low light intensity (20 $\mu Em^{-2}s^{-1}$) with a 16/8 h-light–dark regime at all the stages.

In conclusion, it was found that somatic embryogenesis could be obtained in *E. tereticornis* using a well-defined medium without any additional supplements when cultured under low light conditions at all the stages.

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Brachyuran crab diversity in natural (Pitchavaram) and artificially developed mangroves (Vellar estuary)

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The brachyuran crab diversity was studied in four stations of Pitchavaram mangroves and three stations of Vellar mangroves. A total of 38 species of brachyuran crabs was recorded in the Pitchavaram mangroves (18 species of grapsids and 8 species of ocypodids besides others), while 8 species were recorded in Vellar mangroves (5 species of grapsids and 3 species of ocypodids). The abundance of crabs also varied between the two mangrove habitats (65–82/m^2 in Pitchavaram mangroves and 27–40/m^2 in Vellar mangroves). The Pitchavaram mangrove forest has been in existence since sixteen to seventeen hundred years. In Vellar estuary, mangrove was established 13 years ago. The mangroves with vast network of roots and trunks offer a good niche for the brachyuran crabs. Due to its age and vast extent, the Pitchavaram mangrove forest has higher brachyuran crab diversity. When the mangroves were established in Vellar estuary, the mangrove-associated crabs were not present. But subsequently due to larval transport from the Pitchavaram mangroves, few species got established. Due to the above process, the remaining species may also get established. But how much time it will take? It is an interesting question worth investigating. Continuous monitoring of brachuran crab diversity may provide the answer.

THE coastal and marine environs have some of the richest biodiversity areas. They include extensive areas of complex and specialized habitats such as enclosed seas and tidal systems, estuaries, salt marshes, coral reefs, sea grass beds and mangroves.

The association of brachyuran crabs with mangrove flora, behaviour, feeding and ecology is of great interest to biologists[1]. The brachyuran crabs are interesting in that they walk on their sides. Another important feature is the much-expanded body in contrast to the elongated one in other decapod crustaceans. Among all the macrofauna inhabiting the mangrove swamps, brachyurans are among the most important taxa with regard to species diversity and total biomass. They make up as much as 80% of the macrofaunal biomass in mangroves[2] and densities reach[3] as much as 80–90 m^2. Among the brachyuran crabs, grapsids, ocypodids, portunids, xanthids and gecarcinids are dominant in the mangroves. In particular, the sesarmids have attained extreme diversity and richness in the Indo-Pacific mangroves.

Crabs also play many important roles in the mangroves. Degradation of mangrove leaf litter by crabs, sesarmids

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in particular, plays a key role as a major link between primary and secondary producers. The faeces of the crabs, which contain nitrogen, carbon, phosphorus and trace metals form a rich source of food for other consumers[4]. Their burrowing habit aids in aeration and free circulation of water, which promotes the growth of seedlings of mangroves. The burrowing members are of immense use in recycling of nutrients by ploughing. They also help in the breakdown of particulate organic matter by exposing them to microbes. The burrowing habit assists in oxidizing the sulphide that builds up due to high rate of organic decomposition in mangrove swamps[5]. They form the food for many birds, snakes and predatory fishes and their larvae are also consumed by many carnivores; thus crabs play an important role in the food chain[3]. In a way, the saying 'no mangroves, no prawns' is more applicable to the crabs. In the present study, the diversity of brachyuran crabs was studied and compared between the natural mangroves in Pitchavaram and artificially developed mangroves in Vellar estuary.

