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Mangrove species distribution and abundance in relation to local environmental settings: a case-study at Tumpat, Kelantan Delta, east coast of peninsular Malaysia

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Abstract

We studied mangrove vegetation at Tumpat to estimate different tree structural parameters (e.g., stem density and basal area) at selected sites (PCQ method). There were five dominant taxa in the vegetation, i.e., *Sonneratia caseolaris*, *Nypa fruticans*, *Avicennia alba*, *Rhizophora mucronata*, and *Bruguiera gymnorrhiza* in order of importance. Total tree density varied between 79 and 132 stems 0.1 ha^{-1}, and basal area from 0.14 to 4.9 m^2 0.1 ha^{-1}. Based on species composition and stem density, the mangrove sites were separable into two groups (Bray-Curtis similarity: 60%). While Group-1 (sites G9, J5, K4, N6 and O4), dominated by *S. caseolaris* and *N. fruticans*, was distributed throughout the forest, Group-2 (sites C6 and G6), represented largely by *A. alba*, was present close to the bay-mangrove boundary. Elevation measurements indicate that Group-1 species occupied low-lying to elevated grounds (0.87–2.23 m above mean sea level) with a (mean) salinity between 0.38 and 14.6 psu, whereas Group-2 occurred preferentially at low to medium elevations (0.86–1.29 m) and high salinity (14.6 psu). Discrete mangrove associations (=groupings) were discerned, wherein the distribution of species was governed by factors such as proximity of land or sea, freshwater input and elevation.

Keywords: Kelantan Delta; Malaysia; mangrove species association; PCQM; vegetation structure.

Introduction

Mangroves host a unique variety of plants and animals (Cannicci et al. 2008, Nagelkerken et al. 2008), and provide ecosystem functions on tropical coasts (Gilman et al. 2008, Walters et al. 2008), including protection against the disasters like tsunamis (Kathiresan and Rajendran 2005, Dahdouh-Guebas et al. 2005a, Alongi 2008, Bahuguna et al. 2008). Unfortunately, these forest ecosystems have been degrading over time (Dahdouh-Guebas and Koedam 2008, Ellison 2008) to the extent that a world without them has been predicted recently (Duke et al. 2007). Signs of direct and indirect human pressure are visible world-wide but often become clear, or are taken seriously, only when natural disasters offer unequivocal proof of loss of ecosystem functions and their consequences (Farnsworth and Ellison 1997, Alongi 2002, Dahdouh-Guebas et al. 2005a,b, Worm et al. 2006).

Mangrove forests have complex interactions with the surrounding environment (Sherman et al. 1998, Gleason et al. 2003, Otero et al. 2006, Berger et al. 2008) wherein the growth of individual species is influenced by both physical and chemical characteristics of soil and seawater (Tomlinson 1986, Smith 1992, Matthijs et al. 1999, Satyanarayana et al. 2002). For conservation purposes, we need to understand drivers of vegetation structure (Berger et al. 2008, Komiyama et al. 2008, Krauss et al. 2008, Triest 2008) and develop mangrove rehabilitation plans (Bosire et al. 2008) and plans to better manage mangroves (Glaser and da Silva Oliveira 2004).

In Malaysia, mangroves occupy 564,606 ha, with nearly 16% (91,779 ha) distributed along the west coast of peninsular Malaysia (Shamsudin and Nasir 2005). Mangroves are more prevalent here due to the sheltered environment, in comparison to the east coast (mangrove extent=5738 ha), which is entirely exposed to the South China Sea (Mohd-Lokman and Sulong 2001). Watson (1928) was perhaps the first to present an overview of the mangrove forest on the Malay Peninsula. The Matang mangrove forest reserve there has been under concerted scientific management since the beginning of the 20th century (Shamsudin and Nasir 2005). Sasekumar (1974, 1981) and MacIntosh (1984) carried out significant work on the fauna and flora of mangrove swamps of Malaysia.

The bay, mangrove and estuary waterways at Tumpat (Kelantan Delta) experience run-off due to seasonal rainfall and offshore currents (northerly and southerly) that regularly modify the coastal morphology (e.g., sandbar configuration) and hydrographical conditions in this area (Mohd-Suffian et al. 2004). Among several others, recent works of Sulong et al. (2001, 2002), Kasawani (2003), and Kasawani et al. (2006) are constructive. However, no substantial efforts have been made to assess the ecological distribution of mangroves vis-à-vis the surrounding environment. In this paper, we analyze the distribution of mangrove species in relation to local environmental settings, i.e., water quality and sediment characteristics. Furthermore, mangrove association patterns are presented on the basis of species composition and stem density (stems 0.1 ha^{-1}).

