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Research Paper

An Ecological Analysis of Mangroves Ecosystem of Odisha on the Eastern Coast of India

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The present paper deals with ecological investigation of mangrove ecosystem of Bhitarkanika sanctuary in Odisha. The structural parameters like height, diameter and basal area of mangrove tree species at four sites of the sanctuary viz., Bhitarkanika, Dangmal, Thakurdia and Kakranasi, were measured and compared with the mangroves of other parts of the world. Dominance diversity curve was found lognormal in shape for this area representing high diversity condition. Of the 29 species recorded from the study sites, only 8 species were common at all sites. The trees with higher DBH classes were found in the protected core sites of Bhitarkanika and Dangmal. *Avicennia officinalis* and *Sonneratia apetala* formed the top storey in the river bank regions in Bhitarkanika and Dangmal forest blocks, whereas *Sonneratia caeseolaris* and *Rhizophora mucronata* formed top canopy in the river bank areas of Thakurdia and Kakranasi blocks. *Exocaria agallocha* and *Hertiera fomes* generally have higher basal area and they formed the top storey in the interior forest areas at all sites. Across all sites and species, it was observed that *Exocaria agallocha*, *Avicennia officinalis* and *Hertiera fomes* accounted for more than 50% of the total Importance Value Index (IVI) in Bhitarkanika sanctuary. The mangroves of Bhitarkanika have lower heights, low basal area and higher number of plants compared to other mangroves of the world. The Riverine species of Bhitarkanika ecosystem have much higher complexity index values than other mangrove ecosystems of the world, which indicates that this ecosystem is favourable to a diversity of mangrove species.

Key Words: Mangroves; Bhitarkanika; Dominance-Diversity Curve; Niche Width; Complexity Index; IVI; Basal Area

Introduction

Mangroves grow throughout the tropics and are limited in their subtropical distribution due to lack of low temperature resistance (Dodd *et al*., 1995) and are available along almost 75% of the coastline (Day *et al*., 1987) between 25°N and 25°S latitudes. Mangroves represent only 1% (100000 km^2) of the area of tropical forests with tree species number showing decline from equatorial region to sub-tropical region with increase of latitude. Dominated by estuarine trees, the mangroves draw their physical, chemical and biological characteristics from the influences of the sea, inflowing fresh water and upland forests, therefore, these are ecotone communities between land and sea and elements from both are stratified horizontally and vertically between the forest canopy and subsurface soil (Rao and Deshmukh, 1994). Mangroves often survive in non-saline habitats also (Cintron and Schaeffer-Novelli, 1983; Walsh, 1974), but a saline environment is needed for stable mangrove ecosystems. Around the world, some 54-70 species (including hybrids) from 20-27 genera and 16-19 families fit comfortably into this broad category (Tomlinson, 1986; Cronquist, 1981; Duke, 1992). Mangroves vary both in their salinity tolerance and in the degree to which salinity may be necessary to maintain their growth and competitive dominance (Ellison and Farnsworth, 2001). The typical responses of mangrove

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communities to declining rainfall and temperature are reduction in species diversity, forest height and the size of the trees (Singh, 1996). The mangroves contribute enormously to the food chain that supports the coastal fisheries. These ecosystems are quite productive and may show a strong, weak or no spatial zonation (Tomlinson, 1986; Ellison *et al*., 2000 Upadhyay *et al*., 2008), although the abundance of individual species may follow the gradient of salinity (Helalsiddiqui, 1999). Most of the species are quite plastic to salinity and prefer a salinity range of 5- 30 parts per thousand (ppt).

Low floristic richness of mangrove forests does not necessarily imply a low value. Mangrove ecosystems are being studied worldwide because of their economic importance in support of commercial fisheries alone (Cintron *et al*., 1980). They protect coastal populations, support livelihood (Kathiresan and Bingham, 2001) and diverse variety of wildlife (Ong, 1995) due to high leaf production, leaf fall and rapid breakdown of the detritus (Aksornkoae, 1986). These ecosystems are vital in reducing coastal erosion and flooding, buffer salinity changes and intrusion, supply and regenerate nutrients, retard runoff (Lugo and Snedaker, 1974; Othman, 1994; Tri *et al*., 1998) and act as shelter belts for protection of inland homesteads, agricultural crops, livestock, and aquaculture (FAO, 1994).

Out of 4639 km^2 of mangrove wetlands (3% of the world's mangrove vegetation) in India, only 1405 km^2 is very dense, 1659 km^2 moderate dense and 1575 km^2 is present as open mangroves (FSI, 2009). However, there is net increase in mangrove forest cover from 4046 km^2 in 1987 to 4639 km^2 in 2007. In Odisha, mangroves are spread over an area of 221 sq. km (FSI, 2007). We carried out an ecological assessment to analyse various ecological attributes to find out the changes in quality and quantity of the vegetation cover of mangroves of Bhitarkanika wildlife sanctuary in Odisha located on eastern coastal region of India. We expect that our findings on the ecological status of mangroves forests of Bhitarkanika will help forest management authorities in developing programmes for long-term forest sustenance, community livelihood and averting cyclonic impacts.

Materials and Methods

Study sites

The study site is located at 20^{0}4'- 20^{0}8' N Lat and 86^{o}45'- 87^o 5' E Long in the state of Odisha, India (Fig. 1). Four forest blocks in the Bhitarkanika wildlife sanctuary were selected for carrying out vegetation survey (Upadhyay and Mishra, 2010). The area of Bhitarkanika forest block is 1712 ha, Dangmal 636 ha, Kakranasi 310 ha, and Thakurdia 272 ha (Chadha and Kar, 1999). These sites experience tide of semi diurnal type. The mean sea level in the region is about 1.66 meters. Two of the forest blocks viz Thakurdia and Kakranasi are situated closer to the Ekakula Nasi (sea) at Maipura River mouth region. The Dangmal and Bhitarkanika Blocks situated at a distance of about 15 kilometres from the Maipura River mouth constitute the core area of the Bhitarkanika wildlife sanctuary and are given maximum attention for conservation and management. The soil sediments are divided into two categories indicating recent or sub-recent forms (newer alluvium) and Pleistocene forms (older alluvium) (GSI, 1974). The recent sediments are characterized by sand, silt, and clay, dark and loosely compact assorted boulders and pebbles with high moisture content. The Pleistocene deposits comprise of clay, sand, silt, and 'kankar', with reddish brown cemented pebbles and gravels due to high degree of oxidation (Banerjee and Rao, 1990).

