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# Decomposition rates and nutrient Leaching efficacy of the Dominant Macrophytes in Lake Ziway, Ethiopia

**Girum Tamire[1]*, Seyoum Mengistou[2] and Gezahegn Degefe[1]**

1) Debre Berhan University, College of Natural and Computational Sciences, Department of Biology, Ethiopia.
2) Addis Ababa University, Life Sciences College, Zoological Sciences Program Unit, Ethiopia.

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**Abstract:** Decomposition of macrophytes is an important process that facilitates nutrient and carbon cycle in aquatic ecosystems. The role of macrophytes decomposition in nutrient dynamics of a lake was studied in slightly alkaline tropical lake, Lake Ziway, using laboratory and field incubation experiment (litter bag technique) between January to October 2013. The objective of this study was to assess the role of macrophytes to nutrient cycle and organic matter accumulation in Lake Ziway. *Potamogeton schweinfurthii* decomposed faster (K= 0.0409 $d^{-1}$) than other macrophytes while *Arundo donax* was the most resistant to decaying (K = 0.0073 $d^{-1}$). Net increase in total nitrogen concentration was observed for the macrophytes' litters during field decomposition experiments. Increase was highest (4.38 fold) for *Cyperus papyrus*. Phosphorous concentration decreased for all macrophyte litters, except *Cyperus articulatus.* The highest reduction was observed for *P.schweinfurthii* (82.6%). Laboratory incubation experiments were also done by incubating macrophyte litters with the lake water in bottles and an increment in soluble reactive phosphate concentration was observed at the end of the experiments except in two bottles, but the opposite trend was observed for nitrate in all bottles. The overall results of the experiments showed that most of the macrophytes decomposed faster and serve as net source of phosphorous, although the contribution of decomposition of these macrophytes to the change of water quality of the lake seems to be low. On the other hand, *A. donax* plays little role in the dynamics of major nutrients and may contribute to organic matter accumulation in the lake. Both laboratory and field experiments showed that all the macrophytes, except *C. articulatus,* served as net SRP to the lake system. In spite of higher decomposition rate of the macrophytes in the lake, the contribution of decomposition in changing the physico-chemical condition of the lake is still insignificant.

**Keywords**: Decomposition, Leaching, Macrophyte, Ziway

## Introduction

Macrophytes are the most important source of organic matter production in many aquatic ecosystems (Wetzel, 1990). The production of these plants is expected to be relatively higher in tropical aquatic ecosystems than in temperate because of higher temperatures and presence of sufficient solar radiation (Silva and Esteves, 1993; Camargo and Esteves, 1995). However, vast amount of the organic matter synthesized in lakes remains in littoral parts and only minor portion of the produced material is consumed by consumers (Wetzel and Likens, 1991). The remaining part, ungrazed organic matter, ultimately goes into detrital pool and undergoes decomposition (Kuehn *et al*., 2000).

Decomposition of macrophytes is an important process that facilitates nutrient and carbon cycle in aquatic ecosystems. It results in the release of nutrients stored in organic matter into the system (Puriveth, 1980). However, complete breakdown of macrophyte tissues may take up to years or longer period in some cases (Pietro *et al*., 2006). Thus, a considerable part of the produced organic matter can be buried in the sediments causing immobilization of nutrients (Richardson and Marshall, 1986). Determining decomposition rates contributes to the understanding of how nutrient dynamics operate in a specific aquatic system. According to Murkin *et al*. (1989), studies about decomposition rates of different macrophyte species present in aquatic systems is important to determine nutrient availability in the system. The decomposition of macrophyte depends upon structural composition of the plant, the metabolic activity of microorganisms, shredding effects of invertebrates, and abiotic factors such as temperature, pH and availability of nutrients (Verhoeven, 1986).

The tissues of aquatic plants are made up of fibers which constitute particulate organic matter (POM), soluble organic matter (DOM) and inorganic compounds (Little, 1979; Henry-Silva *et al*., 2001).

(✉) tamiregirum1@gmail.com

During decomposition processes, these components break down at different rates.

The remains of macrophyte litter, after decomposition, accumulate in the sediment at the lake bottom and usually this rate is higher than decomposition rate (Xiao *et al*., 2011). The accumulated organic matter will produce a long-term accumulation of plant litter if large biomass of the macrophytes is channeled to the pool (Lan *et al*., 2012). The phenomena can eventually speed up the terrestrialization of the lake or encroachment of the littoral zone and succession to marshy environment (Costantini *et al*., 2009). Therefore, it is important to determine the rate of decomposition or organic matter accumulation to assess the status and fate of a particular lake especially in shallow lakes, such as Lake Ziway, where the water level is declining due to anthropogenic and climatic factors.