Materials and methods

Study area

The Kelantan Delta is a distinctive unit in the northeast corner of Malaysia that is about 1500 km^2 in area and flanking the lower course of the broad, meandering River Kelantan (Figure 1). The mangroves are distributed in several patches consisting of 17 islands with an estimated total area of 1200 ha (6°11′–6°13′ N; 102°9′–102°14′ E) (Shamsudin and Nasir 2005). The local topography, which is influenced by strong tides/current during monsoons, is related to this patchy mangrove distribution (Mohd-Suffian et al. 2004). The mean annual temperature of Kelantan and its surrounding environment is 26.8°C (Satyanarayana et al. 2009).

Sampling stations and fieldwork

Altogether, 21 sites covering an area of ~24 km^2 (6°12′00″–6°13′30″ N; 102°09′30″–102°13′30″ E) were selected for ground inventory (Figure 1). The sites were chosen according to a pre-determined grid at 1 km intervals and covering the entire Delta. Of 21 sites selected, seven were representative of mangroves proper (sites C6, G6, G9, J5, K4, N6 and O4 with natural growth), and the rest comprised aquaculture ponds, mangrove plantation, agriculture/terrestrial vegetation and rural settlements. A global positioning system (GPS Garmin 45, Olathe, KS, USA) was used in travelling to all the field sites.

Study of forest structure or management of a forest for silvicultural purposes requires plant structural parameters, such as density, basal area and biomass (Saenger 2002, Dahdouh-Guebas and Koedam 2006). We used the point-centered quarter method (PCQM) (Cottam and Curtis 1956, Cintrón and Schaeffer Novelli 1984, Dahdouh-Guebas and Koedam 2006) (at representative mangrove sites) to estimate tree density (stems 0.1 ha^{-1}) and basal area (m^2 0.1 ha^{-1}) because these are useful parameters in determining vegetation structure, i.e., stem densities are generally negatively correlated with stand biomass or wood volume (Satyanarayana et al. 2002). The nomenclatures suggested by Tomlinson (1986) and Duke (2006) were followed for mangrove species identification.

Environmental parameters

Water quality data (i.e., depth, Secchi-disc transparency, temperature, salinity, pH and dissolved oxygen) were collected from nearby mangrove (11) sites (Figure 1) using YSI 6600 multi-parameter water quality probes (YSI Inc., Yellowsprings, OH, USA). At each site, a minimum of three readings was obtained for both surface and bottom water parameters. The sediment samples (about 250 g) at each mangrove site were analysed for sand, silt and clay composition using an initial (wet) sieving method (mesh no. 240, British Standard) followed by pipette analysis (Krumbein and Pettijohn 1938). The weights of sand, silt and clay were converted into percentage of total sample dry weight. The oxidation dichromate acid technique (Holme and McIntyre 1971) was followed to determine percentage of total organic carbon (TOC) in the sediments. The elevation (with reference to mean sea level, MSL) at each representative mangrove site was measured using surveyor's levelling equipment (Topcon, AT-G7 N, Tokyo, Japan).

Mangrove community structure

Multivariate methods were used (Plymouth Routines in Multivariate Ecological Research, Plymouth, UK; PRIMER) to compare the extent to which two (or more) samples shared particular species at comparable levels of abundance. The procedure is based on similarity coefficients calculated between every pair of samples. These then facilitate either a classification or clustering of samples into groups that are internally similar (Clarke and Warwick 1994, Clarke and Gorley 2001). In the present study, mangrove stem density (stems 0.1 ha^{-1}) (square root-transformed) was used to distinguish the community structure by hierarchical clustering (Bray-Curtis similarity) and accompanying non-metric multidimensional scaling (MDS) ordination plots produced by PRIMER *v*.5. ArcView GIS 3.2a software was used to illustrate total tree density and basal area distribution in the study area.

Results

Mangrove species composition at Tumpat was represented by five dominant taxa, i.e., *Avicennia alba* Bl., *Bruguiera gymnorrhiza* Lamk., *Nypa fruticans* (Thunb.) Wurmb., *Rhizopora mucronata* Lamk., and *Sonneratia caseolaris* (L.) Engler. Table 1 presents stem density and basal area estimates (based on PCQM) at the mangrove sites encountered. Overall, tree density varied between 79 and 136 stems 0.1 ha^{-1} at sites G6 and O4 (Table 1), while basal area was least (0.14 m^2 0.1 ha^{-1}) at site G9 and highest (4.9 m^2 0.1 ha^{-1}) at site J5 (Table 1). Figure 2A,B shows the distribution of total tree density and basal area. Among mangroves, *N. fruticans* and *S. caseolaris* were the main contributors to high stem density and basal area (e.g., sites G9, J5, K4, N6 and O4).