The Pitchavaram mangrove (lat. 11°27′N; long. 79°47′E), which lies between the Vellar and Coleroon estuaries, is a heterogenous mixture of mangrove elements (Figure 1). The mangroves spread over an area 10 km^2. The Vellar estuary flowing over the southeast coast of India at Parangipettai (lat. 11°29′N; long. 79°46′E) is one of the fertile estuaries in Tamil Nadu. Nearly 1.5 km upstream from the mouth at the tidal zone and in the northern bank of the estuary, a mangrove plantation covering an area of 10 ha was established in 1991 by Kathiresan (Figure 1). The crab diversity was studied in four stations of the Pitchavaram mangroves (station I located in the Kanankeluthi canal, station II in Peria Kadavu, station III in Alasi odai and station IV in Chinnavaikkal) and three stations of the Vellar estuary (station V in *Rhizophora* zone, station VI in mixed zone and station VII in *Avicennia* zone) in the newly developed mangroves. In the first station, *Rhizophora apiculata* and *R. mucronata* are present in the periphery and *Avicennia marina*, *A. officinalis*, *Bruguiera cylindrica* and *Ceriops decandra* are seen in the interior. Station II has dense mangroves. The dominant mangrove species here are *R. apiculata*, *A. marina* and *A. officinalis*. In station III, where the neretic influence is more, the dominant mangrove plants are *R. apiculata*, *A. marina* and *B. cylindrica.* Station IV, is characterized by stunted growth of mangroves like *A. marina and Excoecaria agallocha.* In station V, located opposite the Marine Biological Station, the plantation comprised of *R. apiculata* and *R. mucronata*. Station VI situated nearly 50 m away from the previous station towards the upstream, had mixed vegetation (*R. apiculata*, *A. marina* and *Acanthus illicifolius*). Station VII situated further upstream has *A. marina* and *A. illicifolius.* Density of crabs was estimated by simple random sampling design using 50 × 50 cm quadrate[6]. In each station, ten samples were collected during low tide (five horizontally and five vertically from the high tide mark up to water level) to estimate the abundance. Crabs were procured by hand-picking and by digging burrows. The collected crabs were identified using the manual of Sethuramalingam and Ajmal Khan[7]. As this manual has figurative keys for identifying the crabs occurring in Pitchavaram mangroves and adjacent areas, identity of the crabs was established without any ambiguity. The diversity of brachyuran crabs was calculated following the Shannon–Wiener index using the formula

$$H' = \frac{3.3219(N\log - \sum ni - \log ni)}{N},$$

where H' is the species diversity in bits of information per individual, ni is the proportion of the samples belonging to the ith species (number of individuals of the ith species), and N is the total number of individuals in the collection and $\sum$ is the summation. Species richness was calculated following the Margalef index (d) using the formula $d = (S-1)/\log_e N$, where S is the number of species and N the total number of crabs. The evenness (J') was computed using the following formula of Pielou:

$$J' = \frac{H'}{\log_2 S} \text{ or } \frac{H'}{\ln_2 S},$$

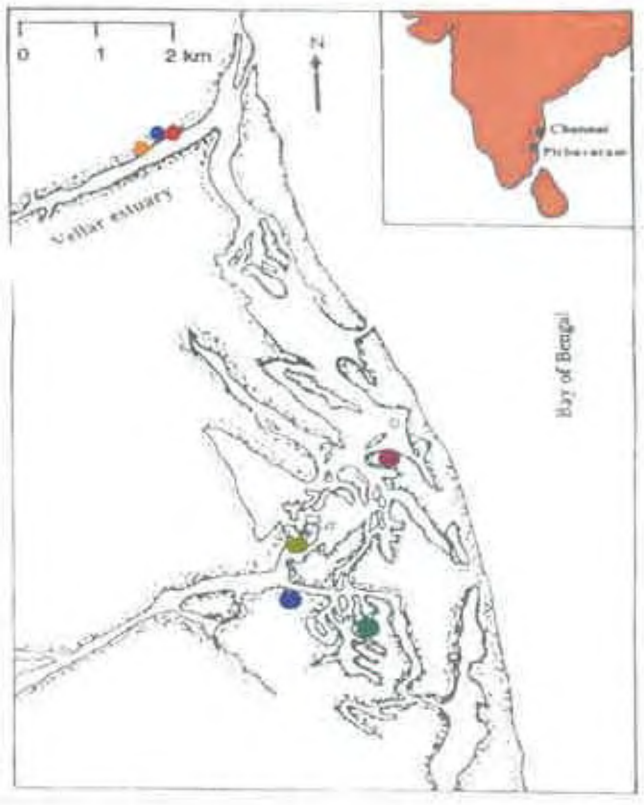

Figure 1. Stations sampled in mangroves of Pitchavaram (I–IV) and Vellar (V–VII). I, Kanankeluthi canal ●; II, Periya Kadavu ●; III, Alasi odai ●; IV, Chinnavaikal ●; V, *Rhizopora* zone ●; VI, Mixed zone ●; VII, *Avicennia* zone ●.