Some recent works reported an increment of nutrient status in Lake Ziway as a result of allochthonous enrichment which could result in the eutrophication of the lake and deterioration of water quality (e.g. Berhanu Rabo, 2008). On the other hand, Beneberu and Mengistou (2009), reported that the phytoplankton biomass (as chl a) showed declining trend compared to earlier data, although nutrients tended to increase, and they suggested that increase in turbidity and competition with macrophytes could be factors for the decline of algal biomass. Few attempts have been done to investigate how nutrients dynamics operates in the lake (e.g. Tebebe, 2016). Particularly, the role of macrophyte and other autochthonous sources of nutrients were never investigated in previous research works in the lake. Some researchers have reported that the leaching process of phosphorous from aquatic macrophyte litters can provide considerable contribution to the eutrophication in some aquatic ecosystems (Park and Cho, 2003). The relative contribution of decomposition of macrophytes to the enrichment of nutrients in Lake Ziway is not known and has to be assessed.

Determining decomposition rate of the dominant macrophytes will help to answer whether the macrophytes in the lake serve as nutrient sink or source. Furthermore, as the majority of studies on this aspect considered only a few species, information on decomposition rates of various types of macrophytes will help to generalize about decomposition trends across various species (e.g. Padial and Thomaz, 2006). It is because macrophyte tissues of different life forms and taxa have widely different characteristics.

## Materials and Methods

### Description of the study area

Lake Ziway is an open, shallow (with maximum depth of 8.9 m), freshwater lake that lies in the Ethiopian rift valley at 8° 01' N/38° 47' E and at an altitude of 1636 m above sea level (Von Damm and Edmond 1984). It is fed by Ketar and Meki Rivers that drain from the Southeastern and Northwestern highlands, respectively, and drains into Lake Abijata through the Bulbula River in the south (Fig. 1). Climatic condition of Lake Ziway region is a semiarid type. The annual precipitation ranges between 650 and 1200 mm whereas mean annual temperature is between 15 and 25 °C (Legesse *et al*., 2001).

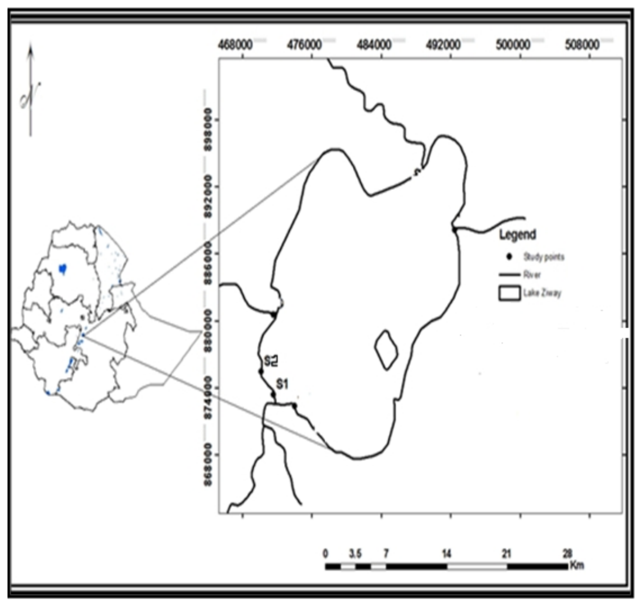


**Fig. 1: Map of Lake Ziway showing the study sites (S1: Bulbula, S2: ZFR).**

Recently, much effort has been done to assess the ecology and biology of the lake in attempts to conserve the lake resources and come up with better management options. The ecology of phytoplankton (Tilahun, 2006), zooplankton (Dagne *et al*., 2008), and fish (Yohannes, 2003) were extensively described by these authors and many other studies and their results showed that undesirable changes are taking place and prompt response are required . Particularly there is a knowledge gap in understanding the contribution of aquatic plant in nutrient dynamics of the lake.

### Sampling and *in situ* incubation

Decomposition rates of seven macrophytes, *Arundo* *donax, Echinochloa colona, Potamogeton schweinfurthii, Cyperus articulatus, Typha latifolia, Cyperus papyrus* and *Nymphaea lotus,* were studied using 'litter bag' technique in the field following Wetzel and Likens (1991) and Gantes and Torremorell (2005) and laboratory experiments after Gaudet and Muthuri (1981). The macrophytes were collected from two sites S1 (near to mouth of Bulbula River) and S2 (near Ziway Fishery Research Center (ZFR)) (Fig. 1) and incubated at littoral zone. These sites were selected because macrophyte composition in these sites represents the lake and the dominant macrophytes are concentrated in these sites.

Fresh macrophyte samples of each species were harvested from the littoral sites of the lake. Each sample of the macrophytes species was washed to remove debris and other attached material, chopped and weighed. 30 gm of culm of each species was used for the incubation study after drying for 3 h in the air (Kufel *et al*., 2004). The macrophytes litters were transferred to 84 litter bags made of nylon net (replicated for each species) with standard size of 15 x 20 cm and a mesh size of 1.5 mm as it was done in Kufel *et al*. (2004). The bags were incubated *in situ* at 0.5m below the surface (near the sediment) in the littoral zone by tying with cemented stands following Wetzel and Likens (1991). Two litter bags of each species were retrieved after 0, 15, 46, 66, 81 and 106 days for the determination of change in dry weight over time. Dry weight was measured after drying the plant material overnight at 105˚C in an oven for 24 hours before incubation and during all collection periods (Wetzel and Likens, 1991).