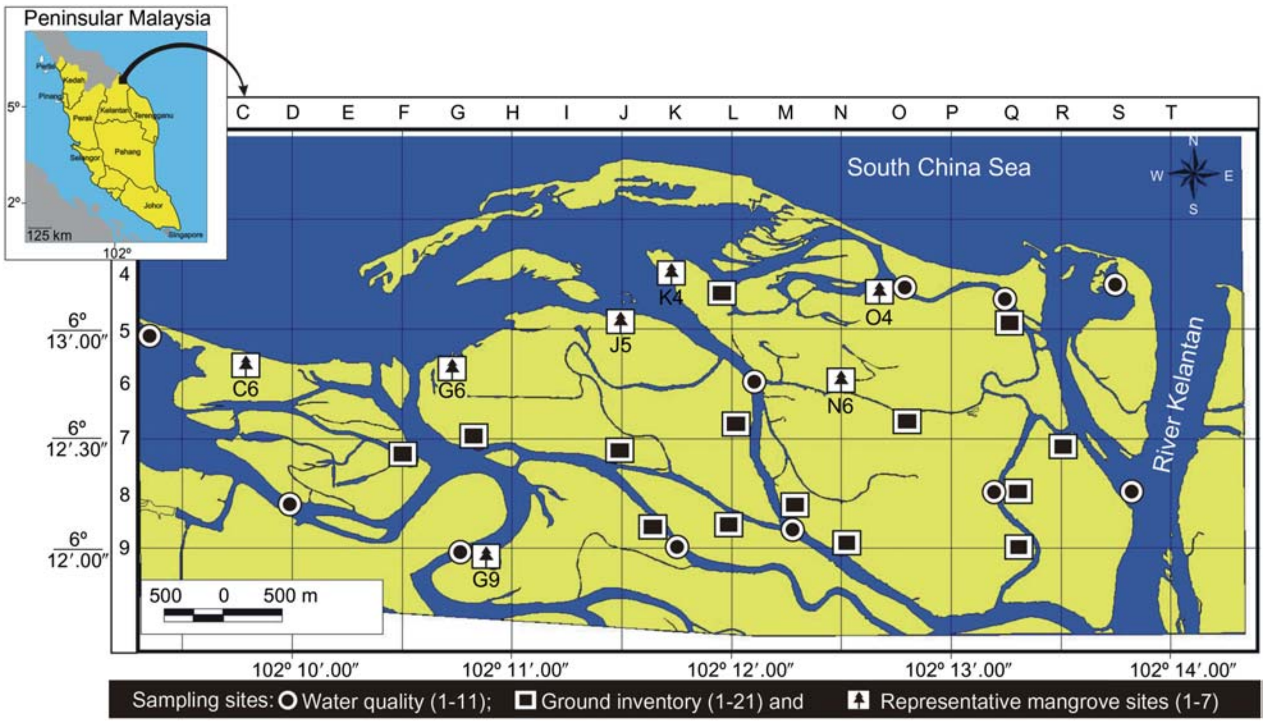

Figure 1 Study area showing Tumpat mangroves and sampling sites in the Kelantan Delta on the north-east coast of the Malaysian Peninsula.
Geographical coordinates for 7 representative mangrove sites: (C6) 06°12′.50″ N, 102°09′.51″ E; (G6) 06°12′.50″ N, 102°10′.42″ E; (G9) 06°12′.01″ N, 102°10′.50″ E; (J5) 06°13′.03″ N, 102°11′.30″ E; (K4) 06°13′.13″ N, 102°11′.41″ E; (N6) 06°12′.45″ N, 102°12′.28″ E; (O4) 06°13′.09″ N, 102°12′.36″ E.
Geographical coordinates for 11 water quality sites: (A5) 06°12′.57.5″ N, 102°09′.10.8″ E; (D8) 06°12′.09.7″ N, 102°10′.01.3″ E; (G9) 06°12′.00.0″ N, 102°10′.45.0″ E; (K9) 06°12′.00.0″ N, 102°11′.45.5″ E; (L-M6) 06°12′.45.4″ N, 102°12′.04.7″ E; (M8) 06°12′.03.8″ N, 102°12′.17.4″ E; (O4) 06°13′.15.3″ N, 102°12′.41.7″ E; (Q4) 06°13′.16.0″ N, 102°13′.15.8″ E; (Q8) 06°12′.12.2″ N, 102°13′.12.7″ E; (S4) 06°13′.09.7″ N, 102°13′.54.9″ E; (S8) 06°12′.16.8″ N, 102°13′.57.0″ E.

Figure 3A,B displays hierarchical clustering of mangrove sites based on species composition and tree density (stems 0.1 ha^{-1}) at Tumpat. It was possible to divide the sites into two groups (Bray-Curtis similarity: 60%) (Figure 3A), which were significantly different (one-way ANOVA, $p=0.006$). The first group (upper cluster with two sub-groups, A and B) consisted of sites O4, N6, G9, K4 and J5. While Group-1A (sites O4, N6 and G9) indicates the abundance of *Nypa*

Table 1 Mangrove tree density (stems 0.1 ha^{-1}) and basal area (m^2 0.1 ha^{-1}) at Tumpat based on the point-centered quarter method (PCQM).

