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MORPHOLOGICAL PLASTICITY OF *HALODULE* SPECIES IN RESPONSE TO DIFFERENT ENVIRONMENTS

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ABSTRACT

Halodule species is widely distributed along the south and east coasts of Peninsular Malaysia, Sabah and Sarawak. Five locations were selected for the study based on different habitat characteristics; sub-tidal shoal (Merambong-2 sites; Tg. Adang Laut-2 sites), coastal lagoon (Merchang-2 sites), inter-tidal beach front (Lawas-1 site) and reef atoll lagoon (Pulau Layang-Layang-1 site). Samplings and collections of *Halodule* plants were conducted from August 2002 until May 2004. The result of the study found that *Halodule* species are found at depth of -1.5 to-2.7 m in various habitats with substrates from sandy, coralline sand, calcareous sandy-mud, sandy-mud to muddy substrates and can survive in a wide range of salinity, 18-34 psu. They adapt in the different environmental conditions through changes in morphology. Water depth (associated with ambient light), sediment type and sediment depth have an influence on the morphology of vegetative components e.g. leaf length, leaf width, erect stem length and rhizome growth pattern. Leaf tip morphology was not affected by habitat types and the environmental characteristics. Leaf tips for *H. uninervis* are similar in morphology between young and mature leaves. Leaf tips for *H. pinifolia* varied with an obvious differences between young and mature leaf tips.

Keywords: Seagrass, *Halodule*, Habitat characteristics, Morphoplasticity

INTRODUCTION

Halodule species is widely distributed along the coasts of the Indian Ocean and the western Pacific. Along the eastern coast of Africa it extends from the Red Sea as far south as the province of Natal. The eastern border of the area reaches from Japan to the Tonga Archipelago and Queensland, the Ryukyu Islands and the Philippines through Malesia (den Hartog, 1970) in Papua New Guinea at Port Moresby, Daru, Manus Island and Gaile (Johnstone, 1978) and along the cost of Tamil Nadu, Southern India (Parthasarathy *et al.*, 1991).

In Malaysia *H. uninervis* (Forssk.) Aschers. and *H. pinifolia* (Miki) den Hartog are widely distributed in the waters of Peninsular Malaysia and East Malaysia. *Halodule* species inhabit various habitats growing in various substrates and under a wide range of salinity and depth. They adapt in such environment through changes in their morphology (Japar Sidik *et al.*, 1999). In other parts of the world e.g. the Red Sea coast of Saudi Arabia, in sheltered muddy localities, *H. uninervis* has wide leaves while on more exposed sandy shores and in places with a very unstable salinity, the leaves are narrow (Aleem, 1979). At Shark Bay, Australia, *H. uninervis* with short and narrow leaves are found on firm and silty substrate while longer and wide leaves are on muddy sites (McMillan, 1983). Other *Halodule* species e.g. *H. emarginata* as reported by Oliveira *et al.* (1983) have shorter leaves when expose to air compared with those permanently immersed. *Halodule wrightii* exhibits different leaf widths in habitats with different emergence at low tide. Narrow-leaved variants are found growing in shallow bays (e.g. northern Gulf of Mexico) and wide-leaved variants are associated with coral

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reefs (Phillips, 1960). The reported observations described above illustrated morphological plasticity of *Halodule* under variable habitats and environmental conditions. This present study reports on morphological variability in the local *Halodule* species in response to the different environments with respects to habitat characteristics and conditions and their association with other seagrasses at six sites in Peninsular Malaysia and two sites in East Malaysia.

