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Review

Research Progress on the Decomposition Process of Plant Litter in Wetlands: A Review

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Abstract: Wetland is a transitional area where terrestrial ecosystems and aquatic ecosystems interact and influence each other, and it is an important ecosystem on the Earth's surface. Due to the special characteristics of wetland ecology, the decomposition of wetland plant litter is slightly different from litter in forests, grasslands, and meadows and other traditional areas. The role of litter mineralization in the wetland ecological C cycle and the functional role of plant litter have been neglected. This study analyzes the decomposition mechanism and decomposition model of wetland litter material and focuses on the effects of the decomposition process of wetland litter material on the structure of the soil fauna community, decomposition of soil organic matter, sediment properties, and the dynamic changes in the C cycle of the biological system by combining domestic and international studies from recent years. Finally, we propose that the direction of future research on wetland litter decomposition should be to reveal the mechanism of wetland biodiversity and ecology, as well as the ecological correlation between aboveground and belowground biodiversity, with a view to providing a decision-making basis for wetland phytoremediation and wetland wastewater treatment.

Keywords: wetland; litter composition; soil organic matter; sediment

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1. Introduction

Litter refers to the dead material formed during the death and decay of plants, including debris, dead branches, fallen leaves, flowers, fruits, and withered roots [1–3]. Wetland ecosystems bridge the terrestrial and aquatic ecosystems and play an essential role in global climate change. Their carbon cycle is a crucial part of the global carbon balance, and litter decomposition is the primary source of wetland carbon [4–6]. Plant decomposition has physical, chemical, and biological effects and is an important process that regulates the nutrient content and net productivity of ecosystems [7]. Litter decomposition affects the moisture, light, and temperature conditions required for the growth of surrounding plants [8], and it impacts the microbial community structure, soil physicochemical properties, and organic matter escapism and content of wetland sediments. There are several studies on plant litter in forests, grasslands, and meadows; however, plant decomposition in wetlands remains to be explored further [9–11]. Wetlands, as special natural sites of land–water interactions, are host to very complex decomposition of litter plants due to their wet–dry alternation and sedimentation characteristics. The decomposition of wetland plant litter plays an extremely important role in the material cycle, energy flow and information transfer in the system, which is different from that of terrestrial ecosystems and aquatic ecosystems and is more affected by the interaction between land and water (e.g., dry–wet alternation, water accumulation conditions, sedimentation behavior and characteristics, etc.) [12]. It is an important component of wetland nutrient cycling and energy flow, as well as a major process in maintaining wetland ecosystem function.The role of plant litter in ecosystem functioning relationships was shown in Figure 1.

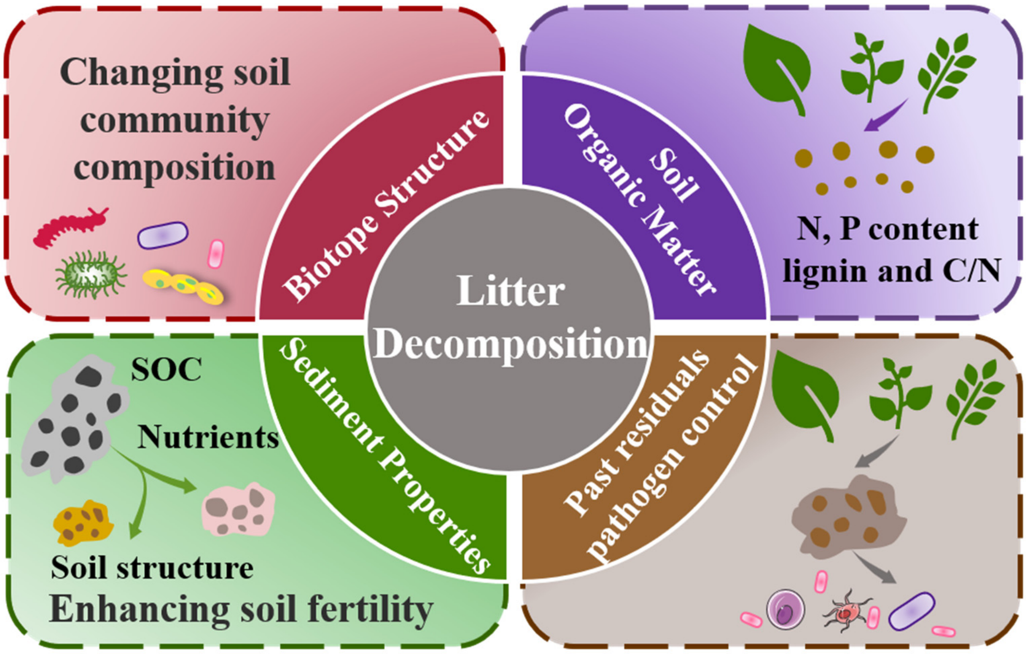

Figure 1. The role of plant litter in ecosystem functioning relationships.