Sites	C6	G6	G9	J5	K4	N6	O4
Density							
Avicennia alba	64	70	–	–	–	–	–
Bruguiera gymnorrhiza	–	6	–	–	–	–	–
Nypa fruticans	19	3	132	37	31	97	109
Rhizophora mucronata	3	–	–	–	–	–	–
Sonneratia caseolaris	3	–	–	75	94	32	27
Total	89	79	132	112	125	129	136
Basal area							
Avicennia alba	1.653	1.804	–	–	–	–	–
Bruguiera gymnorrhiza	–	0.014	–	–	–	–	–
Nypa fruticans	0.024	0.002	0.14	0.045	0.016	0.197	0.248
Rhizophora mucronata	0.021	–	–	–	–	–	–
Sonneratia caseolaris	0.024	–	–	4.858	0.336	2.051	2.619
Total	1.722	1.82	0.14	4.903	0.352	2.248	2.867

See Figure 1 for site locations.

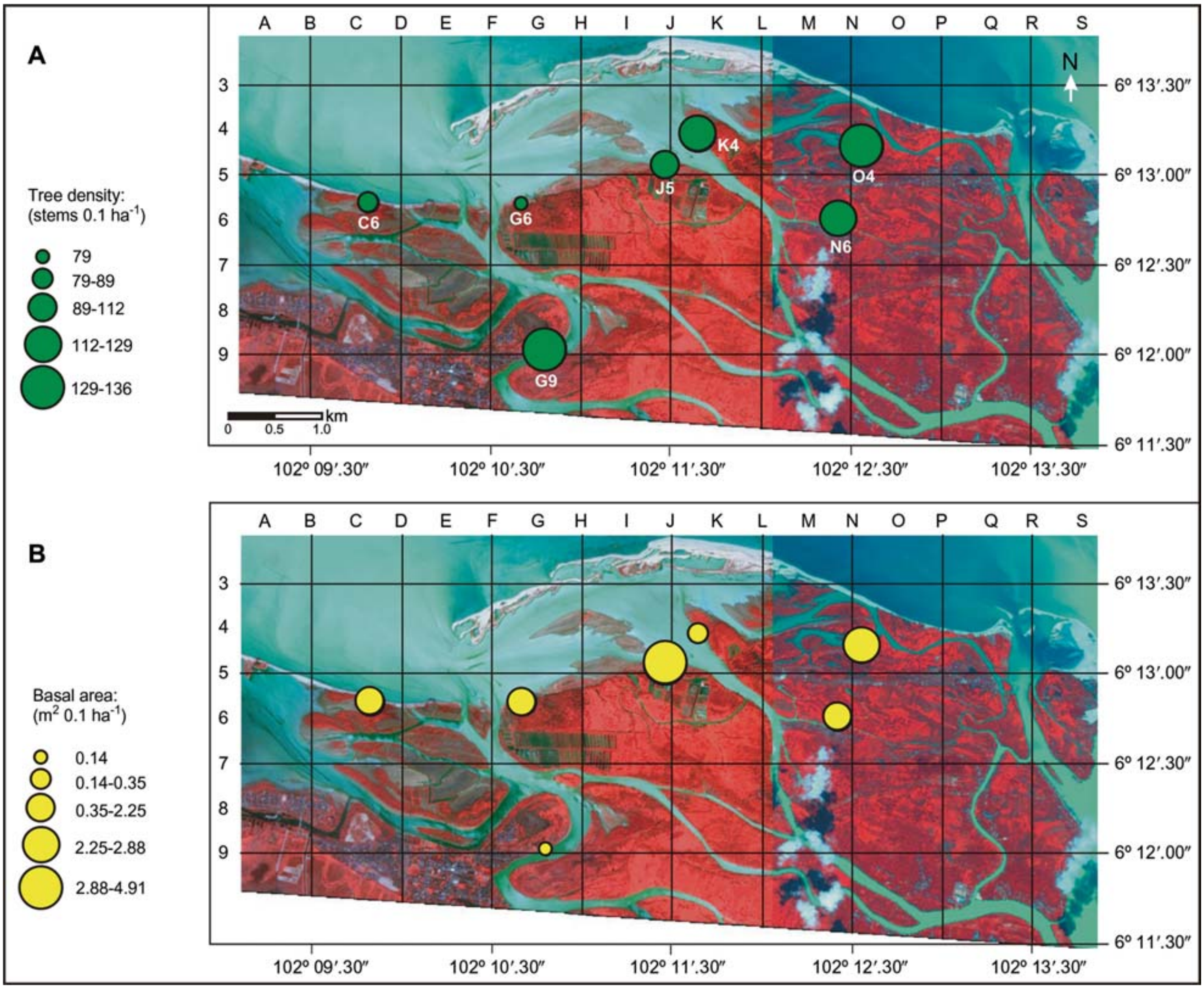

Figure 2 Ranges of (A) total tree density and (B) total basal area at mangrove sites at Tumpat, Kelantan Delta (background: QuickBird 2006 satellite image).

