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Characterization of *Porteresia coarctata* beds along the Goa coast, India

Tanaji G. Jagtap *, Siddharth Bhosale, Singh Charulata

Biological Oceanography Division, National Institute of Oceanography, Dona Paula, Goa 403004, India

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Abstract

Porteresia coarctata, forms an important constituent in the plant succession leading to formation of mangrove communities along the estuaries in India. Major beds along the Mandovi estuary of Goa were monitored for their various ecological and environmental parameters. Nitrate and nitrite values in the over lying waters of beds varied from 0.12 to 1 μg at NO_2–N L^{-1} and 1.2 to 6.7 μg at NO_3–N L^{-1}, while salinity values were in the range of 0–36‰, and gradually increased from August to September reaching its maximum during the month of April–May. The biomass values ranged from 39.3 ± 5.6 to 145.2 ± 32.2 g dry weight m^{-2}. Biomass and growth were negatively correlated (r = 0.53–0.80) with salinity while the same were positively correlated with nitrite (r = 0.73–0.87) and nitrate (r = 0.63–0.80) from the surface water. The growth of *P. coarctata* mainly continued by tiller formation. The density of seed producing shoots varied from 1 to 3 m^{-2}. The major vegetative characters of *Porteresia* indicated significant spatial and temporal variations. Sediments from the beds were rich in organic carbon (1.5–7.9%) and organic nitrogen (0.1–2.3%).

Keywords: Wetland; Marine macrophyte; Pioneer species; Ecology; Growth; Biomass

1. Introduction

Wetlands under tidal influence are an important constituent of coastal ecosystems for their ecological, socio-economic and aesthetic values. Mangrove habitats in the tropics particularly in the belt of 25°N–25°S are the most predominant wetlands. *Porteresia coarctata* [Roxb.] Tateoka, a perennial halophytic wild grass relative of rice, and *Halophila beccarii* Aschers., an estuarine seagrass, members of Poaceae and Hydrocharataceae respectively, act as pioneer species in the succession process of mangrove formation along the estuaries of India (Jagtap, 1985). These species establish on the newly deposited sediments and help enhance sedimentation, developing favourable substratum for the growth of mangroves (Plate 1). *Porteresia coarctata*, though of great significance to estuarine and deltaic environments, is very poorly understood ecologically, compared to other marine and estuarine vegetation. Temporal and spatial patterns in growth and biomass production of *P. coarctata* were evaluated with regard to its immediate environmental characteristics at selected localities along the banks of Mandovi estuary, Goa, India. The present investigation enriches existing information of *Porteresia* habitat and is significant to the coastal zone management programme of the country.

2. Materials and methods

2.1. Description of the study area

2.1.1. Geomorphology and geography

Goa coast of India has ~120 km coastline indented with seven major estuaries including Mandovi. The coastal landmass is built of Deccan lava mainly composed of granites and gneisses with rocks of laterite covered beds (Ahmad, 1972). The coastal plains, particularly under regular inundation by tide, are composed of alluvium of variable soils. The coastal strip is highly indented with sea-cliffs, notches and promontories alternating with rias, rivers and estuaries, and bounded by the Arabian sea to the west and by the Sahyadri ranges on the east. The steep topography has formed fringes of inter-tidal zones in the study area (12°28′–15°52′N and 73°46′–73°54′E).

* Corresponding author. Tel.: +91 832 2450390; fax: +91 832 2450602/2450603.
E-mail addresses: tanaji@csnio.ren.nic.in, tanaji@darya.nio.org (T.G. Jagtap).

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Plate 1. The habitat of *Porteresia coarctata* from Mandovi estuary, Goa.

2.1.2. Climatology

The climate of the study area is moist and moderate (Anon, 1999). Atmospheric temperature varies from 19 to 33 °C with maximum and minimum during May and January, respectively. Average humidity ranges from 75 to 89% and remains higher during the period of monsoon (July–August). The west coast receives rain from southwest monsoon winds with annual average rainfall of 2470 mm, of which 90% occurs during the months of July and August. The wind speed usually is in the range of 4.6–18 km h^{-1}.

2.1.3. Tides

The tidal fluctuation along the Goa coast ranges from −0.13 to 2.48 m (Anon, 2003).