### Tissue nutrient analysis

After determining dry weight of the litters, the remaining tissues were ground for analysis of total nitrogen and phosphorous on 0, $15^{th}$, $46^{th}$ and $66^{th}$ day after incubation. After $66^{th}$ day enough litter were not available for analysis of some of the macrophytes. The change in total nitrogen (in % N) in the macrophyte litters during the study period was determined by Kjeldahl method as stated in Bremner and Mulvaney (1982) after digesting with sulphuric acid whereas total phosphorous concentration in the macrophytes tissue was determined by ash drying (Vanadate-molybdate yellow) method following the procedure of Chapman and Pratt (1961), after ashing and nitric acid digestion. Organic matter content in the macrophytes and their detritus was determined using a 'loss on ignition' method by incineration of plant samples at 550˚C (Wetzel and Likens, 1991). Ash free organic dry matter values were multiplied by 0.465 to obtain carbon concentration (Westlake, 1965).

### Laboratory experiments

Release of nutrients during decomposition of the macrophyte litters was investigated in the laboratory using 1 litter glass bottles into which lake water and 3 gm of dried macrophyte culms were placed (separately for each species) following Gaudet and Muthuri (1981). The bottles were maintained in the dark in an incubator at 25˚C representing the average lake water temperatures found in the site. The changes in nutrient content of each jar were analyzed after periods of 0, 8, 15, 26, 40, 65 and 90 days by taking 25 ml of water from the duplicate for the determination of Soluble Reactive Phosphorus (SRP) and ammonium and 10 ml for nitrate. Nitrate was analyzed with Sodium salicylate method, Ammonium with Indo-Phenol blue method (APHA, 1995) and SRP with Ascorbic acid method (APHA, 1999). pH and conductivity were also measured at the beginning and end of the experiment.

Decomposition rate was estimated with a single exponential decay model after Olson (1963) using the following formula.

$$\ln (W_t/W_o) = -Kt$$

$$K = (-\ln(W_t/W_o))/t$$

where K is decay coefficient (per day), Wo is initial weight, Wt final weight and t is time (days).

### Data Analysis

One way ANOVA was employed to check if the variation in decomposition rate among species was statistically significant using SPSS version 15 followed by Tukey test to determine which species were specifically different. Pearson correlation was employed to assess the association between decomposition rate of each species and the respective C:N ratio in their tissue.

## Results

### *In situ* decomposition rate of the macrophytes

There was significant variation among decomposition rate of the macrophyte litters (one way ANOVA, $F_{6,28}$= 4.3, $p<0.05$). Tukey test, Games-Howell, ($p<0.05$) showed that significant variation lies between *P. schweinfurthii* and *A. donax*, *C. articulatus* and *C. papyrus*. The decomposition rates of *P. schweinfurthii*

(K=0.0409 $d^{-1}$) and *N. lotus* (K=0.0329 $d^{-1}$) were higher than the other macrophytes (Tab. 1). Almost 100% of the tissue of these macrophytes litter decomposed at the end of the *in situ* experiment on the 106th day (Fig. 2).

**Tab. 1: Mean K values of each macrophyte species tissue during *in situ* decomposition (a refers macrophyte that had significantly higher decomposition rate than other groups, Tukey Games-Howell test, p< 0.05).**

| Species | Mean K value ($d^{-1}$) |
|---|---|
| *Arundo donax* | 0.0073 |
| *Cyperus articulatus* | 0.0117 |
| *Cyperus papyrus* | 0.0078 |
| *Echinocloa colona* | 0.02047 |
| *Nymphaea lotus* | 0.0329 |
| *Potamogeton schweinfurthii* [a] | 0.0409 |
| *Typha latifolia* | 0.0140 |

