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Nutrient Dynamics in Four Macrophyte Species in a Flood Wetland along the Little Ruaha River in Iringa Municipality, Tanzania

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Abstract

Studies were carried out on nutrient dynamics in a flood wetland in a tropical environment. The studies involved wetland water quality characteristics, nutrient accumulations in four macrophyte species and in the sediments. The plant species studied included: Polygonum senegalense, Ludwigia stolonifera, Typha domingensis and Cyperus dives. Standard methods were used for water quality characterization, and for the plants, nutrient levels were determined in the various plant organs. Dried and milled below-ground and above-ground plant organs were digested with a strong oxidizing agent, after which total nitrogen and total phosphorus determined. Sediment sample treatments and analyses were as described for the plant materials. The water had pH 6.45. Ammonium nitrogen and soluble reactive phosphorus concentrations were 0.20 mg l^{-1} and 0.18 mg l^{-1}, respectively. Total nitrogen and phosphorus in the water were 0.99 mg l^{-1} and 0.33 mg l^{-1}, respectively. L. stolonifera accumulated 10.89 mg g^{-1} nitrogen and 5.92 mg g^{-1} phosphorus, which were the highest for the four plant species. C. dives accumulated a mean of 6.81 mg g^{-1} nitrogen and 2.72 mg g^{-1} phosphorus. P. senegalense plants had averages of 6.55 mg g^{-1} and 2.49 mg g^{-1}, nitrogen and phosphorus, respectively. T. domingensis accumulated the least amounts of the nutrients, being 2.04 mg g^{-1} nitrogen and 0.60 mg g^{-1} phosphorus. The above-ground plant components had on average higher nutrient levels than the below-ground plant components. L. stolonifera can be classified as a hyperaccumulator for the two nutrients and could be used in wastewater treatment. T. domingensis seems to be the least suited in water treatment.

Keywords: Flood wetland, Nutrient dynamics, *Polygonum senegalense*, *Ludwigia stolonifera*, *Cyperus dives*, *Typha domingensis*

1. INTRODUCTION

Wetland ecosystems are complex and the processes within them are poorly understood. They have been recognized as playing important roles in buffering inputs from the basin catchments waters, and hence reducing eutrophication in receiving waters (Chale, 1987; Fisher and Acreman 2004; Dhote and Dixit, 2007). Because of their ability to remove suspended solids, nutrients, feacal coliform bacteria and other pollutants, wetlands are used as alternatives to wastewater treatment facilities (Vymazal, 2005; Schulz et al 2003). Chale (1985) showed that *Cyperus papyrus* swamps were able to reduce plant nutrient concentrations from sewage effluents to very low levels which were unlikely to cause environmental degradation in the receiving waters.

Nutrient uptake by macrophytes seems to be an important pathway in the reduction of nutrients in wetlands (Shardendu et al, 2012; Pajevic et al, 2003). Shardendu et al (2012) reported luxury uptake of phosphorus by *Pistia stratiotes*. Similar observations have been reported for *Phragmites mauritianus* (Sekiranda and Kiwanuka 1997) and also for *Ceratophyllum demersum* (Pajevic et al, 2003). The luxurious uptake of nutrients in wetland systems could further be advantageous in the removal of nitrogen. Since wetland environments are normally anoxic, nitrate and

nitrite ions could be reduced to the ammonium ion which would be oxidized to gaseous nitrogen and be liberated into the atmosphere.

Macrophytes have also been shown to incorporate high amounts of salts, including plant nutrients in their biomass (Macek and Rejmankova, 2007; Shardendu and Ambasht 1991). Pajevic, et al (2003), reported that *Ceratophyllum demersum* accumulated in its tissue, nitrogen (3.0 %), phosphorus (0.39%), potassium (4.13%) and sodium (0.80%). Sekiranda and Kiwanuka (1997) reported that *Phragmites mauritianus* rooted in laterite-gravel removed more than 90% phosphorus and more than 60% nitrogen in five days.

Wetland sediments have been shown to be good reservoirs for plant nutrients (Chimney and Pietro 2006; Cheesman et al 2010).

Very little information is available on nutrient accumulation by tropical marginal aquatic systems. In order to understand nutrient dynamics in a tropical wetland, studies were carried out using *Polygonum senegalense* Meisn., *Ludwigia stolonifera* Guill. & Perr. Raven, *Typha domingensis* Pers. and *Cyperus dives* Del. at a small flood wetland along the Little Ruaha river in Iringa municipality, Tanzania. The studies were carried out in November at the beginning of the rainy season. During the study period, the river was still low and the wetland received only runoff from the surroundings.

