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Decomposition of dominant submerged macrophytes: implications for nutrient release in Myall Lake, NSW, Australia

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Abstract

Breakdown and nutrient dynamics of submerged macrophytes were studied in Myall Lake, Australia. Mass loss of *Myriophyllum sulsagineum* was the lowest (64.90%) among the studied macrophytes during the 322 days followed by *charophytes* (60.79%), whereas *Najas marina* and *Vallisneria gigantea* lost 91.15 and 86.02% of their respective initial mass during that time. The overall exponential breakdown rates of *Najas marina* and *Vallisneria gigantea* were similar, with *k*-values of 0.24 and 0.23 day^{-1}, respectively. These rates were significantly higher than the break down rates of *charophytes* (0.007 day^{-1}) and *M. sulsagineum* (0.008 day^{-1}). During growth phase, water column depicted lower nutrient concentrations while during decay period, significant increase in water column nutrients resulted. Release of nutrients from decomposing macrophytes and incorporation of these nutrients into sedimentary phase as well as uptake of nutrients by the growing macrophytes, can present a considerable cycling pathway of nutrients in Myall lake system. The results of this study suggest that different submerged macrophytes may differ appreciably in quality and may exhibit different decomposition rates, patterns and nutrient dynamics in aquatic ecosystems in general, and Myall lakes in particular.

Introduction

Decomposition of aquatic macrophytes can considerably influence nutrient cycling and energy flow in aquatic ecosystems (Battle and Mihuc 2000; Masifiwa et al. 2004). The breakdown of organic matter releases inorganic components including nutrients that were chemically incorporated in plant tissues. Investigations have demonstrated the importance of internal processes for nutrient cycling in aquatic ecosystems through decomposition of aquatic macrophytes (Carpenter and Adams 1979; Pieczynska 1990; Wrubleski et al. 1997; Gessner 2000; Kim 2001; Villar et al. 2001; Asaeda et al. 2002; Masifiwa et al. 2004; Xie et al. 2004).

Decomposition studies of aquatic macrophytes such as Salvinia sp. indicated that nutrient release was rapid during the initial four days and was attributed to physical leaching (Ogwada et al. 1984; Sharma and Goel 1986; Asaeda and Nam 2002). This was followed by slow nutrient release attributed to microbial decomposition. Under laboratory conditions, Reddy and Sacco (1981)

found higher rates of soluble phosphorus (SRP) release under anaerobic than aerobic conditions during macrophyte decomposition. They also found that after herbicide application that resulted in death of water hyacinth in a canal, there were higher concentrations of soluble nitrogen and phosphorus in the canal drainage water than before herbicide was applied.

During growing season, macrophytes accumulate nutrients from both water and sediment. When the macrophytes die, decomposition process is set up. The release of nutrients raises the nutrient concentration in the water (Goldshalk and Wetzel 1978; Howard-Williams and Allanson 1981; Godshalk and Barko 1985). Decomposition of aquatic macrophytes can therefore substantially regulate the recycling of nutrients in fresh water ecosystems for a long time (Richardson 1994; Carpenter and Lodge 1986; Asaeda et al. 2002), and is essential to the nutrients dynamics of fresh water ecosystems (Rich and Wetzel 1978; Webster and Benfield 1986; Battle and Mihuc 2000; Asaeda et al. 2001).

Researchers have attributed the limitation of aquatic macrophyte decomposition to both physical and chemical conditions in water (e.g., temperature, pH and redox conditions) as well as biochemical properties (e.g., nutrient and fibre content) of the decomposing plant materials (Goldshalk and Wetzel 1978; Day 1982; Kok and Van der Velde 1994). It has further been hypothesized that higher nutrient concentrations are important factor in controlling decomposition rates (Xie et al. 2004; Lan et al. in press); the reason being that nutrient demands associated with decomposer activity often exceeds nutrient supply from decomposing material (Enríquez et al. 1993). Some studies on the effect of nutrients on the decomposition of macrophytes however, have reported positive or neutral results (Carpenter and Adams 1979; Federle et al. 1982; Newbold et al. 1983; Brock et al. 1985; Peterson et al. 1993; Villar et al. 2001).

In this study, the decomposition rates of the dominant aquatic macrophytes: Charophytes (*Chara fibrosa* var. *fibrosa* and *Nitella hyalina*), *Najas marina*, *Myriophyllum sulsagineum*, and *Vallisneria gigantea* were investigated with the implications to the nutrient release in Myall Lakes. We chose these species to answer the question whether or not their decomposition rates were the same.

