Multivariate methods distinguishing mangrove community structure of Coringa in the Godavari Delta, East coast of India

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Multivariate analysis (PRIMER) based on mangrove tree density and basal area measurements in Coringa, a Bay-Mangrove ecosystem in the Indian sub-continent, revealed 6 different floristic groups. While Group-1 and Group 2 characterized by a combination of Sonneratia apetala *and* S. caseolari-Avicennia alba, *reflected conditions typical of low-lying swamps, Group-3, consisting of* Xylocarpus mekongensis*,* Rhizophora mucronata*,* R. apiculata *and* Bruguiera gymnorrhiza, *was found close to the sea where high saline conditions prevailed. Group-4 species,* Avicennia marina*,* A. officinalis *and* Excoecaria agallocha, *represented widespread distribution and were found almost everywhere within Coringa. Group-5 consisted of* Lumnitzera racemosa, Ceriops decandra *and* Aegiceras corniculatum *which occurred at sites not very far from the influence of Gautami-Godavari estuary, suggestive of their preference to low salinity regimes. Finally, Group-6 typically represented by* Bruguiera cylindrica *was seen interiorally at sites under the direct influence of Bay waters. Delineation of sample sites and species records based on extensive field data will be invaluable for appropriate management (e.g. plantation) and conservation measures for Coringa.*

Keywords: basal area and density, PRIMER, management and conservation, mangrove species' association, vegetation structure

Introduction

Mangroves constitute a taxonomically diverse assemblage of several unrelated angiosperm families with special adaptations (Tomlinson, 1986; Abeysinghe et al., 2000), providing benefits ranging from protection against coastal erosion to the multiple forest products used by local population (Zhang et al., 2006; Gilman et al., 2008; Walters et al., 2008). They have been observed to mitigate the

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effects of natural disasters like tsunamis (Kathiresan and Rajendran, 2005; Dahdouh-Guebas et al., 2005; Alongi, 2008; Bahuguna et al., 2008). Rainfall and temperature are the basic climatic factors governing the composition and geographical distribution of mangrove species (Chapman, 1976; Tomlinson, 1986; Palihawadene and Pinto, 1989; Duke, 1992; Singh, 1996; Ellison and Farnsworth, 2001). Within a site however, individual mangrove species may occupy distinct and discrete zones along a tidal gradient (i.e. seaward fringes or upland reaches) attributable to inter-specific differences in tolerance to variation in degree of tidal inundation, salinity or other measurable edaphic gradients that co-vary with tidal elevation (reviewed by Snedaker, 1982; Smith, 1992). In many parts of the world, a conspicuous zonation of tree species into almost monospecific bands parallel to the coastline has been reported (Snedaker, 1982).

Lugo et al. (1975), in a study of the role of photosynthesis, respiration and transpiration on mangrove formations in south Florida, concluded that the gradient of metabolic efficiency could be a basis for the observed (mangrove) zonation where gross photosynthesis and transpiration are highest in the outer zone than decreased towards land. Wells (1982) conducted extensive fieldwork in the mangroves of northern Australia and noticed seedlings of several species could grow in soils with salinity over 65 psu (e.g. *Avicennia marina*, *A. officinalis* and *Rhizophora stylosa*). Bunt et al. (1982) noted that some species common at the seaward mouth of an estuary are not present near the fresh, more riverine headwater regions of the estuary. Duke (1992) presented 4 categories of mangroves (plants preferring low-tide level; low to mid-tide level; mid-tide level and mid to high-tide level), based on their habitat selection i.e. estuary location and intertidal position. In river dominated swamps where episodic inflows could drive drastic changes in salinity, the extent of inundation or inundation frequency (with respect to landward, mid-forest or seaward sites) could play an important role in structuring mangrove distributions (Satyanarayana et al., 2002; Satyanarayana, 2005).

Mapping mangroves is a prerequisite to understanding vegetation structure for conservation and management objectives (e.g. establishment, protection and management of afforestation). This paper discusses results of an extensive survey of mangrove density (stems 0.1 ha^{-1}) and basal area (m^2 0.1 ha^{-1}) data used for clustering and ordination of species in the Coringa Reserve Forest. The specific objective (besides taxonomic listing of mangrove species) was to examining mangrove (species) association patterns and their distribution in terms of diversity and richness (tree density and wood volume) looking at mangrove rejuvenation work currently underway for this important but highly vulnerable habitat.