where H' is the species diversity in bits of information per individual and S the total number of species. The newly introduced diversity index, taxonomic diversity (Δ), which measures the average taxonomic distance between any two individuals chosen at random belonging to separate species was calculated using the formula

$$\Delta = [\Sigma\Sigma_{i<j}\omega_{ij}\, x_i\, x_j]/[N(N-1)/2],$$

where the double summation is over all pairs of species i and j and $N = \sum_i x_i$, the total number of individuals in the sample. New diversity indices that have the statistical framework to compare the biodiversity between samples/habitats such as average taxonomic distinctness index (Δ^+) and variation in taxonomic distinctness index (Λ^+) were also calculated. Δ^+ was calculated using the equation

$$\Delta^+ = [\Sigma\Sigma_{i<j}\omega_{ij}]/[S(S-1)/2],$$

where S is the number of species present, the double summation is over the set $\{i = 1; j = 1, S;\ldots S$, such that $i < j\}$ and ω_{ij} is the 'distinctness weight' between species i and j.

Λ^+ was calculated using the formula

$$\Lambda^+ = [\Sigma\Sigma_{i<j}(\omega_{ij} - \Delta^+)^2]/[S(S-1)/2],$$

where ω_{ij} is the variance of the taxonomic distance between each pair of species i and j about their mean value of Δ^+ and S is the number of species. As these indices are helpful in finding out statistical deviation in biodiversity between the two mangrove forests, these were calculated for plotting the 95% funnel and ellipse plots. Total phylogenetic diversity index (sPhi+), which vouches safe for the taxonomic breadth of the crabs present in various stations, was calculated by finding out cumulative branch length of the full taxonomic tree drawn using the Linnaean classification. To compare the biodiversity between the two forests, dominance plots were drawn by ranking the species in decreasing order of abundance. Relative abundance expressed as percentage of abundance in the sample was plotted across the species, against the increasing rank as the x-axis, the latter on a log scale. On the y-axis, the cumulative percentage was plotted. This cumulative curve is referred to as the dominance plot.

The similarity in species composition was studied by calculating the Bray–Curtis coefficient[8]. It was calculated based on species composition and abundance. The coefficient was calculated by the following formula:

$$S_{jk} = S_{jk} = 100\left\{1 - \frac{\sum_{i=1}^{p} |\, y_{ij} - y_{ik}\,|}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}\right\}$$

$$= 100\frac{\sum_{i=1}^{p} 2\min(y_{ij}, y_{ik})}{\sum_{i=1}^{p} (y_{ij} + y_{ik})},$$

