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Nutrient Dynamics in an *Avicennia marina* (Forsk.) Vierh., Mangrove Forest in Vamleshwar, Gujarat, India

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Abstract

The study was carried out to determine the nutrient budget of plants, sediments and nutrient dynamics in an *Avicennia marina* (Forsk.) Vierh., dominated forest in Vamleshwar near Narmada estuary, West Coast of Gujarat for a period of one year from November 2008 to October 2009. The average tree height of the mangrove is 1.5 to 2 m without much vertical stratification. Allometric methodology was used to measure the biomass, and yield a figure of 86.47 t ha^{-1} and the litter fall rate amounted to 2.9 t ha^{-1}. Nutrient stocks of N, P and K in this mangrove were 137.05, 14.38 and 241.29 kg ha^{-1}, with an annual accumulation of 55.74, 12.38 and 83.94 kg ha^{-1}, and an annual return of 51.30, 10.83 and 13.52 kg ha^{-1}, respectively, in the form of litter. The annual uptake for N, P and K were 61.04, 14.28 and 97.46 kg ha^{-1}, and turnover rates of N, P and K were estimated at 3, 6 and 14 years, respectively, for the study period. Flow coefficients, which reveal the dynamic processes of nutrients between mangrove plants and sediments, are also explained. The present study concluded that the *A. marina* dominated mangrove plantation is more efficient in nutrient use and conservation.

Keywords: annual accumulation, annual return, annual uptake, flow coefficient, nutrient stocks

Introduction

Mangroves are unique intertidal woody communities, common in tropical and subtropical coastlines. They are important not only in protecting coasts from erosion by storm tides, but also maintaining the diversity of coastal ecosystems by contributing quantities of food/nutrients and providing favorable habitats for other plants and animals (Tomlinson, 1986). Nitrogen, phosphorus and potassium are elements essential to a variety of biological and chemical processes, both at the organism level (e.g. somatic growth, reproduction) and on the scale of ecosystems. Nutrients are made available to most forests from precipitation and dry atmospheric fallout and from the weathering of rocks and soil minerals. With little surface drainage entering from the surrounding environment, mangrove forests depend mostly on the nutrients from sediment (released from decomposed organisms) which may receive replenishment of nutrient supplies from periodic flooding. Several studies have indicated that mangroves are nutrient limited (mainly N and P) (Akamatsu *et al.*, 2009; Boto and Wellington, 1983; Islam *et al.*, 2008; Uchiyama *et al.*, 2000).

Frugal use of nutrients has been hypothesized for mangrove plants, and a nutrient transfer prior to fall off senescent leaves has been well documented (Erskine *et al.*, 2006; Kimmins, 2004; Schwartz *et al.*, 2000; Woodwell

et al., 1975). Progress has been made on the contribution of mangrove detritus to adjacent near-shore areas, but comparatively few data are available on nutrient pool transformations and flux within mangrove forests (Alongi, 1989; Boto, 1992). Nevertheless, nutrient dynamics have been studied in estuaries, salt marshes and tropical mangrove ecosystems (Gong and Ong, 1990; Wiebe, 1987) although relatively less in subtropical mangroves (Lin *et al.*, 1987; Schwendenmann *et al.*, 2006; Shaiful, 1987). An excellent review has presented on comprehensive picture of nitrogen and phosphorus cycling in mangrove ecosystems, including the distribution, transformation and fluxes of various nitrogenous and phosphorus species in mangrove sediments and in tidal creek waters, with particular reference to the Australian mangroves by Alongi *et al.* (2005). In the present study, we examined the biological cycling and dynamics of N, P and K elements between mangrove plants and the sediments in Vamleshwar mangrove forest, Near Narmada Estuary, West Coast of Gujarat, India. Moreover, various works have been carried out by Nirmal Kumar *et al.* (2010a; 2010b; 2011) in the field of fuel wood properties, seasonal changes of bio elements and assessment of carbon stock in the Teak and Butea forest ecosystem, Western India, Rajasthan. Quantification of nutrients and decomposition of litter have been studied in Teak and Butea forests of Rajasthan, Western India by Nirmal Kumar *et al.* (2010c; 2009a; 2009b).

