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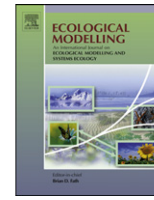

Effects of plant species on macrophyte decomposition under three nutrient conditions in a eutrophic shallow lake, North China

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ABSTRACT

Macrophyte decomposition can significantly influence aquatic carbon and nutrient cycling, especially in eutrophic shallow lakes, in which incomplete decomposition of detritus may lead to sediment accumulation and accelerate lake aging. In order to explore the role of macrophyte decomposition in lake terrestrialization, six major aquatic plants (two submerged, two floating, and two emergent species) in Lake Baiyangdian were investigated in this study. Detritus of these species were placed at three sites with different pollution intensities to investigate the contributions of plant species, site nutrient condition, and their interactions on detritus decomposition. Detritus decomposition was represented by detritus mass remaining at each sampling time. Results of this study suggest that although decomposition processes are species and site specific, and the effects of species are stronger than site conditions. Initial detritus phosphorus (P)-related indicators were proved to be effective controllers for detritus decay at the later stage of the experiment. Significant interactions between site and species indicate that plant species also influenced site controls on detritus mass loss. Site effects on decomposition were significant for submerged and floating species ($P < 0.01$), and slightly significant for emergent species ($P < 0.05$). A mathematic two-stage decomposition model was developed based on the experimental results using stepwise analysis to analyze effects of detritus quality and site conditions on decomposition. The detritus quality indicators were the main contributors for both early and later stages of detritus decomposition, while the site nutrients only affected decomposition at the later stage.

1. Introduction

Macrophyte decomposition is an essential process in carbon (C) storage and nutrient cycling for eutrophic shallow lakes (Carpenter, 1980; Debusk and Reddy, 2005). Enhanced primary production due to enriched environments and increased organic material accumulation because of the incomplete decomposition can reduce lake water area and raise water level, accelerating lake terrestrialization (Partanen and Luoto, 2006; Papastergiadou et al., 2007; Liao et al., 2008). Therefore, improved knowledge of characteristics of decomposition for different plant species is needed to better understand ecological processes in eutrophic shallow lakes.

Detritus quality, defined as chemical characteristics of decomposition substrate, is considered as the main determinant of detritus decomposition (Nziguheba et al., 1998; Villar et al., 2001; Kim and Rejmánková, 2005; Chimney and Pietro, 2006; Shilla et al., 2006). Plant species vary widely in detritus nutrient contents and differ greatly in the decomposition rates (Hoorens et al., 2003; Alemanno et al., 2007). High decomposition rate species are generally characterized by high contents of initial nitrogen (N) and phosphorus (P), and low values of initial C:N, C:P, and N:P ratios. Concentrations of detritus nutrients significantly impact early leaching and subsequent chemical decomposition stages (Aerts and De Caluwe, 1997; Berg and McClaugherty, 2008). Recently, many studies have suggested that lignin:N ratio, an indicator of carbon quality, was significantly related to decomposition rate (De Neiff et al., 2006). However, the C:N ratio performs better than the lignin:N ratio in describing decomposition rate when plant detritus contains a broad range of lignin content (Taylor et al., 1989).

Aquatic environmental conditions also influence detritus decomposition. In aquatic ecosystems, temperature, pH, and nutrient availability in water columns are considered to be important indexes that control detritus decomposition (Royer and Minshall, 2001; Rejmánková and Houdková, 2006; Cunha-Santino and Bianchini, 2008). It is recognized that higher nutrient availability in the environment generally supports faster decomposition rates (Newman et al., 2001; Gulis and Suberkropp, 2003; Gulis et al., 2006; Breeuwer et al., 2008). Most studies assumed that the effects

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of environmental condition on decomposition are identical for all types of species (Hobbie, 2000; Hobbie and Gough, 2004; Breeuwer et al., 2008; Austin et al., 2009; Lang et al., 2009). However, the significant interaction between species and site in these studies suggest that site quality effects on decomposition may vary with the plant species.

In eutrophic lake ecosystems, the enriched nutrient content can create a favorable habitat for aquatic macrophyte growth. As a result, macrophytes usually spread rapidly in this kind of ecosystem. Macrophyte decompositions are important for the development of lakes. Although plant detritus from enriched environments is often characterized with high nutrient contents and high decomposition rates (Aerts and De Caluwe, 1997; Villar et al., 2001; Debusk and Reddy, 2005), a substantial part of dead plant tissues can accumulate in lake sediment due to incomplete decomposition and contribute to organic material accumulation (Chimney and Pietro, 2006). Lake sediment layers are raised and further stimulate the overgrowth of macrophytes. Because the increased macrophytes and reduced lake area can greatly damage animal habitats and accelerate lake succession, detritus decomposition is important for many ecological processes of nutrient-enriched lake ecosystems. Meanwhile, since nutrient conditions in eutrophic lakes can vary spatially due to various pollution sources, detritus decomposition often demonstrates spatial heterogeneity and further complicated the decomposition studies in this kind of lakes. To better understand how detritus decomposition is controlled by internal and external factors, the effects of detritus and site on decomposition were analyzed and studied through simulated modeling.

