[SI-2]

Wetland Biogeochemistry and Environmental Challenges

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1. Backgrounds on and importance of wetlands

1) Definition and distribution of wetlands

Wetlands are transitional zones between terrestrial and aquatic ecosystems, having many distinguishing features. In spite of high diversity of wetland types, they are often characterized by the presence of standing water, a unique type of soil (e.g., hydric soils), and the dominance of hydrophilic vegetation.
Globally, wetlands are concentrated in the high latitudes of the north (50-70 ° N), mainly as peatlands, and in the tropic (20 ° N - 30 ° S) mostly as swamps. In the temperate regions, wetlands can be developed along rivers as riparian systems or marshes at estuaries.

2) Importance of wetlands

From a global perspective, r3
First, many wetlands, northern peatlands in particular, are a net carbon sink. It was reported that boreal and subarctic peats alone contain 455 Pg of carbon, which is comparable to the total atmospheric carbon storage of 670 Pg. As the atmospheric concentration of CO_2 is increasing continually along with the greenhouse effects from such increment, carbon dynamics of wetlands is of great importance in global carbon cycling. Secondly, wetlands are a substantial source of other greenhouse gases such as CH_4 and N_2O, which are 25 times and 300 times more radiatively active gases, respectively, than CO_2 on molar basis. For example, approximately 25% of annual CH_4 emissions are originated from wetlands including rice paddies. Likewise, more than 30% of annual N_2O emission is contributed by humid tropical forests which are rich in wetland areas. Thirdly, riparian systems (natural) or constructed wetlands (artificial) have been widely studied and applied for water quality amelioration. The physical location and ecological functions allow them to sequester and transform various nutrients which might cause eutrophication of lower aquatic ecosystems. Wetlands have been successfully employed to remove BOD, suspended solids, inorganic nutrients (e.g., nitrate and phosphate), and heavy metals. The details mechanisms are not yet fully understood, but plant and algal uptake, microbial assimilation and transformation, absorption to soil matrix, chemical

precipitation, and loss by insect and fish uptake have been delineated as some of the major mechanisms.

2. Significance of enzymes in organic matter dynamics in wetlands

1) Controlling variables of enzymes in diverse wetlands

In laboratory conditions, temperature, pH, and water content have been acknowledged as key controlling variables of enzymes in wetland soils. A intensive field survey of three natural wetlands in north Wales, and a global survey of various types of wetlands revealed several major controlling variables of the enzyme activities in field conditions. Phosphatase is strongly affected by pH, while arylsulfatase activity is mostly influenced by temperature. Water table draw-down increased enzyme activities, possibly by increasing the redox potential, whereas phenolics in wetland pore-water appeared to inhibit enzyme activities. Carbon mineralizing enzymes (β-glucosidase, cellobiohydrolase, and β-xylosidase) seemed to be influenced by the quality and quantity of dissolved organic carbon in the wetland (Figure 1). The influence of the existence of vegetation on enzymes appeared to be facilitated by influencing microorganisms, which were the main source of enzymes in wetlands.

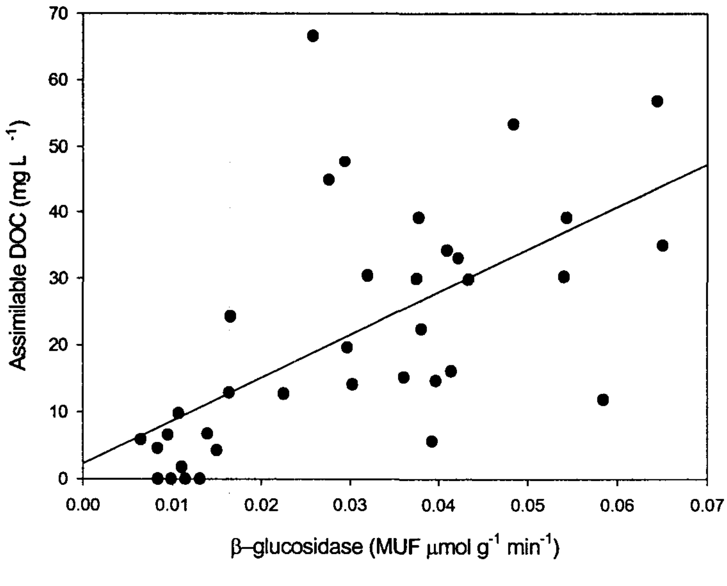

Figure 1. Relationship between β-glucosidase and assimilable DOC

2) Enzyme activities and trace gas emission

Positive correlations between carbon mineralizing enzyme activities and trace gas emissions (CO_2 and N_2O) were found when data from three wetlands were composited (Figure 2). Laboratory-based manipulation experiments (i.e., enzyme-addition experiments) confirm the field observation. However, the same approach exhibited no significant correlations between the enzyme activities and CH_4 emission. Other factors (inhibition by SO_4^{2-} or the effects of water table) were more dominant controlling variables for CH_4 emission than carbon supply through enzyme reactions.