Human population of villages, within the sanctuary and surrounding it, has been growing very fast due to heavy influx of refugees and outsiders. Habitations are reported to have started by clearing mangrove forests. A total of 81 villages are situated adjacent to the mangrove forests. The human population increase is also attributed as one of the reasons for decrease in quality of mangrove cover. Thakurdia and Kakranasi blocks can be said to be frequented by humans more than Dangmal and Bhitarkanika blocks. The latter two sites are better protected and thus accessibility is poor. All the forest blocks are islands of varying sizes.

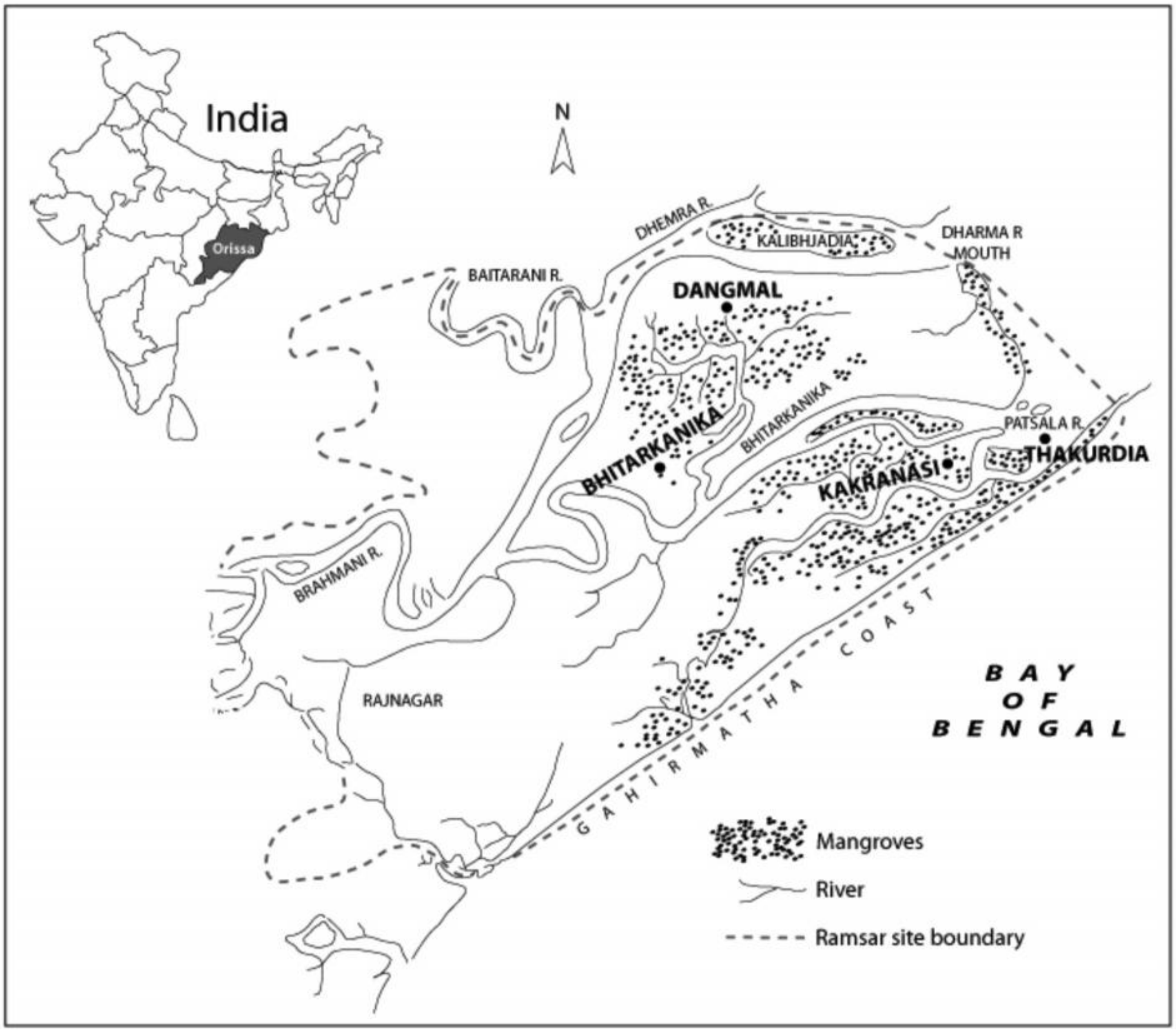

Fig. 1 : Location of study sites (in bold) in Bhitarkanika Mangrove Sanctuary, on the eastern coast of the state of Odisha, India (Source: Upadhyay *et al*., 2008a)

Climate

Coastal region of Odisha falls under the tropical monsoon climate with three pronounced seasons: winter (October to January), summer (February to May) and rainy (June to September). The maximum temperature is recorded in April and May and the minimum in January. Relative humidity ranges from 70% to 84% throughout the year. Wind speed during March to June is over 20 km per hour, and the predominant wind direction is from south and south-west. Rainfall is around 1642.34 cm per annum with maximum rainfall reported between June and October. Most important weather phenomenon is the prevalence of tropical cyclones. The mean track of the cyclone passes over this region (Singh and Panda, 1999). The Bhitarkanika sanctuary is bounded by River Dhamra on the north, River Hansua on the west and Bay of Bengal on the eastern and southern sides. The area is notified as marine sanctuary, which also covers 35 km seacoast known as 'Gahirmatha Coast'. This area, with about 200 km of water body inside the sanctuary, is located in the eastern region of the Rivers Brahmani, Baitarani, Kharasrota, Dhamra, Pathasala, Maipura, Hansua, and Hansina, with numerous creeks, channels, and nallahs, thus, providing the peculiar ecological niche for the growth and development of rich and varied mangrove life forms, both flora and fauna, along with their associates.