Material and Methods

The Coringa mangrove forest (N: 16°32′-16°55′ and E: 82°11′-82°21′) is located in the Godavari Delta south of Kakinada Bay in the State of Andhra Pradesh (Fig. 1). Altogether, 128 sites (based on a pre-determined grid at 0.9–1.8 km intervals) were investigated of which 84 represented mangroves proper. All field sites were reached with the help of a Global Positioning System (Model 45, Garmin Electronics, USA). A Point-Centered-Quarter Method (PCQM) (Cintron and Novelli, 1984) was used to estimate different tree structural variables such as density (stems 0.1 ha^{-1}), basal area (m^2 0.1 ha^{-1}), relative density (%), relative dominance (%), absolute frequency (%), and species individual rankings at each mangrove sampling point.

Multivariate methods used during this study take into account comparison of two (or more) samples i.e. the extent to which they share particular species at comparable levels of abundance. The analysis can cluster records of sampling sites and species into several groups in relation with their closely resembling characteristics (Evans et al., 2002). The procedure is based on similarity coefficients (distance matrix) calculated between every pair of samples which in turn facilitates either a classification or clustering of samples into groups or an ordination plot in which the samples are "mapped" (in 2 or 3 dimensions) in such a way that the distances between pairs of samples reflect their relative dissimilarity of species composition. During this study, stem density and basal area were used to distinguish mangrove community structure on the basis of hierarchical clustering (Bray-Curtis similarity, clustering mode: group average) and ordination through Non-metric Multi-dimensional Scaling (MDS) implemented in PRIMER v.5 (Clarke and Warwick, 1994; Clarke and Gorley, 2001).

Results

The mangroves at Coringa were comprised of 15 species – classified according to Tomlinson

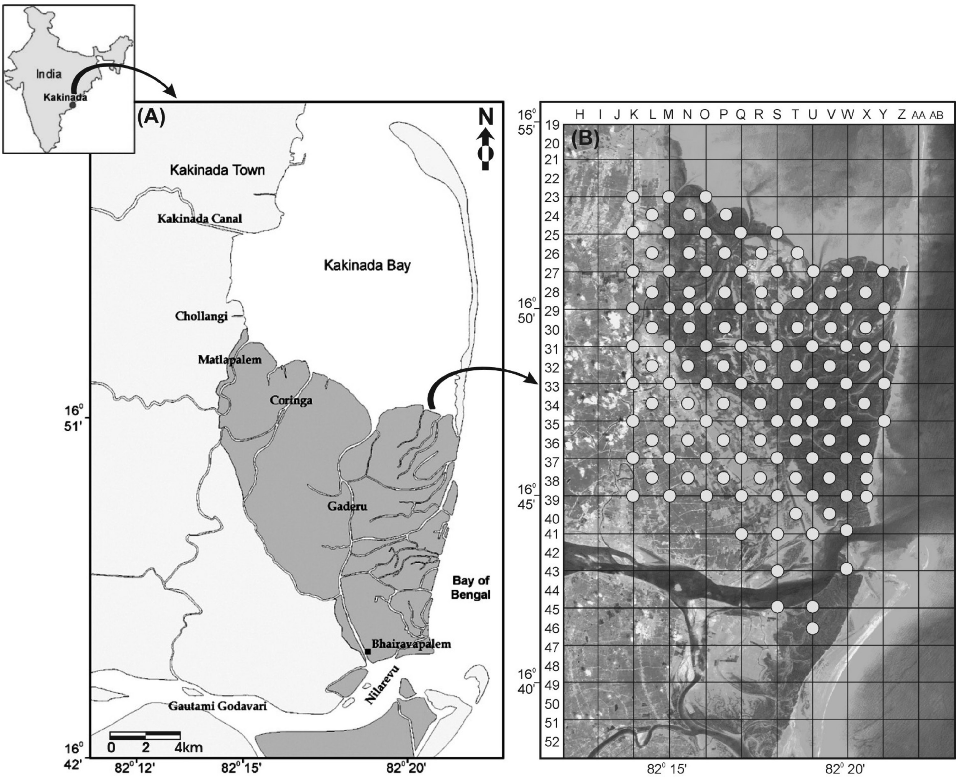

Figure 1. (A) Study area showing the Coringa mangroves (dark shade) on the east coast of India flanked by a shallow bar-built bay on its north and Gautami-Godavari to the south. The major waterways, namely Matlaplaem, Coringa and Gaderu emanating from River Goadavri are important. (B) Sampling sites (1–128) selected for floristic surveillance.