Materials and methods

Study area

Myall Lake is the largest and most poorly flushed of the four connected coastal lakes in a largely forested catchment in temperate east Australia. It has a surface area of 62.8 km^2, being characterized by salinity (~2.2‰), very low catchment runoff, high water clarity, and low plankton biomass (Wilson and Dasey 2002). The lake is situated 75 km North of Newcastle on the central coast of New South Wales, Australia (152°201 E, 32°251 S). The average depth of the lake is about 2.8 m, the deepest part being 4.5 m. A series of shallow bays are located in the northern and western coastlines. Most of the lake is covered with organic mud (gyttja) (about 1–2 m deep) except for small areas near the shore. Sampling campaigns were conducted on August 2003 for biomass sample collection used for the decomposition experiment.

For this study, we used the fragments of five submerged macrophytes growing in Myall Lake: Charophytes (*Chara fibrosa* var. *fibrosa* and *Nitella hyalina*), *Najas marina*, *Myriophyllum sulsugineum* and *Vallisneria gigantea*, collected in 14th August 2003 from shallow area of the Corrigans and Neranie bays. All materials were air dried at 20°C to constant weight (fresh weight). However, the samples still contained high water content, thereby five 22 g of the air dried samples of each category were oven dried at 50 °C for more than 72 h to a constant weight to obtain the relation between the air dried samples and oven dried weight (dry weight).

Twenty-five of nylon mesh bags (1.5 mm) containing approximately 2 g of air dried macrophyte fragments of each species material were then tied together, fastened to the heavy chain and placed on the charophyte mat (about 30 cm thick) on the gyttja bed (about 1 m thick) at Corrigans bay (152°25′9.3″ E and 32°23′50.2″ S) at a depth of 1 m and measurements of weight loss were taken over 11 months. The tied bags were attached to an individual rope (~2 m long) which was left floating on water surface.

Five replicates of mesh bags for each plant species were collected on 5 dates: 14th September 2003 (31 days), 1st November 2003 (79 days), 17th December 2003 (125 days), 14th February 2004

(184 days) and 1st July 2004 (322 days). The removal of the mesh bags were accomplished by tracing the floating ropes to the substrate surface, and carefully removing the bags from the substrate without disturbing other samples. The samples were then removed from the bags and washed to remove soil and extraneous plant and animal materials, and were dried to constant weight at 50 °C.

The original oven dried samples were ground into powder and analysed for total nitrogen (TN), total phosphorus (TP), magnesium (mg), calcium (Ca) and iron (Fe). While TN was analysed using Yanoco® CHN corder, TP was determined by Molybdenum blue calorimetric method after pretreatment of the powdered samples with $K_2S_2O_8$ and digestion on autoclave (120 °C) for 30 min (APHA 1995; Murphy and Riley 1962). Calcium (Ca) and magnesium (Mg) were determined using HACH® U4000 spectrophotometer based on EDTA-EGTA complexometry following dry ashing the sample at 550 °C for 3 h and dissolution of the residue in 0.1 N HCl.

We assumed that macrophyte decay could be described by a simple exponential decay equation. The chief advantage of the assumption is that comparisons can be made between incubations that were carried out for different time (Carpenter and Adams 1979). Decay coefficients k (defined as an instantaneous mass loss rate) in days^{-1} were calculated using incubation time t in days, initial (original weight) of the sample in grams (W_o), and weight remaining at time t (W_t):

$$\ln(W_t/W_o) = -kt \text{ or } W_t/W_o = \exp(-\text{kt})$$

Large valued of k indicates a rapid rate of decay. Data were statistically analysed using SPSS for windows version 11.

Results

Table 1 shows the initial weight of the samples used for the decomposition experiment, the weight loss after a specified period of 322 days and the decay rate of the studied macrophytes. The mean concentration of total phosphorus (TP) in sediment and water, and total nitrogen (TN) in the water column is given in Table 3.

Comparison of decay rates (day^{-1}) among the studied macrophytes

Charophytes (*Chara fibrosa* and *Nitella hyalina*) decomposed very slowly with a decay rate of 0.008 day^{-1} contrary to rapid decay rates of *Najas marina* and *Vallisneria gigantea* with respective decay rates of 0.042 day^{-1} and 0.030 day^{-1}. *Myriophyllum sulsugineum* also decomposed slowly with a decay rate of 0.009 day^{-1} (Figures 1 and 2; Table 1).

Initially, *N. marina* decomposed rapidly followed by *V. gigantea* whereas the decomposition of charophytes was similar to that of *M. sulsugineum* during the initial stages of decomposition. The decomposition rate of *M. sulsugineum* remained slightly higher at latter stages compared to that of charophytes until the fulfillment of 322 decomposition days (Figures 1 and 2).

The time (in days) required for the macrophytes to decompose to 50% of their initial weights was variable among the studied macrophytes. The rapidly decomposing *N. marina* and *V. gigantea* required respectively 39 and 50 days to decompose to half of its initial weight while *Charophyte* spp. and *M. sulsagineum* required a long time (120 and 110 days respectively) to do so under the same exposure conditions (Table 1).