Methods for Phytosociological Analysis

Vegetation sampling was done by quadrat method and by the methods described by Misra (1968), Kershaw (1973), Cintron and Schaefer-Novelli (1984) and Snedaker and Snedaker (1984). Each site was divided into 6 segments of 1 km each along tidal line from the riverbank. A line transect was laid in each segment towards landward side from water line and six quadrats were established on the transect at 0, 50, 100, 150, 200 and 250 meter intervals for vegetation analysis. Thus, thirty quadrats of 10 mX10 m size were laid at each site for phytosociological analysis, totalling to 120 quadrats covering an area of 12,000 m^2. The data were analysed for structural parameters like density, diameter at breast height (DBH), height, basal area and Importance Value Index, etc. Data was also used to further calculate species diversity and concentration of dominance, species evenness and richness, niche width, B-diversity and complexity index. All the trees with height above 1-meter occurring inside the quadrat were measured. Girth of the trees was measured at breast level (for *Rhizophora* trees with high prop roots, measurements were done above the highest prop root level). Plants above 2.5 cm diameter were classified as trees (Cintron and Schaefer-Novelli, 1984; Amarasinghe and Balasubramaniam, 1992).

Beta Diversity (ß-diversity) was calculated following Whittaker (1972) as:

$$\beta\text{-diversity} = (S/\alpha) - 1,$$

where, S is the total number of species and α is the mean species richness.

Niche Width was calculated to ascertain the adaptability of different species to tolerate conditions at the interface between different habitat types (Levins, 1968). The formula used to calculate Niche Width is as follows:

$$\text{Niche width or } \beta i = (\Sigma Nij)^2/\Sigma Nij^2,$$

where, Nij is the density value for species i on stand j and ßi is the niche width of the species i.

The Complexity Index (Ic) is calculated as a product of the following formula (Holdridge, 1967; Pool *et al*., 1977):

Complexity Index or Ic = No. of species X Total Stand Density X Basal Area X Stand Mean Height X 10^{-3}

Result and Discussion

Vegetation Diversity

A total of 29 mangrove species were recorded across all 4 sites (Table 1). *Hertiera littorasis* and *Tamarix troupii* were found only at Dangmal site, *Instiga bijuga* only at Bhitarkanika and *Avicennia marina* at Thakurdia. Eight species exhibited their presence at all the four sites. The species diversity depends upon adaptation of species which increases with stability of community (Singh *et al*., 1994). Bhitarkanika site is highly diverse, whereas dominance is more pronounced in Dangmal block (Mishra *et al*., 2005). The Dangmal and Kakranasi and Thakurdia and Bhitarkanika blocks exhibited least similarity in species composition with each other. Thakurdia and Kakranasi blocks and Bhitarkanika and Dangmal blocks are highly similar to each other in species composition (Mishra *et al*., 2005). The sites showing greater similarity between each other are in close proximity to each other indicating that there is great deal of species mix. ß-diversity is a measure to track the change in species diversity from habitat to habitat. Maximum species turnover was observed in the case of Bhitarkanika followed by Kakranasi. Species evenness (also termed as equitability) and species richness influence the species diversity. Species evenness at Thakurdia and species richness at Bhitarkanika forest was greater (Table 2 a, b).

Dominance-Diversity Curves

Whittaker (1965, 1969) suggested plotting of ‘dominance-diversity curves’ (D-D curves) as a method of exploring species abundance relationships. This is drawn by ordinating IVI (log values) against the species sequence, which helps in assessing the community organisation in terms of resource share and niche space. This is based on the assumption that there is some correspondence between the share of community's resource a species utilizes and the share of community's niche space it occupies. Thus, degree of resource apportionment is considered as a measure of resource conservation (Pande *et al*. 2001). The D-D curve is log normal in shape for all the four blocks (Fig. 2). This indicates that large number of factors determines the number of species (diversity) in a community. A log normal condition represents high diversity condition (Pande *et al*., 2002). The species exhibiting geometric series conform to the 'niche pre-emption' hypothesis (Whittaker, 1975). The geometric form is often exhibited by vascular plant communities having low species diversity and competition among the species (Whittaker, 1972). IVI of species is proportional to the amount of the resources available to a particular species. In the present study *H. fomes, E. agallocha, C. ramiflora* and *A. officinalis* in Dangmal and Bhitarkanika are the dominant species and thus use most part of the resources available in these forest blocks. The D-D curve shows a steep downfall after these four species. In Kakranasi block, *E. agallocha, C. decandra, A. officinalis*, and *L. racemosa* utilize most of the resources. IVI values were subjected to Analysis of Variance test and data indicates significant differences in IVI values across species and sites ($p<0.01$).

The average value of DBH for different species (Table 1) are generally higher at Bhitarkanika and Dangmal compared to Thakurdia and Kakranasi sites. *Avicennia officinalis* exhibited highest DBH value followed by *T. troupii*, *C. ramiflora* and *A. corniculatum* in Bhitarkanika and Dangmal. *S. caeseolaris* and *A. officinalis* in the Thakurdia and *R. apiculata* in the Kakranasi exhibited highest DBH. Species with lowest DBH values in these two blocks are *C. decandra, A. corniculatum* and *L. racemosa*. Analysis of Variance indicates significant differences in diameter across species and site ($p<0.01$). The average value of height for different species in the four forest blocks is given in Table 3. *A. officinalis* is the top storey species in the riverbank regions (up to 500 meters from the bank) followed by *S. apetala* in Bhitarkanika and Dangmal. *H. fomes* and *E.*