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Materials and methods

Study site

The study was conducted at *A. marina* plantation, Vamleshwar, Narmada estuary covering an area of 100 ha (GEC) from November 2008 to October 2009, which is located at a latitude of 21°30'11.55"N and longitude of 72°43'53.68"E 45 km to west of Ankleshwar, Gujarat, India towards Arabian Sea (Fig. 1). The study area has various natural resources, vast array of biological diversity and coastal and riverine fishing activities. The average tree height is 1.5-2 m with no vertical stratification. The climate of this area is dry, with mean annual relative humidity of 46.18%. The mean annual air temperature is 30.42°C, with minimum and maximum values at 19.2°C (in January) and 38.7°C (in June), respectively. Annual precipitation is 800 mm, and the rainy season is from June to September. The mangrove area is inundated by an incoming tide twice a day and the tidal range is about 2.1 m. The sediment is darkly coloured and gives off an odour of H_2S, suggesting an obviously anaerobic condition in the soil.

Estimation of biomass annual growth

Ten quadrats each of 10 m × 10 m, were laid within the mangrove forest to determine the stand biomass. The dbh and height of each tree were recorded. The biomass
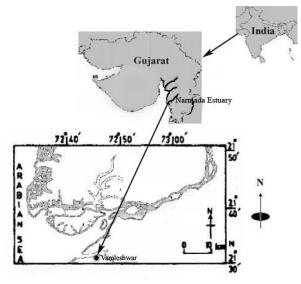

Fig. 1. Location of the study area

of the plant community was estimated by the allometric equation formulated from the harvested data (Dittmar *et al.*, 2006; Komiyama *et al.*, 2008):

$$Y = a + bX$$

where, *Y* is the biomass of the component, *a* and *b* are the constants, X is the DBH.

Thirty trees of *A. marina* were randomly chosen from the quadrats. The individual tree was harvested and the aerial parts were separated into stem, branch and leaf. The fresh weights of these components were recorded. Subsamples were dried at 80°C to constant weight.

A tree of *A. marina* was harvested for growth ring analysis. Stem discs were cut at the base, 0.2, 0.5, 1.0, 1.3 and 1.8 m. All lateral growth measurements are in terms of south–north direction. The average and annual growth of timber volume can be calculated following the traditional forestry method (Anuchin, 1970), which has been applied to mangrove forests (Lin and Zheng, 1986). The annual growth rate of timber volume was defined as the annual net increment of timber volume per year divided by the total timber volume. This rate is 0.1482 for *A. marina*.

Sampling of sediments, plants and chemical analyses

In the study area, surface soil samples (0–30 cm) were taken at regular intervals from landward to seaward region. Triplicate samples were collected, air dried, passed through a 2 mm sieve and then analysed for nutrients. Meanwhile, at the same interval where sediment samples were collected, mature leaves of *A. marina* were taken. At three points (landward, middle and seaward of the mangrove), triplicate samples of root and stem were collected, respectively. Separated parts of plant samples were oven dried at 80°C and then ground into powder. Total Nitrogen was determined by micro-Kjeldahl digestion followed by steam distillation. Total Phosphorous was determined colorimetrically by the molybdate method (Murphy and Riley, 1962) and total K by flame photometry. NH_4^+, NO_2^- and NO_3-N (extracted with 2N KCl at 1:4 ratio followed by distillation), available P (Prasad, 2005) and extractable K (extracted with 1M ammonium acetate (pH 4) at 1:5 soil: water ratio) were also measured for soil samples. Stock and allocation of nutrients in different components were calculated by multiplying nutrient concentration values with corresponding biomass. Mean values were used in the calculation.

Litter production, annual return, accumulation, uptake of nutrients, and turnover rate

Assuming annual net leaf production was zero, i.e. annual leaf growth equaled annual leaf litter fall (Bala Krishna Prasad and Ramanathan, 2008), annual accumulation was actually the nutrients accumulated in the woody components and was calculated using the nutrient contents multiplied by the respective net growth. Annual uptake is the sum of annual accumulation and annual return of nutrients (Duvigneaud and Denaever-De Smet, 1970). Annual uptake indicates the need for nutrients by mangrove plants. Turnover rate is the ratio of the stock of an element in biomass divided by the return of the element in yearly litter fall.

Results and discussion

Biomass, stock and allocation of nutrients

Nutrient concentration varied from tissue to tissue (Tab. 1). Highest N concentration was found in the leaf tissues but lowest in the roots, while P and K were rich-

est in the roots but lowest in the stems. Nutrient levels in litter components have been less studied than in fresh tissue (YiMing and Sternberg, 2007; Woodroffe *et al.*, 1988; Twilley, 1986). No data were available for *A. marina* litter nutrient contents. For *Kandelia*, Lin and Zheng (1986) measured N, P and K contents in litter accounts for 1.79, 0.14 and 0.66%, respectively. As compared with these values, litter nutrient levels in the Vamleshwar mangrove were significantly lower with N-0.257%; P-0.092% and K-0.456%.