(1986). *Avicennia marina* (Forsk.) Vierh., *A. officinalis* Linn., *A. alba* Blume., *Lumnitzera racemosa* Willd., *Rhizophora apiculata* Bl., *R. mucronata* Lamk., *Bruguiera gymnorrhiza* (Linn.) Lamk., *B. cylindrica* (Linn.) Bl., *Ceriops decandra* (Griff.) Ding Hou., *Sonneratia apetala* Buch-Ham., and *S. caseolaris* (Linn.). Engler constituted the major components while, *Excoecaria agallocha* Linn., *Xylocarpus mekongensis* Pierre, *Aegiceras corniculatum* (Linn.) Blanco and *Scyphiphora hydrophyllacea* Gaertn.f. formed minor components.

A. marina was the most important species since it contributed up to 43% of the total mangrove basal area (mean 0.9 m^2 0.1 ha^{-1}) found at 76 of 84 sites examined (mean absolute frequency 78%) (Table 1) with a mean density of 123 stems 0.1 ha^{-1}. *A. officinalis* contributed 39% of the basal area (1.1 m^2 0.1 ha-$^{1)}$ for this region. This species was found at 57 sites (frequency 40%) and had a density of 25 stems 0.1 ha-^{1}.

E. agallocha (found at 53 sites) ranked third and contributed up to 12% of the basal area (0.4 m^2 0.1 ha^{-1}) with 72 stems 0.1 ha^{-1}. All other species in this forest represented only 6% of the total basal area with their (mean) stem densities ranging from 6 to 52 stems 0.1 ha^{-1} and frequency 12–32% (Table 1). *S. caseolaris* on the other hand was noticed rarly (34 stems 0.1 ha^{-1}) at a single site (frequency 20%) where Gaderu joins Kakinada Bay. *S. hydrophyllacea* was also poorly represented, confined to the southern half of Godavari mangrove complex.

From the species cluster (Bray-Curtis similarity: 20%) and the accompanying MDS plots (based on stem density per basal area) across all 84 sites (Fig. 2), that the mangrove community of Coringa can be grouped into 6 combinations. These are (1) the *S. apetala* stand, (2) *S. caseolaris* and *A. alba* combination, (3) *X. mekongensis*, *R. mucronata*, *R. apiculata* and *B. gymnorrhiza* combination, (4) *A. marina*, *A. officinalis* and *E. agallocha* combination, (5) *L. racemosa, C. decandra* and *Aeg. corniculatum* combination, and (6) the *B. cylindrica* stand. Based on these findings, it was possible to further categorize the distribution of mangroves

Table 1. Mangrove structural attributes (min, max and mean) based on PCQ-Method in the Coringa Reserve Forest.