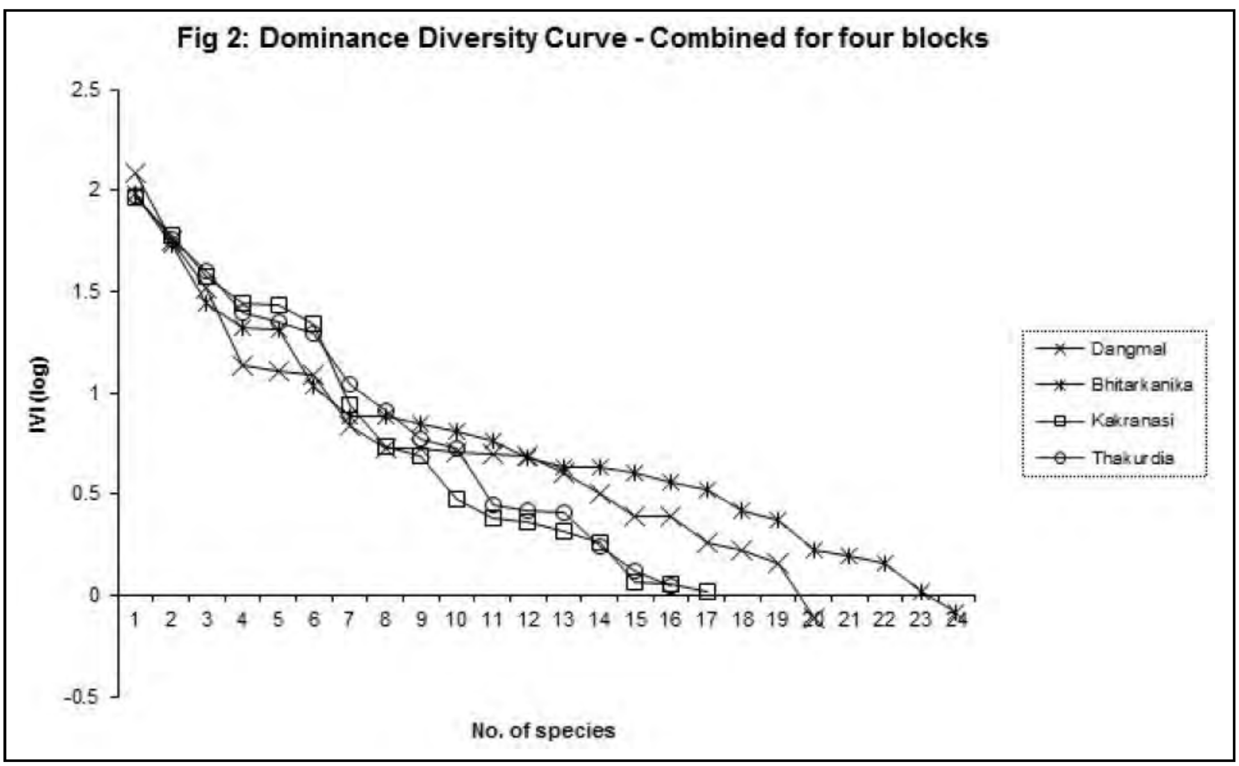

Fig. 2: Dominance diversity curve for the Mangrove species of four study sites at Bhitarkanika Sanctuary, Odisha, India

Table 1: Average values of Diameter at breast height (in cm) ± SD of tree species at various sites

S.No.	Species	Dangmal	Bhitarkanika	Thakurdia	Kakranasi
1	*Excoecaria agallocha*	5.00 ± 2.31	5.66 ± 2.4	3.93 ± 1.91	4.31 ± 2.15
2	*Heritiera fomes*	6.21 ± 3.89	6.77 ± 2.90	4.11 ± 1.93	4.67 ± 2.28
3	*Cynometra ramiflora*	3.43 ± 0.97	4.13 ± 1.26		
4	*Phoenix paludosa*	4.08 ± 0.58	5.48 ± 0.80	3.35 ± 1.43	
5	*Hibiscus tiliaceous*	6.79 ± 0.95	10.45 ± 1.74		4.35 ± 0.65
6	*Pongamia pinnata*	7.81 ± 2.68	11.54 ± 5.66		
7	*Avicennia officinalis*	16.63 ± 7.90	18.74 ± 9.39	9.21 ± 3.31	4.68 ± 3.82
8	*Sonneratia apetala*	11.99 ± 2.80	10.73 ± 6.93	9.11 ± 1.60	5.57 ± 2.12
9	*Kandelia candel*	4.30 ± 1.06	6.61 ± 2.62	3.29 ± 1.44	
10	*Amoora cucullata*	9.75 ± 1.08	9.93 ± 4.00		
11	*Rhizophora mucronata*	5.72 ± 1.35	10.13 ± 6.77	7.87 ± 3.49	5.2 ± 1.15
12	*Hertiera littoralis*	7.74 ± 1.98			
13	*Cerebra manghas*	7.45 ± 1.52	11.45 ± 3.89		
14	*Xylocarpus granatum*	7.78 ± 1.92	10.48 ± 2.90	7.37 ± 2.32	9.11 ± 3.39
15	*Aegiceras corniculatum*	3.02 ± 0.70	3.4 ± 0.98	3.02 ± 1.05	2.54 ± 1.60
16	*Bruguiera gymnorrhiza*	6.75 ± 2.33	4.89 ± 1.09	7.09 ± 3.71	
17	*Ceriops decandra*	4.86 ± 0.85	7.55 ± 0.90	2.53 ± 1.04	3.19 ± 1.25
18	*Tamarix troupii*	2.69 ± 0.65			
19	*Xylocarpus molluccensis*	8.59 ± 0.00	8.14 ± 2.70		
20	*Brownlowia tersa*	6.85 ± 0.68	4.66 ± 0.68		
21	*Sonneratia caeseolaris*		8.04 ± 3.37	11.58 ± 2.09	4.5 ± 4.28
22	*Intsia bijuga*		11.38 ± 4.28		
23	*Avicennia alba*		19.84 ± 0.49	4.68 ± 2.78	3.90 ± 2.69
24	*Thespesia populnea*		6.21 ± 0.69	5.79 ± 1.60	6.77 ± 0.11
25	*Rhizophora Apiculata*		6.21 ± 1.92		13.26 ± 6.44
26	*Xylocarpus mekongensis*		7.78 ± 3.12		8.75 ± 2.34
27	*Aegialitis rotundifolia*			4.95 ± 2.55	4.91 ± 3.66
28	*Lumnitzera racemosa*			4.94 ± 2.15	3.37 ± 3.21
29	*Avicennia marina*			6.21 ± 2.76	