In this study, the decomposition of wetland litter and its influence on wetland performance are described to provide a reference for wetland phytoremediation and wetland effluent treatment.

2. Studies on the Decomposition of Litter in Wetlands

2.1. Research Methodologies for Exploring the Decomposition of Wetland Plant Litter

Indoor simulation tests and field experiments have been utilized to investigate litter decomposition in wetlands, with three approaches being typically used in field experiments. The first is the decomposition bag method, which involves sewing a nylon bag made of soft and non-degradable nylon nets [13], then filling it with an appropriate amount of plant litter, placing it on the soil surface or in the 5–10 cm soil layer to simulate natural decomposition, and finally burying it. The material to be decomposed can be buried in the soil layer for more than two years [14]. This method does not significantly change the decomposition environment of standing dead plants in the natural state, which ensures the integrity of the experimental results and also reduces the losses caused by the loss of plant tissue fragments, and can be used in the field for a long observation time [14]. Furthermore, it is simple to operate and is one of the most commonly used methods in the study of the decomposition of standing dead plants [15–17]. However, there are some shortcomings to this method: the mesh size of the decomposition bag may hinder some small animals in the soil and slow down the decomposition rate [14], though this can be avoided by choosing a decomposition bag with an appropriate mesh diameter. In the second method, the decomposing material is bundled up and secured in a particular place. In situ decomposition methods include the sampling method and the litter labeling method. The sampling method refers to the delineation of several sample plots in the study area and the analysis of standing dead plant samples within the sample plots. The litter labeling method refers to the labeling of standing dead plant samples in the field and regular monitoring. The in situ decomposition method can be used to monitor the senescence and in situ death rate of standing dead plant litter [18,19], the diurnal variation in CO_2 release [20,21], and the fungal biomass and biotope characteristics of standing dead litter [18,19]. The data measured by this method are close to the actual values, but the experiment cannot be carried out for a long period due to the limited number of plant samples that can be labeled and the fact that they are easily broken or lost at the time of collection.

The indoor culture method is a method in which standing dead and dying plants retrieved from the field are cultured indoors according to the experimental requirements. By controlling the environmental conditions, this method can allow researchers to study the effects of specific factors on the decomposition of standing dead and withered material. For example, Zhang et al. [20] used indoor incubation to study the effect of temperature on the CO_2 release rate of standing dead litter, and Kuehn et al. [21] used indoor incubation to study the effect of moisture on the CO_2 release rate of standing dead litter. The incubation time of this method is short, and the effect of specific factors on the litter-decomposing species can be measured; however, there are more human interventions, and the gap between the demarcation environment and the field is large, meaning the method cannot truly reflect the litter species in their natural state and, thus, the results of such a study are only of relative significance [14]. The decomposition bag method is one of the most commonly used research methods and is simple and convenient. However, some researchers believe [9] that the decomposition bag method lacks scientific validity because there are many environmental factors in wetlands, and the isolation of decomposition bags will impact soil fauna and microbial activities. Furthermore, the approach may not adequately estimate mass loss and energy changes. Nonetheless, there have been observed to be no significant differences between the decomposition bag method and the natural decomposition rate in soil.