2.1.4. Sampling

The area estimates for *Porteresia* patches at various localities in the study region were manually made by measuring length and breadth of individual beds. Three stations namely S-I (73°46′57.3″E, 15°30′49.3″N), S-II (73°52′10.6″E, 15°30′42.7″N) and S-III (73°54′06.5″E, 15°30′01.4″N), with major meadows (>500 m^2) of *Porteresia*, along Mandovi estuary were monitored monthly for hydrological and vegetative characteristics. Monthly samplings were carried out at ebb during the period from September 1996 to December 1997.

2.1.5. Hydrological and sediment characteristics

Standard methods were used for studying hydrological and sediment characteristics (Strickland and Parson, 1972; Folk and Ward, 1957; Folk, 1968). The atmospheric and water temperatures from the immediate vicinity of *Porteresia* beds were measured. Sediments from station S-I were collected at three points, and each sample was analysed in triplicate for granulometry during premonsoon (February–May), postmonsoon (October–January) and monsoon (June–September). However, sediments from all the stations were monthly estimated for their organic carbon (OC) and organic nitrogen (ON) contents by the methods of El Wakeel and Riley (1957) and Bremner (1965), respectively. The vegetative structure from various tidal zones at each station (Fig. 1) were assessed by using line transect and quadrat methods (Jagtap, 1996).

2.1.6. Vegetative structure

Monthly sampling for biomass estimation was carried out. A perpendicular belt (~50 m width) transect to the shore was laid in the *Porteresia* beds from low tide to high tide mark at each station. The length of transect varied from 20 to 250 m depending upon the horizontal extent of beds to the shore. Each transect was divided into three zones, namely, low tide (LT), mid-tide (MT) and high tide (HT). Sampling interval varied at different stations from 5 to 50 m, depending upon the transect length. At each station, two to three perpendicular transects were laid down, depending upon the extent of beds parallel to the shore. The biomass was estimated by removing all the plants along with roots, rhizomes and shoots from three quadrats (each of 625 cm^2 size), from each tidal zone. Plant material was thoroughly washed in the ambient water immediately after collections, as well as with tap water, to remove adhering debris and sediments. The various vegetative parts (above and below ground) were separated, and sun dried, and weighed after drying the same again in an oven at 60 °C to a constant weight. Biomass data from all the quadrats at sampling stations were pooled and the results were expressed as g dry weight (DW) m^{-2} on an average basis for different tidal zones.

Quantitative data on other parameters of vegetative structure such as shoot height (PH), number of leaves (NL), number of tiller formations (NT), leaf length (LL), breadth (LB), were also collected at the time of biomass sampling. The results were expressed on an average of 20 shoots from five quadrats of 1 m^2 each, at all the biomass sampling points. Data on fertile shoots such as total number (NP), number of flowering (NFP) and seed (NPS) bearing shoots, were also collected monthly, during the period June–January when flowering and seed formation occurred. Two-way ANOVA was used to find out spatial and temporal variations in the different plant characters.