Species	Density (stems 0.1 ha^{-1})	Basal area (m^2 0.1 ha^{-1})	Absolute frequency (%)
Avicennia marina (n = 76)	1–1731 (123)	0.02–5.6 (0.9)	10–100 (78)
A. officinalis (n = 57)	2–118 (25)	0.002–12.0 (1.1)	8–100 (40)
A. alba (n = 6)	1–243 (52)	0.003–2.2 (0.5)	10–100 (32)
Aegiceras corniculatum (n = 29)	2–202 (31)	0.0004–0.4 (0.05)	5–70 (28)
Bruguiera gymnorrhiza (n = 5)	4–34 (17)	0.01–0.2 (0.06)	10–43 (23)
B. cylindrica (n = 9)	1–41 (14)	0.001–0.03 (0.02)	9–54 (23)
Ceriops decandra (n = 18)	2–48 (13)	0.002–0.02 (0.008)	8–40 (18)
Excoecaria agallocha (n = 53)	2–1412 (72)	0.004–8.5 (0.4)	8–100 (48)
Lumnitzera racemosa (n = 21)	2–59 (14)	0.003–0.2 (0.03)	5–60 (24)
Rhizophora apiculata (n = 7)	2–51 (17)	0.01–0.4 (0.12)	5–60 (26)
R. mucronata (n = 6)	3–17 (7)	0.01–0.1 (0.05)	10–30 (16)
Sonneratia apetala (n = 2)	10–23 (16)	0.3–0.5 (0.4)	50–60 (55)
**S. caseolaris* (n = 1)	34	0.4	20
Xylocarpus mekongensis (n = 5)	3–9 (6)	0.03–0.1 (0.08)	8–20 (12)

*Found only at a single site in the reserve forest.

in relation to their preferential areas of colonization (Fig. 3: available at www.aehms.org/Journal/12_4_Satyanarayana_Figure 3.html).

Discussion

Lugo (1980) summarized inter-relationships in mangals involving substrate, climate and topographical variables. Bunt and Williams (1981) defined 29 "association groups" in their analysis of 35 species that occurred in 1391 sites in northern Australia and in the same extent, Semeniuk (1983) noticed a seaward assemblage of *Avicennia* and *Sonneratia* followed by a *Rhizophora* zone transitional to the zone of greatest diversity, which itself grades into an extensive salt flat devoid of mangroves in north-western Australia. In Coringa, Satyanarayana et al. (2002) examined mangrove zonation (north-south) and found *Avicennia* in the lower intertidal region, *Bruguiera, Rhizophora, Ceriops, Aegiceras* and *Lumnitzera* in the middle and *Xylocarpus* at elevated grounds. They also observed *Avicennia* and *Sonneratia* with a close concordance of measured salinity in the southern part of the Bay (east-west). Satyanarayana (2005) observed natural geomorphologic processes (e.g. shoreline) and diel/annual events (neritic incursion and freshwater inflow) with the potential to create the observed (zonation) patterns in Coringa. Apart from such theoretical scenarios, Ellison et al. (2000) statistically assessed the distribution of mangroves in Sundarbans, Bangladesh. They explained that their results did not support expectations from decades of studies documenting local zonation in mangrove forests. Ashton and Macintosh (2002) mention tree similarity matrices and univariate measures have shown a complex interplay of factors (e.g. soil, pH, salinity etc), governing species distribution in the Sematan mangrove forest in Malaysia. The patterns and processes controlling mangrove species distribution may therefore warrant careful reconsideration (Duke et al., 1998; Ellison et al., 2000).

Groups-1 and 2 (i.e. the combinations of *S. apetala* and *S. caseolaris-A. alba*) reflected

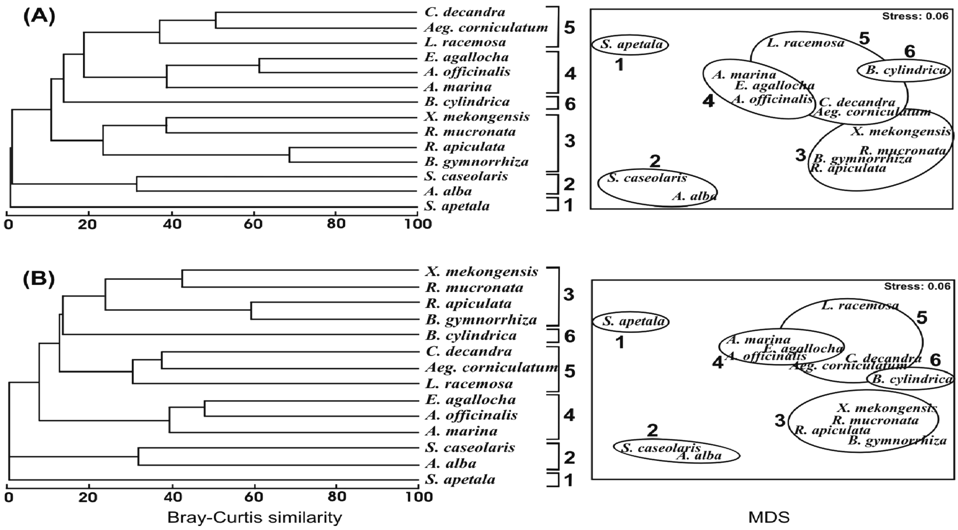

Figure 2. Mangrove species similarity at 84 sites: (A) Species cluster and MDS ordination based on stem density (stems 0.1 ha^{-1}). (B) Species cluster and MDS ordination based on basal area (m^2 0.1 ha^{-1}).

