Wetland Influence on Downstream Organic Composition in Temperate Regions

Wetland ecosystems (especially forested swamps common in New England and similar temperate regions) are major sources of dissolved organic matter to downstream watersheds. As water flows through wetland soils and plant litter, it leaches a complex mix of organic compounds. These compounds and the biological processes in wetlands significantly shape the organic chemical composition of streams and rivers that drain them. Below we outline the key types of dissolved organic compounds (DOC) wetlands contribute, the role of microbial communities in transforming this organic matter, and how seasonal patterns, weather, and water residence time affect the degradation (biological and photolytic) of DOC.

Types of Dissolved Organic Compounds from Wetland Plants and Soils

Wetland plants (trees, shrubs, mosses) and peat-rich soils release a variety of dissolved organic compounds as they decompose. Key DOC components from wetlands include:

- **Humic substances (fulvic and humic acids):** These large, dark-colored molecules form from the breakdown of plant material (notably lignin and cellulose) and give wetland water a tea-brown color edis.ifas.ufl.edu
. Humic substances are high in aromatic carbon content and can bind metals and nutrients. Their presence in lakes and rivers often indicates strong wetland influence in the watershed edis.ifas.ufl.edu
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- **Lignin-derived phenols:** Wetland soils export biomarkers of vascular plant tissue decomposition such as lignin phenols (e.g. vanillyl, syringyl, and cinnamyl phenols). These originate from woody plant litter and contribute to the aromatic fraction of DOC. Wetland-derived dissolved organic matter is often "humic-like," rich in lignin breakdown products and other aromatics repository.library.noaa.gov
. High concentrations of lignin phenols in stream water are a signature of inputs from peatlands, swamps, and forest floor litter.
- **Tannins and other polyphenols:** Many wetland plants (leaves, bark, roots) contain tannins, which are complex polyphenolic compounds. As leaves and wood litter soak in water, tannins leach out, adding color and astringent properties to the water. Wetland-exported organic matter tends to be high in such polyphenols with high molecular weight and aromaticity repository.library.noaa.gov
. These tannin-rich contributions are especially pronounced in autumn when leaf litter accumulates, often causing spikes in humic, phenolic DOC downstream mdpi.com
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- **Carbohydrates and other labile organics:** In addition to recalcitrant humics, wetlands release more labile compounds. Carbohydrate-rich molecules from plant sap, cellulose

fragments, and microbial by-products dissolve into the water. Freshly produced DOC from algae, aquatic plants, or recent leaf litter tends to consist of low-molecular-weight compounds (such as simple sugars and organic acids) that are readily biodegraded edis.ifas.ufl.edu
. This labile DOC fraction, though short-lived, serves as an important energy source for microbes in downstream ecosystems.

- **Organic acids and other molecules:** Wetland decomposition also generates small organic acids (e.g. acetic, propionic acid), alcohols, and other soluble molecules. For example, peat soils can leach fulvic acids (a type of humic substance) as well as low molecular weight acids. In waterlogged, oxygen-poor conditions, partial decomposition produces fermentation by-products like short-chain fatty acids and alcohols that contribute to the DOC pool. These various compounds reflect the diverse chemistry of wetland inputs, ranging from complex humics to simple metabolites.

Role of Microbial Communities in Transforming Organic Matter

Microbial communities (bacteria, fungi, and archaea) in wetlands play a central role in breaking down and transforming organic matter, thereby altering the composition of DOC that flows downstream. In the saturated, often oxygen-poor soils of swamps, decomposition is dominated by microbes using anaerobic processes. **Fermentation** is a primary mode of organic matter degradation in waterlogged peat and sediments, where microbes break down complex plant polymers into smaller compounds like organic acids, alcohols, and CO_2

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. For instance, studies of temperate wetland sediments show accumulation of fermentation products (ethanol, isopropanol and others) as intermediate stages in the decay of plant material
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. These fermentation by-products can subsequently fuel other microbes (e.g. methanogens that convert acetate and hydrogen to methane in anoxic conditions). In aerobic microzones (such as shallow water or soil surfaces), **microbial respiration** occurs, where heterotrophic bacteria and fungi mineralize DOC completely to CO_2 (or to CO_2 and water), consuming any available oxygen in the process. Thus, wetland microbes orchestrate a chain of processes: initial enzymatic breakdown of large organic molecules, fermentation of the resulting monomers in anaerobic zones, and aerobic/anaerobic respiration that ultimately converts part of the organic carbon to gases (CO_2 or CH_4). This microbial processing can remove a portion of DOC or transform it into more bioavailable forms for downstream food webs.