agallocha represented the top storey in the interior forest areas interspersed with *Xylocarpus spp*, *H. tiliaceous, A. cucullata* etc, in patches. *S. caeseolaris* and *R. mucronata* formed the top most crown cover in the riverbank areas whereas the interior regions (Thakurdia and Kakranasi) were dominated by *E. agallocha, H. fomes and A. officinalis* etc. Analysis of variance also indicated significant differences in height across species and site (p<0.01). Kathiresan *et al*. (1994) and Muniyandi, (1986) reported that Pichavaram mangrove forests of Tamil Nadu have trees with low diameter (3-18 cm) and short canopies (4.8 to 5.9 m). These Indian sites have short height compared with the height of mangroves of South Sumatra (55 m), Philippines (25-30 m) and Mexico (17 m) (Pool *et al.,* 1977). *R. apiculata* (30 to 35 m height) occupies the topmost crown among mangroves of Malaysia (Tanouchi *et al*., 2000).

The individuals are maximum in the DBH class of 5.1 to 10 cm (45.73%), followed by >2.5-5 cm DBH category (40.46%) in Bhitarkanika. Plants of

Table 2a: Species attributes in the study area

Forest block	Species evenness	Species richness	Beta diversity
Dangmal	0.28	2.47	2.871
Bhitarkanika	0.25	2.98	3.312
Thakurdia	0.23	1.76	2.967
Kakranasi	0.24	1.92	3.215

Table 2b: Similarity Index in species composition among study sites

Site	Dangmal	Bhitarkanika	Thakurdia	Kakranasi
Dangmal	100			
Bhitarkanika	86.36	100		
Thakurdia	61.11	65	100	
Kakranasi	59.46	73.17	78.79	100

>15 cm DBH are only 3.74%. In the Dangmal Forest Block, individuals in the DBH Class of 2.5-5 cm are more (59.61%) followed by 5.1-10 cm category (31.63%) and plants with >40 cm DBH are absent. 77.87-80.75% of total individuals fall in 2.5-5.0 cm DBH category in Thakurdia Kakranasi. There are no plants with >20 cm DBH in Thakurdia. The classification usually done for terrestrial forests (Misra, 1968) to determine seedlings, saplings and trees etc. does not apply to mangroves as large number of individuals in these forests belong to DBH category 2.5-5 cm. The data of DBH and height of species were subjected to statistical treatment for correlation coefficient. There is positive and statistically significant relationship between these two structural parameters with coefficient of determination ranging between 0.593 and 0.904 (p<0.01). The Dangmal site exhibited high correlation than other sites.

Table 4 provides a comparative account of height and density across different latitudes in Asian and Australian mangroves areas and the species reported from Bhitarkanika. *H. fomes* and *E. agallocha* exhibited highest basal area and IVI at Dangmal and Bhitarkanika sites (Table 5). This was expected, as average diameter of these plants was greater at the former sites. *H. fomes* constitutes 56.98% of the total basal area followed by *E. agallocha* and *A. officinalis* in the Dangmal. Together, these three species accounted for 81% of the basal area. *H. fomes* accounted for 35. 46% of the total basal area followed by *A. officinalis*, *E. agallocha*, and *S. apetala* in the Bhitarkanika forest block, thus, together contributing 78% of the total basal area.

E. agallocha, L. racemosa, *C. decandra*, and *H. fomes* accounted for 74-75% of the total basal area in Thakurdia and Kakranasi blocks. Correlation coefficient (r) between density and basal area for each of the forest blocks was found statistically significant (r = 0.866-0.938; p<0.001). *H. fomes* is adapted to low soil and water salinities and becomes stunted, rare, and ultimately disappears with increase in salinity. It is known as 'top dying' (trees shedding their leaves due to stress and could be dying) in parts of Bangladesh (Siddiqi, 1998) and Sunderbans because of increase in demand for freshwater in dry season, damming of rivers that result in downstream increase in soil salinities (Blasco *et al*., 2001). Therefore, this species is a leading dominant in the mangroves of Bhitarkanika due to good ecological conditions (e.g. protection). However, caution has to be exercised to ensure that the conditions that are now suitable continue to be so. In the mangrove areas of Myanmar, *H. fomes* was available in plenty between the mouth of Mayu and Lamu cities about 50 years back and has been completely depleted due to high salinity stress (Blasco *et al*., 2001). Others have also reported about die back of *Heritiera fomes* due to increase in soil salinity (Christensen and Snedaker, 1984; Chaffey *et al*., 1985).

Although number of plants is higher in the Thakurdia and Kakranasi blocks, the total basal area is higher in Dangmal and Bhitarkanika forests. This is because of the new accretion forests in the Kakranasi mouth area with large patches of dense vegetation of *S. caeseolaris,* and *A. Corniculatum,* which tend to form thickets. The Dangmal and Bhitarkanika forests receive more fresh water and the forest seems to be more mature.