MATERIALS AND METHODS

Field surveys were undertaken from August 2002 until May 2004 and samples of vegetative axes of *Halodule* plants were collected by hand during low tide or by SCUBA diving during high tide. Sampling were conducted at Merambong shoal (Lat. 1° 19' 89.9" N, Long. 103° 35' 80.7" E), Tanjung Adang Laut shoal (Lat. 1° 19' 52.9" N, Long 103° 34' 0.05" E), Johore; Merchang (Lat. 5° 02' 15.0", Long. 103° 17' 53.0"), Terengganu; Pulau Layang-Layang (Lat. 7° 20' 00" N, Long. 113° 45' 00" E) off Sabah and Lawas (Lat. 4° 54'21.6" N, Long. 115° 22' 25.5" E), Sarawak. The sites selected were based on different habitat characteristics; subtidal shoal, coastal lagoon, reef atoll lagoon and inter-tidal beach front. At these sites, substrates and plant life forms (pure population or associated with other seagrasses) were recorded within 0.5 m x 0.5 m quadrat with sub-divisions of 10 units. Replicates of both plants and substrates were taken within the sub-division of the quadrat. At the same site, water temperature, salinity, depth, pH where possible, were recorded using Hydrolab Surveyor 4a or SCT meter and light availability using Li-Cor model 250 Quantum Light Meter. The plants collected were washed *in situ* with the seawater and place in a labelled plastic bag and kept in an ice chest before processing in the laboratory. In the laboratory, plants were washed with distilled water and carefully separated. The vegetative parts dimensions; mature leaf length and width, erect stem length and internodes length were recorded using Mitutoyo Digimatic Vernier Caliper (measured to two decimal points). Image of plant were recorded digitally using Nikon Coolpix 995 Digital Camera. In addition, leaf tips morphology of young and mature leaves were recorded as digital images. Specimens were stored as wet collection in 8% formalin and some are pressed as herbaria according to Menez *et al.* (1983). Analysis of variance (ANOVA, $p < 0.05$) and post-hoc Duncan's Multiple Range Test (DMRT, $p<0.05$) were used to compare the vegetative parts dimensions of *Halodule* between the habitats.

RESULTS AND DISCUSSION

Morphological plasticity in *Halodule uninervis*

Halodule uninervis with shorter leaves (Fig. 1a) are found in an area that is exposed to air for at least 3-4 hours during extreme low tide (e.g. at Merambong). *Halodule uninervis* plants with long leaves (Figs. 1b, 1c, Table 1) are those in shaded area, under the canopy of *Enhalus acoroides* (e.g. at Merambong) and in area under continuous submergence (e.g. at P. Layang-Layang). Plants with long leaves (Table 1) also possess long erect stems (e.g. at Merambong, under the canopy *E. acoroides*) or long and branching erect stems (e.g. at P. Layang-Layang). The modification in leaf and stem dimensions is a strategy for reaching and obtaining sufficient light. Plants (Fig. 1d, at Tg. Adang Laut) from an area of great instability where heavy sedimentation occurred also had long erect stems which may be associated with their adaptive strategy, where the sediment covered erect stem dropped their leaves (leaving the stem bare with a series of nodes) and propagate upwards producing new leaves well above the sediment surface. *Halodule uninervis* with long and branching erect stems possessing roots at nodes (Fig. 1c, at P. Layang-Layang) is an adaptation to environment instability (where the substrate is loose coralline sand) as well as preventing the plants from being swept away (Japar Sidik *et al.*, 1999). In other locations e.g. at Shark Bay, Australia, *H. uninervis* leaves are longer under the canopy of sand patch than above bare sand and increased in leaf dimensions for plants in the shade of over-hanging rocks (Walker, 1989). In contrast other seagrass e.g. *Posidonia sinuosa* when under shading leaf-bearing shoots, leaf density and leaf length were reduced with no changes in leaf width when under shading (Gordon *et al.*, 1994).

In terms of leaf width dimension (Table 1), plants can be distinguished into wide-leaved and narrow-leaved variants. Wide-leaved plants occurred in a variety of substrates; coralline sand (at P. Layang-Layang), muddy (at Merambong, under the canopy of *E. acoroides*) and calcareous sandy-mud (at Tg. Adang Laut) and narrow-leaved plants (at Merambong) are on sandy substrate