The difference in decomposition rates of *N. marina* and *V. gigantea* were significant (ANOVA, $p < 0.05$, Table 2) for 322 decomposition days. Likewise, *Charophyte* decomposition rates differed significantly (ANOVA, $p < 0.05$) from decomposition rates of *N. marina* and *V. gigantea* throughout the decomposition period.

Table 1. Summary of the data on initial weight, weight loss (in grams and percentage) and decay rate constant k, during 322 decomposition days; Data in brackets represents standard deviation.

Plant species	Initial wt (g)	% weight after 322 days (%)	Decay rate (day^{-1})	Days for 50% decay
Charophyte sp	2.057 (0.206)	39.213 (3.601)	0.008 (0.003)	110
N. marina	1.329 (0.039)	8.85 (1.553)	0.035 (0.010)	39
M. sulsagineum	2.521 (0.115)	35.101 (2.117)	0.009 (0.002)	120
V. gigantea	1.160 (0.067)	13.98 (6.615)	0.027 (0.009)	50

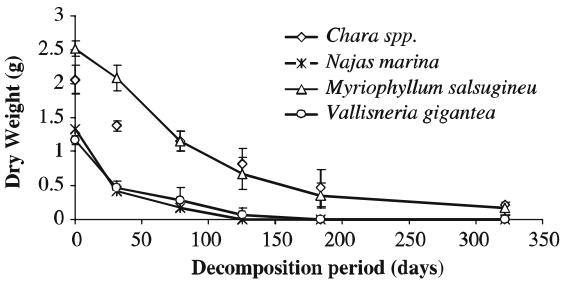


Figure 1. Loss in dry weight (g) of the four macrophytes species during 322 decomposition days in the waters of Myall Lakes, Australia.

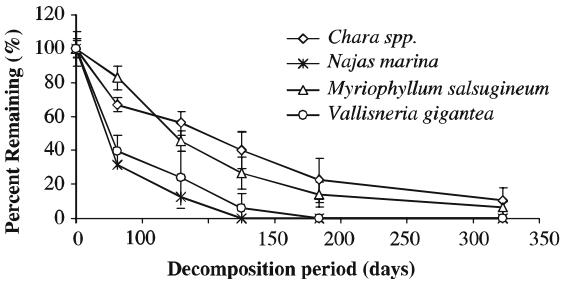


Figure 2. Loss in percentage weight (%) of the four macrophytes species during 322 decomposition days in the waters of Myall Lakes, Australia.

At the end of the 322 days of decomposition period, both *N. marina* and *V. gigantea* lost 91.15% and 86.02% of their respective initial weights. On the contrary, Charophytes and *M. sulsagineum* lost 60.79% and 64.90% of their respective initial weights (Table 1). The fastest decomposing species, *N. marina*, therefore, retained only 0.05% of its initial weight while the slowest decomposing *Charophytes* spp., retained 10% of its initial weight over 322 decomposition days under the same conditions.

Nutrient concentrations in water column and sediment before and after decay of macrophytes

TN/TP ratio in water observed for Corrigans bay was relatively high. Considerable decrease in nutrient (total phosphorus (TP) and total nitrogen (TN)) levels was observed during the growing season (October–December) before summer peak. On the other hand, considerable increase in nutrient levels was observed during the decay season (February–July) after summer peak (Table 3). TN and TP content in sediment were higher after macrophytes decay than during the growing season. Analysis of the top most gyttja layer revealed higher concentration of TN and TP. High amount of organic matter has been reported at sites where the macrophyte biomass was high in Myall Lake (Siong and Asaeda in press).

Table 2. ANOVA table showing the variability in decay rates k, among the studied macrophytes.

Plant species	Decay rates (day^{-1})	F	df	p-value
Charophyte spp.	0.008 (0.003)	5.412	3	0.043
Najas marina	0.035 (0.010)	6.054	3	0.002
Myriophyllum sulsagineum	0.009 (0.002)	5.578	3	0.042
Vallisneria gigantea	0.027 (0.009)	5.797	3	0.005

Discussion

Decomposition rates of aquatic macrophytes are highly site specific and depends on the microorganisms available and involved in the decomposition process, levels of microorganism activities as well as other climatic and physico-chemical parameters. Decomposition rates of *Najas marina* and *Vallisneria gigantea* were generally greater than the rates of decomposition of charophytes and *Myriophyllum sulsagineum* in this study. The pattern of decomposition was such that the initial phase was characterized by rapid weight loss from the decomposing materials probably caused by leaching of soluble compounds (Pagioro and Thomaz 1998; Kim 2001). This phase was followed by an extended slow period of active microbial decomposition of the remaining materials (Swift 1979). Decomposition of structural components such as cellulose, hemicellulose and lignin by bacteria and fungi occur in this step of the process (Goldshalk and Wetzel 1978). The mass loss during 322 decomposition days included both the first and second stage.