Litter is the link between plants and nutrient cycling in wetland environments, and its decomposition process is critical to the composition and cycling of carbon (C) and nitrogen (N) pools in wetland ecosystems [22–24]. Litter decomposition not only promotes the release of soil C to the atmosphere but also drives changes in ecosystem diversity, structure, and function, and it is important for the formation of soil organic matter and the rate of nutrient release from wetland sediments. Furthermore, litter decomposition releases organic matter and nutrient elements to the sediments, which is important for the maintenance of soil fertility [25–27]. More than 90% of the nutrients absorbed by plants and more than 60% of the mineral elements in most ecosystems come from nutrient recirculation, where nutrients are returned to the soil by vegetation [28]. Litter input and decomposition are key processes for maintaining the soil organic carbon content, as well as improving soil quality, microbial activity, and soil nutrient effectiveness, and they play an important role in the composition and cycling of carbon and nitrogen pools in wetland ecosystems. Globally, about 70% of the annual net primary productivity is deposited in the soil as organic carbon (OC) through the litter, and therefore the input of plant litter into the soil is a key and effective way to improve the C sink capacity of the ecosystem and to mitigate the increase in atmospheric CO_2 and global warming [29]. Currently, the mechanism of C and N circulation during litter decomposition is a fundamental scientific issue for the accurate prediction of C and N cycling in terrestrial ecosystems, and thus has become the focus of researchers' attention. Indoor simulation experiments are often used with isotopic techniques and near-infrared spectroscopy (NIRS). The 15N and 14C procedures are the most widely used in laboratories because decomposing litter is entirely in contact with the surrounding environment and is not limited by the container. This method is primarily used to investigate the effects of litter decomposition and soil mixing on soil decomposition and can yield results within a short period [30]. When applying isotope technology, tracing the chemical and spatial structure of any component or metabolite in the decomposition process of litter in soil, including the involvement of animals in the soil, can enable researchers to determine the chemical changes in litter during natural conditions. However, isotope technology has certain limitations, and the 15N and 14C technologies are currently limited to laboratory conditions to avoid environmental issues caused by radioactive isotopes. Furthermore, isotope technology requires quite complex equipment and specially trained experts, which presents certain limitations [13].

In contrast, NIRS is a rapid, inexpensive, and non-destructive technique that can accurately measure carbon and nutrients in plant litter and plays a role in qualitative analyses of the decomposition stages of litter. Near-infrared (NIR) spectrometry, which is based on the use of a regression model of the spectral information of a set of samples and their reference values, allows for the determination of initial characteristics of a lot of litter and the comparison of the initial characteristics with the NIR spectra in terms of their ability to predict the capacity of litter to decompose, as well as the development of indices of litter decomposability related to the NIR spectra. The predictive equations provide a reference for field experiments on litter material. The method has some drawbacks, and the low accuracy in predicting the results of field experiments may be due to contamination or loss of litter material [31–33]. Bouchard et al. [30] employed the NIRS approach to predict the decomposition of distinct components of litter; in their study, they used chemical substances that revealed the absorption characteristics in the near-infrared spectral region to quickly determine the carbon and nutrients of litter decomposition as well as the stage of decomposition when analyzing the decomposition rate of saline marsh litter. They also predicted the chemical composition of the halophytic litter and its stages of decomposition, which were used to establish and calibrate the prediction equations in the laboratory through microscopic experiments. These calibrated equations were then applied to field data to test to predict %C, %N, and litter mass loss (LML) metrics. When applying external spectroscopy, McLellan and Joffre found in their study that near-infrared spectroscopy (NIRS) can predict the chemical composition of litter material [34]. Gillon concluded that the changes in the content and properties of one or more chemical components of litter material during litter decomposition can be determined by NIRS, establishing a correlation between the spectral characteristics of the initial litter material and the decomposability of litter material [35]. This method is relatively fast and convenient and may bring about an important change in the litter decomposition research methods. In addition, the nuclear magnetic resonance (NMR) technique can determine the decomposition characteristics of different organic carbon fractions of litter matter, to understand the relative stability of different litter matter fractions in soil. Alternatively, the gas chromatography–mass spectrometry (GC/MS) system can observe the molecular composition of litter fractions and link the decomposition characteristics of litter fractions with the formation of soil organic matter, which can be applied to the study of litter decomposition and soil carbon sequestration.

2.2. Decomposition of Wetland Standing Dead Matter

Fresh samples from undecomposed, standing dead, fallen, submerged, and sedimented marshes represent the most common types of late-stage marsh plant development. The actual inundation is divided into two phases; in the process of aerial decay, the quality of litter decomposition decreases considerably, which is accompanied by the microbial activity indicated by the colonization, growth, and mineralization (production of CO_2) that form parts of litter decomposition by microorganisms. Plant decay and mineralization begin simultaneously; therefore, the inversion stage is the decomposition time at water contact [36,37]. Standing dead matter is the litter decomposition of the plant parts that remain on the branches or in the air after dying. The decomposition process of standing dead is unique in that this sample does not come into direct contact with the sediment in the water, the nitrogen and phosphorus contents at the beginning of decomposition are relatively stable, and the nutrient concentration changes in the standing dead part are markedly smaller throughout the process than those of traditionally studied litter decomposition [38,39]. The decomposition of standing dead is closely related to carbon, nitrogen, and other nutrient element cycles [40]. In freshwater marshes, Zhang et al. [41] discovered that increasing nitrogen changes the mass of senescing leaves and that the residual nutrient content of standing dead leaves is negatively correlated with the starting nutrient concentration. Nitrogen significantly affects the decay process of standing dead leaves by changing the initial mass. Nitrogen enrichment from industrial activities substantially affects carbon and nutrient cycling in wetlands, particularly when additional N inputs are considered, and may have a feedback effect on global climate change.