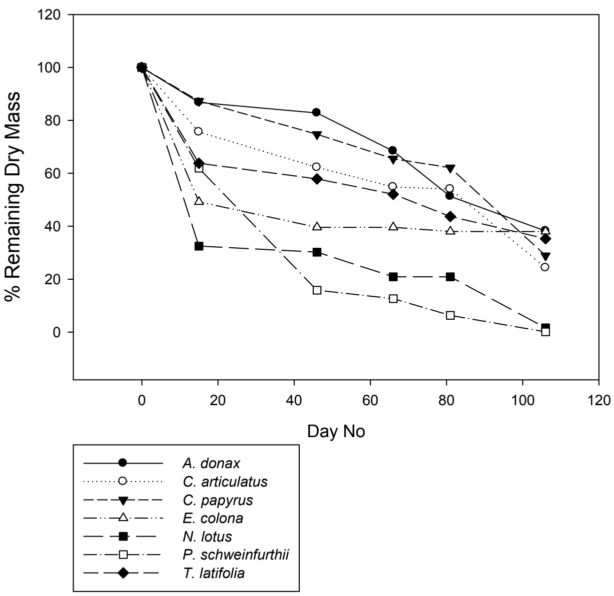


**Fig. 2: Trend of dry mass loss of macrophyte litters during the study period during *in situ* experiment.**

On the other hand, decomposition rates were lower for *A. donax* (K=0.0073 $d^{-1}$), *C. papyrus* (K=0.0078 $d^{-1}$), *C. articulatus* (K=0.012 $d^{-1}$) and *T. latifolia* (K=0.014 $d^{-1}$), respectively. *A. donax* was found to be the most resistant species to decomposition in this study and 38.2 % of its initial mass was found at the end of the experiment. *C. papyrus* and *C. articulatus* were left with 28.9 and 24.3 % of their initial weights at the end of the experiment, respectively (Fig. 2). Although *T. latifolia* had relatively faster decomposition rate at the start of the experiment than some of the macrophytes, its rate slowed down after day 15, and 35 % of its initial weight was found at the end of the experiment. The decomposition rate of *E. colona* was intermediate (K=0.0204 $d^{-1}$) but large portion of its weight (38%) remained on 106th day (Fig. 2). The decomposition rate was the highest in the first two weeks for all species except *P. schweinfurthii,* which decomposed more rapidly between 15th and 46th day.

Based on their respective mean Net Aboveground Primary Productivity (NAPP) and decomposition rate data, it can be estimated that *A. donax* had the highest Production/Mass lost (P/M) which showed that the plant contributed more persistent plant material annually with respect to its NAPP. On the other hand, *P. schweinfurthii* and *N. lotus* had the lowest P/M ratio which can indicate that these species lost much portion of their production through decomposition (Tab. 2).

**Tab. 2: Annual production, mass lost and remaining for each macrophyte species.**

| Species | NAPP (g DW $m^{-2}$ $y^{-1}$) | Mass remaining (g DW $m^{-2}$ $y^{-1}$) | Mass lost (g DW $m^{-2}$ $y^{-1}$) | NAPP/Mass lost |
|---|---|---|---|---|
| *Arundo donax* | 864.22 | 655.42 | 207.8 | 4.15 |
| *Cyperus articulatus* | 622.8 | 361.68 | 261.12 | 2.38 |
| *Cyperus papyrus* | 2196.2 | 1309.8 | 886.4 | 2.47 |
| *Echinochloa colona* | 662.93 | 282.41 | 380.52 | 1.74 |
| *Nymphaea lotus* | 712.16 | 140.44 | 571.72 | 1.24 |
| *Potamogeton schweinfurthii* | 774.2 | 40.1 | 734.1 | 1.05 |
| *Typha latifolia* | 2394.5 | 949.7 | 1444.8 | 1.65 |

## Change in Tissue Nutrient Content during Decomposition

The change in total nitrogen content in decomposing tissues of macrophytes showed two kinds of trends in this study. The total nitrogen concentration in *A. donax*, *E. colona* and *T. latifolia* decreased gradually during decomposing period but in the other macrophyte litters, it showed a slight reduction in the first week followed by higher net increment (Fig. 3).

*Arundo donax* lost only 2.19 % of its initial nitrogen during decomposing period whereas *T. latifolia* and *E. colona* lost 44.21 and 45.16%, respectively. The final total nitrogen concentration (on 66th day) in *C. papyrus* litter was 4.38 fold of the initial concentration which was the highest increment. The increase in total nitrogen concentration at the end of the experiment was 83.3 %, 57.1 % and 54.3 of initial weight of *C. articulatus, N. lotus* and *P. schweinfurthii.* Phosphorous release from the macrophytes tissue showed different trends with nitrogen in this study. All the species showed a gradual decreasing trend in their total phosphorous concentration of their litter during decomposition period, except *C. articulatus* which showed a reduction in its phosphorous concentration only for the first week but later increased highly by 108 % (Fig. 4). The loss of total phosphorous was high for *P. schweinfurthii* (82.6%) and the least for *A. donax* (6.59%). *C. papyrus*, *E. colona, N. lotus* and *T. latifolia* lost 54.68, 27.8, 51.9 and 52.7 % of their initial total phosphorous, respectively, during the decomposition period.