Table 3: Average values of height (in meters) of tree species at various sites

S.No.	Species	Dangmal	Bhitarkanika	Thakurdia	Kakranasi	Average for the area	St. Dev.
1	*E. agallocha*	4.13	4.73	4.37	3.98	4.30	0.327
2	*H. fomes*	4.64	5.32	4.63	4.11	4.68	0.496
3	*C. ramiflora*	3.02	3.81			3.41	0.559
4	*P. paludosa*	3.60	4.00	3.55		3.71	0.247
5	*H. tiliaceous*	6.26	8.60		3.78	6.21	2.410
6	*P. pinnata*	6.11	6.15			6.13	0.028
7	*A. officinalis*	7.83	8.80	5.83	3.58	6.51	2.311
8	*S. apetala*	7.40	6.02	5.00	5.00	5.86	1.137
9	*K. candel*	3.56	5.19	3.33		4.02	1.014
10	*A. cucullata*	7.42	6.36			6.89	0.749
11	*R. mucronata*	4.33	6.79	7.78	4.00	5.73	1.851
12	*H. littoralis*	5.79				5.79	-
13	*C. manghas*	6.20	6.54			6.37	0.240
14	*X. granatum*	6.18	8.18	4.00	6.63	6.25	1.726
15	*A. corniculatum*	2.79	3.41	3.50	2.30	3.00	0.563
16	*B. gymnorrhiza*	4.95	4.94		4.75	4.88	0.113
17	*C. decandra*	4.58	3.31	2.92	3.16	3.49	0.743
18	*T. troupii*	2.00				2 .00	-
19	*X. molluccensis*	6.00	5.58			5.79	0.297
20	*B. tersa*	4.75	3.25			4.00	1.061
21	*S. caeseolaris*		5.73	9.60	3.66	6.33	3.015
22	*I. bijuga*		7.13			7.13	-
23	*A. alba*		10.00	4.60	3.25	5.95	3.572
24	*T. populnea*		4.00	4.20	3.50	3.90	0.361
25	*R. apiculata*		4.83		6.67	5.75	1.301
26	*X. mekongensis*		6.40		6.67	6.53	0.191
27	*A. rotundifolia*			2.78	1.81	2.29	0.686
28	*L. racemosa*			4.89	3.03	3.96	1.315
29	*A. marina*			4.24		4.24	-

Pool *et al*. (1977) found that the riverine mangrove forests are the most structurally developed at Costa Rica coast with largest basal area. Nevertheless, the mangrove forests develop less basal area compared to other terrestrial tropical forests. Reduced flow of freshwater results in reduction in nutrient input to mangrove areas and increases the salinity level with increase in evaporation. These factors affect the mangroves that results in short canopies, low basal area and low complexity indices and overall suppressed structural development of the forests (Cintron *et al*., 1975; Pool *et al*., 1977). Mean value of number of plants per hectare for all the species across all the four blocks is 11036 and mean basal area for all the species across all the four sites is 26.74 m^2 ha^{-1}. The mangroves on sea fronts generally have high basal area (24.6-33.6 m^2 ha^{-1}). The riverine mangrove ecosystems are more diversified and mixed type and are richer in species having tree density >3000 trees ha^{-1}. Regression

Table 4: Comparison of height and density /ha in mangrove forests in Asian and Australian areas with Bhitarakanika

Latitude (^{0})	Height (m)	Density/ ha.	Major species	Locality	Authors
1.2	21.3	Data not available	*Sonneratia spp.*	Indonesia	Komiyama *et al*. (1998)
1.2	22.3	,,	*R. apiculata*	,,	Komiyama *et al*. (1998)
1.2	22.4	,,	,,	,,	Komiyama *et al*. (1998)
1.2	15.5	,,	,,	,,	Komiyama *et al*. (1998)
1.2	26.4	,,	*B. gymnorrhiza*	,,	Komiyama *et al*. (1998)
5	15	,,	*R. apiculata*	Malaya	Ong *et al*. (1981)
8	11	,,	*R. apiculata*	Thailand	Christensen (1978)
8.2	3.9	,,	*Rhizophora spp.*	Sri Lanka	Amarasinghe & Balasubramanium (1992)
8.2	7.2	,,	,,	,,	Amarasinghe & Balasubramanium (1992)
8.2	10.3	,,	,,	,,	Amarasinghe & Balasubramanium (1992)
12	12.5	,,	*R. mucronata*	Andaman Island *R. apiculata*	Mall *et al*. (1991)
12	22.5	Data not available	*B. gymnorrhiza*	Andaman Island *C. teal*	Mall *et al*. (1991)
20	5.07	7186	*H. fomes* *E. agallocha*	Dangmal bock Bhitarakanika, Orissa	Present study
20	4.11	13536	*E. agallocha* *C. decandra*	Kakranasi bock Bhitarakanika, Orissa	Present study
20	4.70	16094	*E. agallocha* *C. decandra*	Thakurdia bock Bhitarakanika, Orissa	Present study
21	5.2	13000	*Vinna spp*	India	Choudhury (1991)
21	5.4	10800	*Avecennia spp*	,,	Choudhury (1991)
21	1.2	12300	*B. gymnorrhiza*	,,	Choudhury (1991)
24	5.5	Data not available	*R. mucronata*	,,	Suzuki & Tagawa (1983)
27.2	16.4	463	*A. marina*	Australia	Mackey (1993)
33.5	7	Data not available	*A. marina*	Australia	Briggs (1977)
37	0.4	16000	*A. marina*	New Zealand	Woodroffe (1985)
37	2.7	3350	*A. marina*	New Zealand	Woodroffe (1985)

equations were developed between density and basal area for selected dominant mangrove species in the four forest blocks (X = density/ha and Y = Basal area per m^2/ha). The relationship was found positive and highly significant ($p<0.001$ for *H. fomes* and *A. corniculatum* and $p<0.05$ for *E. agallocha, A. officinalis* and *C. decandra*. The relationship between Shannon wiener diversity index and basal area for four forest blocks also indicated significant positive relationship ($r = 0.741$-0.892; $p<0.001$). Fromard *et al*., (1998) observed that in mature coastal and adult riverine mangrove sites in French Guiana forests, *Avicennia* exhibited the highest IVI (144-181) followed by *Rhizophora* species. These homogenous mangrove types are more frequent in Guiana, dominated by *A. germinatus*. *H. fomes* and *E. agallocha* exhibited dominance with high value of IVI followed by *A. officinalis* on Odisha coast.