where y_{ij} represents the entry in the ith row and jth column of the data matrix, i.e. the abundance for the ith species in the jth sample; y_{ik} is the count for the ith species in the kth sample; $|\ldots|$ represents the absolute value of the difference; 'min' stands for the minimum of the two counts and Σ represents the overall rows in the matrix. In the cluster analysis, hierarchical agglomerative clustering was used. Taking similarity matrix as the starting point, the samples were successively fused into groups and the groups into larger clusters, starting with the highest mutual similarities and then gradually lowering the similarity level at which the groups are formed. This process ends with a single cluster containing all the samples. In non-metric multidimensional scaling (MDS), the Bray–Curtis similarity was used to construct a map in which those having more similarity were placed near and samples having lower similarity far away. The goodness of fit of the MDS was found by calculating the stress value using the formula, Stress = $\sum_j\sum_k(d_{jk}-d_{jk})^2/\sum_j\sum_k d_{jk}^2$. Similarity percentage was calculated to identify the species primarily accounting for the observed differences between the two mangroves. Bray–Curtis similarity was decomposed into contributions from each species. By looking at the overall percentage contribution each species made to the average dissimilarity between two mangroves, species in decreasing order of their importance in discriminating the two mangrove forests were listed. The abundance of the four most important discriminating species between the two mangrove forests was drawn in the MDS plot using the bubble, where the smaller bubble indicates less abundance and larger bubble, indicates relatively higher abundance. Making use of the abundance table and the aggregation table giving information regarding the taxonomy of the species, the funnel and ellipse plots were drawn. The funnel was drawn after 250 random selections of all the species identified from the two mangrove forests. The variation in taxonomic distinctness value calculated for each sample was superimposed on the funnel to find out the deviation from the normal distribution (within the 95% confidence limit or not). It can also be plotted for the average taxonomic distinctness value. As this will occupy more space, it was not done. Moreover, a funnel drawn with variation in taxonomic distinctness, tests the variance between the samples. Therefore, it was considered adequate. The above and the average taxonomic distinctness values calculated after 250 random selections from the table were used to draw the ellipse plot and these values for all the samples were superimposed. In the plot 95% contours were drawn for the range of species noticed in the Pitchavaram mangroves, to test statistically the difference in diversity between the

Table 1. Abundance (m^2) of brachyuran crabs in various stations of Pitchavaram and Vellar mangroves (names in parentheses indicate the family)

Species	Pitchavaram				Vellar		
	I	II	III	IV	V	VI	VII
Scylla serrata (Portunidae)	2	1	1	1	0	0	0
S. tranquebarica	0	1	1	1	0	0	0
Portunus sanguinolentus	0	0	0	1	0	0	0
P. pelagicus	0	1	1	1	0	0	0
Charybdis lucifera	0	0	0	1	0	0	0
C. feriatus	0	0	1	0	0	0	0
C. helleri	0	2	1	0	0	0	0
Thalamita crenata	0	2	1	1	0	0	0
T. chaptali	0	1	0	1	0	0	0
Podopthalmus vigil	0	1	0	1	0	0	0
Galene bispinosa (Xanthidae)	2	1	0	1	0	0	0
Heteropanope indica	2	1	0	0	0	0	0
Ocypode platytarsis (Ocypodidae)	0	0	0	2	0	0	0
O. macrocera	0	2	0	3	0	0	0
Uca annulipes	24	26	21	15	16	19	15
U. triangularis	7	3	7	4	4	7	5
Macrophthalmus depressus	2	1	1	1	0	0	0
M. erato	0	1	0	2	0	0	0
Dotilla myctiroides	0	0	0	4	3	3	0
Grapsus strigosus (Grapsidae)	0	1	1	0	0	0	0
G. tenuicrustatus	0	1	0	0	1	0	1
Metapograpsus maculates	0	1	2	0	0	0	0
M. messor	2	1	2	4	0	0	0
Ptychognathus altimanus	0	1	1	0	0	0	0
Pseudograpsus intermedius	1	1	1	1	0	0	0
Nanosesarma (Nanosesarma) minutum	0	1	1	0	0	1	4
N. batavicum	3	1	0	2	1	1	0
Sesarma andersoni	1	1	2	0	0	0	0
S. brocki	12	15	14	7	0	8	8
S. plicatum	7	7	3	11	0	0	0
S. bidens	0	2	1	4	0	0	0
Neoepisesarma tetragonum	2	1	1	4	0	0	0
N. mederi	0	2	0	0	2	1	0
Plagusia dentipes	0	1	0	1	0	0	0
P. depressa	0	1	0	0	0	0	0
Metaplex elegans	1	0	0	2	0	0	0
M. distincta	2	0	0	2	0	0	0
Cardisoma carnifex (Gecarcinidae)	1	0	1	0	0	0	0

two mangrove forests. All the diversity indices and other calculations were done using the PRIMER package developed by the Plymouth Marine Laboratory, UK.