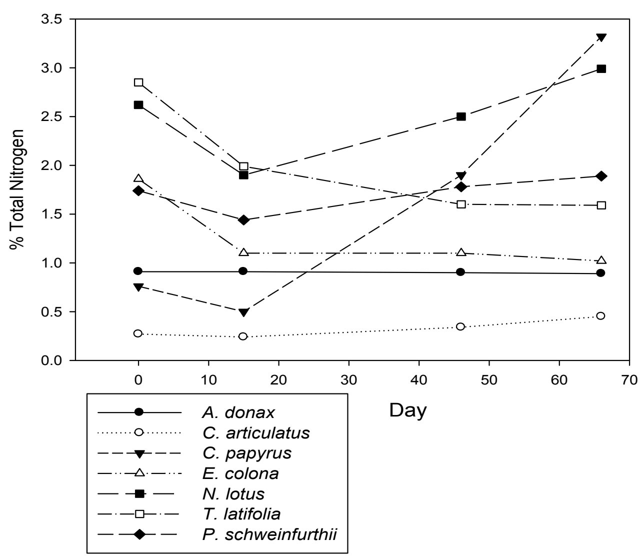


**Fig. 3: Nitrogen loss from the decomposing macrophyte tissues during *in situ* experiment.**

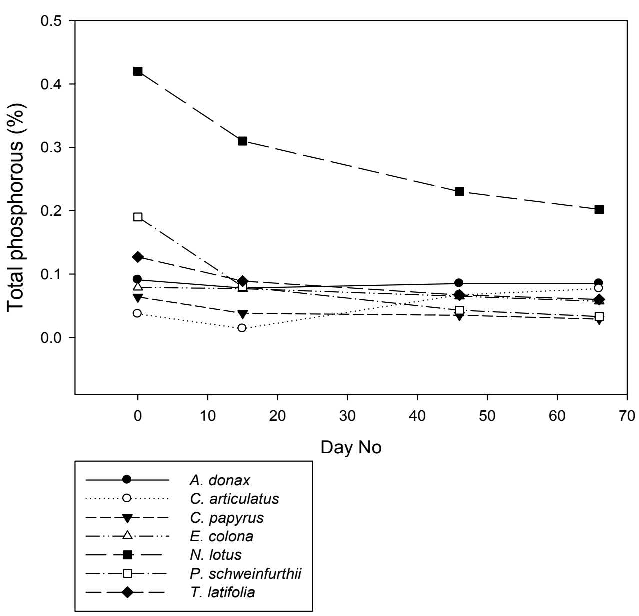


**Fig. 4: Phosphorous loss from the decomposing macrophyte tissues during *in situ* experiment.**

### Trend of weight loss and nutrient release by macrophytes during laboratory incubation study

Decomposition trend during laboratory incubation followed similar pattern to that of *in situ* experiment, where *P. schweinfurthii* and *N. lotus* decomposed faster than other species and *A. donax*, *C. articulatus* and *C. papyrus* were more resistant to decomposition (Tab. 3). An increasing trend in SRP and ammonium was observed in all bottles incubated with the macrophytes except in *C. articulatus* bottle, but decreasing trend was observed in nitrate concentration in all bottles (Figs. 5, 6 and 7). pH and conductivity showed an increment trend during decomposition in all bottles (Tab. 4).

**Table 3. Mean K values of each macrophyte tissue during laboratory experiments**

| Species | Mean K value ($d^{-1}$) |
|---|---|
| *Arundo donax* | 0.00695 |
| *Cyperus articulatus* | 0.007233 |
| *Cyperus papyrus* | 0.006467 |
| *Echinocloa colona* | 0.026333 |
| *Nymphaea lotus* | 0.03556 |
| *Potamogeton schweinfurthii* | 0.03803 |
| *Typha latifolia* | 0.008933 |

**Tab. 4: Changes in pH and conductivity in incubated bottles during laboratory decomposition experiments**

| Species | pH (at day 0) | pH (at day 90) | Conductivity (at day 0) in µS/cm | Conductivity (at day 90) in µS/cm |
|---|---|---|---|---|
| *Arundo donax* | 8.5 | 8.7 | 425 | 603 |
| *Cyperus articulatus* | 8.5 | 9.2 | 472 | 665 |
| *Cyperus papyrus* | 8.6 | 9.5 | 461 | 773 |
| *Echinocloa colona* | 8.4 | 9.2 | 440 | 607 |
| *Nymphaea lotus* | 8.21 | 9.4 | 415 | 841 |
| *Potamogeton schweinfurthii* | 8.27 | 9.2 | 437 | 867 |
| *Typha latifolia* | 8.3 | 8.9 | 452 | 645 |

## Discussion

### *In situ* decomposition trend of the dominant macrophytes

The decomposition rates of the studied macrophytes were clearly different depending on their respective life forms. The rate was highest for *P. schweinfurthii* (submerged) followed by *N. lotus* (floating). Both had lower initial C:N which indicated that the plants had lower structural integrity. On the other hand, the emergent macrophytes had lowest decomposition rate and higher initial C:N ratio or higher structural integrity