Tab. 1. Concentrations of nutrients in different components of *Avicennia marina*

Component	N	P	K
Stem	0.473±0.183	0.076±0.032	0.372±0.051
Leaf	1.172±0.219	0.133±0.011	0.421±0.019
Root	0.438±0.293	0.166±0.019	1.480±0.138
Average of above	0.694	0.125	0.758
Litter	0.257±0.03	0.092±.001	0.456±.006

Values are mean (%) ±SD (n =30)

The biomass of this mangrove community was estimated to 86.47 t ha^{-1}. The total nutrient stocks for N, P and K were 437.05, 90.38 and 588.29 kg ha^{-1} (Tab. 2). Allocation of nutrients was affected most heavily, of course, by the biomass of plant tissues. It was also affected by the nutrient content of plant components in greatest abundance. Leaves, for instance, appeared to have the lowest nutrient stocks although they contained the highest amount of N. On the whole, the elemental stocks followed the order of K>N>P.

Tab. 2. Stock and allocation of nutrients in *Avicennia marina* mangrove

Component	Biomass	N	P	K
Stem	57.45	271.85	44.04	213.74
Leaf	5.20	60.95	6.89	21.92
Root	23.82	104.25	39.45	352.63
Total	86.47	437.05	90.38	588.29

Biomass values are in t dry wt ha^{-1}, and other values are in kg ha^{-1}

Nutrient concentrations in mangrove plant tissues are results of long-term adaptations to the nutrient availability in the surrounding environments. As the nutrient concentrations of leaf tissue reflected the soil nutrient status which differed significantly, the leaf N, P and K contents of the plant species would vary from mangroves to mangroves (Carlos *et al.*, 2007; Tam *et al.*, 1995). However, Chen and Lindley (1983) reported, after working on the nutrient characteristics of several estuarine mangrove forests along north-east Hainan coasts, that the correlation coefficients between leaf and soil nutrients were fairly low or even negative, i.e. -0.33 for N, -0.55 for P and -0.43 for K. These revealed that the nutrient levels in plant tissues were not determined much by the nutrient abundance in the soil. Mangrove plants can selectively absorb what they need from the sediments.

Annual growth and accumulation of nutrients

The annual nutrient accumulation and partitioning have been presented in Tab. 3. The total annual accumulation for N, P and K amounted to 55.74, 12.38 and 83.94 kg ha^{-1}, respectively. N seemed to accumulate mainly in stems (72.3%), while K mainly in roots (62.3%). K accumulation in plant was many folds greater than P and N (1.5–5.8 times).

Tab. 3. The annual accumulation of nutrients in *A. marina* mangrove

Components	Growth	N	P	K
Stem	4965	40.29	6.53	31.68
Root	4024	15.45	5.85	52.26
Total	8989	55.74	12.38	83.94

All values are in kg ha^{-1}

Annual nutrient uptake

The total uptakes of N, P and K were 61.04, 14.28 and 97.46 kg ha^{-1} (Tab. 4), with return/accumulation ratios of 0.92, 0.87 and 0.16, respectively. The N and P ratios were about 1.0, but the K ratio was much lower, suggesting that dynamic N and P processes were near equilibrium, and K was strongly consumed by the plants.

Tab. 4. Annual uptake of nutrients in *A. marina* mangrove

	N	P	K
Accumulation (kg ha^{-1})	55.74	12.38	83.94
Return (kg ha^{-1})	51·30	10.83	13·52
Uptake (kg ha^{-1})	61.04	14.28	97.46
Return/Accumulation ratio	0.92	0.87	0.16

Turnover rate

The turnover rates of N, P and K in this mangrove were calculated to be 3, 6 and 14 years, respectively, using the litter values of 2008-2009 and comparisons of turnover rates among mangroves are given in Tab. 5. Turnover rate may correlate to the age of the forest. Gong and Ong (1990) revealed that the increased age, the forest has a longer nutrient turnover period before it reaches maturity. Turnover rate is affected by biomass, litter production and the