In the Pitchavaram mangroves, the number of crab species recorded in various stations was more in the range of 16–30/m^2 (Table 1). While the maximum number of species was found in station II, the minimum was found in station I. In the Vellar mangroves, the number of species was low, in the range of 5–8, with maximum number of species in station VI and minimum in station VII. The abundance of crabs also varied between the two mangrove habitats (65–82/m^2 in Pitchavaram and 27–40/m^2 in Vellar mangroves). Totally, 38 species of brachyuran crabs were recorded in the Pitchvaram mangroves. These included 10 species belonging to family Portunidae, 2 to family Xanthidae, 7 to family Ocypodidae, 18 to Grapsidae and 1 species to family Gecarcinidae. The most dominant species in the Pitchavaram mangrove forest was *Uca annulipes* followed by *Sesarma brocki.* Species found in all the stations include *Scylla serrata, Uca annulipes, U. triangularis*, *Macrophthalmus depressus*, *Metapograpsus messor*, *Pseudograpsus intermedius* and *Sesarma plicatum.*

The number of species recorded in the Vellar mangroves was only 8. The species found in mangroves of Vellar were *U. annulipes, U. triangularis, Dotilla myctiroides* (Ocypodidae), *Grapsus tenuicrustatus, Nanosesarma (Nanosesarma) minutum, N. batavicum, S. brocki* and *Neoepisesarma mederi* (Grapsidae). While the number of species of grapsids, which are typical of the mangrove environment, was 18 in Pitchavaram, it was only 5 in Vellar mangroves. The grapsid species not found in Vellar mangroves were *Grapsus strigosus*, *Metapograpsus maculates*,

Table 2. Diversity indices of brachyuran crabs in Pitchavaram (stations I–IV) and Vellar mangroves (stations V–VII)

Station	*S*	*H'* (log 2)	*d*	*J'*	Delta	sPhi+	Lambda+
I	16	2.7094	2.3352	0.6773	60.7382	1100	353.0093
II	30	3.3879	4.2816	0.6904	70.6842	1800	329.8836
III	21	2.8301	3.1677	0.6443	65.7263	1300	371.4034
IV	26	3.2962	3.7607	0.7012	68.2388	1533.3330	318.2117
V	7	1.8752	1.2106	0.6679	45.9061	466.6667	488.7881
VI	8	2.2696	1.3186	0.7565	60.9411	500	510.2041
VII	5	1.6698	0.7549	0.7191	47.4958	366.6667	500

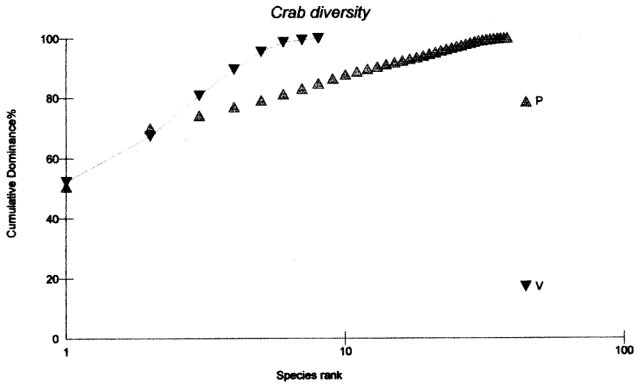

Figure 2. Dominance plot for brachyuran crabs showing higher diversity in Pitchavaram (P) than in Vellar (V) mangroves.

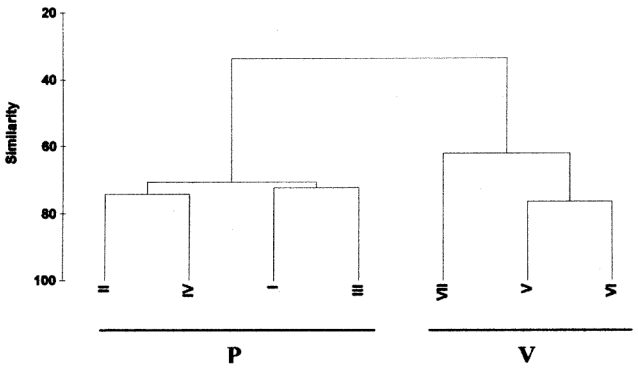

Figure 3. Dendrogram of brachyuran crabs recorded in various stations of Pitchavaram and Vellar mangroves (samples I–IV from Pitchavaram-P and samples V–VII from Vellar mangroves-V) showing grouping of stations from the two mangroves separately.