Under natural conditions, the decomposition of standing dead is divided into three processes, namely, leaching and biotic and abiotic processes, and the initial state of decomposition of dead sediment is standing dead, with in situ decomposition being the most critical decomposition stage. Liao et al. [42] evaluated the decomposition rates of three forms of litter—standing dead, surface, and soil in the Yangtze estuary wetlands. They discovered that the standing dead litter had the slowest decomposition rate among the three categories of litter decomposition. The findings presented above suggest that the decomposition rate during the standing dead period may be the slowest in the decomposition of dead sediment. However, this hypothesis has not been adequately tested, and a comparison of decomposition between standing dead and litter remains to be conducted.

2.3. Decomposition of Traditional Litter in Wetlands

2.3.1. The Decomposition Process of Wetland Litter

From a chemical perspective, in the degradation process of plant litter, first, visible plant tissues are decomposed into soluble and insoluble macromolecules. An increasing number of studies [5,43,44] have demonstrated that plant litter initially releases a large amount of unstable C, which promotes the accumulation of soil organic carbon and accelerates the mineralization of native soil organic carbon faster. Next, glycolysis occurs to integrate soluble low molecular organic acids, and the final step is condensation to stabilize H_2S or decomposition to produce CO_2 [42]. The degradation of plant litter is generally divided into three processes: first, the leaching of soluble material through precipitation and immersion, followed by microbial decomposition and nibbling by animals in the soil; second, microbial decomposition of structural components such as cellulose, lignin, and hemicellulose; and finally, abiotic processes such as wet and dry alternation, icing, weathering, and thawing. However, the actual decomposition of wetland litter is usually a cumulative effect of the above three processes.

In wetland ecosystems, leaching is a significant process of decomposition, and nitrogen and phosphorus are generally lost rapidly and in large amounts during leaching, resulting in a dry mass loss of approximately 30% of the litter decomposition; however, the process is short-lived, generally lasting a few days or weeks. One study reported [45] that almost all the inorganic substances persisting in Malaysian eyebrights were leached and released into the water on day 6 of decomposition. Moreover, leaching is often accompanied by the activities of animals in the soil and the abovementioned abiotic processes, which fragment the litter. The fragmented litter is then utilized and microbially degraded by fungi, bacteria, and actinomycetes [46–49], and microbial decomposition mainly depends on the microbial secretion of extracellular enzymes to decompose hard-to-degrade substances, such as lignin, hemicellulose, and cellulose. Table 1 depicts the breakdown of the marsh litter decomposition process.

Table 1. The decomposition process of wetland litter [50].

The Decomposition Process of Wetland Litter	Specific Performance
Initial period	First decomposition of water-soluble material with non-lignin carbohydrates, where lignin increases; the degree of material loss is more significant and the nutrient level limits the decomposition rate.
Medium term	Decomposers break down carbohydrates and lignin, lignin content decreases, decomposing litter composition tends to stabilize, material loss tends to slow down, and the decomposition rate is constrained by lignin.

Table 1. *Cont.*

The Decomposition Process of Wetland Litter	Specific Performance
End of the period	The change in lignin content in the decomposing litter gradually decreases, decomposition is almost at a standstill, and the remaining material is gradually eroded by humus.

2.3.2. Modeling the Decomposition of Wetland Litter

Litter decomposition produces a relatively stable accumulation of substances. However, the decomposition of litter is faster at the beginning and slower toward the end; therefore, mass loss is often described using the single exponential model $X_t = X_0 e^{-(kt)}$, where X_0 is the initial mass, X_t is the mass at time t, and k is the decomposition constant. The second model assumes that some part of the litter does not decompose or that the decomposition rate is meager and characterized by a curve profile close to asymptote because the rate of litter decomposition gradually becomes slower or stops as decomposition proceeds. For long-term decomposition experiments [51,52], the commonly used model can be expressed as $X_t t = X_0 e^{(-kt)} + S$, which is essentially a single exponential model with the asymptote S added to it. The decomposition rates and half-lives of the aboveground parts of the common wetland plants are shown in Table 2.