From the data on structural parameters of mangrove species (Table 6), it is observed that these

Table 5: Basal area of mangrove species at study sites (m^2ha^{-1})

S.No.	Species	Dangmal	Bhitarkanika	Thakurdia	Kakranasi	Average for the area
1	*E. agallocha*	3.74	5.24	8.06	9.12	6.54
2	*H. fomes*	13.89	13.13	1.35	1.83	7.55
3	*C. ramiflora*	1.20	1.11			1.15
4	*P. paludosa*	0.12	0.06	0.17		0.11
5	*H. tiliaceous*	0.36	0.22		0.05	0.21
6	*P. pinnata*	0.96	1.15			1.05
7	*A. officinalis*	2.11	6.76	0.37	3.45	3.17
8	*S. apetala*	0.59	3.92	0.09	0.05	1.16
9	*K. candel*	0.04	0.21	0.01		0.08
10	*A. cucullata*	0.22	1.11			0.66
11	*R. mucronata*	0.14	0.73	0.17	0.09	0.28
12	*H. littoralis*	0.23				0.23
13	*C. manghas*	0.07	0.49			0.28
14	*X. granatum*	0.18	0.68	0.05	0.1	0.25
15	*A. corniculatum*	0.13	0.36	1.5	0.11	0.52
16	*B. gymnorrhiza*	0.28	0.12		0.03	0.14
17	*T. troupii*	0.03				0.03
18	*C. decandra*	0.03	0.09	2.35	3.46	1.48
19	*X. molluccensis*	0.02	0.35			0.18
20	*B. tersa*	0.02	0.02			0.02
21	*I. bijuga*		0.30			0.3
22	*S. caeseolaris*		0.45	0.18	3.07	1.23
23	*A. alba*		0.31	1.69	1.71	1.23
24	*T. populnea*		0.03	0.05	0.02	0.03
25	*R. apiculata*		0.07		0.16	0.11
26	*X. mekongensis*		0.14		0.06	0.1
27	*A. rotundifolia*			0.5	0.32	0.41
28	*L. racemosa*			4.27	0.25	2.26
29	*A. marina*			0.89		0.89

structural characteristics of Odisha mangroves are not similar to other riverine mangroves of the world. However, the density of these species is in the same range reported elsewhere. The Odisha mangroves are of low height having less basal area and higher number of species (Tables 3&4) compared to the mangroves of Mexico and Costa Rica (Pool *et al*., 1977). The riverine mangrove forests of Florida, surprisingly, have similar range of height and the basal area as in the forest of the present study. A comparison of density and basal area of species of Bhitarkanika with other mangrove stands of India, Bangladesh, and Malaysia indicate that a few species are common at all sites, however, the dominant mangrove species of Bhitarkanika exhibited more basal area and density compared to the species of other sites.

Niche Width and Complexity Index

The species are able to tolerate or adopt conditions at the interface between different habitat types

Table 6: Density and Mangrove Basal Area in different mangrove ecosystems of India, Bangladesh and Malaysia

Mangrove stand/area	Plants/ha	Basal area (m^2/ha)	Reported by
Coringa Mangroves, Andhra Pradesh, India	4700 to 17310 per hectare (predominantly *Avicennia spp*. Also, *E. agallocha* and *L. racemosa*)	0.1- 10.9 for the entire stand (predominantly *Avicennia* spp.)	Satyanarayana *et al*. (2002)
Krishna mangroves, Andhra Pradesh, India	*E. agallocha*-5009; *S. apetala*-1027 *A. corniculatum*-734; *A. marina*-825		Venkanna & Rao (1993)
Godavari mangroves, Andhra Pradesh, India	*E. agallocha*-6895; *S. apetala*-1145 *A. marina*-874		Venkanna, & Rao (1993)
Puduvyppu mangroves, Kerala, India	*A. corniculatum*-772; *A. officinalis*-2834 *B. sexangula*-148; *E. agallocha*-74	*A. officinalis*-10.40 *B. sexangula*-0.32 *E. agallocha*-0.16	Suresh Kumar & Mohan Kumar (1997)
Puduvyppu mangroves, Kerala, India	*A. officinalis*-700; *E. agallocha*-100 *B. sexangula*-11	*A. officinalis*-2.0 *E. agallocha*-0.4 *B. sexangula*-0.1	Nameer *et al*. (1992)
Sunderbans, Bangladesh (the fresh water zone)	*H. fomes*-1925; *E. agallocha*-1205 *Nypa fruticans*-288		Helalsiddiqui (1999)
Sunderbans, Bangladesh (species in the moderate saline water zone)	*H. fomes*-1040; *E. agallocha*-666 *Avicennia* sp.-520; *B. gymnorrhiza*-1104		Helalsiddiqui (1999)
Sunderbans, Bangladesh (species in the strong saline water zone)	*H. fomes*-224; *E. agallocha*-3834; *Avicennia* sp.-456; *X. mekongensis*-118		Helalsiddiqui (1999)
Sarawak mangroves, Malaysia		32.8±14.4 m^2/ha for the entire stand *X. granatum*-13.29 16.97 m^2/ha (highest for the stand) *E. agallocha*-0.06 0.18 m^2/ha (least for the stand)	Ashton & Macintosh (2002)
Bhitarkanika mangroves, Orissa, India	*E. agallocha*-3586; *C. decandra*-2026 *H. fomes*-2012	*H. fomes*-7.55 *E. agallocha*-6.54 *A. officinalis*-3.17	Present study

(Mishra *et al*., 2000). Niche width measures the degree of specialization of a species and its ability to exploit an environmental range in space and also to maintain its population in different environments (Kalakoti *et al*., 1987). The species with wider niches are considered to be more generalized (Smith, 1980). The generalists are able to utilize a wide range of resources whereas specialists are able to exploit only a specific set of resources. *E. agallocha, H. fomes and R. mucronata* exhibited highest niche width signifying better capacity for resource utilization (Table 7) in all the four forest blocks followed by *K. candel, B. gymnorrhiza, C. decandra*, and *X. granatum*. The species like *H. littoralis, I. bijuga, A. marina* and *T. troupii* have narrow niche width and thus, are limited to a few forest blocks.

