Summary of Doctoral Thesis

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Title	Impact of flooding on soil-water physicochemical properties and microbial communities in floodplain soil

Flood duration and flood frequency are predicted to increase due to climate change. These flood events govern hydrological regimes and biogeochemical processes, influencing carbon and nutrient cycling, soil functioning, and a wide range of biotic and abiotic interactions. Moreover, the impacts of these floods are intensifying, putting ecological areas at risk, especially those in water level fluctuation zones. These areas serve as biogeochemical hotspots for carbon and nutrient cycling. Therefore, understanding the environmental fate of biogeochemical processes, including physicochemical properties and microbial communities interactions, is crucial in wetland soil-water ecosystems during and after flooding. Although wetlands account for only 6–9% of total land, their carbon stocks contribute to 35% of the global carbon reservoir. Carbon, a major component of dissolved organic matter (DOM), predominantly exists in the form of organic carbon. Despite DOM representing a small proportion of the soil organic matter (SOM), < 2% of the total SOM, it is one of the most active components in ecological environments, serving as a crucial nutrient and energy source for microorganisms. And, soil microbes play a vital role in biogeochemical cycling by regulating SOM decomposition, releasing nutrients, and maintaining soil health.

Many studies have revealed the impacts of floods on carbon and nutrient dynamics in aquatic ecosystems. However, limited attention has been given to wetland ecosystems, particularly river floodplains, which are highly sensitive to hydrological changes and play a vital role in DOM export and import. Thus, further investigation into the effects of both flood duration and flood frequency in river floodplain ecosystems, including physicochemical properties (i.e. basic properties and DOM composition) and microbial communities, is needed. Addressing this knowledge gap provides valuable insights into nutrient and carbon cycling in floodplain soils affected by floods. This study, which serves as a bridge connecting the findings from lab-scale experiments to future on-site investigations, aims to explore the impact of floods on soil-water ecosystems within river floodplains/wetlands.

Initially, this study focused on the effect of flood duration on the interaction among microbes, DOM and physicochemical properties (i.e. microbial-physicochemical interactions) in river floodplain soil during and after flooding. A flood simulation was carried out through a column experiment in a controlled lab setting, using topsoil (0–10 cm) from a river floodplain in Japan. A moderate flooding depth (15 cm) was subjected to short-term (1 and 3 d), moderate-term (8 d), and long-term (16 and 30 d) flooding. After flood simulation, soil and water affected by the different flood durations, i.e. 1, 3, 8, 16, and 30 days of flooding (FDs), were investigated. Subsequently, the post-flooding soils were monitored by collecting the soils immediately after flooding (iAF), 2, 5 and 30 days after flooding (DAF) under 3, 8 and 16 FDs. This flood duration experiment was divided into four phases. Firstly, the impact of flood duration (i.e. 1, 3, 8, 16, and 30 FDs) on the water quality was examined, focusing on dissolved oxygen (DO), quantity and quality of DOM and its sources, and trace elements in floodwater, as well as the interaction between floodwater and flooded soils. The results indicated a significant decrease in DO at eight days of flooding (8 FDs), which then remained stable until 30 FDs. Prolonged flooding (up to 30 d) increased DOM aromaticity while depleting DO in the floodwater. Moreover, elevated soil pH enhanced the mobilization of trace elements, including macro- (Na, Mg, K, Ca) and micro- (Mn, Fe, Ni, As) elements, promoting their chelation with DOM compounds. During flooding, the breakdown of soil aggregates released bound metals, contributing to DOM and heavy metal mobilization. This resulted in increased these elements in floodwater, potentially affecting the quality of the receiving water body.

The second phase was to investigate the effect of flood duration on soil properties and water-extractable dissolved organic matter during and after flooding. The study found that flood duration increased soil pH and electrical conductivity (EC), influencing water-extractable organic carbon (WEOC) and total dissolved nitrogen (TDN) in flooded soil. Post-flooding soil properties and DOM variables varied with time; for example, extended post-flooding periods (up to 30 d) resulted in increased soil EC, DOM fluorophore to WEOC ratio, and TDN, with a smaller molecular weight size in DOM (increased E2:E3 ratio). Additionally, flood durations and post-flooding periods influenced DOM composition through soil physicochemical parameters, such as pH and EC, as confirmed by the structural equation modeling. In the third and fourth phases, the study extended the investigation by examining the interactions between soil microbial communities and soil physicochemical properties during and after flooding, respectively. The study showed that 8 FDs shifted soil from aerobic to anaerobic conditions, while the soil after 5 days in the drying processes was crucial for transitioning back to aerobic conditions, influencing soil microbial community and diversity. Flood duration increased the relative abundance of Firmicutes, Actinobacteria, Bacteroidetes and Chlamydiae, which are key bacteria playing an important role in SOM degradation and nutrient releases under the flooding. Moreover, both flood durations and post-flooding periods could either increase or decrease soil bacterial community and diversity, depending on various environmental factors. For example, soil physicochemical properties, such as pH, EC, SOM, WEOC, TDN, and relative DOM, had direct and indirect effects on soil bacterial community and diversity, influencing nutrient cycling. Furthermore, prolonged flooding led to a decrease in bacterial diversity due to DO depletion, while simultaneously promoting an increase in bacterial diversity through SOM degradation. Whereas, extended post-flooding period resulted in increased microbial DOM production, accompanied by a degradation of humic substances in soil. These findings provided insights into SOM decomposition and transformation resulting from soil microbial-physicochemical interactions during and after flooding in river wetland soils.

Afterward, this study further investigated the impacts of flood frequency (repeated flooding) on soil microbial-physicochemical interactions by conducting another column experiment using soil from the same area, a river floodplain in Japan. Similarly to the previous experiment, changes in soil physicochemical properties and soil microbial communities of the flooded soils iAF, 5, 15, and 30 DAF were investigated under one-, two-, or three-time floods (i.e. 1-flood, 2-flood, or 3-flood) at 30-day intervals of the drying processes. Principal component analysis revealed significant variations in both repeated flooding and post-flooding effects on soil properties and DOM variables. The post-flooding effect separated flooded soils into three groups: iAF-5 DAF, 15 DAF, and 30 DAF, and these three groups were clearly separated from the first initial soil. On the other hand, the repeated flooding effect demonstrated an obvious distinction between 1-flood and 2-flood versus 3-flood. Moreover, repeated floods (up to 3 times) led to increases in protein-like fraction (tryptophan-like), accompanied by SOM and humification DOM (HIX) degradation, resulting in decreases in the C:N, pH, and a reduction in DOM molecular weight size. Conversely, increased post-flooding days elevated the fluorescence index (FI) and EC, releasing nutrients (TDN content) with smaller molecular sizes (increased E2:E3) due to biological processes (increased BIX) under reduced water content (WC), together with decreased humic-like fractions. These changes are likely a result of complex interactions between microbial activity and organic matter decomposition and associated biogeochemical processes. Furthermore, the increases in relative abundance of Acidobacteria, Proteobacteria, Bacteroidetes, Chlamydiae and Nitrospirae were coupled with SOM and HIX degradation, resulting in the release of soil nutrient (protein-like fraction); this coincided with increased soil acidity and EC due to decreased soil moisture. This finding indicated that these bacteria play important roles in responding to changes in soil traits, functioning in SOM degradation and nutrient releases. This revealed the complex interactions among microbial-physicochemical properties, providing insights into nutrient cycling in river wetlands. Overall, the present study had significant implications for simulating soil nutrients and functions in areas with hydrological fluctuations, which will be enhanced by the increases in frequency and duration of floods under climate change.