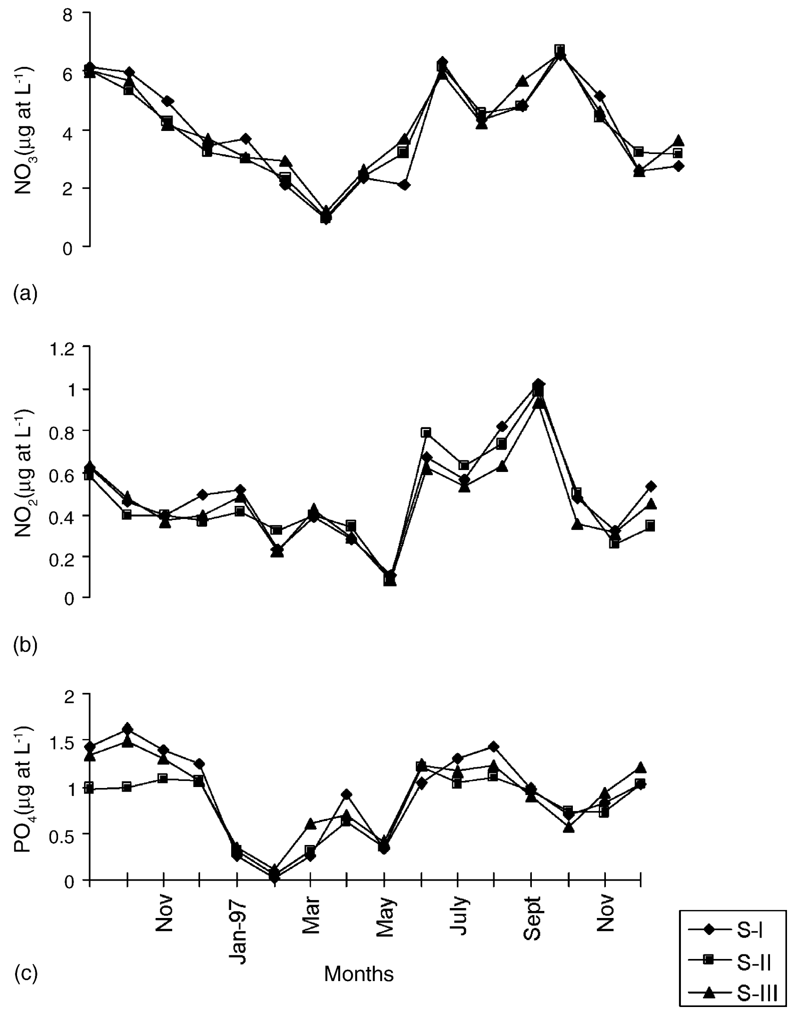

Fig. 1. Monthly variations in physico-chemical parameters associated with *P. coarctata* (a) nitrate, (b) nitrite, (c) phosphate.

3. Results

3.1. Distribution

Porteresia coarctata beds from the study region were limited to mid and upper intertidal regions particularly from euhaline and polyhaline (salinity 18–30‰) zones. The beds were commonly observed in different sized patches ranging from ~50 to 20,000 m^2.

3.2. Hydrological parameters

The surface water temperature varied from 21.5 to 32.5 °C while the pH values ranged from 6.99 to 8.79. The highest (5.64 ml L^{-1}) value of DO was recorded during postmonsoon (POM) period while the lowest value of 2.3 ml L^{-1} was observed during May. Nitrite and nitrate concentrations varied from 0.12 to 1.04 μg at NO_2–N L^{-1} and 1.2 to 6.72 μg at NO_3–N L^{-1} (Fig. 1a and b), respectively, while phosphate remained in the range of 0.021–1.96 μg at PO_4–P L^{-1} (Fig. 1c). The salinity values fluctuated from 0‰ during monsoon (MON) period to 35.65‰ during premonsoon (PRM) period (Fig. 3) while pH values were recorded in the range of 7–8.8.

3.3. Sediment characteristics

The substratum was more of sandy nature at all the stations, showing sand contents in the range of 33.7–42.1% from station I (Table 1). The carbonate concentrations in sediments ranged from 4.1 to 9.1% with relatively higher values (8.1–9.1%) during monsoon period. Organic carbon (OC) and organic nitrogen (ON) values in the sediments were recorded between 1.5–4.6 and 0.1–1.3%, respectively (Fig. 2).

3.4. Vegetative characteristics

Total (above and below ground ± S.D.) biomass ranged from 39.3 ± 5.6 to 145.2 ± 32.2 g DW m^{-2}. In general, the biomass values were observed to be maximum during monsoon (MON) and the higher values were found from the mid intertidal zones of all stations (Fig. 3), when salinity values remained low. The biomass values were observed to be highly correlated (Table 2) with salinity and nutrients (NO_3–N and NO_2–N) values.