fruticans (113±18 stems 0.1 ha^{-1}, mean±SD), Group-1B (sites K4 and J5) indicate the dominance of *Sonneratia caseolaris* (85±13 stems 0.1 ha^{-1}). The second group comprised only two sites (G6 and C6) where the principal species was *Avicennia alba* (67±4 stems 0.1 ha^{-1}). The others (occurring at low densities) included in this group were *Bru-*

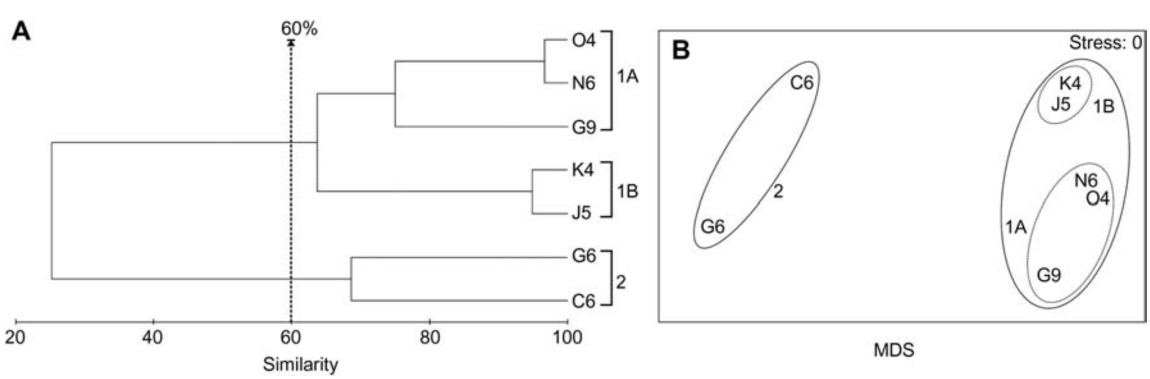

Figure 3 Association of mangrove sample sites based on stem density (no./0.1 ha^{-1}).
(A) Dendrogram by Bray-Curtis similarity; (B) multi-dimensional scaling (MDS) ordination (stress: 0 indicates an ideal ordination with appropriate data transformation). See Figure 1 for site locations.

guiera gymnorrhiza (6 stems) and *Rhizophora mucronata* (3 stems) along with *N. fruticans* (3–19 stems) and *S. caseolaris* (3 stems) (Table 1). The dendrogram provided a separation of fairly convincing groups of sites confirmed by a multi-dimensional scaling (Figure 3B) for the same locations. The group-wise distribution of mangroves in relation to the areas of their stand structure/development (as delineated above) is shown in Figure 4A,B.

The water quality observations in the Kelantan Delta (Table 2) indicated that the majority of the channels were subject to considerable freshwater influence attributable to river discharge and drainage from irrigation canals. The neritic incursion was strong at only few sites located close to the sea (e.g., A5, D8, G9 and K9, Figure 1). The Secchi-disc values indicated superior water transparency in the bay (e.g., A5 and D8, Figure 1) relative to other mangrove and estuary regions. Both (mean) dissolved oxygen (6.73±1.9 mg l^{-1}, mean±SD) and pH (7.03±0.4) were moderate.

Tumpat mangrove sediments were predominantly of clayey silt in nature (Table 3). Total organic carbon varied from 1.19 to 2.43%, with small differences among sites. The mangroves occupied low to moderate (0.86–1.29 m above MSL) (sites C6, G6, J5 and K4) and elevated sites (1.65–2.23 m) (sites G9, N6 and O4) in the Delta (Table 3).

Discussion

The mangroves at Tumpat are ecologically sensitive to anthropogenic perturbation, including the intense aquaculture trade, which has taken a toll in recent years (Sulong et al. 2001, 2002). Between 1988 and 2000, the estimated loss of mangroves was 139.3 ha due to aquaculture, sediment accretion and other physical phenomena, including rural settlements (Kasawani et al. 2006). Most recently, Satyanarayana et al. (2009) estimated mangrove cover at Tumpat as 339.6 ha (based on satellite QuickBird data obtained from the Malaysian Remote Sensing Agency), where a few closely guarded and interior (inaccessible) areas still support some luxuriant vegetation.

In general, both tree density and basal area are important variables used to assess mangrove community structure into ''young/growing'' or ''mature'' forests (Satyanarayana et al. 2002, Satyanarayana 2005). The range of values depends on location i.e., whether inside the closely guarded area, bay-mangrove boundary, inaccessible sites away from human influence or sites regularly invaded by humans and so on. Elevation, inundation frequency, distance from the bay mouth or sea, nature of sediments, etc., are other important determinants.