Table 2. The decomposition rate and half-life of the aboveground parts of common wetland plants.

Wetland Plant Species	Mean k/%	Median k/%	CV/%	t50/d	Reference
Typha orientalis	0.0086	0.0086	—	81	[36,53,54]
Acorus calamus L.	0.0110	0.0110	—	63	[55]
Phragmites australis	0.0039	0.0018	—	180	[56–58]
Juncus effusus	0.0021	0.0021	65	338	[59]
Spartina alterniflora Loisel	0.0025	0.0028	118	21	[60–62]

Notes: Mean k refers to the average decomposition rate of litter per day during the experimental period; Median k refers to the median value when recovering the decomposition rate of litter per day, arranged from large to small or small to large; CV is the coefficient of variation in the decomposition rate; t50/d refers to the time required for the mass to reach 50% of the initial mass during the decomposition of litter.

3. Effect of Decomposition of Litter on the Performance of Wetlands

3.1. Effects of Wetland Soil Biotope Structure

Organisms in the soil are the predominant factor contributing to the rate of wetland litter decomposition, with animal activity including chewing on fragmented and disintegrating litter, along with microbial degradation of components that are difficult to degrade. Microorganisms are a critical link in litter decomposition, and they enable the transformation of nutrients and the decomposition of organic matter [63–65]. Peng et al. [66] investigated the fungal and bacterial community succession of litter breakdown from live plants to various decomposition phases. Fungal communities underwent more marked succession than that of bacterial communities during the breakdown stages. Leaf cellulose, hemicellulose, and lignin levels during litter decomposition are linked to fungal populations. The species variety and richness of microbial communities increase dramatically during litter decomposition, changing community composition and soil interspecific similarity, and contributing to soil ecosystem restoration.

In the early stage of litter decomposition, the number of actinomycetes decreases, and the number of bacteria that can be rapidly converted into degradable carbon sources, such as ammonifying and nitrogen-fixing bacteria, increases. In the middle stage of decomposition, the number of microorganisms that hydrolyze cellulose and nitrifying bacteria increases, and the growth rate is faster than that in the early stage of decomposition [67–69]. In the late stage of decomposition, the energy required for microbial growth decreases owing to nutrient depletion and an increase in lignin content. In contrast, microorganisms promote the release of nitrogen during protein hydrolysis. Soil animals feed on microorganisms or microbial metabolites in the sediment, thereby altering the microbial community structure and affecting litter decomposition. The dominant microbial species in the different types of wetlands are listed in Table 3.

Table 3. Dominant microbial species in different types of wetlands.

Categories	Wetland Types	Dominant Species	References
Fungi	Forest Marsh Wetlands	*Ericoid mycorrhizae* *Cantharellales* *Graminoids*	[70]
Bacteria	Coastal Estuarine Wetlands	*Bacteroides* *Planctomycetes* *Gemmatiomonas*	[71]
	Artificial Wetland (15 years)	*Proteobacteria* *Acidobacteria* *Actinobacteria* *Bacteriodetes* *Verrucomicrobia*	[72]
	Created and Natural Wetlands	*Proteobacteria* *Acidobacteria*	[73]
Bacteria and Archaea	Tidal Freshwater Wetland	*Flavobacteria-Bacteroides* *Acidobacteria* *Proteobacteria* *Euryarchaeota*	[74]
	Restored Tidal Freshwater Wetlands	*Proteobacteria* *Bacteroides* *Euryarchaeota*	[75]

The home field advantage (HFA) of wetland litter decomposition is also related to its effect on microbial community structure. A potential explanation for ecological HFA is that microbial communities have adapted to the plant litter most familiar to them, suggesting that plant litter contains specific decomposers [76,77]. However, consensus on the existence of ecological HFA remains inconclusive, though extensive studies on HFA have been conducted. The suggestion of an HFA is based on the main influences on decomposition, that is, climate, litter quality, decomposer community [78], and substrate–substrate interactions [79]. However, a unified framework for understanding the ecological HFA is currently lacking [80]. Studies in alpine meadow communities to examine whether decomposition rates vary by unabridged soil sources have revealed that a significant HFA exists in systems with low-quality decomposing litter material requiring specialized fungal communities for maximum decomposition. In contrast, any decomposer community can handle high-quality and easily decomposable litter, suggesting that litter home field dominance is strongly related to litter quality. However, other studies have not provided evidence to support the HFA hypothesis [81,82]. Some studies have reported that soil moisture plays a dominant role in certain land use types. Grassland plants did not show home field dominance during decomposition on different land use types. The effect of soil moisture on litter decomposition changed for different land use types—it was greater for grazing/mowing than closed grassland—more so than the changes in litter decomposition quality and microbial communities. One study [83] revealed that the soil denitrification rate increased during weeks of simulated storms, even when the soil was wet. However, the microbial community composition did not change with the changing hydrological cycles. In addition, wetland soil faunal communities were affected by litter decomposition. During litter decomposition, the biomass shares of different feeding functional groups differed, and invertebrates decreased with litter decomposition.