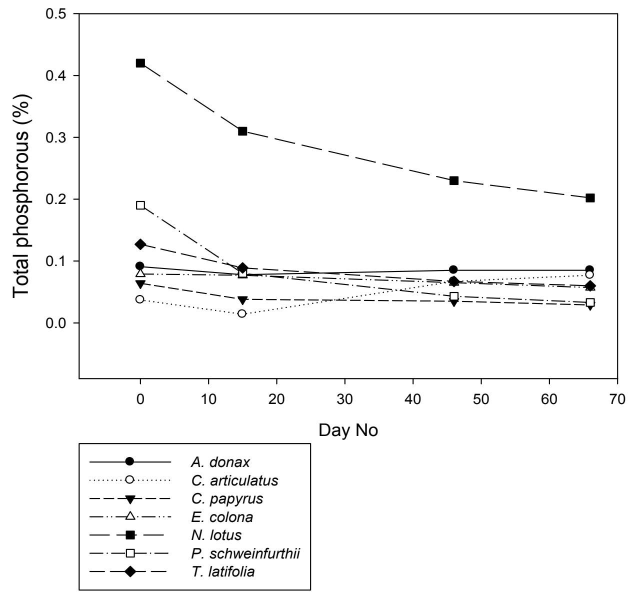


**Fig. 4: Phosphorous loss from the decomposing macrophyte tissues during *in situ* experiment.**

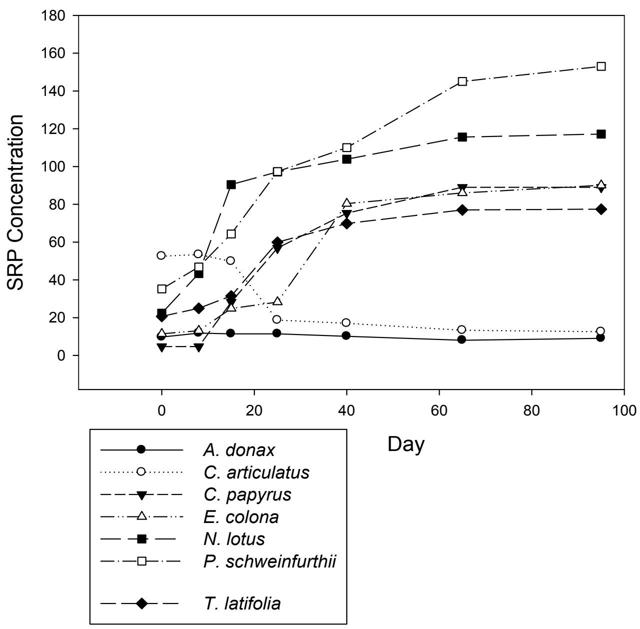


**Fig. 5: Change in Soluble Reactive Phosphate concentration in the incubated bottles during decomposition period in the laboratory.**

than the two macrophytes. These observations agree with the works of many authors. For example, Wetzel (2001) reported that the structural composition of emergent macrophytes make them refractory to microbial decomposition whereas the absence of much structural tissue in submerged and floating macrophytes enhances decomposition. According to Chimney and Pietro (2006), structural carbon in aquatic macrophytes is more intractable and an increase in the proportion of tissue structural carbon generally corresponds with a decrease in decomposition rate. The positive correlation between decomposition and nitrogen concentration in the macrophyte tissues and negative correlation with C:N in this study also agrees with the observation of Shin *et al*. (2007).

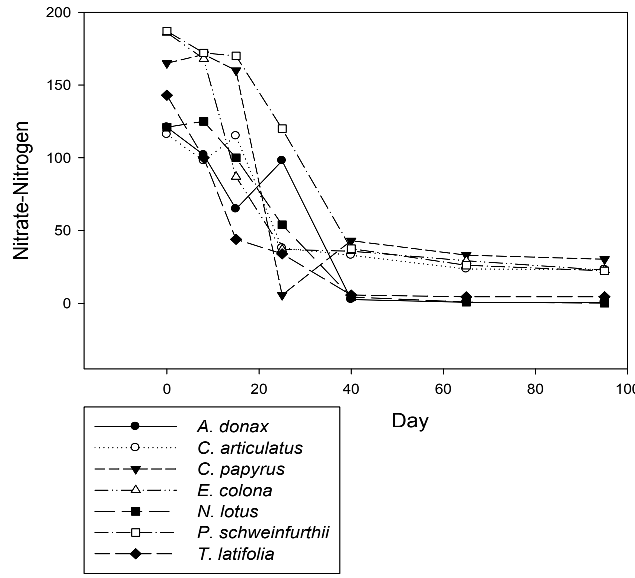


**Fig. 6: Change in nitrate concentration in the incubated bottles during decomposition period in the laboratory.**

There are not many reports specifically on decomposition rate of *P.schweinfurthii* and *N. lotus,* however, the rate of decomposition of these macrophytes were compared to the result of some similar works on these and other similar species (Tab. 5). It can be observed that these plants decomposed faster in Lake Ziway than other waters, especially temperate ones which can be mainly attributed to the environmental factors particularly temperature. Some researchers have reported that the initial litter characteristics of the macrophytes are more important than environmental factors in decomposition process of different macrophytes life forms (Kirschner *et al*. 2001). However, as it is shown in this study, the decomposition rate of similar species of macrophyte could be different depending on different environmental conditions of a lake. Environmental conditions such as temperature, pH and availability of nutrients have been found to greatly affect decomposition rates of macrophytes (Verhoeven, 1986).

The condition (e.g. temperature and pH) of Lake Ziway was favorable for macrophyte decomposition during the study time and could be the main cause for higher decomposition rates of these species. The mean water temperature was 25.2˚c and the pH was 8.5. It is generally known that decomposition is likely to take place more rapidly in water with higher temperatures. It enhances microbial activity by the microbes which in turn assist the rate of ion and nutrient release into the aquatic ecosystem (Carvalho *et al*. 2005).