The overall structure of the mangrove forest at Tumpat is determined largely by the distribution of two important species, namely *Sonneratia caseolaris* and *Nypa fruticans* (Table 1). Among mangrove sites, G9 consisted solely of *N. fruticans* (basal area, 0.14 m^2 0.1 ha^{-1}), and J5 was occupied mostly by *S. caseolaris* (basal area, 4.9 m^2 0.1 ha^{-1}), the former representing a developing forest and the latter a mature stand (Figure 2). Sites C6 (89 stems; basal area 1.72 m^2 0.1 ha^{-1}), G6 (79 stems; basal area 1.82 m^2 0.1 ha^{-1}) and K4 (125 stems; basal area 0.35 m^2 0.1 ha^{-1}) located at

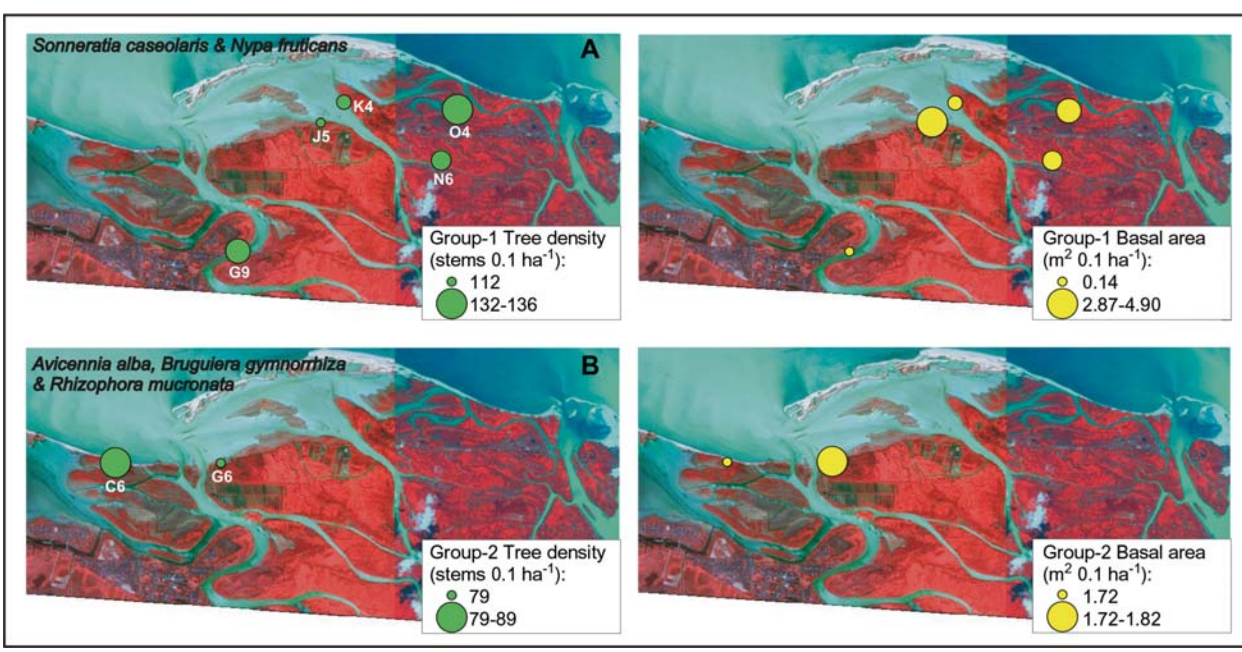

Figure 4 Distribution of mangrove species groupings (see group clusters in Figure 3) based on stem density and basal area. (A) Group 1 and (B) Group 2. Scale: small and large circles in each panel represent minimum and maximum values, respectively (background: QuickBird 2006 satellite image). See Figure 2 for geographical coordinates.

Table 2 Water quality observations at Tumpat, Kelantan Delta (min, max, mean and ±SD), 21–25 October 2007.