The average shoot height (PH) was recorded in the range of 36.1–83.5 cm. The maximum PH (83.5 cm) was measured during the month of September while minimum PH (36.1 cm)

Table 1
Seasonal variation in sediment characteristics from *Porteresia coarctata* beds at S-I

Parameter	Premonsoon		Monsoon		Postmonsoon	
average (n = 9)	Vegetated	Non-vegetated	Vegetated	Non-vegetated	Vegetated	Non-vegetated
Sand %	33.68	38.92	41.28	44.12	42.09	39.26
Clay %	27.4	29.15	30.8	28.02	28.11	35.11
Silt %	29.54	25.14	18.1	17.92	22.28	18.92
Carbonate %	6.54	5.21	8.12	9.11	5.92	4.09
Organic carbon %	2.57	N	2.1	N	2.79	N
Organic nitrogen %	0.3	N	0.3	N	0.28	N
C:N ratio	8.58	N	7.86	N	10.47	N

N, negligible.

was recorded during February. Average number of leaves varied between 5 and 6 plant^{-1} and the average leaf length ranged from 15 to 23 cm with higher values during POM, however, average breadth of leaf was minimum during PRM (Table 3). The reproductive stages in *P. coarctata* shoots commenced at the beginning of rainy season (June) and it continued up to the month of January (Table 4). Flowering and seed formation were observed from June to October. However, maximum seed bearing shoots (6–9%) were noticed during the month of October from stations S-I and S-II (Table 4). The percentages of reproductive (flowering) shoots were highest (39%) during the month of October from the S-I while the density of seed producing shoots in the entire study area varied from 1 to 3 m^{-2}.

4. Discussion

Estuaries along the central west coast, in general are microtidal (<2 m) in nature dominated by tidal currents during most of the year ((Anon, 2003; Anthony et al., 1974). The flood currents dominate the ebb current during PRM period, however, ebb flow dominates the flood velocity during the MON period (Murty and Das, 1972). The steep topography of the region has resulted in the formation of narrow intertidal belts of recent alluvial soils, along estuaries (Ahmad, 1972). The downstream mid and upper inter-tidal mudflats from the harbor fringing mangroves and occasional patches of *P. coarctata* and *H. beccarii* exist in the lower inter-tidal regions (Jagtap, 1985).

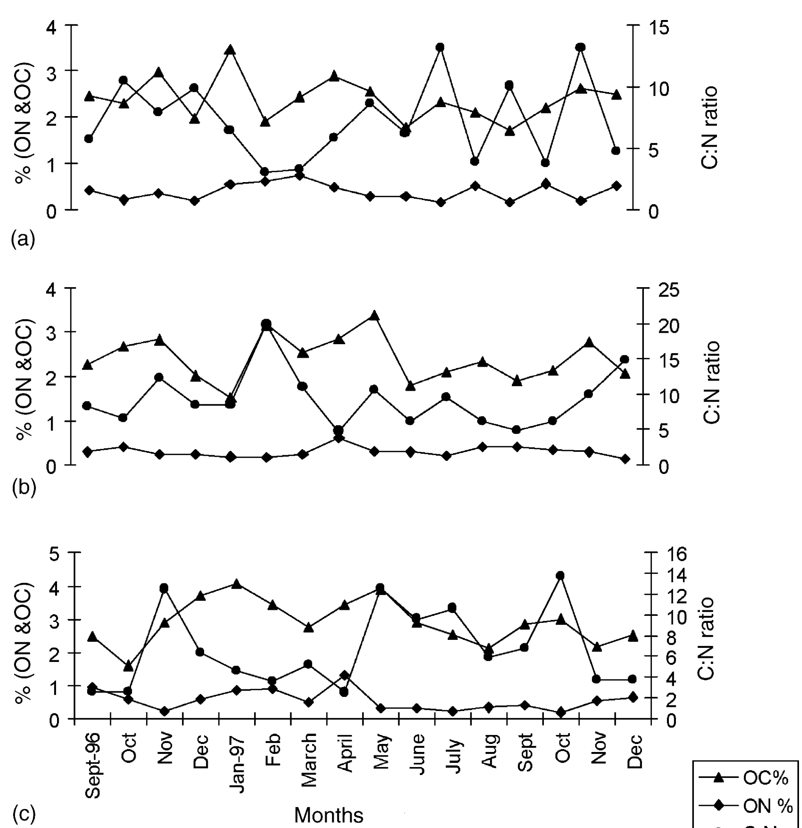

Fig. 2. Monthly variations in organic carbon, nitrogen, C:N ratio in the sediment from *P. coarctata* beds (a) S-I, (b) S-II, (c) S-III.