**Tab. 5: K value records of some *Potamogeton* and *Nymphaea* species in several lakes.**

| Species Name | K ($day^{-1}$) | Location of the lake | Ref. |
|---|---|---|---|
| *Potamogeton pectinatus* | 0.0200 | Temperate | 1 |
| *Potamogeton stenostachys* | 0.0100 | Tropical | 2 |
| *Potamogeton natans* | 0.0123 | Temperate | 3 |
| *Nymphaea sp.* | 0.027 | Tropical | 4 |
| *Nuphara luteum* | 0.0152 | Temperate | 5 |
| *Salvinia natans* | 0.0041 | Temperate | 5 |

**Ref:** 1) Howard-Williams and Davis (1979); 2) Ferreira and de Assis Esteves (1992); 3) Chergui and Pattee (1990); 4) Cunha-Santino *et al.* (2010); 5) Longhi *et al.* (2008)

To compare the effect of environmental factors on decomposition, experiment was done on macrophytes in waters of two lakes with different pH by (Schoenberg *et al*., 1990). The result clearly indicated that decomposition and nutrient release are more inhibited in acidic waters than in basic waters. According to Kok and Van der Velde (1991, 1994), decomposition of *Nymphaea alba* was lower in acidic water than in alkaline. They also concluded that out of four enzymes that catalyze components of cell walls in *Nymphaea species,* polygalakturonase, xylanase and pectin-hydrolyzing enzymes were found to work better in slightly basic water than acidic. However, results on microbial activity and thus decomposition rate in waters of different pH are sometimes contradictory and the discussion is still open (e.g. Kufel *et al*., 2004).

The peculiar environmental condition of the lake seems also to contribute to higher decomposition of *T. latifolia.* The plant decomposed faster in Lake Ziway compared to records in other lakes (especially temperate lakes). K value for *T. latifolia* (0.014) in this study was almost double when compared to the mean K value of 21 similar experiments on the same species which were compiled by Chimney and Pietro (2006). The value was also much higher than the K value range (0.0019 and 0.0035) reported by Nelson *et al*. (1990).

Even though decomposition rate of *C. papyrus* and *C. articulatus* were lower than most of the macrophytes used in this study, they had relatively higher decomposition rate value than records of the same species in some other African waters. For example, according to Kariuki (2012), 73.6% of *C. papyrus* litters weight remained after 300 days of decomposition in Lake Naivasha. Cole (2011) reported that almost > 85 % of dry mass of *C. articulatus* remained after 90 days during their litter bag experiment under different inundation period at Okavango floodplain. Only about 40% of *C. articulatus* dry mass remained after 90 days and 24.3% after 105 days in this study. Similarly, the decomposition rate of *A. donax* was higher compared to the result of similar experiment in other waters, although the rate was the lowest during this study period. The species took more than 9 month to decompose the whole stem in the Western Cape of South Africa that has a Mediterranean-type climate (Guthrie, 2007), which was much longer time than was required in this study (4 1/2 months).

The lower decomposition rate of *A. donax* in this than the other macrophytes can be attributed to its higher cellulose content (e.g. de la Cruz, 1978). The species exhibited high production/mass lost ratio which showed that much of its production persists or remains not decomposed. It is also not preferred by grazers because of its steroid production (Cronk and Fennessy, 2001). Therefore, it may accelerate 'terrestrialization' or encroachment of the littoral zone in the future, particularly if the biomass production of the species increases. On the other side, other species (particularly *P. schweinfurthii* and *N. lotus*) had low P/M ratio and loss much of their production through decomposition.

Higher decomposition rate in the first weeks followed by a slower rate later in this study agrees with the observation of many researchers (e.g. Bruquetas de Zozaya and Neiff, 1991; Pagioro and Thomaz, 1999). It is related to the fact that the pace at which each labile and recalcitrant macrophytes constituents decay varies (Fierer *et al*., 2005). Decomposition of macrophytes includes three different and consecutive processes, leaching, microbial decay and fragmentation (Webster and Benfield, 1986). The initial rapid weight loss observed is due to leaching of soluble organic compounds and it is relatively fast (Polunin, 1984; Riley and DeRoia, 1989). After the leaching phase, the rate of decomposition gradually slows over time (Bruquetas de Zozaya and Neiff, 1991). The next two processes, microbial decay and fragmentation, are always slower because a fraction of the remaining matter dissolves only with difficulty. Changes in the types and amounts of compounds retained by plants may affect the overall decomposition rate by inhibiting colonization by aquatic microorganisms and modifying the palatability of the plant material to herbivorous invertebrates (Bengtsson, 1992; Lan *et al*., 2012).

**Changes in nutrient content of the decomposing macrophyte tissues**

The increase in nitrogen content and decrease in C:N in most of the decomposing macrophyte litters during decomposition period is a common feature observed in many studies (e.g. Twilley *et al*., 1986; Gantes and Torremorrel, 2005). The increase in total nitrogen in decomposing litters is usually attributed to an increase in protein resulting from nitrogen uptake by microbial communities associated with detritus (Pagioro and Thomaz, 1999). The other probable reason could be due to adsorption of non-protein nitrogen into microbial slimes and humification reactions and nitrogen fixation by microorganisms that use the litter as a carbohydrate source (Rice, 1982). All these processes are facilitated by microbes and many sterilization experiments of decomposing litter have shown that only small changes occur in nitrogen content in the absence of these microbes (e.g. Puriveth, 1980).