Wetland water quality, and nutrient accumulations in the various macrophyte plant organs and in the sediments were determined.

The study area is in Iringa municipality which is located at 7° 46' S, 35° 42'E, altitude 1635 m asl. The climate of the area can be described as cool with a mean high day temperature of 24.8°C. November is the hottest month with a mean air temperature of 28°C, while June to August are cold months with a mean day temperature of 23°C. Nights are generally cold, with a mean temperature of 13.5°C. June to September have a mean night temperature of 12°C, December and January have a mean night temperature of 15°C.

The rainy season is between November and May, with the highest rains falling between December and March. The mean annual rainfall is 748 mm.

2. MATERIALS AND METHODS

Water samples were collected in pre-washed and rinsed plastic bottles at two locations within the wetland. The bottles were rinsed with swamp water. Since the sampling location is less than two kilometers from the laboratory, the samples were not preserved in the field. On return to the laboratory, sample pH was determined on unfiltered water with a pH meter (Orion 2 SATAR pH Bench top) after standardizing with pH 4.01 and pH 7 buffers. Suspended solids were obtained by filtering known volumes of water through pre-weighed 0.45 µm GF/C filters and re-weighing the filters after drying at 105°C for 30 minutes and cooling in a desiccator. Total dissolved solids were determined by evaporating known volumes of the filtered samples to dryness in pre-weighed beakers. Normally, 100 ml samples were used. After cooling, the beakers were re-weighed to get the weight differences.

Aliquots of the samples were filtered through 0.45 µm GF/C filter papers and the filtrate frozen in plastic bottles until analyses. Soluble reactive nitrogen was measured as ammonium-nitrogen and nitrate-nitrogen on thawed, filtered samples. Ammonium-nitrogen was determined using the phenol-nitroprusside method (Mackereth et al, 1989) and nitrate-nitrogen was determined as the nitrite ion by the sulphanilamide method (Wetzel and Likens, 1991) after reduction through a cadminium-copper column (Mackereth et al, 1989). Soluble reactive phosphorus was determined as orthophosphate using the ascorbic acid method (APHA 1999) on aliquots of the filtered thawed samples.

Thawed unfiltered water samples were used for the determinations of total nitrogen and total phosphorus. Fifty ml samples volumes were digested with potassium persulphate for two hours and then cooled. After cooling the digests were transferred into 100 ml capacity volumetric flasks, including two rinses of 10 ml each with distilled water. Total nitrogen was determined as the ammonium ion using the phenol-nitroprusside method (Mackereth et al 1989), while total phosphorus was determined as orthophosphate by the ascorbic acid method (APHA 1999).

3. PLANT ANALYSIS

Young and mature plants were uprooted together with their roots and washed with tap water to remove any attached materials and mud, after which they were rinsed with distilled water. The plants were then separated into the various plant organs and air dried for seven days to remove excess water. The air dried plant parts were further dried in an air oven at 110°C for six hours, and cooled. The dried samples were milled using a pestle and mortar to pass a 1 mm sieve.

In the laboratory, subsamples of the milled materials (1.0 g d. wt.) were digested in a mixture of 5:1 conc. H_2SO_4:$HClO_4$ in 100 ml capacity Kjeldahl flasks in a fume hood and then cooled. In each case, 6 ml of digesting solution was used and a piece of porcelain added. The porcelain pieces were added to reduce the chances of solution explosion.

The cooled materials were transferred into 100 ml capacity beakers containing 20 ml distilled water, including two rinses of 20 ml distilled water. The digests were then neutralized with 5N sodium hydroxide and cooled. After cooling, the contents were transferred to 100 ml capacity volumetric flasks, including two rinses each of 10 ml distilled water and the volumes made to the mark.

Total nitrogen was determined as the ammonium ion by the phenol-nitroprusside method (Mackereth et al, 1989) on aliquots of the diluted neutralized digests. Total phosphorus was determined as orthophosphate on aliquots of the diluted digests, using the ascorbic acid method (APHA, 1999).