M. messor, *Ptychognathus altimanus*, *P. intermedius*, *Sesarma andersoni*, *S. plicatum*, *S. bidens*, *Neoepisesarma (Muradium) tetragonum*, *Plagusia dentipes*, *P. depressa*, *Metaplex elegans* and *M. distincta* (Grapsidae).

The results of various diversity indices calculated are given in Table 2. In line with the higher number of species and abundance in Pitchavaram mangroves, the Shannon diversity (log 2) was also more here (2.7094 in station I–3.3879 in station II) than in the mangroves of Vellar (1.6698 in station VII–2.2696 in station VI). The Margalef species richness showed clear differences between the two habitats (2.3353–4.2817 in Pitchavaram and 0.7549–1.3186 in Vellar). Unlike in species diversity and richness, the evenness was comparatively more in the Vellar (0.6679–0.7565) than in Pitchavaram (0.6443–0.7012). The taxonomic diversity index (60.7382–70.6842) and total phylogenetic diversity index (1100–1533.3330) were more in the Pitchavaram mangroves than in the Vellar estuary (45.9061–60.9411 and 366.6667–500). However the variation in taxonomic distinctness index was more in Vellar mangroves (488.7881–510.2041) than in Pitchavaram mangroves (318.2117–371.4034). In the dominance plot, the curve for the Pitchavaram mangroves, which lies on the lower side, extends further and rises slowly due to presence of more number of species. As the percentage contribution of each species is added, the curve extends horizontally (species number is evident in the *x*-axis), before reaching the cumulative 100%. As the curve for the Vellar mangrove has to accommodate only a few species, it rises quickly. Hence it lies over the other curve (Figure 2). This plot also amply proves the rich diversity of crabs in the Pitchavaram mangroves compared to the Vellar mangroves.

The similarity in species composition and abundance among stations of Pitchavaram mangroves was in the range of 68.6951–74.2139% (Table 3), with an average similarity percentage of 71.56. In Vellar mangroves, the similarity was in the range of 52.1375–76.4027%, with an average similarity percentage of 66.95. The dendrogram (Figure 3) drawn revealed clearly the separate grouping of Pitchavaram and Vellar stations. Stations V and VI formed a group with the maximum similarity percentage of 74.4 to which station VII got linked at 62.24. Stations II and IV formed a group at a similarity percentage of 74.21 followed by stations III and I at 72.32. These two groups got linked at 70.7%. The two major groupings (one representing the Pitchavaram mangroves and another the Vellar mangroves) ultimately got linked at a percentage similarity of 33.68. The same pattern was also evident in the MDS plot (Figure 4) where samples from Vellar stations fell on one side and those from Pitchavaram on the other side of the map, again demonstrating the close similarity in species composition among the samples of Pitchavaram than Vellar. The stress value, which was overlying on the MDS plot

Table 3. Bray–Curtis similarity for brachyuran crabs collected from different stations in Pitchavaram (stations I–IV) and Vellar (stations V–VII) mangroves

Station	I	II	III	IV	V	VI	VII
I	0	0	0	0	0	0	0
II	68.6951	0	0	0	0	0	0
III	72.3247	72.9278	0	0	0	0	0
IV	70.6893	74.2139	70.4850	0	0	0	0
V	27.1988	22.7468	24.7851	23.5779	0	0	0
VI	39.9929	33.1067	40.2034	33.2482	76.4027	0	0
VII	43.5601	34.8517	47.7546	33.1536	52.1375	72.3375	0

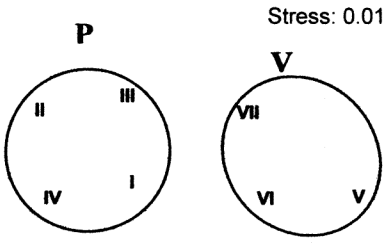

Figure 4. MDS for brachyuran crabs recorded in various stations of Pitchavaram (P) and Vellar (V) mangroves (samples I–IV from Pitchavaram and samples V–VII from Vellar mangroves) showing good ordination and goodness of fit.