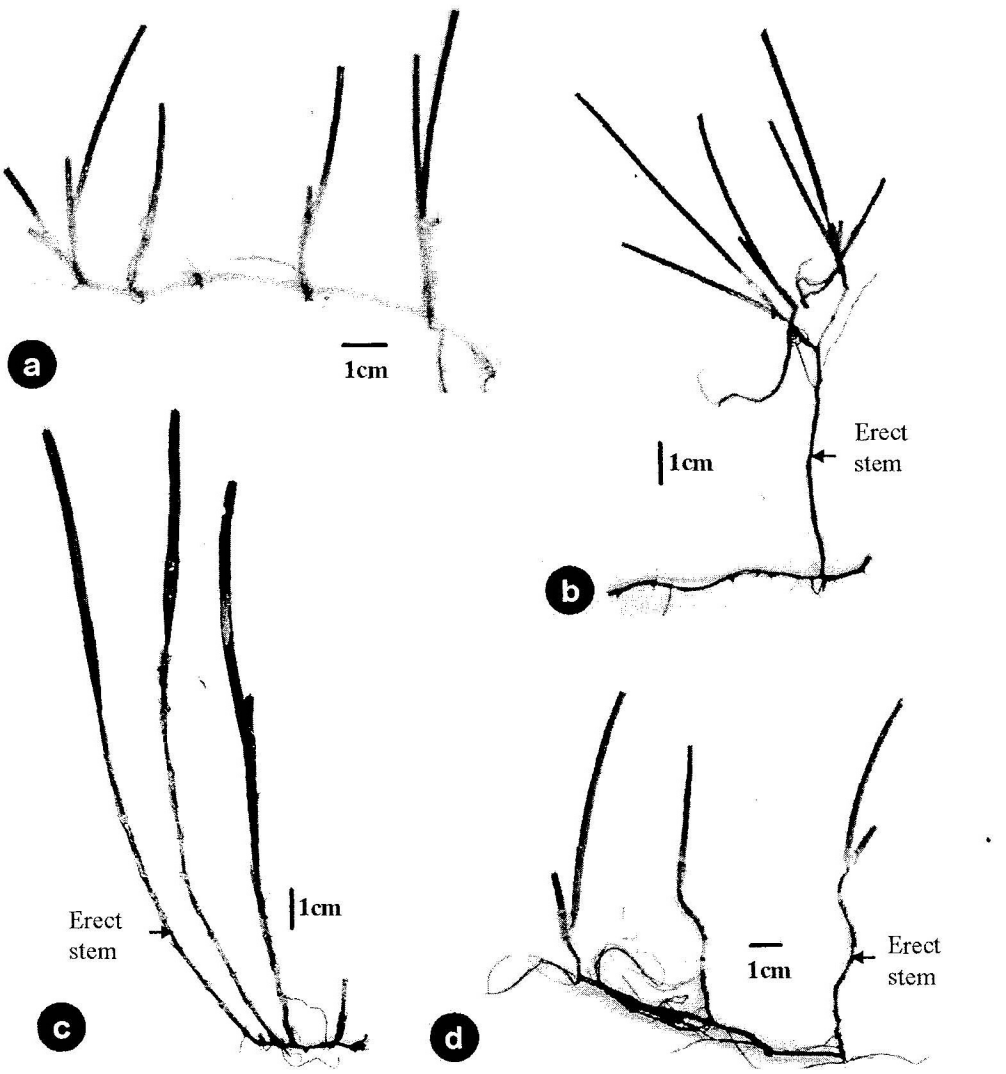

Figure 1. Morphological plasticity in *H. uninervis*; (a) Merambong- short narrow-leaved plant with short erect stem growing as pure population at exposed area on sandy substrate, (b) Merambong- Long wide-leaved plants with long erect stem growing under the canopy of tall *E. acoroides* on muddy substrate and under continuous submergence, (c) P. Layang-Layang- Long wide-leaved plant with long and branching erect stem growing on unstable loose coralline sand and under continuous submergence and (d) Tg. Adang Laut- Wide-leaved plant with long erect stem and under the influence of sedimentation

exposed during spring low tide. A similar observations was observed by Short (1983) for *Zostera marina* where shoots vary in size from short narrow-leaved plants growing in sandy sediment to long wide-leaved plants growing in mud. In addition, plants on loose substrate (at Tg. Adang Laut) and exposed during low tide (at Tg. Adang Laut and Merambong) have horizontal rhizomes with constant length of internodes.

Morphological plasticity in *Halodule pinifolia*

As with *H. uninervis*, *H. pinifolia* plants also exhibit morphoplasticity (Table 1) in response to different environments. *Halodule pinifolia* plants (at Merchang) in deeper area (depth of 2 m) tend to have long and wide leaves (Fig. 2a) compared to plants (Fig. 2b) in shallow (depth of 0.2 m) and exposed area. Long-leaved plants (Fig. 2c, at Lawas) are also found in an area which is not exposed to air and remain under continuous submergence in waters. The long leaves are adaptation of plant to cope with light changes. In additions, plants (at Merchang) with long erect stems are also found in lagoon, where water currents carrying suspended loads enhancing sedimentation at this site and the elongation of erect

Table 1. Location, environmental parameters and dimension analysis (given in mm) of vegetative structures of *Halodule* species from different habitats. Different alphabets indicate significant differences at $p<0.05$ (ANOVA, post-hoc Duncan's Multiple Range Test). Values in parenthesis are the ranges. N is number of samples. MSL-mean sea level