Sites	Depth (m)	Secchi disc (m)		Temperature (°C)	Salinity (psu)	pH	Dissolved oxygen (mg l^{-1})
A5	1.2	1.0	S	25.5–26.0 (25.7±0.2)	4.8–4.9 (4.9±0.1)	7.5* (7.5±0.02)	7.5–7.7 (7.6±0.1)
			B	28.0–28.3 (28.1±0.2)	24.0–24.5 (24.2±0.2)	7.3–7.4 (7.4±0.02)	3.2–3.3 (3.2±0.1)
D8	1.0	0.9	S	25.5–25.7 (25.6±0.1)	3.9–4.0 (3.9±0.01)	6.5–6.6 (6.6±0.1)	6.0–6.1 (6.1±0.1)
			B	27.0–27.1 (27.0±0.1)	11.5–11.9 (11.7±0.2)	6.9–7.0 (6.9±0.1)	6.4–6.5 (6.5±0.03)
G9	1.5	0.7	S	26.3–27.0 (26.6±0.4)	2.9–3.0 (2.9±0.1)	6.4–6.5 (6.4±0.1)	4.0–4.1 (4.0±0.1)
			B	26.0–26.5 (26.3±0.3)	3.4–3.5 (3.4±0.1)	6.4–6.5 (6.4±0.1)	3.4–3.5 (3.5±0.03)
K9	2.9	0.5	S	26.5–26.8 (26.6±0.2)	0.9–1.2 (1.0±0.1)	7.0–7.1 (7.1±0.01)	7.9* (7.9±0.01)
			B	29.0–30.0 (29.4±0.5)	29.9–30.5 (30.1±0.3)	7.9–8.0 (8.0±0.03)	4.5–4.6 (4.6±0.02)
L-M6	2.6	0.4	S	26.4–26.8 (26.6±0.2)	0.2–0.3 (0.3±0.05)	7.0–7.1 (7.1±0.02)	9.2–9.4 (9.3±0.1)
			B	25.8–26.0 (25.9±0.1)	0.5–0.6 (0.6±0.03)	6.5–6.6 (6.6±0.01)	6.3–6.4 (6.3±0.05)
M8	1.9	0.5	S	26.9–27.2 (27.0±0.2)	0.2–0.3 (0.2±0.02)	7.0–7.1 (7.0±0.06)	9.6–9.7 (9.7±0.1)
			B	26.7–26.9 (26.8±0.1)	0.2–0.3 (0.3±0.01)	7.0–7.1 (7.1±0.03)	8.9–9.0 (8.9±0.04)
O4	0.7	0.6	S	26.9–27.0 (26.9±0.06)	0.1–1.2 (0.1±0.06)	7.0–7.1 (7.1±0.01)	5.2–5.3 (5.2±0.06)
			B	27.0–28.0 (27.4±0.4)	1.2–1.4 (1.3±0.1)	6.9–7.0 (7.0±0.01)	4.2–4.3 (4.3±0.04)
Q4	0.4	0.2	S	27.0–28.0 (27.8±0.2)	0.2–0.3 (0.2±0.02)	7.0–7.2 (7.1±0.1)	6.7–6.8 (6.8±0.03)
			B	27.0–28.0 (27.5±0.3)	0.2–0.4 (0.3±0.1)	7.0–7.1 (7.1±0.01)	6.7–6.9 (6.8±0.1)
Q8	1.1	0.3	S	27.0–28.0 (27.8±0.2)	0.3–0.4 (0.4±0.03)	7.4–7.5 (7.5±0.1)	7.8–7.9 (7.8±0.05)
			B	27.0–28.0 (27.8±0.3)	0.3–0.4 (0.4±0.02)	7.0–7.1 (7.0±0.05)	8.4–8.5 (8.5±0.02)
S4	1.5	0.3	S	26.7–26.8 (26.7±0.06)	0.5–0.6 (0.6±0.01)	7.0–7.2 (7.1±0.1)	7.7–7.8 (7.8±0.05)
			B	27.0–27.3 (27.1±0.1)	0.5–0.6 (0.6±0.02)	6.9–7.0 (6.9±0.06)	7.1–7.2 (7.2±0.01)
S8	3.6	0.2	S	26.4–26.8 (26.6±0.2)	0.3–0.4 (0.4±0.02)	7.2–7.3 (7.2±0.05)	8.1–8.2 (8.2±0.03)
			B	26.9–27.0 (27.0±0.06)	0.4–0.5 (0.5±0.01)	6.4–6.6 (6.5±0.06)	7.8–8.0 (7.9±0.06)

See Figure 1 for site locations.
B, bottom water; S, surface water. n=3 for all surface and bottom measurements of temperature, salinity, pH and dissolved oxygen; * same value for all three measurements.

the bay-mangrove boundary, consisted of a young and growing forest. High basal area at sites O4 (2.87 m^2 0.1 ha^{-1}) and N6 (2.25 m^2 0.1 ha^{-1}) is due to their inaccessibility and distance from the major transportation channels.

Water quality measures (Table 2) indicated an important tidal incursion and also a large freshwater runoff in the Kelantan Delta. Considerable salinity gradients observed (e.g., site K9 showed mean surface salinity 1.0, and a bottom value of 30.1 psu) were evidently caused by a mix between tidal water on the one hand and river discharge on the other. This implies also that the bay-mangrove system at Tumpat is subject to significant daily (tidal cycle) and annual variations in salinity.

Mangrove soils are mostly alluvial in nature, with a high salt and water contents, low oxygen, and abundant hydrogen sulphide (Rao 1987, Matthijs et al. 1999); nutrient cycling and biogeochemical processes may be complex (Kristensen et al. 2008). Silt levels generally increase in the direction of

Table 3 Mangrove sediment characteristics at Tumpat.