Wetland microbes also **alter the chemical character of DOC** through selective consumption and production. Labile compounds (such as simple sugars, amino acids, etc.) are rapidly consumed – their turnover in wetlands can be on the order of multiple times per day

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. In contrast, complex aromatic molecules (humic and phenolic compounds) are more resistant; specialized microbes (including certain fungi and bacteria) produce extracellular enzymes like phenol oxidases to slowly break these down
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. This process converts recalcitrant high-molecular-weight DOM into smaller, more labile forms that other microbes can then utilize
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. Over time, even the "recalcitrant" fraction (which dominates wetland DOC) is incrementally degraded by microbial activity in the wetland or downstream. However, the rate of microbial decomposition in wetlands is relatively slow compared to physical export processes. In fact, the persistent humic fraction in wetland waters can sometimes inhibit microbial degradation until other processes (like photochemical breakdown) act on it
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. Microbial communities are therefore crucial in transforming the organic matter: they decompose plant litter into dissolved compounds, ferment and respire those compounds, and ultimately influence which DOC components remain (or are produced anew) in water leaving the wetland.

Effects of Weather, Seasons, and Water Residence Time on DOC Degradation

Environmental conditions – from seasonal temperature changes to rainfall patterns – strongly influence how DOC is processed or persists in wetlands. These factors affect both **biological degradation** by microbes and **photolytic degradation** by sunlight:

- **Seasonal temperature and biological activity:** Microbial decomposition in wetlands accelerates in warm conditions and slows in cold. During summer, higher temperatures and abundant microbial activity enhance the breakdown of organic matter (increasing respiration and fermentation rates). In winter, cold temperatures (and in New England, soil freezing or ice cover) suppress microbial metabolism, so organic matter accumulates and DOC persists longer. As a result, DOC exported in winter may be less processed (richer in high-molecular-weight compounds) compared to summer. When spring arrives, thawing and warming can lead to a surge in microbial decomposition of the accumulated litter, potentially releasing a flush of DOC into streams.

- **Organic matter inputs and fall leaf drop:** Seasonal changes in vegetation input affect DOC quality. In autumn, deciduous swamps receive an influx of freshly fallen leaves that leach dissolved organic compounds (especially tannins and other polyphenols). This leads to higher DOC concentrations and a greater proportion of humic, aromatic compounds in downstream waters during the fall
  mdpi.com
  . Studies show that riparian leaf litter inputs in the fall commonly raise stream DOC levels and increase humic-like DOM dominance mdpi.com
  . Likewise, spring and summer plant growth can contribute labile DOC (e.g. exudates

from wetland plants and algae), whereas in autumn the input skews toward more refractory, aromatic litter leachate.

- **Sunlight and photolytic degradation:** The amount of solar radiation a wetland receives (which varies with season and canopy cover) controls photochemical breakdown of DOC. Sunlight, particularly UV, can directly degrade dissolved organic molecules. Humic substances absorb sunlight and can be photolyzed into smaller compounds or mineralized to CO_2. Notably, natural sunlight can break down the humic fraction of DOM much faster than microbes can in some cases
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. Experiments have shown that solar radiation rapidly degrades humic DOM that is otherwise resistant to microbial decay edis.ifas.ufl.edu
. During sunny summer months, shallow wetlands and surface waters experience significant photodegradation of DOC, which bleaches the water color and produces more bioavailable by-products. In contrast, during winter or periods of low light (or under thick forest canopies), photolytic processes are reduced, allowing more high-color, high-MW DOC to persist. Sunlight exposure can also work in tandem with microbes – by breaking large molecules into more digestible forms, photolysis can **enhance subsequent microbial utilization** of wetland DOM repository.library.noaa.gov
. Thus, seasonal daylight availability and wetland water transparency govern how much of the DOC is lost or transformed via photochemical pathways.