conditions (with high inundation) typical of the low-lying marginal swamps at the bay-mangrove interface (Fig. 3A-B available at www.aehms.org/Journal/12_4_Satyanarayana_Figure 3A-B.html). These species are known to occur as important pioneers along the open coasts on silty and silty-sandy substrates (Chapman, 1976; Tomlinson, 1986; Gallin et al., 1989; Satyanarayana et al., 2002; FAO, 2007). Group-3 (*X. mekongensis*, *R. apiculata*, *R. mucronata* and *B. gymnorrhiza*) occur close to the sea indicating tolerance to a wide range of salinity (Wells, 1982; Tomlinson, 1986). Group-4 species included *A. marina*, *A. officinalis* and *E. agallocha*, with widespread distributions found almost everywhere in Coringa (Fig. 3C-D available at www.aehms.org/Journal/12_4_Satyanarayana_Figure 3 C-D.html).

Between *A. marina* and *A. officinalis*, *A. marina* was prevalent due to its physiological (aerenchyma) superiority through efficient root ventilation (Naidoo et al., 1997). While *A. marina* typically displayed a bimodal frequency distribution occurring from Bay side towards interior areas and up to estuary (Satyanarayana et al., 2002), *A. officinalis* was predominant at mid-tide level, possibly due to a lower tolerance to floods. Despite its equally widespread occurrence, *E. agallocha*, however, seemed to prefer landward (elevated) locations where the species exhibited high stem density (1412 stems 0.1 ha^{-1}) and basal area (8.5 m^2 0.1 ha^{-1}) evidently due to its adaptability to such grounds (Tomlinson, 1986; Dahdouh-Guebas et al., 2000). Group-5 consisted of *L. racemosa*, *C. decandra* and *Aeg. corniculatum* occurring along the Coringa main channel and at sites east of Gaderu, not very far from the influence of Gautami-Godavari estuary suggestive of their preference to low salinity regimes (Fig. 3A-B available at www.aehms.org/Journal/12_4_Satyanarayana_Figure 3A-B.html).

In the Coringa channel, surface salinity is low (mean, 14.37 ± 1.53 psu) mostly owing to drainage from the neighboring agriculture fields (EC Final Report, 2003). Similarly, the east Gaderu creeks experience salinity of the order of 12.81–21.23 psu caused by rather persistent flow from Gautami-Godavari. The occurrence of *C. decandra* with its highest abundance at salinity between 8–13 psu was reported by Ellison et al. (2000). Group-6 represented by *B. cylindrica* was characteristically present at interior sites under the direct influence of Bay waters. Absence of *B. cylindrica* with such dominance at other sites (see Fig. 3 available at www.aehms.org/Journal/12_4_Satyanarayana_Figure 3.html). indicated the species' preference for these locations.

These local patterns of species distributions in mangroves are qualitative and site-specific rather than quantitative (Watson, 1928). Moreover, the mangrove formations are particularly susceptible to natural geomorphological and climatic