Recently, there are numerous methods to simulate and predict decomposition processes (Moorhead et al., 1996; Cunha-Santino and Bianchini, 2008). Ecological models have been used to describe decomposition process. Some of these models are processed based and can simulate the underlying processes in detritus decay (Palosuo et al., 2005; Zhang et al., 2008). Some other models, like statistical and mathematical models, are more concerned with system behavior at a specific level of interest, such as nutrient cycles at the system level, microbial growth at the population level (Moorhead et al., 1996). The most common model is a negative, exponential model proposed by Olson (1963) to describe mass loss from detritus. Because effects of site and detritus may be enhances in a nutrient-enriched lake due to spatial heterogeneity in nutrient distribution, a more detailed model considering both site and species effects on decomposition is expected. Here, we developed a two-stage regression model based on the field experiment to identify contributions of both detritus and site factors to detritus decomposition.

Our study area is Lake Baiyangdian which is a shallow eutrophic lake in North China. Due to elevated water nutrients, high primary production has been observed in past decades in the lake. The aims of this study are (1) to compare decomposition processes of different dominant species under three nutrient conditions; (2) to test the role of plant species on decomposition processes and determine main detritus quality factors contributing to decompositions; (3) to demonstrate the effects of environmental conditions on decomposition and its interaction with plant species; and (4) to develop a mathematic mode to analyze species and site effects on detritus mass loss.

2. Materials and methods

2.1. Site description

Lake Baiyangdian is the largest freshwater lake in North China (38°21′N, 115°54′E, see Appendix A in online supplement). Climate in this area is a temperate continental monsoon climate with an annual mean precipitation of 510 mm. The lake has a surface area of 366 km^2 with high nutrient contents, high macrophyte density, and low water depth. Until the middle of the 20th century, the lake had been seldom affected by human activities, and the average water depth was 2.5 m. Since the 1950s, constructions of dams and reservoirs occurred upstream. After that, hydrological conditions in this area deteriorated, causing a sharp decline in the water depth. In addition, nutrient input from adjacent farmlands and pollutions from residential areas have contributed greatly to water eutrophication in the lake.

Major primary producers in this lake are six species of aquatic macrophytes. They are *Ceratophyllum demersum* L., *Potamogeton pectinatus* L., *Lemna minor* L., *Nelumbo nucifera*, *Phragmites australis*, and *Typha angustifolia* L. The decreased water depth combined with elevated nutrient levels favored overgrowths of these aquatic macrophytes and increased detritus accumulation in the lake sediment, which further stimulated macrophyte growth, accelerating the terrestrialization process of the lake.

In order to study the effects of water nutrient contents on detritus decomposition, three sampling sites that differed greatly in pollution intensity were selected for our decomposition experiment: Caiputai, Shaochedian, and Dazhangzhuang. The Caiputai site is a region with the least human disturbances and low nutrient pollutions. The Shaochedian site is influenced by non-point and point source nutrient pollutions. And the Dazhangzhuang site is subjected to the most severe nutrient pollutions of all three sites because it is the closest to human residential areas.

2.2. Decomposition experiment design

Macrophyte decomposition experiment was conducted in the field using the litterbag method. We collected detritus of the six dominant macrophytes from the three sampling sites on 24 September 2009. The detritus samples of the same species were mixed together and then air-dried for two weeks before use in the experiment. For the field experiment, the detritus samples were placed in litterbags of 15 cm × 15 cm with 0.5 mm mesh size. Each bag was filled with 5 g of air-dried detritus. Five randomly selected samples of each species were oven-dried (60 °C) before the field experiment to estimate the initial dry mass and C, N, and P contents. The initial total C and N contents in detritus were estimated with an Elemental Analyzer (Elementar, Inc., Germany). The total P content in detritus was analyzed using an Auto Analyzer (Bran + Luebbe GmbH, Inc., Germany).

On 2 December 2009, 96 litterbags were placed at each site to allow for three replicates and eight sampling times for six species. All litterbags were affixed to square metal cages to keep them close to the lake bottom. Three replicates of each species were randomly chosen and collected after 3, 7, 13, 115, 148, 178, 207, and 270 days (the lake was frozen for approximately 14 weeks after the 13th day of the experiment). After collection, the samples were hand washed gently with deionized water and then oven-dried at 60 °C until constant weight for about a week to measure dry mass remaining.

2.3. Site chemistry analyses

The water chemistry was also measured at each sampling time at Caiputai, Shaochedian, and Dazhangzhuang. Water samples were collected 0.2–0.5 m above the sediment layer with a stainless-steel water sample. Water pH was determined immediately after these sample collected by a portable Hach pH meter (Hach, Inc., USA). Then, the water samples were taken back to our