Species	*H. uninervis*				*H. pinifolia*			
Location	Merambong, Johore		Tg. Adang Laut, Johore	Pulau Layang-Layang, Sabah	Merchang, Terengganu		Tg. Adang Laut, Johore	Lawas, Sarawak
Longitude/ Latitude	1° 19' 89.9" N, 103° 35' 80.7" E		1° 19' 52.9" N 103° 34' 0.05" E	7° 20' 00" N 113° 45' 00" E	5° 2'15.0" N, 103° 17' 53.0" E		1° 19' 52.9" N 103° 34' 0.05" E	4° 54' 21.6" N 115° 22' 25.5" E
Site	1	2	3	4	5	6	7	8
Habitat type	Subtidal shoal	Subtidal shoal	Subtidal shoal	Reef atoll lagoon	Coastal lagoon	Coastal lagoon	Subtidal shoal	Intertidal beach front
Association	Pure population	Growing under *E. acoroides*	Growing under *E. acoroides*	Pure population	Pure population	Growing with *H. ovalis*	Growing under *E. acoroides*	Mixed population
Exposed to air	Yes	No	Yes	No	Yes	No	Yes	No
Substrate	Sandy	Muddy	Calcareous sandy-mud	Coralline sand	Sandy	Sandy mud	Calcareous sandy-mud	Sandy-mud
Depth (m)	-1.6 m MSL	-2.1 m MSL	-2.0 to -2.7 m MSL	-2 to 2.5 m MSL	-2.2 m MSL	-2.5 m MSL	-2.0 to -2.7 m MSL	-1.5 to -2.7 m MSL
Ambient light ($\mu molm^{-2}s^{-2}$) (% of natural light)	396.8 (21%)	254.6 (12.9%)	249 (12.5%)	NA	620.4 (31%)	446.6 (22.3%)	249 (12.5%)	NA
Salinity (psu)	27.98-33.72	27.98-33.72	31.43	31.34	18-34.47	18-34.47	31.43	24-25
pH	7.48-8.15	7.48-8.15	6.94	-	7.31-7.32	7.31-7.32	6.94	6.04-8.81
Leaf length (mm)	56.28 ± 1.62^{c} (20.29-135.27) N=224	77.94 ± 1.66^{a} (15.79-149.22) N=246	68.57 ± 3.09^{b} (31.70-127.72) N=42	$76.31\pm2.59^{a,b}$ (37.42-112.95) N=42	35.90 ± 1.01^{c} (16.56-76.51) N=109	85.09 ± 2.87^{b} (39.96-137.95) N=66	42.37 ± 1.58^{c} (32.31-68.10) N=39	102.64 ± 3.00^{a} (37.36-239.08) N=175
Leaf width (mm)	1.46 ± 0.03^{d} (0.55-2.47) N=224	1.86 ± 0.02^{c} (1.09-2.62) N=246	2.03 ± 0.04^{b} (1.53-2.67) N=60	3.16 ± 0.03^{a} (2.36-3.88) N=65	0.73 ± 0.01^{b} (0.53-1.02) N=121	0.97 ± 0.01^{a} (0.66-1.24) N=102	0.52 ± 0.01^{c} (0.34-0.70) N=39	0.93 ± 0.01^{a} (0.55-1.33) N=208
Erect stem length (mm)	14.48 ± 0.86^{c} (1.52-72.79) N=194	21.08 ± 1.31^{c} (1.96-107.13) N=186	34.70 ± 3.57^{b} (2.95-89.00) N=41	86.44 ± 8.02^{a} (8.21-139.70) N=27	23.14 ± 3.38^{a} (6.09-49.91) N=19	28.25 ± 3.54^{a} (4.71-81.48) N=34	5.98 ± 1.35^{b} (1.79-23.34) N=18	6.75 ± 1.11^{b} (2.09-25.77) N=29
Internode length (mm)	$9.07\pm0.28^{a,b}$ (0.27-46.80) N=735	11.64 ± 0.35^{a} (0.66-52.77) N=593	$8.96\pm0.56^{a,b}$ (0.36-38.70) N=239	5.70 ± 1.32^{b} (3.05-10.44) N=5	8.96 ± 0.71^{b} (1.93-27.04) N=56	12.79 ± 5.54^{a} (2.53-25.10) N=47	6.86 ± 1.21^{b} (0.69-33.39) N=28	15.45 ± 0.71^{a} (0.93-59.27) N=212

stem is a response to this instability (Japar Sidik *et al.,* 1999). Plants (Figs. 2c, 2d; at Lawas and Tg. Adang Laut respectively) with short erect stems were observed to grow nearer to the surface of sediments. Plants (Fig. 2b, at the deeper area of the lagoon in Merchang) with compressed rhizomes and having inconsistent rhizome internode length were growing in very dense population, where limited spaces were available for expansion. As a response to the limited space for expansion, a horizontal rhizome has to grow vertically. Plants growing in stable sediment (Fig. 2c, at Lawas) and in less dense population (Fig. 2d, at Tg. Adang Laut), rhizome internodes length are longer and constant suggesting that there are spaces available for expansion in the environment.