(0.01), showed an excellent ordination of the samples collected.

The average dissimilarity in species composition of crabs between stations of Pitchavaram and Vellar was 66.32%. Crab species which contributed to 70% of the observed dissimilarity between Pitchavaram and Vellar mangroves were *U. triangularis*, *U. annulipes*, *S. brocki*, *S. plicatum* and *M. depressus*. The bubble plot (Figure 5) clearly showed the higher abundance of *U. triangularis*, *U. annulipes*, *S. brocki* and *S. plicatum* in Pitchavaram mangroves. While *U. triangularis* and *U. annulipes* were found in all the stations of Vellar mangroves, *S. brocki* was absent in station V and *S. plicatum* was absent in all the stations.

The 95% confidence funnel generated for the variation in taxonomic distinctness values of all the stations is shown in Figure 6. All the stations in Pitchavaram fell within the confidence funnel showing no deviation from the normal deviation. In Vellar, while stations V and VII fell on the border, station VI fell outside the confidence limit. In the ellipse plot (Figure 7) drawn combining the average taxonomic distinctness and variation in taxonomic distinctness values, statistically significant departure of the stations at Vellar from those at Pitchavaram can be seen clearly.

Crabs thrive well in the mangroves mainly due to a variety of microhabitats available in the form of various roots of mangrove plants. Species arboreal in nature, particularly sesarmids abound here. Also, the densely shaded portions of mangroves provide a good habitat to species intolerant to bright sun and dry air[9]. The present study was undertaken to compare the diversity of crabs in the artificially developed mangroves in Vellar with that of the natural mangrove in Pitchavaram. In a way the brachyuran crab diversity can be considered to reflect the well-being of the mangrove habitats. Having this in mind, the present study was undertaken to ascertain the crab diversity in the newly developed mangroves in Vellar estuary *vis-à-vis* Pitchavaram mangroves.

A total of 38 species of crabs was found in the Pitchavaram mangroves among which 18 species belonged to the family Grapsidae and 8 to the family Ocypodidae. This is high compared to the 8 species of crabs found in the Vellar mangroves, among which 5 species were grapsids and 3 were ocypodids. Prior to the development of mangroves, grapsids were not found in the Vellar estuary[7]. After the development of mangroves at the Vellar estuary, the grapsids got established through the larval transport from the Pitchavaram mangroves. Davie[10] recorded 32 species of grapsids from the mangroves of Hong Kong and Australia, which is higher than the ones noticed in the present study. Adiwiryono *et al.*[11] recorded as many as 16 species of grapsid crabs (slightly lower than the present study) and 18 species of ocypodid crabs (higher than the present study) from the mangroves of Indonesia. Tan and Ng[12] found 51 species of grapsids from the mangroves of Peninsular Malaysia. The grapsid crabs are mainly herbivorous in nature. The chelate legs of these crabs are sharp with short cutting edges and are used effectively to tear-off pieces of vegetation. Mangroves with a lot of litterfall offer them a haven and therefore grapsid diversity is more in mangroves. In turn they also play many useful roles as elaborated earlier. The ocypodids are deposit and suspension feeders. Mangroves with a lot of detrital and suspended materials, provide them a good habitat. Thus, the diversity of crabs, in particular that of grapsids and ocypodids is more. Variation in the number of grapsids and ocypodid species could therefore be related to the extent of the mangroves, species of mangrove plants present, their diversity and hydrographical conditions[10].