Sites	Sand (%)	Silt (%)	Clay (%)	TOC (%)	Elevation (m)
C6	1.10	65.42	33.08	2.43	0.86
G6	2.37	64.41	33.24	1.19	1.29
G9	2.43	61.59	35.97	1.41	1.65
J5	3.73	69.31	26.95	2.03	0.87
K4	8.92	75.33	27.74	1.29	0.99
N6	2.67	66.32	31.01	2.38	2.23
O4	1.82	64.44	33.75	2.31	1.72

See Figure 1 for site locations.
TOC, total organic carbon.

the estuary, while clay characterises mangrove sediments (Satyanarayana 2005). The soils at Tumpar, however, were predominantly of clayey silt (Table 3), demonstrating the influence of freshwater input in the vicinity. High organic contents in the mangroves are normally due to enrichment through leaf litter, humus and other biogeochemical transformations (Lyimo et al. 2002, Bouillon et al. 2004, Kristensen et al. 2008). TOC was relatively high at sites C6, J5, N6 and O4 (Table 3), which were mostly represented by mature trees.

In the deltas of large tropical rivers, where some of the most luxuriant mangroves occur, or even in shallow bays without a large freshwater input, mangroves appear to distribute in response to microtopography (Dahdouh-Guebas et al. 2007, Di Nitto et al. 2008). They occupy distinct and discrete zones along certain sections of the tidal gradient (i.e., seaward fringes or upland reaches) according to interspecific differences in tolerance to variation in degree of tidal inundation, salinity or other measurable edaphic gradients that co-vary with tidal elevation (Snedaker 1982, Smith 1992, Saenger and Siddiqi 1993, Matthijs et al. 1999, Ellison et al. 2000, Dahdouh-Guebas et al. 2002, Satyanaranayana et al. 2002, Krauss et al. 2008). Based on the elevation (Table 3) and tide data measurements (JUPEM 2007) at Tumpat, we demarcated mangrove sites into low-lying areas, elevated grounds and/or sites that are submerged only rarely. For instance, sites C6, J5 and K4 near the periphery (elevation <1.0 m) are flooded by every high tide, giving an inundation frequency of 50–60 times a month (tides in the delta are semi-diurnal). Site G6 (also at periphery but obstructed by a sand dune) (elevation, 1.29 m) is inundated during moderately high water conditions and $\sim$30–50 times a month. The other interior sites, G9 (elevation, 1.65 m), O4 (1.72 m) and N6 (2.23 m) submerge only 10–23 times a month.

Duke (1992) presented four categories of mangroves (plants preferring low-tide level; low to mid-tide level; mid-tide level and mid to high-tide level), based on habitat preference i.e., estuary location and intertidal position. Ashton and MacIntosh (2002) mentioned that tree similarity matrices and univariate measures demonstrate a complex interplay of factors (e.g., salinity, tidal inundation, and soil) that govern species distribution in the Sematan mangrove forest in Malaysia. In river-dominated swamps where episodic inflows may change salinity drastically, the extent of inundation or inundation frequency (with respect to landward, mid-forest or seaward sites) could play a potent role in structuring mangrove distribution (Satyanarayana 2005).

At Tumpat, Group-1 species (i.e., the combination of *Sonneratia caseolaris* and *Nypa fruticans*) occurred widely and were found at almost every site (Table 1) (Figure 4A). This group occupied low-lying to elevated grounds (0.87–2.23 m) (low to high tide level) with a (mean) salinity between 0.38 and 14.6 psu. While *N. fruticans* is known to occur on soft, fine-grained substrata with a perennial (high) input of freshwater (i.e., salinity up to 15 psu), *S. caseolaris* grows as an important pioneer along the open coasts on silty and silty-sandy soils (Tomlinson 1986, Gallin et al. 1989, Blasco et al. 1996, Satyanarayana et al. 2002, Satyanarayana 2005, FAO 2007). It is, however, significant that both these species occurred on elevated grounds (e.g., site N6) with stagnant water/infrequent inundation. Existence of some natural mangroves (e.g., *S. caseolaris*, *Bruguiera gymnorrhiza* and *B. sexangula*) in landlocked and tideless areas has been previously reported from Australia, Christmas Island (Indian Ocean) and Papua New Guinea (Saenger 2002). Group-2 species (i.e., *Avicennia alba* along with *B. gymnorrhiza* and *Rhizophora mucronata*) occurred close to the sea, indicating their tolerance of high salinity (14.6 psu) (Wells 1982, Tomlinson 1986, Imbert et al. 2000, Saenger 2002) (Figure 4B). The virtual absence of the group in other sites is suggestive of the species' preferences for the bay-mangrove boundary (Blasco et al. 1996) with an elevation of 0.86–1.29 m above datum. While both *A. alba* and *R. mucronata* grew at low to mid-tide level, *B. gymnorrhiza* was characteristic of the interior sites (mid to high tide level) under the direct influence of bay waters (Saenger 2002, Satyanarayana et al. 2002). The mangrove distribution patterns described above appeared to be largely determined by their location (sea or landward), freshwater runoff and the extent of inundation. Moreover, delineation of sample sites and species records based on ground data is invaluable for appropriate management (e.g., plantation) and conservation measures at Tumpat, Kelantan Delta.

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