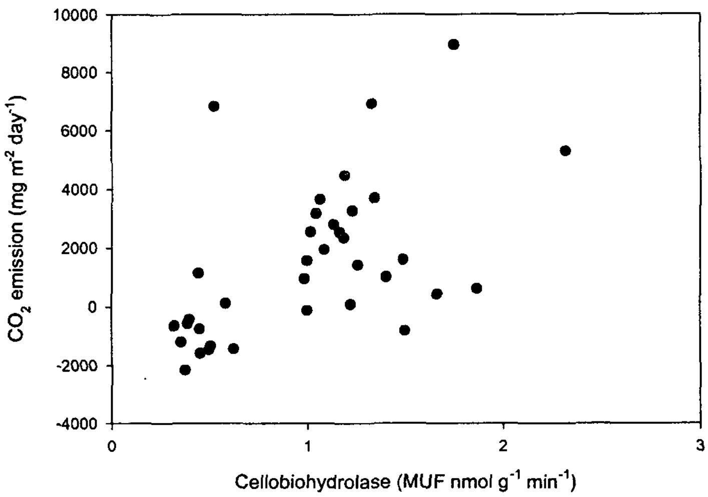

Figure 2. Relationship between cellobiohydrolase and CO_2 emission

3. Wetlands and water quality improvement

1) Constructed wetlands and inorganic nutrients removal

Wetlands have been reported to function as sinks or transformers for various pollutants including nutrients, and have consequently been widely applied for water quality amelioration. Many studies have shown that wetlands have a substantial efficiency in the removal of high loadings of BOD, suspended solids, inorganic nutrients, and enteric bacteria. In addition, the results of my studies have suggested that constructed wetlands would be a valuable tool as an advanced water treatment facility. Surveys conducted in three different wetlands in USA and Korea showed that around 50% of inorganic nitrogen and phosphorus were removed from the water body, of which inflow concentrations were low (e.g., 2-3 mgL^{-1} of TN, 2 mgL^{-1} of

TP). It is widely known that phosphorus is treated mainly through soil absorption or organic matter accumulation, while denitrification is the key process by which nitrogen is removed. However, studies for optimized designs for constructed wetlands is still warranted, because the two processes are maximized in different physico-chemical conditions.

2) Impediment of enzyme activities in wetlands

There is a close relation between the nutrient retention and accumulation of organic matter in wetlands. First, the immobilized nutrients should be 'locked-up' as organic matter to be retained in the wetlands. Secondly, the accumulation of organic matter also affects other removal functions such as denitrification and phosphorus absorption. Since the accumulation of organic matter is determined by the balance between productivity and the rate of decomposition, it is anticipated that organic matter decomposition and enzyme activities in wetlands would be lower in wetlands compared to those in adjacent uplands. The results of my study clearly showed that enzyme activities decreased in wetlands, which was attributed to lower microbial biomass as well as inhibition of immobilized enzymes by various ions including Fe.

4. Global climatic changes and feedback from wetlands

Recent global circulation models suggest that conditions which ensure the integrity of wetlands may eventually be compromised as a consequence of global climatic changes, such as elevated CO_2 concentrations in the atmosphere, increased temperature, and increased frequency of droughts. Impacts of such changes are of great importance in the stability and persistence of wetlands themselves as well as other ecosystems (e.g., aquatic systems). Several experiments were conducted to reveal possible impacts and consequences of such global climatic changes on wetland biogeochemistry.

First, elevated CO_2 conditions induced significantly higher biomass (root + shoot + algal mat), higher emissions of N_2O and CO_2, and higher concentration of pore-water DOC (dissolved organic carbon) in the wetland cores. However, no significant differences were found in CH_4 emission or soil enzyme activities (β-glucosidase, phosphatase, and N-acetylglucosaminidase) in the bulk soil. No changes in CH_4 emission was attributed to enhanced CH_4 oxidation under elevated CO_2 conditions, which offset higher CH_4 production (Figure 3). Overall results of my study suggest that elevated CO_2 will induce higher primary production and DOC input in northern peatlands, which then may result in a positive feedback to global climatic changes by releasing more greenhouse gases back to the atmosphere.

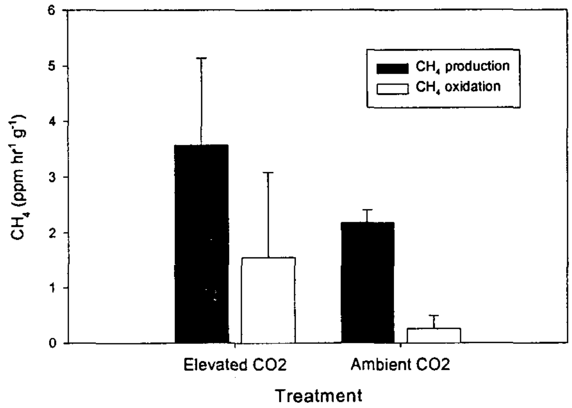

Figure 3. Effects of elevated CO_2 on CH_4 production and oxidation in norther fen peat

Secondly, higher temperature would accelerate microbial decomposition in the northern wetlands resulting in higher trace gas emissions and DOC supply to aquatic ecosystems. This result indicate that northern wetlands may lose their role as a net carbon sink, turning into carbon source from a global perspective.

Finally, water table draw-down may create conditions where CO_2 emission increases while CH_4 emission decreases. Detailed biochemical analysis revealed that the regulation of CH_4 flux occurs primarily through decrease in CH_4 production rather than enhanced CH_4 oxidation (Figure 4).

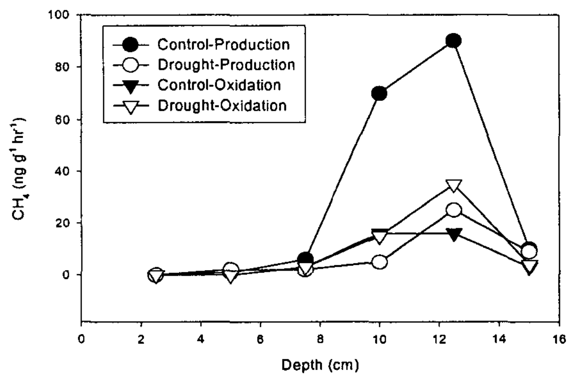

Figure 4. Effects of water table draw-down on methane production and oxidation in drought-simulated and control wetlands