Bastardo (1979) reported that *Chara* sp. decomposed at a rate of 0.0084 day^{-1} while Murty (unpubl.) reported a decay rate of 0.042 day^{-1} for *Najas* sp. On the other hand, Carpenter (1980) documented a decay rate of 0.163 day^{-1} for *Vallisneria* sp. While Bastardo

Table 3. Values of the chemical parameters ($n = 10$), Total Phosphorus (TP) in water column and sediment, Total Nitrogen (TN) and their ratio (TN/TP), Calcium (Ca), Magnesium (Mg) and Iron (Fe) of the water column in Myall Lake, Australia.

	TP (Water)	TP (sediment)	TN (Water)	TN/TP (Water)	Ca (Water)	Mg (Water)	Fe (Water)
Average	0.011	0.367	0.566	51.455	21.800	94.700	0.058
Growing season	0.005	0.112	0.275	55.000	21.000	81.300	0.046
Decay season	0.016	0.268	1.063	66.438	21.000	93.120	0.073

(1979) found that *Myriophyllum* species decomposed at a rate of 0.0315 day^{-1}. In our study, we found that decay rates for Charophytes was 0.008 day^{-1} and that of *Najas marina* was 0.043 day^{-1}, quite similar to that reported by Bastardo and Murty in their studies. We found less decay rates for both *V. gigantea* and *M. sulsagineum* as compared to the values reported by Carpenter (1980) and Bastardo (1979). The explanations for the above variability of k values may be attributed to the modifications on content, structure and configuration of plant skeleton compounds, which is typical of each habitat as they interact in a different way with microorganisms that had a significant role in the decomposition (Bastardo and Rivera 1986).

Goldshalk and Wetzel (1978) in their study demonstrated that those macrophytes whose decomposition rates were low possessed high amount of lignin fibers. They further stressed that the resistance of particulate tissues to microbial decomposition was strongly influenced by the composition of the plant species. Although we didn't analyze the fiber content of the studied macrophytes it has been reported elsewhere (e.g., Goldshalk and Wetzel 1978; Bastardo 1979) that the fiber contents of *Charophyte* and *Myriophyllum* spp. are significantly higher compared to *Najas* and *Vallisneria* spp. Our results agreed with the findings above as the decay rates were related to the initial tissue nutrients; and considering the findings of Goldshalk and Wetzel (1978), that *Charophytes* and *Myriophyllum* spp. have higher fiber contents relative to *Najas* and *Vallisneria* spp., the concept of 'high-nitrogen, and low-fiber' macrophytes decomposing most rapidly (higher decay rates) holds water. Goldshalk and Wetzel (1978) also found that the rate of conversion of particulate matter to carbondioxide and/or dissolved organic matter (DMO) was regulated primarily by temperature, tissue nitrogen and fiber content.

The slower breakdown of *M. sulsagineum* and *charophyte* spp. compared to *N. marina* and *V. gigantea* concurs with the pronounced differences in the anatomy and chemical make-up (Bosman 1985; Armstrong et al. 1996) of their plant parts. This correspondence between plant composition and decay rates indicates that, as in other decomposition systems (e.g., Melilo et al. 1984; Gallardo and Merino1993; Gessner and Chauvet 1994), plant quality as defined by chemical composition and anatomical structure, markedly influences the decomposability of different types of plants.

Decomposition of aquatic macrophytes is essential for releasing organic and inorganic components in aquatic ecosystems (Acharya 1935). Most plant tissues eventually enters the detritus pool, and microbes (both bacteria and fungi) become involved in the mineralization processes. Aquatic ecosystem detritus based, with decaying plant matter can act as an important energy source.

Nutrients regeneration in Myall lakes is a function of plant nutrient content and sediment retention capacity. Even though most of the nutrients may be leached from the plants during decomposition process into the water column, they will subsequently be trapped into sedimentary phase. These turnover rates represent significant fluxes of nutrients to the water column in Myall Lakes (Robert et al. 1985; Asaeda et al. 2000). During decomposition of the studied macrophytes, the nutrient status of the water column was higher than during the growth phase, meaning that nutrients and other chemical constituents were released into the water column. Harry and Michael (1981) in their laboratory experiment reported that decomposition of macrophytes resulted in the regeneration of much of the plants' initial phosphorus content to the water column. Although excretion of nutrients like phosphorus from the studied macrophytes is minimal in Myall lakes Wilson (2004), the potential contribution of

nutrients indirectly from sediment via macrophyte uptake and subsequent decomposition was appreciable.

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