Does this advantage exist in wetland ecosystems? In a transplanting apomictic decomposition experiment, three apomictic species—sedge, silver grass, and reed leaves—were transplanted to the wetland of Poyang Lake. The HFA of wetland litter decomposition was clear, with sedge and silvergrass litter having a home field advantage and reed litter having a home field disadvantage [84]. Primary litter quality (especially total nitrogen and cellulose), enzyme activity, and nutrient release patterns all affected the effectiveness of HFA. Changes in decomposer communities were significantly influenced by decay time, followed by apomixis type and decay site. Differences in decomposer community composition among litter decreased with decomposition time, and the initial mass of wetland litter and decomposer communities (mainly bacteria) together drove the HFA of litter decomposition. In addition to considering the effects of microbial communities and plant species in the soil, it should also be taken into consideration that plant inter-root effects may induce an HFA, and plant inter-root environments are simultaneously affected by wetland hydrological conditions [78]. In a field experiment in a subtropical wetland system, it was found that incubation of three root apomictic species (*Rumex dentatus* L., *Carex thunbergii Steud*., and *Polygonum cripolitanum Hance*) from this wetland ecosystem in the soil microclimate may be important in driving the C cycle, either directly by altering environmental conditions, litter quality, and plant trait profiles, or indirectly by interrupting interactions between litter and decomposers. For these reasons [85], the chemical traits of tropical freshwater swamp forests and non-swamp tree species in Singapore are different, and the rate of litter decomposition ultimately depends on local abiotic conditions such as hydrology.

The role that animals in the soil play in the decomposition of wetlands is often overlooked; the fragmentation of litter by such animals provides not only a food source but also water and energy for the growth and reproduction of microorganisms. Generally, animals in the soil are involved in litter decomposition in two ways: first, by synergistically promoting litter decomposition leaching, and second, by directly ingesting bacteria, fungi, and microbial propagules to alter the physicochemical properties of the surrounding environment, thereby influencing the rate of litter decomposition [86–89]. However, there have been few studies on the influence of animals in wetland soil on litter decomposition, or on the effect of complex interactions between them and microorganisms on litter decomposition, which has important practical implications for wetland plant restoration.

3.2. Effects of Wetland Soil Organic Matter

Soil organic matter (SOM) mainly refers to carbon-containing compounds in the soil, and soil organic carbon is an important indicator for evaluating the quality of wetland soils because of the high carbon storage in wetlands. It is estimated [90] that the carbon loss caused by the destruction of 1 hectare of coastal wetland is equivalent to that of 10–40 hectares of temperate forest, and in wetlands, litter decomposition plays an essential role in maintaining soil fertility and improving soil structure. Litter decomposition releases large amounts of nutrients. Peng et al. [91] designed microstructures and conducted an in situ investigation of carbon emissions from different vegetation zones in the Chongming wetlands to simulate the effects of tidal changes on carbon emissions and litter decomposition in estuarine wetlands on daily and monthly timescales. The results revealed that the added decomposing matter contributed to CH_4 and CO_2 emissions from wetland soils; however, tidal changes in estuaries reduced the contribution of wetland carbon emissions. Fresh litter decomposition inputs promote or inhibit the decomposition of SOM while contributing to an increase in active soil organic carbon content, which is also referred to as the excitation effect [92]. The direction and intensity of the generated excitation effect are related to the composition of newly introduced organic matter. Litter decomposition also affects the organic matter content of the soil. In a study conducted by Di et al. [93] to study the effect of litter decomposition of three plants—*Suaeda glauca*, *Spartina alterniflora*, and *Phragmites australis*—on the microbial carbon (MBC) and soluble organic carbon (SOC) content of wetland soils in the Jiaozhou Bay wetlands, in terms of increasing the rate of mineralization and cumulative mineralization of the soil, *Suaeda glauca* was the most effective, followed by *Spartina alterniflora* and finally *Phragmites australis*. It was observed that different methods of litter decomposition had different effects on soil organic carbon content. In addition, it has been demonstrated [92] that the decomposition of SOM is closely related to litter decomposition quality (N and P content, lignin, lignin/N, and C/N), and Patoine et al. [94] observed that lignin/N is the main factor in the late stage of decomposition. In contrast, in the early stages of organic matter decomposition, the N concentration is the most critical factor that controls the decomposition rate.

