin. Microbial colonization typically begins within days after leaf material enters the water and largely determines the rate of decomposition. Environmental factors such as temperature, oxygen availability, and water quality strongly influence microbial activity (Tank et al., 2010). Elevated nitrogen and phosphorus concentrations in streams can affect primary productivity and cause fluctuations in oxygen levels, potentially leading to changes in species diversity. However, excessive nutrient input often triggers rapid algal growth. Intense algal blooms reduce light penetration, increase turbidity, and elevate biological oxygen demand (BOD), ultimately resulting in lower dissolved oxygen levels. As these processes progress, eutrophication defined as the over-enrichment of aquatic systems with nutrients can occur (Tuğrul et al., 2011; Chislock et al., 2013).

During the decomposition of forest litter, essential nutrients such as carbon (C), nitrogen (N), and phosphorus (P) are released into the water column and sediments. These nutrients serve as important resources for aquatic organisms, supporting productivity and ecological functioning. Carbon release, in particular, contributes to energy flow within the ecosystem as part of the global carbon cycle. These processes highlight the critical role of forest litter in supplying nutrient inputs to aquatic environments (Gessner & Chauvet, 1994; Webster & Benfield, 1986).

Rising water temperatures reduce dissolved oxygen levels and accelerate evaporation. Biologically, elevated temperatures also promote the proliferation of undesirable cyanobacteria (blue-green algae) and other harmful microorganisms. Cyanobacteria can release toxic compounds into the water, leading to a decline in water quality. Even small increases in temperature by just a few degrees can negatively impact fish life cycles, migration patterns, spawning behavior, and reproductive success (Chang, 2003).

Leaf litter and woody debris serve as an important food source, particularly for macroinvertebrates such as shredder larvae, aquatic worms, and crustaceans. These organisms contribute to the breakdown of litter into finer particles, thereby initiating energy flow within the aquatic ecosystem (Wallace et al., 1997). Beyond serving as a nutrient source, litter input also provides habitat complexity by offering shelter and breeding grounds for numerous small aquatic organisms. Fish larvae and benthic invertebrates, in particular, can utilize the structural complexity of litter for protection (Giller & Malmqvist, 1998). The organic matter produced through litter decomposition forms the base of the aquatic food web.

Ecological and Management Importance of Forest Litter in Aquatic Ecosystems

Forest litter is not only a natural component of aquatic ecosystem functioning but also plays a critical role in their sustainable management by contributing to the structural integrity and ecological functionality of aquatic habitats. Leaf litter and other organic inputs serve as key sources of nutrients within the aquatic nutrient cycle. These materials provide essential elements for the development of benthic organisms, thereby supporting the base of the aquatic food web (Wallace et al., 1997). Moreover, the physical structure formed by litter in aquatic environments offers shelter and breeding sites for fish and other aquatic organisms (Giller & Malmqvist, 1998).

Forestry activities alter stream hydrology, leading to irregular flow patterns that manifest as either high flow peaks or abnormally low discharge levels. Such fluctuations pose significant challenges for aquatic organisms, particularly during high flow events. Increased discharge can dislodge vegetation that shelters eggs and juveniles, compromising their survival. Benthic invertebrate habitats are also disrupted by irregular flows, resulting in the displacement of organisms and a subsequent decline in population stability and food availability. Nutrient deficiencies further exacerbate these effects, potentially leading to reduced organism abundance. In addition, logging residues left in or near streams can contribute to declines in both fish and invertebrate populations. Each species requires specific environmental conditions for survival, including adequate dissolved oxygen levels especially during periods of low flow. The removal of riparian vegetation and the shallowing of stream banks elevate water temperatures and reduce oxygen concentrations, thereby lowering the survival rates of aquatic organisms. Flow variability can also wash away primary producers, which serve as the main food source for benthic invertebrates. This reduction in invertebrate populations can, in turn, alter the density, size, and community structure of fish populations (Jackson, 2006).

Streams are fed by both groundwater and surface water, transporting essential minerals and dissolved oxygen. These water bodies support aquatic and riparian life by delivering minerals leached from the landscapes they traverse, along with oxygen derived from atmospheric exchange or produced through chemical and biological processes within the water itself (Girgin, 2010). Sustainable fisheries management depends on maintaining the natural cycle of organic matter within aquatic ecosystems. Protecting forested areas and preserving healthy riparian buffer zones ensures the consistent input of forest litter, which plays a crucial role in nutrient cycling. Conversely, deforestation or excessive forest clearance can diminish litter inputs, disrupting nutrient dynamics and affecting the productivity of aquatic systems (Allan & Castillo, 2007).

The extent of pollution resulting from silvicultural practices varies depending on land characteristics, climatic conditions, and the management strategies employed by forestry personnel. Sources of such pollution include sediment accumulation, fluids and lubricants used by machinery operators, nutrients and fertilizers applied in harvesting areas, and chemical inputs such as pesticides and herbicides used in forest management.

In addition, rising water temperatures also referred to as thermal pollution represent a significant concern. Inadequate oversight of forestry operations can result in the degradation of high-quality water sources and negatively impact aquatic ecosystems, including fish and invertebrate populations (Wear & Greis, 2002). Elevated sediment levels in streams, in particular, have been linked to declines in the abundance of fish and aquatic invertebrates (Waters, 1995).