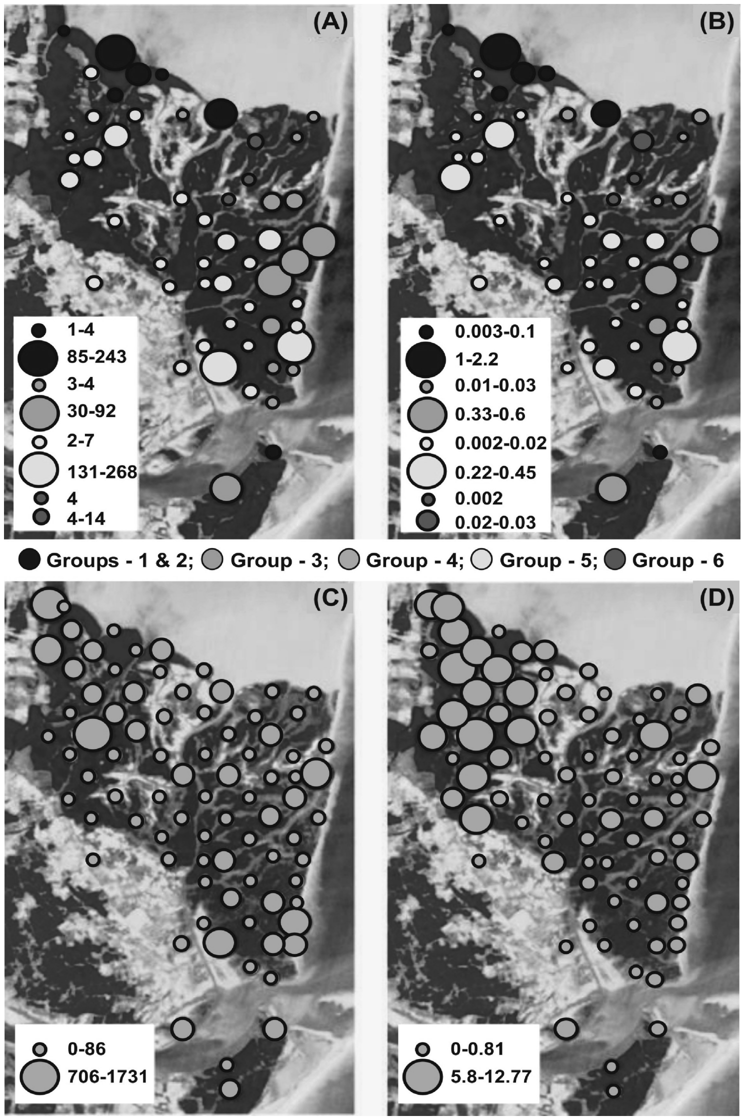

Figure 3. Distribution of mangrove species groupings in Coringa: (A) Groups – 1&2 (*S. apetala*, *S. caseolaris* and *A. alba*), Group-3 (*X. mekongensis*, *R. mucronata*, *R. apiculata* and *B. gymnorrhiza*), Group-5 (*L. racemosa, C. decandra* and *Aeg. corniculatum*), and Group-6 (*B. cylindrical*), based on stem density (stems 0.1 ha^{-1}) and, (B) Basal area (m^2 0.1 ha^{-1}). Group-4 (*A. marina*, *A. officinalis* and *E. agallocha*) distribution based on stem density (C) and basal area (D) (scale: small and big circles in each panel represent minimum and maximum values of the corresponding groups).

perturbations (Smith et al., 1994), which can regulate the extent and structure of mangrove forests and may mask the local importance of spatial or temporal variation in salinity by limiting distribution or abundance of individual species (Ball and Pidsley, 1995; Ellison et al., 2000; Teh et al., 2008). Recent work suggests that establishment/growth of mangroves (particularly seedlings) could be influenced by several abiotic and biotic factors such as light availability, soil condition, tidal current, salinity, animal predation, propagule size and dispersal, intra- and interspecies competition etc. (Berger and Hildenbrandt, 2000; Zhang et al., 2006; Green et al., 2006; Cannicci et al., 2008). In this context, the account on species groupings and distribution in Coringa, and its applicability to other mangrove regions is rather tentative unless similar attempts are made and compared.

Conclusions

In summary, our findings in the Coringa region have shown the presence of discrete mangrove associations (groupings) largely determined by geographic location (sea or landward), freshwater runoff and the extent of inundation. Delineation of sampling sites and species through procedures of the kind employed during this study would be advantageous for monitoring and management purposes considering that mangrove rejuvenation efforts with a preference given to species' association/location can avoid interspecies competition. In this context, it would be appropriate to take into account the sparse populations of *S. caseolaris* and *S. hydrophyllacea* in the Coringa forest that require immediate conservation efforts.

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