In the morphological structure of ecosystems, litter decomposition occurs in the ground cover layer below the tree, shrub, and herb layers. The layer effect of litter decomposition can directly or indirectly affect SOM decomposition through physical, chemical, and biological effects. Further, the litter decomposition layer can intercept solar radiation and adiabatic soil. Therefore, the litter decomposition layer can change the soil temperature, thereby altering the activities of plant roots and soil microorganisms and changing the rate of SOM decomposition [95]. Another critical source of wetland SOM is the inter-root carbon deposition effect, where plant roots release root organic and inorganic matter into the soil. Studies have shown [96] that 30–60% of net plant primary productivity is used in the underground root system during a year, of which 40–70% is released into the inter-root layer as organic carbon.

3.3. Impacts of Wetland Sediment Properties

Organic matter and total nitrogen in wetland sediments are essential indicators of soil fertility, and their content directly or indirectly affects the growth of the surrounding vegetation. When the content was excessively high, severe eutrophication of the sediment was observed. Litter decomposition is an essential component of sediment organic matter in wetlands. Some researchers observed that the contribution of mutualistic rice grass litter decomposition to sediment organic matter during decomposition could reach 37–100%, and mangroves could reach 6.36–36.88% [97]; Yan et al. [5] investigated the effect of leaf and stem litter inputs on SOC dynamics under 13C isotope-based techniques and showed that the contribution of leaf and stem litter carbon inputs to total soil organic carbon was increased by 37.6% and 15.5%, respectively. Wetland litter decomposition and sediment-associated β-glucosidase are essential drivers of sediment surface formation, respectively (Figure 2).