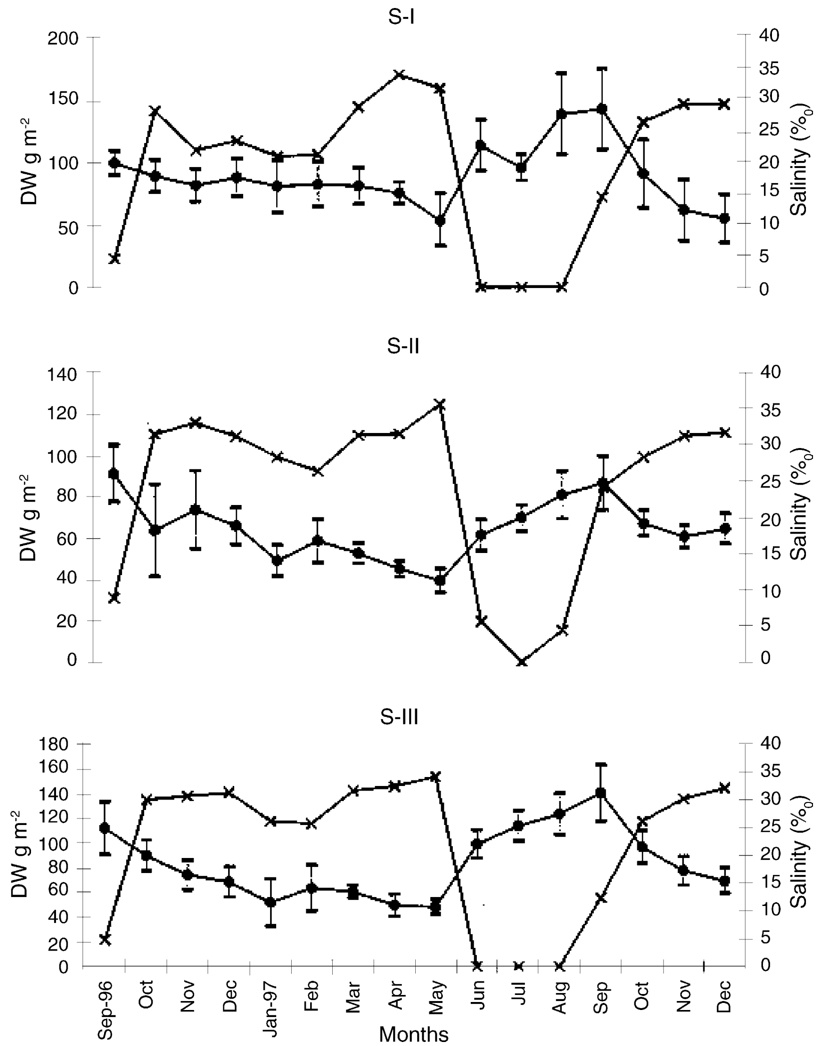

Fig. 3. Seasonal biomass (●) production of *P. coarctafa* in relation to salinity, (×) along the Mandovi estuary (error bars represent standard deviation).

The humid and moderate climate-prevent desiccation of juvenile and delicate flora from the intertidal zone during the exposure at ebb. The pH values of water influencing *Porteresia* beds always tend to be alkaline, however, fresh water inputs during MON period result in the lowering of pH due to dilution of salts. The fluctuation in pH values might also be due to the changes in the sulphur oxidation state, resulting in strongly acidic conditions and high redox potentials as in the case of mangrove ecosystem (Benmoussa et al., 1997). The relatively higher (2.3–5.6 ml L^{-1}) concentrations of DO in the waters over *Porteresia* beds to the same (1.5–5.0 ml L^{-1}) from the mangrove environment (Jagtap, 1985) could be due to the relatively moderate decomposition activities in beds compared to the later. The input of fresh water enriched with oxygen led to the higher concentrations of DO during MON.

Porteresia beds though commonly confined to polyhaline (18–30‰) zones, survive wide (0–35.65‰) salinity range (Fig. 3). The pioneer species like *H. beccarii* and *P. coarctata* as well as seedlings of different mangrove species prefer lower salinity for their germination and early growth (Jagtap, 1985). Salinity of the waters gradually increases from September onwards reaching at its peak during the month of May (Fig. 3).