The initial rapid loss of nutrient composition of the tissue of macrophytes in this study was also observed by Gaudet and Muthuri (1981) on *Cyperus immensus* which was attributed to leaching of plant tissue which took only a few days. The absence of net increase in total phosphorous observed in the macrophyte litters in this study was contrary to the observation of Chimney and Pietro (2006) and Shin *et al*. (2007) who attributed the increase to the uptake by decomposer microbes and net immobilization of phosphorous by the decomposing plant tissue. This indicates that there could be probably variation in nature of microbial activity in different aquatic systems. In addition, in Lake Ziway, phosphorous mobilization from decomposing tissue of the macrophytes appears to dominate rather than immobilization. This result was also corroborated by laboratory incubation experiment where there was net increase in SRP in the bottles of incubated macrophytes, except for *C. articulatus*.

**Decomposition trend of the macrophytes in laboratory incubation**

The trend of weight loss of the litters during laboratory decomposition followed similar pattern as *in situ* experiments, although the rate was slower in laboratory experiments. It is normally expected that decomposition rate of macrophytes is lower in enclosed laboratory incubation experiments than in the natural water due to the absence of invertebrate decomposers and natural dynamics of environmental factors which would enhance the decomposition process.

The trend in change in nitrate and SRP during incubation experiment is in agreement with the observation from the change in total nitrogen and phosphorous concentration in field experiment. The decrease in nitrate concentration in incubating bottles could be either due to the microbial utilization of nitrates by microbes for protein production or due to ammonia volatilation (Reddy and Sacco, 1981) which was also evidenced by higher pH value recorded during incubation in the bottles.

Gaudet and Muthuri (1981) observed similar trend in decomposition incubation experiment on *Cyperus immensus* not only for nitrogen but also for sulphur and phosphorous. However, the increment in phosphorous during this study, where the maximum increase was from 35 to 160µg/l in *P. schweinfurthii* bottles, was much lower when compared with Gaudet's experiment (with similar mass of litter) who observed an increase from 100 µg/l to 11500 µg/l of phosphorous.

The higher decomposition rate of *P. schweinfurthii* and *N. lotus* with decreasing trend in their total phosphorous during decomposition and an increment in SRP in incubated bottles suggests that the species may play a role as a source of SRP and have lower importance in removal of phosphorous from the system. Similarly, the result of this study indicated that *T. latifolia*, *C. papyrus* and *E. colona* contribute net SRP to the lake water, although the rate of decomposition of these macrophytes was lower than *P. schweinfurthii* and *N. lotus*.

Some researchers have reported that the leaching process of phosphorous from aquatic macrophyte litters can provide considerable contribution to the eutrophication in some aquatic ecosystems (Park and Cho, 2003). However, the enrichment of Lake Ziway with phosphorous from decomposition of macrophytes appears to be low. The concentration of SRP is still low (29.6 µg/L) in the littoral zone of the lake. The change in physico-chemical parameters observed during laboratory experiment was narrow compared to similar experiments in other lakes (Gaudet and Muthuri, 1981). The lower impact of decomposition on the lake could be most probably due to lower biomass production of the plants that enter detrital pool, especially those macrophytes that had higher decomposition rates (Tamire and Mengistou, 2014). According to Gurtie (2007), higher decomposition rate alter nutrient status of the system only if large amounts of litter are produced. The other reason could be that the produced nutrients in the lake could be flushed out of the system continuously via river outlet (Burlakoti and Karmacharya, 2004). Gibtan and Abera (2012) reported much higher phosphate concentration (212µg/l) in river outlet (Bulbula River mouth) than recorded in the lake.

The high pH (7.85-8.72) and low conductivity (399.45-450.6 µS/cm) of the littoral zone of the lake could show the absence of significant effect of decomposition on the lake water quality parameters. Kansiime and Nalubega (1999) pointed out that high rate of macrophyte decomposition and mineralization is responsible for low pH in wetlands due to the formation of humic and fluvic acid. Gaudet (1979) also stated that higher decomposition and mineralization of the macrophytes could be the reason for the lower pH and higher conductivity in the northern region of Lake Naivasha. But the opposite condition was observed in the natural water of Lake Ziway during this study where the littoral zone of the lake had higher pH and lower conductivity.

*Arundo donax* and *C. articulatus* may play a negligible role in the release of SRP but rather may serve as a sink for phosphorous, which was also corroborated by their lower decomposition trend. There was almost no considerable variation in SRP before and after decomposition in *A. donax*-incubated bottles. The change in total nitrogen in decomposing tissue of the *A. donax* was also insignificant. All these observations suggest that *A. donax* and *C. articulatus* may play very limited role in the dynamics of nutrient cycle in the lake. The plants may be efficient in removal of nutrients and can serve as a sink, so that both species could be good candidates for waste water treatment researches.

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