Tab. 5. Turnover rates of N, P and K in some mangroves

Forest type	Age (years)	Location	N (years)	P (years)	K (years)	Sources
Rhizophora mangle		Panama	-	23	8	Golley *et al.* (1975)
R. apiculata	1–10	Matang	12.29	7.12	4.95	Gong and Ong (1990)
	11–20	Malaysia	19.46	8.15	10.43	
	21–30		30.81	10.71	10.45	
Avicennia marina	1-10	Vamleshwar, Gujarat, India	3	6	14	Present study

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nutrient contents of both components. Biomass increases as the forest grows, in contrast, litter fall is, instead, controlled more by physical factors such as temperature and precipitation and does not necessarily increase with age. All factors which influence the litter fall can also change the turnover rate value.

Sediment nutrient pool

The nutrient status of mangrove sediments in Vamleshwar is presented in Tab. 6. The soil N and P levels declined gradually with the distance away from the land, but K remained relatively constant. Seasonal variations were found to exist for K, but not very clear for P and N (Wong *et al.*, 1995). Mean concentrations of N, P and K were 0.154, 0.169 and 1.72%, respectively, well within the reported ranges (0.018-0.4% for N, 0.004-0.160% for P and 0.48-5.02% for K). Taking 0-30 cm surface soil into consideration (mainly because most of the mangrove roots are distributed in this layer), the total nutrient stocks of N, P and K in the sediments were 3883.4, 3209.8 and 36073.5 kg ha^{-1}, i.e. 6.3, 27.7 and 47.3 times as much stock as in the plant community. These were undoubtedly the large potential nutrient pools for mangrove plants. The large quantities of nutrients in the sediments were not readily available to plants because most of them are refractory. Only 4.04% of the total N exists in inorganic form. 5.42% of the total P and 1.36% of the total K are extractable.

Tab. 6. The nutrient status of mangrove soils (0-30 cm) in *A. marina* mangrove

Nutrients	Amounts
Total N (%)	0.154±0.001
NH$_4^+$-N (kg ha^{-1})	157.17±2.47
NO$_3^-$-N (kg ha^1)	ND
Total P (%)	0.163±.018
PO$_4^{3-}$-P (kg ha^{-1})	173.97±0.21
Total K (%)	1.72±0.27
Ext. K (kg ha^{-1})	490.60±17.38
Total N pool (kg ha^{-1})	3883.4
Total P pool (kg ha^{-1})	3209.8
Total K pool (kg ha^{-1})	36073.5

Values are mean ±SD. ND: Not detected

Flow coefficients

Nutrients are absorbed from the soil, part of which is retained in the plant tissues as the growth of biomass, and parts are returned to the soil via litter fall to join another cycle. These soil–plant–soil nutrient flow processes can be depicted with absorption coefficient (AC), utilization coefficient (UC) by Chen and Lindley (1983) and cycling coefficient (CC) by Larcher (1983). Flow coefficients of nutrients in the Vamleshwar mangroves are presented in Tab. 7. The N absorption coefficient (0.027) was about three times as much as P, and 7 times as high as K. However, utilization coefficient does not vary significantly. Cy-

Tab. 7. Flow coefficients of nutrients in *A. marina* mangrove

	Avicennia marina			Kandelia candel		
	N	P	K	N	P	K
AC[a]	0.022	0.008	0.003	0·027	0·019	0·205
UC[b]	0.242	0.268	0.174	0·228	0·194	0·002
CC[c]	0.286	0.108	0.039	0·607	0·498	0·544
Sources	Present study			Lin *et al.* (1987)		

[a]AC, absorption coefficient. Annual uptake amount of an element by plants per ha/stock amount of the element in soil pool per ha (0–30 cm).
[b]UC, utilization coefficient. Annual uptake amount of an element by plants per ha/stock amount of the element in plants per ha.
[c]CC, cycling coefficient. Annual return rate of an element/annual uptake amount of the element

cling coefficients in Vamleshwar mangrove were considerably lower than *Kandelia* forests by Lin *et al.* (1987) which were also reflected by its longer turnover rate.

Conclusions

Our study fills a gap not only in the regional understanding of nutrient dynamics in these systems but in the general understanding of several seasonally driven mangrove systems. Based on our flux results, nitrogen, phosphorus, and potassium appeared fairly well balanced in terms of annual imports and exports in the present study system. Greater utilization coefficients in this *A. marina* dominated mangrove plantation suggest that it is more efficient in nutrient use and conservation.

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