Table 2
Correlation (r) between biomass of *P coarctata* with associated hydrological ($n = 9$) and within hydrological parameters ($n = 16$)

Hydrological parameters/stations	Salinity	Nitrite	Nitrate	Salinity–nitrate	Salinity–nitrite	Nitrite–nitrate	Nitrate–phosphate
S-I	0.722[a]	0.865[a]	0.627[b]	0.605[c]	0.686[c]	0.733[b]	0.658[d]
S-II	0.531[a]	0.725[a]	0.712[a]	0.545[c]	0.688[c]	0.711[b]	0.702[d]
S-III	0.804[a]	0.725[a]	0.795[a]	0.654[c]	0.664[c]	0.689[b]	0.570[d]

[a] $p < 0.001$.
[b] $p < 0.01$.
[c] $p < 0.0001$.
[d] $p < 0.05$.

Table 3
Temporal variations in vegetative characters of *Porteresia coarctata* along Mandovi estuary of Goa

Month	S-I PH	S-I NL	S-I NT	S-I ALL	S-I ALB	S-II PH	S-II NL	S-II NT	S-II ALL	S-II ALB	S-III PH	S-III NL	S-III NT	S-III ALL	S-III ALB
1996															
September	6.3	4.0	1.0	25.0	5.6	4.5	4.0	1.0	22.0	4.1	5.8	5.0	1.0	20.0	6.7
October	5.0	4.0	1.0	24.0	6.0	5.0	5.0	1.0	21.0	5.2	6.8	5.0	2.0	19.0	7.0
November	6.3	4.0	0.0	25.0	6.4	4.2	3.0	1.0	22.0	6.7	6.2	5.0	2.0	20.0	6.8
December	5.2	5.0	0.0	24.0	6.5	4.2	3.0	0.0	21.0	6.0	6.4	5.0	1.0	18.0	7.1
1997															
January	6.3	5.0	0.0	23.0	7.0	4.2	3.0	0.0	20.0	6.7	5.2	4.0	0.0	19.0	6.7
February	5.0	3.0	0.0	20.0	5.5	4.5	3.0	0.0	17.0	5.8	5.0	3.0	0.0	16.0	6.1
March	5.0	3.0	0.0	18.0	6.5	5.0	2.0	0.0	18.0	5.9	4.9	3.0	0.0	15.0	6.0
April	6.1	2.0	0.0	22.0	5.8	4.9	2.0	0.0	18.0	5.8	5.0	2.0	0.0	15.0	6.7
May	6.0	3.0	0.0	21.0	6.2	4.6	2.0	0.0	20.0	5.6	4.9	2.0	0.0	19.0	6.5
June	5.9	4.0	2.0	25.0	6.4	4.5	3.0	0.0	22.0	6.5	5.8	3.0	1.0	20.0	7.1
July	5.8	5.0	2.0	24.0	6.5	3.9	3.0	1.0	19.0	6.4	6.0	4.0	1.0	21.0	7.6
August	6.3	4.0	1.0	12.0	6.6	3.9	5.0	1.0	20.0	6.1	6.7	5.0	1.0	22.0	8.1
September	5.9	5.0	2.0	21.0	6.1	4.5	4.0	1.0	22.0	5.5	8.0	5.0	1.0	25.0	8.8
October	6.1	4.0	2.0	22.0	3.5	6.4	5.0	2.0	22.0	5.7	6.8	5.0	1.0	22.0	8.0
November	6.5	5.0	2.0	25.0	6.7	6.3	5.0	2.0	23.0	6.0	5.8	4.0	1.0	20.0	7.8
December	6.1	5.0	0.0	20.0	7.0	6.8	5.0	1.0	24.0	6.0	5.4	3.0	0.0	19.0	7.9

PH, plant height (cm); NL, number of leaves per shoot; NT, number of tillages per shoot; ALL, average leaf length (cm); ALB, average leaf breadth (cm).