Fish are ectothermic (cold-blooded) animals, meaning their body temperature is regulated by the surrounding environment. A 1°C increase in ambient water temperature can elevate their metabolic activity by approximately 10%. Rising stream temperatures increase the oxygen demand of fish while simultaneously decreasing the concentration of dissolved oxygen, as cold water retains more oxygen than warm water. Water temperature influences numerous biological processes in fish and other aquatic organisms, including species composition, life cycles, and reproductive behavior. Each species has a specific thermal tolerance range required for survival. Generally, most fish species grow and develop within a temperature range of 0 to 25°C, with species-specific upper and lower limits. Exceeding these optimal thermal thresholds can lead to increased disease prevalence, impaired growth and reproduction, disrupted migration patterns, and in severe cases, mortality. High summer temperatures and the associated decline in dissolved oxygen can also cause physical changes in fish, such as alterations in spot patterns or mouth morphology (Chang, 2003). For these reasons, water temperature is regarded as a critical and limiting factor for the health and sustainability of aquatic life in stream ecosystems (Grant & Lee, 2004).

For optimal fish health, the concentration of suspended solids in aquatic environments is generally recommended to remain below 30 mg/L, with a maximum threshold not exceeding 100 mg/L (Chang, 2003). In Turkey, specific guidelines suggest that this limit should remain under 50 mg/L for trout species (Atay & Pulatsü, 2000). Elevated levels of suspended solids can obstruct fish gills, impairing respiration and potentially forcing fish to abandon their habitats (Reynolds et al., 1989).

Suspended solids that accumulate in rocky and gravelly substrates preferred by fish for spawning can fill interstitial spaces, thereby reducing the availability of suitable habitat. Larvae hatched from eggs generally seek out coarse, rocky substrates to avoid fine sediments that may hinder development (Grant & Lee, 2004). Elevated levels of suspended solids negatively impact larval habitats and can contribute to alterations in streambed structure and habitat complexity (Koralay et al., 2015).

Conclusion

Although riparian zones are often narrow strips of vegetation along streams, they play a critical role in maintaining water quality. The removal or degradation of riparian forests can adversely affect water quality in multiple ways. These forested buffers provide shade that helps regulate stream temperature, reduce sediment input, and filter out fertilizers and chemical pollutants before they reach the waterbody, thereby enhancing overall water quality. Given their ecological importance, riparian areas should be strictly protected, and extractive or production-oriented activities should be prohibited within these zones (Koralay et al., 2015).

Forest litter particularly organic materials such as leaf and branch debris provides essential ecosystem services that support the sustainability of aquatic ecosystems. These inputs supply allochthonous carbon and nutrients to aquatic environments, initiating microbial activity and forming the foundation of detritus-based food webs (Vannote et al., 1980; Gessner et al., 1999). Moreover, coarse particulate organic matter (CPOM), including leaves and branches, creates habitats and spawning grounds for benthic invertebrates, thereby indirectly supporting fish populations by enhancing habitat structure and reproductive success (Wallace et al., 1997).

Local studies particularly those conducted on streams in the Black Sea and Aegean regions have demonstrated that forest litter directly influences water quality, dissolved oxygen concentrations, and aquatic biodiversity (Yıldız & Arslan, 2015; Demir & Kırgız, 2020). Improper forestry practices in forested areas with hydrological functions have been shown to degrade water quality and cause ecological harm to aquatic systems. Interventions that alter the quantity or quality of water within a watershed can have cascading effects on numerous life forms, including aquatic macro- and microorganisms, riparian vegetation, wildlife, and even human populations.

However, while forest litter provides numerous ecological benefits, its accumulation beyond a certain threshold can have adverse effects on aquatic environments. Excessive litter input may lead to hypoxic conditions, reduced pH due to decomposition, and increased sedimentation. In addition, rising stream temperatures, elevated sediment and nutrient loads, and declining dissolved oxygen levels collectively contribute to water quality degradation. Therefore, forestry activities must be carefully planned and implemented to preserve the ecological value and hydrological functions of water resources within and surrounding forested areas. This necessitates a balanced and integrated forest–water management approach.

Recommendations

- **Integrated Ecosystem Management**: In the management of aquatic ecosystems, it is essential to consider not only water resources but also the structure and condition of surrounding forested areas. These two systems are ecologically interconnected and must be planned and managed in an integrated manner.
- **Recognition of Forest Litter as a Resource**: Leaf and branch litter should be recognized not merely as waste, but as a valuable ecological input. Its potential use in aquaculture systems such as serving as a natural substrate for feeding or shelter should be systematically investigated.
- **Climate Adaptation Measures**: Climate change may alter forest structure and leaf fall phenology, thereby influencing both the quantity and seasonal timing of litter input into aquatic ecosystems. Adaptive strategies should be developed to mitigate and manage these changes.
- **Awareness and Education**: Public awareness regarding the ecological role of forest litter especially its impact on aquatic production should be enhanced among local communities and aquaculture stakeholders. Concepts such as nature-based solutions and ecosystem services should be incorporated into formal and informal educational programs.

- **Long-Term Monitoring and Local Research**: The decomposition dynamics of forest litter, its role in nutrient cycling, and its influence on aquatic biodiversity in various environments (e.g., streams, ponds, reservoirs) should be subject to continuous monitoring. In addition, research efforts should focus on locally specific conditions to support evidence-based forest water management.

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