The Complexity Index was defined by Holdridge (1967) and applied to mangroves by Pool *et al*., (1977) for quantitative description of the structural complexity of the tropical vegetation. Holdridge (1967) considered only those trees greater

Table 7: Niche Width for different species across all sites (D = Dangmal; B = Bhitarkanika; T = Thakurdia; K = Kakranasi)

Species	Niche width	Basal area m^2/ha	Density/ ha	Site(s) of presence
Excoecaria agallocha	3.10	6.54	3585.50	DBTK
Heritiera fomes	3.00	7.55	2011.50	DBTK
Cynometra ramiflora	1.90	1.15	979	DB
Phoenix paludosa	1.69	0.11	84.33	DBT
Hibiscus tiliaceous	1.85	0.21	124.33	DBK
Pongamia pinnata	1.65	1.05	123.50	DB
Avicennia officinalis	1.56	3.17	384.50	DBTK
Sonneratia apetala	1.70	1.16	79.00	DBTK
Kandelia candel	2.23	0.08	30.00	DBT
Amoora cucullata	1.59	0.66	81.50	DB
Rhizophora mucronata	3.71	0.28	43.25	DBTK
Hertiera littoralis	1.00	0.23	47.00	D
Cerebra manghas	1.68	0.28	30.00	DB
Xylocarpus granatum	2.54	0.25	33.25	DBTK
Aegiceras corniculatum	1.78	0.52	639.25	DBTK
Bruguiera gymnorrhiza	2.20	0.14	45.66	DBK
Ceriops decandra	2.06	1.48	20.00	DBTK
Tamarix troupii	1.00	0.03	2026.25	D
Xylocarpus molluccensis	1.15	0.18	21.50	DB
Brownlowia tersa	1.83	0.02	10.00	DB
Sonneratia caeseolaris	1.18	1.23	27.00	BTK
Intsia bijuga	1.00	0.30	367.33	B
Avicennia alba	1.98	1.23	568.33	BTK
Thespesia populnea	2.64	0.03	13.33	BTK
Rhizophora Apiculata	1.80	0.11	15.00	BK
Xylocarpus mekongensis	1.56	0.10	21.50	BK
Aegialitis rotundifolia	1.82	0.41	155	TK
Lumnitzera racemosa	1.16	2.26	1012.5	TK
Avicennia marina	1.00	0.89	246	T

than 10 cm diameter for calculation of Complexity Index (Ic). The mangroves forests have considerably larger number of stems in the diameter class between 2.5 and 10 cm. Although these smaller individuals affect the total basal area very little, yet give a better representation of the stand by emphasizing the importance of a large number of small stems (Pool *et al*., 1977). The Complexity Index (Ic) is calculated

Table 8: Comparison of Complexity Index from different mangrove areas of the world (ref. Pool *et al*., 1977*, Fromard *et al*., 1998, Amarasinghe & Balasubramaniam,1992****)**

Site	DBH	
Florida, USA*	>2.5 cm	>10 cm
Ten Thousand Islands (over wash /fringe/riverine)	13.56	1.5
Rookery Bay (Basin mangroves)	23.4	1.9
Turkey Point (Scrub mangroves)	1.5	0.0
Puerto Rico		
Pinones (Basin mangroves)	16.75	2.47
Vacia Talega (riverine)	15.4	6.5
Ceiba (fringe)	16.2	0.2
Mona Island (basin)	30.8	15.9
Aguirre (fringe)	29.9	5.6
Jobos Bay		
- overwash mangrove	26	<0.1
- fringe mangrove	97.5	<0.1
Punta Gorda (Fringe)	0.9	<0.1
Mexico		
Roblitos (Riverine)	10.6	3.5
Isla La Palma (Riverine)	73.2	41.3
Isla Roscell (Overwash)	10.1	5.7
El Calon (Basin)	8.5	0.9
Rio de las Canas (riverine)	49.7	27.7
Costa Rica		
Moin (riverine)	84.5	72.0
Boca Barranca (riverine)	10.3	6.0
Santa Rosa (fringe)	4.9	3.6
French Guiana (for all tress > 2.5 cm DBH) **		
Avicennia Pioneer Stage	33	
Mature Coastal Mangrove (Pure mangrove)	18	
Adult Riverine Mangrove (Mixed mangrove)	65-71	
Sri Lanka ****		
Riverine Mangroves	8.11- 22.16	
Fringe Mangroves	1.38- 6.78	
Island Mangroves	1.95	
India: Bhitarkanika (for all tress > 2.5 cm DBH) (Present Study)		
Dangmal	177.58	
Bhitarkanika	77.07	
Thakurdia	220.79	
Kakranasi	268.41	

as a product of the following formula: *Ic = No. of species X Total Stand Density X Basal Area X Stand Mean Height* x 10^{-3}. Kakranasi exhibited highest Ic values followed by Thakurdia, Dangmal and Bhitarkanika. These values for Odisha mangroves are far greater than elsewhere (Table 8). Holdridge *et al*. (1971) project a value of 5.6 for "mature natural forest associations without any excessively favourable or restrictive growth factors". Cintron *et al*. (1980) reported that riverine mangroves develop the most structural complexity than fringe and basin forests and generally, exhibit much higher value of complexity index than other habitats (Table 8). Species diversity is often higher in lower estuaries with larger catchment areas, as well as with those in areas of higher rainfall (Duke, 1992; Duke *et al*., 1998). The Odisha mangroves forests represent both riverine and estuarine habitats with large network of rivers and delta discharging fresh water sediments and nutrients in this region. Our results indicate that the riverine mangroves ecosystem of Odisha is favourable habitat for a diversity of mangroves species.

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