Excessive evaporation due to high temperature during PRM cause increased salinity in the *Porteresia* beds. Nutrients in the waters from beds were relatively lower compared to waters from mangrove regions (Jagtap, 1985). In the estuarine systems oxidation of NH_4–N and reduction of NO_3–N are chief sources of NO_2–N. The relatively poor nutrient waters over *Porteresia* stands could be attributed to the relatively lower decomposition activities and lower accumulation of organic matter. However, beds were enriched with nutrients during MON because of fresh water inflow bringing heavy nutrient load from terrestrial and mangrove habitats (Fig. 1).

Various factors such as physical, physiological and biotic phenomenon govern the process of intertidal and coastal sedimentation and formation of soil (Hedges et al., 1997; David et al., 2002; Gale et al., 2000). The open mudflats along the estuaries and creeks are generally subjected to the intensive erosion, particularly because of speedy runoff during MON period as well due to the strong waves caused by blowing of speedy winds during the period of PRM. The *Porteresia* beds, which generally grow towards the waterfront, could be of importance in minimizing erosive processes and enhancing the sedimentation rate. The predominant sandy nature of substratum (Table 2) indicated the adaptability of *P. coarctata* to establish on newly deposited unstable sediments and helps further enhance the land building process.

Coastal margins are dynamic regions where carbon inputs are typically derived from both terrestrial and marine sources. Carbon and nitrogen contents in the sediments determine the nutritive importance of the particular ecosystem. The lower contents of carbon (1.5–7.9%) and nitrogen (0.1–1.3%) in the

Table 4
Phenological characteristics of *P. coarctata* (Roxb.) along the Mandovi estuary, Goa

Month	S-I TP	S-I NF	S-I PS	S-I RP	S-II TP	S-II NF	S-II PS	S-II RP	S-III TP	S-III NF	S-III PS	S-III RP
1996												
January	43.0	0.0	0.0	0.0	48.3	0.0	0.0	0.0	49.7	0.0	0.7	1.4
1997												
June	41.3	1.3	0.0	3.4	44.0	0.3	0.0	0.8	39.0	1.0	0.0	2.7
July	46.0	6.0	0.0	13.1	46.0	4.3	0.0	9.5	44.0	9.7	2.7	28.7
August	42.0	9.3	2.0	27.0	44.3	8.3	1.0	21.0	43.0	9.7	2.7	28.7
September	49.3	11.3	5.8	33.9	48.7	7.7	3.7	23.7	44.0	9.3	5.8	33.0
October	44.0	8.3	8.7	39.0	49.0	6.3	5.0	23.7	45.7	8.7	6.7	33.6
November	42.3	5.7	5.7	25.9	45.7	1.7	3.7	11.3	43.3	3.3	8.7	27.7
December	43.0	0.3	1.7	4.6	43.0	0.0	0.0	0.0	40.3	0.0	1.7	4.1

TP, average total number of shoots (m^{-2}); NF, average flowering shoots (m^{-2}); PS, average number of shoots (with seeds) (m^{-2}); RP (%), Reproductive shoot percentage (m^{-2}).

sediments of *Porteresia* beds compared to sediments from mangrove environment (Jagtap, 1985), may be due to low organic production, degradation activities and less accumulation of domestic and agriculture organic matter. Moreover, because of location towards waterfront *Porteresia* beds are subjected to relatively more disturbances from water movements, causing removal of organic matter from the system. Carbon and N contents in the sediments are highly correlated with microbial population and to the grain size (Gorres et al., 1999). Therefore, low OC and ON contents from the sediments could also be attributed to the sandy nature of the substratum. The amount of detritus and its further decomposition by microbes, influence the C and N contents in the sediments and is considered to be an important factor influencing its value as primary food source for benthic organisms. The higher C:N ratio in the sediments from beds probably reflects the extent of preferential bacterial degradation of sediment organic nitrogen (Lomstein et al., 1998). The dietary requirement of protein for most of detritus feeders is 16.5% by dry weight, equivalent to C:N ratio of 17:1 (Fell et al., 1984). The higher C:N ratio during the MON suggesting excess nutrients may be because of domestic and agricultural seepage (Park et al., 1995). Fluctuation in sediment C:N ratio is influenced by freshwater inputs (Fig. 2), indicating contribution of terrigenous organic matter besides continuous production by biotic communities in the *Porteresia* stands.