4. NUTRIENT CONTENTS IN SEDIMENTS

Mud samples were collected by hand and immediately transferred to plastic bags. In the laboratory, the samples were sun dried for six hours to drain excess water. Then the samples were mixed thoroughly by hand, oven dried at 105^{o}C to constant weights, cooled in a desiccator and milled to powder.

Known weights of the powdered materials (about 1.0 g) were digested in 5: 1 conc. H_2SO_4:$HClO_4$. Treatments of the digests and nutrient analyses were as described above for plant materials.

5. RESULTS

5.1. Wetland Water Characteristics

The water quality characteristics of the flood wetland showed that the wetland was acidic with soluble reactive nitrogen existing in its reduced form of ammonium nitrogen (Table 1). Total nitrogen levels were high and this would imply that most of the nitrogen in the water existed as particulate nitrogen. Nitrate nitrogen was absent and this could be indicative of anoxic conditions in the wetland. Dissolved oxygen could not be determined using the Winkler method due to the wetland's dark color. The dark color of the swamp water may have been a result of humic acids. Phosphorus concentrations were low both as soluble and total phosphorus (Table 1).

TABLE 1*: Mean Wetland Water Characteristics*

Parameter	Amount
pH	6.45
NH_4^+-N (mg l^{-1})	0.20
NO_3^- -N (mg l^{-1})	0
TN (mg l^{-1})	0.99
PO_4^{3-} - P (mg l^{-1})	0.18
TP (mg l^{-1})	0.33
TDS (mg l^{-1})	56.0
SS (mg l^{-1})	17.0

5.2. Macrophytes and Sediment Nutrients Contents

Table 2 shows the mean nutrient contents of the four macrophyte species and wetland sediment.

TABLE 2: *Total Nitrogen and Total Phosphorus in Plants Organs and Sediments*

Plant Species	Organ	Parameter	
		TN (mg g^{-1})	TP (mg g^{-1})
P. senegalense	Rhizomes	2.68	1.36
	Roots	6.37	0.83
	Culms	3.05	3.55
	Leaves	10.78	2.92
	Flowers	9.89	3.77
L. stolonifera	Roots	6.78	8.70
	Culms	6.44	2.34
	Leaves	19.45	6.71
T. domingensis	Roots	3.35	0.88
	Rhizomes	2.12	0.38
	Culms	1.69	0.16
	Leaves	1.0	0.97
C. dives	Roots	2.44	2.02
	Culms	3.67	2.77
	Leaves	10.19	3.40
	Flowers	10.93	2.69
Sediment		1.45	0.86

From the table, it is observed that on average *L. stolonifera* accumulated the highest amount of nitrogen (mean 10.89 mg g^{-1} d. wt.), while *C. dives* had the next highest nitrogen accumulation (mean 6.81 mg g^{-1} d. wt.) and *P. senegalense* accumulated a mean nitrogen content of 6.55 mg g^{-1} d. wt. *T. domingensis* had the least nitrogen accumulation in its tissue (2.04 mg g^{-1} d. wt.). The amount of nitrogen in the sediment was lower than in the plants.

Similarly, *L. stolonifera* had the highest amount of phosphorus in the tissue (mean 5.92 mg g^{-1} d. wt.), followed by *C. dives* and *P. senegalense*, whose mean phosphorus levels were 2.72 mg g-1 d. wt. and 2.49 mg g^{-1} d. wt., respectively *T. domingensis* had the lowest mean amount of phosphorus in its tissue (0.60 mg g^{-1} d. wt.). The amount of amount of phosphorus in the sediment was 0.86 mg g^{-1} d. wt.

With the exception of *T. domingensis*, the above ground parts of the other three macrophyte species accumulated more nitrogen than the below ground parts (Table 3).

TABLE 3: *Mean Nutrient Accumulations in Above-ground and Below-ground Macrophyte Parts*

Plant Species	Belowground		Aboveground	
	TN (mg g^{-1})	TP (mg g^{-1})	TN (mg g^{-1})	TP (mg g^{-1})
P. senegalense	4.53	1.10	7.91	3.41
L. stolonifera	6.78	8.70	12.95	4.53
T. domingensis	2.74	0.63	1.35	0.57
C. dives	2.44	2.02	8.26	2.95

L. stolonifera roots had higher phosphorus levels than the mean phosphorus accumulation in the aboveground parts (Table 3). Similarly, *T. domingensis* accumulated more phosphorus in its below-ground parts than the above-ground parts.