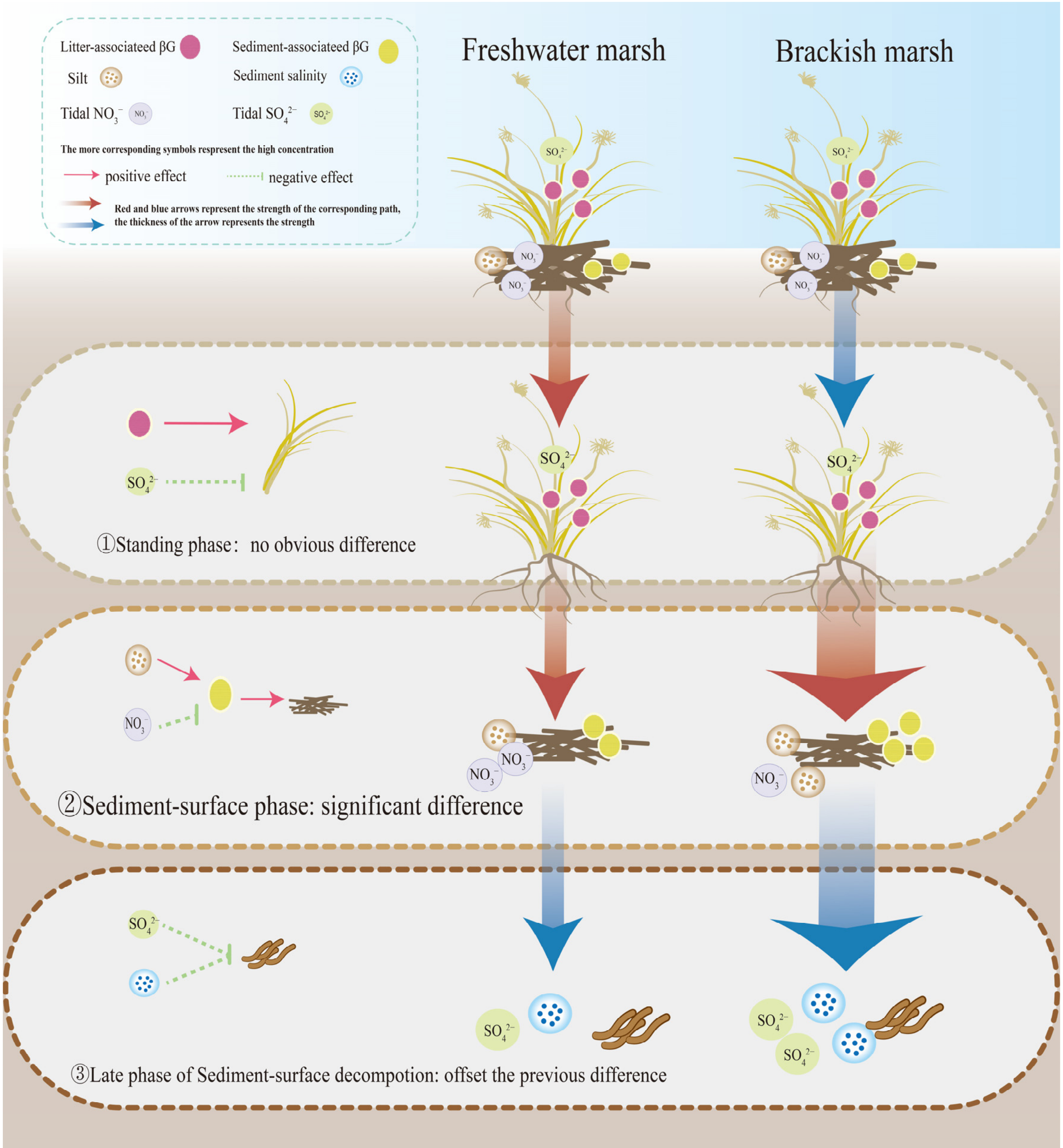

Figure 2. Schematic diagram of litter decomposition in the saltwater marsh and freshwater marsh [98].

Uncertainties remain regarding the relative contributions of different plant carbon input sources (litter decomposition versus inter-root sediment) to soil-soluble organic matter, which may limit our understanding of soil carbon dynamics. This study aimed to investigate the effects of plant carbon inputs from inter-root deposition and decomposition of litter material (leaves, stems, rhizomes, and root litter material) of *P. australis* on SOM composition. The effect of inter-root deposition on soil soluble organic matter altered the soil salinity and increased soluble organic matter and xanthate C3 content under saline conditions. This may have resulted from differences among plant tissues, with the more complete decomposition of leaves and stems and a significant increase in fulvic acid C3 content. These findings highlight that inter-root deposition and litter decomposition markedly influence soil-soluble organic matter [99]. In addition, litter decomposition promotes the release of Fe and Mn in sediments. Some researchers assessed the rate of litter decomposition and release of trace elements using mixed litter decomposition of *Larix gmelinii* in a forest system with plantations and found that litter quality significantly affected N and Mn release, with an increase in the average content of Mn [100]. In addition, in a study on the litter decomposition of dominant tree species in China, metals commonly accumulated in trace elements during root decomposition [101]. In conclusion, wetland plant litter decomposition is a significant component of wetland carbon sources and is a key factor affecting sediment fraction changes.

4. Conclusions and Future Perspectives

The decomposition of wetland plant litter occurs through three processes, namely, leaching and biotic and abiotic processes. As wetlands are remarkable terrestrial and aquatic ecosystems, their decomposition process is slightly different from that of the litter in traditional areas, such as forests, grasslands, and meadows. In addition, decomposition leads to the input of foreign substances owing to the metabolism of soil organisms, activities, and environmental factors, which, in turn, cause changes in the performance parameters of wetlands, such as soil structure, SOM, and sedimentation. Currently, research on the decomposition of wetland plant litter remains to be matured, mainly in the following regards.

(1) Decomposition of matter above- and belowground. Most studies have revealed that the rate of litter decomposition is considerably faster than that of root litter decomposition and that there is a substantial difference between above- and belowground litter decomposition [102]; this difference and its effects are not well understood, and the influences of root litter decomposition and soil physicochemical properties remain unclear.

(2) Mixed litter decomposition. The decomposition rate of mixed litter is usually more unstable than that of single litter [103]. Few studies have been conducted on the mechanism and model of hybrid litter decomposition, though the decomposition process has little relevance for wetlands.

(3) The effects of matter decomposition on the sorption properties of wetland soils. Litter decomposition promotes the decomposition of organic matter in the soil, changes the physical and chemical properties of the soil, and improves soil structure. With the sub-discharge of industrial wastewater, wetland soils are increasingly polluted by heavy metals, and soil adsorption of heavy metals can reduce their mobility. However, the effect of litter decomposition on the ability of soil to fix heavy metals and other pollutants remains unclear.

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