Leaf tip morphology in *H. uninervis* and *H. pinifolia*

Leaf tips were showed no distinct modifications in relation to different environments. The leaf tip morphology can be used to distinguish *H. uninervis* from *H. pinifolia* (den Hartog, 1970, Japar Sidik *et al.,* 1999). Leaf tips are tridentate and the lateral teeth are pointed whereas the middle tooth is blunt for *H. uninervis,* with no obvious variation in young and mature leaves. Leaf tips for *H. pinifolia* showed obvious difference between leaf ages. The young leaf tips are round or pointed in shape with serratures, intramarginal veins inconspicuous, both end in a very small tooth while the mature leaf tips are obtuse with irregular serration, lateral teeth are temporarily developed or totally absent. Midrib conspicuous, sometimes bifurcate at the apex.

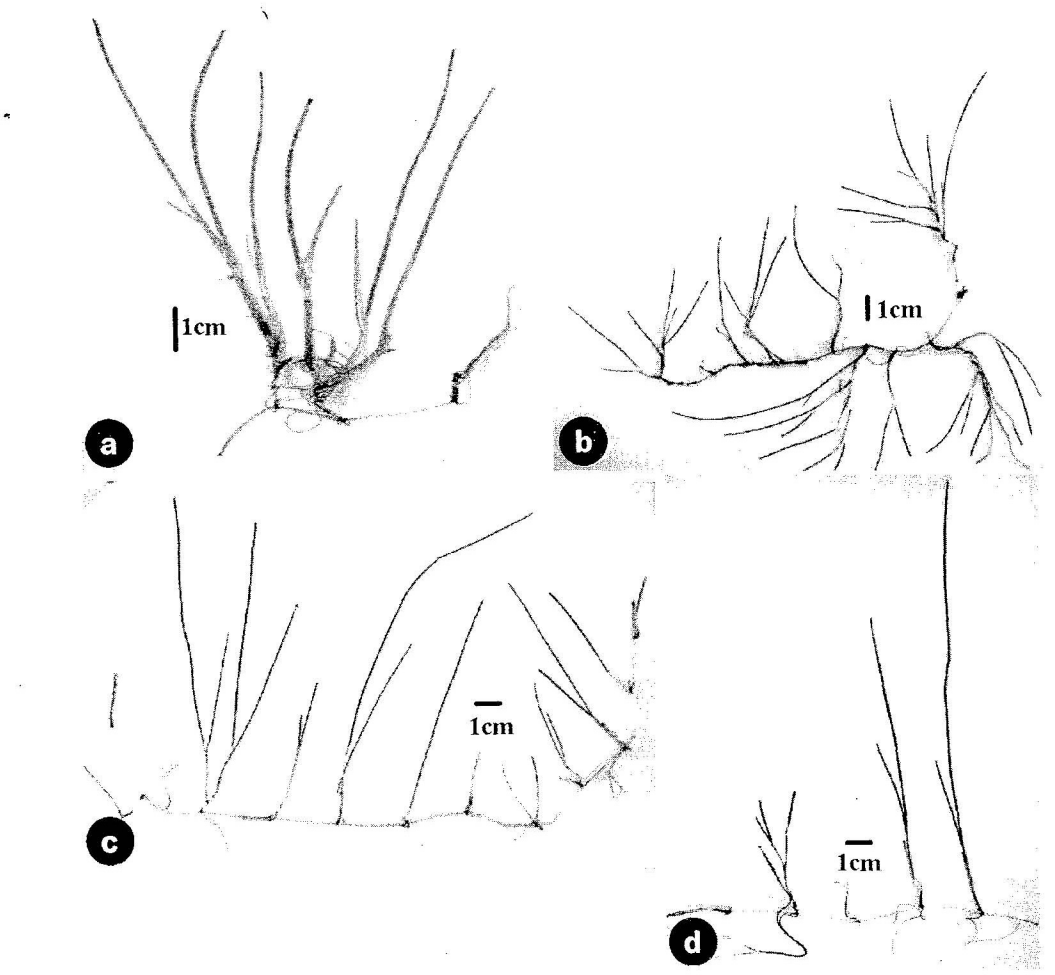

Figure 2. Morphological plasticity in *H. pinifolia*; (a) Merchang-in dense population rhizomes are compress and horizontal rhizomes have to grow vertically (b) Merchang-rhizome with inconsistent internode length (c) Lawas–in less dense population a horizontal rhizome have constant internode length (d) Tg. Adang Laut-horizontal rhizome with constant internode length

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