6. DISCUSION

The water quality of the wetland was typical of swamp water with low pH value, presence of reduced forms of nitrogen and devoid of dissolved oxygen (Table 1). Chale (1987) reported that wetland environments were normally anoxic and nitrogen existed mainly as ammonium nitrogen. Similar observations have also been reported by Chale (2007) when studying nitrogen dynamics in a constructed wetland receiving sewage effluents. The acid conditions found in the wetland may have been a result of the degradation of the dead plants through bacterial decomposition forming humic acids. Soluble reactive phosphorus concentrations found in the wetland may have been a result of input from the surrounding area through run off, leaching from the wetland soil and also through the decomposition of the dead plants. Chimney and Pietro (2006) showed that decomposition of aquatic macrophytes returns nutrients to the water column. The water had low dissolved mineral salts which may have been due to low inorganic mineral content in the catchment soils.

All the macrophyte species accumulated more nutrients in their tissues than the sediments (Table 2) or water (Table 1). *Ludwigia stolonifera* accumulated the highest amounts of both nitrogen and phosphorus, followed by *Cyperus dives* (Table 2). *Typha domingensis* accumulated the least amounts of the nutrients. Nutrient uptake and incorporation by macrophytes have been reported to be important pathways in the reduction of nutrients in wetlands (Shardendu et al, 2012; Macek and Rejmankova 2007; Pajevic et al, 2003; Shardendu and Ambasht1991; Chale 2012). Shardendu et al (2012) reported that *Pistia stratiotes* accumulated more phosphorus than required for its metabolism, while Pajevic et aL (2003) showed that *Ceratophyllum demersum* accumulated very high amounts of nitrogen, phosphorus and potassium. The high rates of nutrient uptake and accumulation by aquatic macrophytes have found use in wastewater treatment in constructed wetlands.

Aquatic macrphytes have been found to reduce eutrophication in receiving waters (Fisher and Acreman 2004; Dhote and Dixit 2007). Sekiranda and Kiwanuka (1997) showed that *Phragmites mauritianus* rooted in laterite-gravel could remove very high levels of phosphorus and nitrogen in five days. Similarly, Chale (1985) showed that *Cyperus papyrus* swamps were able to reduce nutrient concentrations from sewage effluents to very low levels which were unlikely to cause eutrophication in the receiving waters. In the current study, *Ludwigia stolonifera* seems to be the more suited macrophyte species in waste water treatment, while *Typha domingensis* is the least suited.

Three macrophyte species stored more nitrogen in above ground parts than in the below ground organs (Table 3). *L. stolonifera* had the highest above ground nitrogen accumulation, followed by *C. dives, and P. senegalense*. Since these species accumulate more nitrogen in their above ground parts, they can be classified as hyperaccumulators for nitrogen (Mganga et al, 2011; Pajevic et al 2003), while T. domingensis which accumulates less nitrogen and phosphorus in its above ground organs may be classified as a nutrient excluder (Mganga et al, 2011). *L. stolonifera* had less phosphorus in its above ground tissues (Table 3) and could be classified as a phosphorus excluder (Mganga et al 2011).

Apart from *T. domingensis*, the other three macrophyte species accumulated more nitrogen in their leaves and for *P. senegalense* and *C. dives* also in their flowers (Table 2).

From the study, it is observed that *L. stolonifera* is more suited for waste water renovation, followed by *P. senegalense*. *C. dives* and *T. domingensis* are perennial sedges and their growth rates might not be as fast as for the perennial shrubs, *L. stolonifera* and *P. senegalense*.

7. CONCLUSION

In the flood wetland studied, higher amounts of nutrients were accumulated in the plant tissues compared to the water or sediments. However, nutrient levels in the four macrophyte species were not equal, with *Ludwigia stolonifera* accumulating higher amounts of both nitrogen and phosphorus. *Cyperus dives* was next in importance in the amounts of the plant nutrients accumulated. *Typha domingensis* was the least efficient in nutrient accumulation. *L. stolonifera*, *C. dives* and *P. senegalense* stored higher amount of nitrogen in their above-ground organs than

below-ground organs. *L. stolonifera* stored more phosphorus in its below-ground parts compared to the above-ground parts. *T. domingensis* had higher nitrogen and phosphorus concentrations in the below-ground organs than the above-ground organs. *L. stolonifera* can be regarded as a hyperaccumulator of the two nutrients and could be used in wastewater treatment.

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