The biomass and growth of *P. coarctata* also appeared to be strongly influenced by rich nitrite and nitrate contents and lower salinity (Figs. 1 and 3, Table 3). Nutrients, particularly nitrogen richness in the particular habitat enhances the plant productivity (Rigollet et al., 1998; Tamasko and Hall, 1999). The luxuriant growth and higher biomass of *P. coarctata* during MON could certainly be attributed to the high nutrient contents and lower salinity. The poor biomass from S-I during MON period could be attributed to cattle grazing (Jagtap, 1985). The estuarine mangroves and seagrasses require lower salinity during their seed germination and early stages of growth (Jagtap, 1985; Khan et al., 2000). The less saline conditions favours the initiation of tiller primordial and luxuriant growth resulting in the higher biomass (Table 4) during MON period. Though the seeds are produced by a few numbers of plants, the propagation in *P. coarctata* continues only by tiller formation. The experimental data indicated longer seed dormancy and perhaps very rare germination in seeds of *P. coarctata* (Bhosle, 2003). Similar observations have also been reported in a number of marine as well as terrestrial angiosperms (Horne and Khan, 2000; Koornneef et al., 2002).

The increased size of leaves in *P. coarctata* during the MON months might be in response to decreased sunlight (Takemura et al., 2000) due to likely overcast conditions (Anon, 2003). Relatively high temperatures and lack of precipitation during PRM months increase the salinity causing physiological stress on biota from the habitat. Marine plants overcome stress either by accumulation or exclusion of salt, and by minimizing surface area and number of stomata (Takemura et al., 2000; Richard et al., 2001). Therefore, relatively reduced size of the leaves in *P. coarctata*, during PRM and POM periods may be attributed to high temperatures (31–33 °C) and increased (>30‰) salinity (Table 4). The major vegetative features such as TP, PS, RP, PH, NT and ALL showed significant temporal and spatial variations (Table 5).

The C:N ratio of 21.31 (Bhosle, 2003) *P. coarctata* leaves indicated it is an excellent source of energy for benthic fauna and cattle. It is one of the natural fodders for camels in the dry and arid northwest regions of India such as Gulf of Kuchchh in the state of Gujarat. The C:N ratio in *P. coarctata* further indicated that it could be used as compost, organic fertilizer and in aquaculture, similar to some of the other angiosperms (Bauersfeld et al., 1969). Considering ecological significance, tolerance to wide salinity range and adaptability to sandy and muddy substrate, *P. coarctata* could be of a great value in protection, conservation and restoration of estuarine and creek systems. These habitats in the country have been categorized under ecologically sensitive zone, and protected vide CRZ

Table 5
Spatial and temporal variations in characteristics of *Portersia coarctata* using two-way ANOVA

Temporal/spatial parameter	Vegetative parameters							
	TP		NF		PS		RP	
	F	P	F	P	F	P	F	P
Station ($n = 3$)	4.010	0.042[a]	3.310	0.019	7.190	0.007[b]	9.310	0.003[b]
Month ($n = 8$)	4.020	0.041[a]	35.010	0.000[b]	21.010	0.000[b]	27.350	0.000[b]

Temporal/spatial parameter	Phenological parameters									
	PH		NL		NT		ALL		ALB	
	F	P	F	P	F	P	F	P	F	P
Station ($n = 3$)	10.450	0.000[b]	2.114	0.130	0.022	0.800	4.630	0.018	15.220	0.000[b]
Month ($n = 16$)	1.090	0.400	4.830	0.000[b]	4.290	0.000[b]	1.930	0.061	1.390	0.214

TP, average total number of shoots (m^{-2}); NF, average flowering shoots (m^{-2}); PS, average number of shoots (with seeds) (m^{-2}); RP (%), reproductive shoot percentage (m^{-2}); PH, plant height (cm); NL, number of leaves per shoot; NT, number of tillages per shoot; ALL, average leaf length (cm); ALB, average leaf breadth (cm).

[a] Significant.

[b] Highly significant.

(coastal regulation zone) Act of 1990, along with mangroves. However, *Porteresia* habitats continue to be under constant threat from ever increasing anthropogenic demands, and hence warrants for strict implementation of CRZ rule for their protection.

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