- **Hydrologic events (rainfall and runoff vs. drought):** Weather patterns that alter water flow have immediate impacts on DOC export and processing. Intense rainfall and high-flow events tend to **flush out** accumulated DOC from wetlands into streams. As the water table rises and runoff increases, DOC that built up in peat and surface soils is mobilized, often resulting in spikes of aromatic, humic-rich DOC in downstream waters
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. For example, in a forested headwater stream of Massachusetts, higher discharge was linked to increased export of humic, high-aromatic DOM from the surrounding wetland soils raymond-lab.yale.edu
. Wet periods with greater hydrological connectivity between wetlands and streams deliver large pulses of terrestrially derived DOM via shallow groundwater flowpaths
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. In contrast, during dry weather or drought, water flow through wetlands is reduced and the connectivity to streams drops. Low-flow conditions often mean **longer water residence time** in the wetland and greater opportunity for in situ DOC processing. Extended dry periods can actually concentrate DOC in remaining pools but also allow more complete microbial degradation of labile fractions. One study noted that during a drought, the prolonged residence time increased the potential for DOM removal within a wetland via microbial respiration, photodegradation, and other processes
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. Additionally, drought can expose wetland soils to air, shifting decomposition from anaerobic to aerobic pathways and causing a burst of nutrient and DOC release when re-wetted edis.ifas.ufl.edu
. Thus, heavy rains and fast flow tend to export DOC downstream with minimal

processing, whereas dry spells slow the flow, enabling more local breakdown or alteration of DOC.

- **Water residence time in wetlands:** The duration water spends in a wetland (which is influenced by hydrology and wetland size) is a key factor in DOC fate. **Short residence times** (quick throughput) mean DOC generated in the wetland is swiftly delivered downstream with little change. **Long residence times** give DOC more exposure to both microbial metabolism and sunlight. In a wetland with stagnant or slow-moving water, microbes have more time to consume labile organics and even gradually attack recalcitrant DOC, and sunlight has more opportunity to penetrate and photochemically alter the DOM. Longer residence (for example, in a large swamp or during seasonal low flow) has been associated with greater overall loss of DOC (through mineralization or sorption) and a shift in the remaining DOC toward more refractory components
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  . In practical terms, a headwater swamp that acts as a sink can retain and transform a portion of the incoming organic carbon, whereas a quick-draining wetland will mostly pass its organic load downstream. Management and studies of temperate wetlands have noted that residence time, along with factors like water depth and mixing, controls the balance between DOM export versus internal processing (via microbial uptake, photodegradation, or peat adsorption) pmc.ncbi.nlm.nih.gov
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In summary, New England swamps and similar temperate wetlands supply downstream waters with abundant dissolved organic carbon, particularly rich in humic substances, lignin-derived aromatics, tannins, and other plant-derived compounds. Microbial communities in these wetlands decompose and transform the organic matter through processes like fermentation and respiration, influencing which DOC compounds persist or become more bioavailable. The interplay of climate and hydrology – seasonal temperature shifts, leaf fall, sunlight exposure, flood vs. drought cycles, and water residence time – further governs the extent to which wetland-derived DOC is degraded in situ or exported. **Wetlands often export highly colored, aromatic DOC under wet conditions, and this material can be partially broken down by microbes and sunlight along the way**

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. Meanwhile, long quiescent periods allow wetlands to act as biogeochemical "processors," attenuating the organic load through microbial uptake and photolysis before it ever reaches downstream ecosystems
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. By understanding these dynamics, researchers can better predict how changes in weather or land use will affect carbon and nutrient fluxes from wetlands to receiving waters.

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