The Shannon–Wiener diversity, which is widely used for comparing diversity between various habitats[13], clearly showed the diverse nature of the Pitchavaram mangroves (2.7094–3.3870). With the number of species only in the range of 5–8, the H' values recorded in the Vellar mangroves (1.6698–2.2696) are slightly on the higher side,

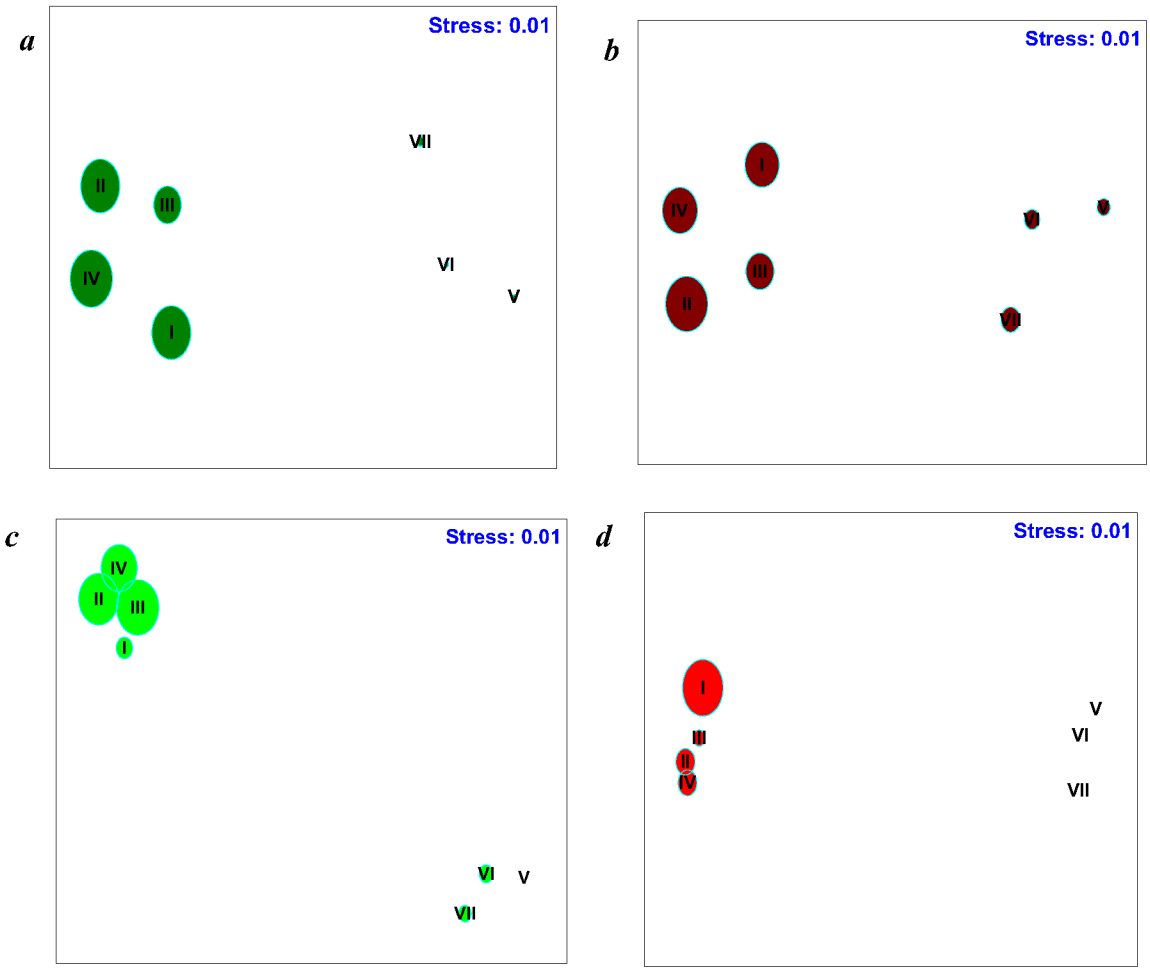

Figure 5. Bubble plot for brachyuran crabs (samples I–IV from Pitchavaram and samples V–VII from Vellar mangroves) showing higher abundance of *Uca triangularis* (***a***), *U. annulipes* (***b***), *Sesarma brocki* (***c***) and *S. plicatum* (***d***) in Pitchavaram mangroves and lower abundance/absence in Vellar mangroves.

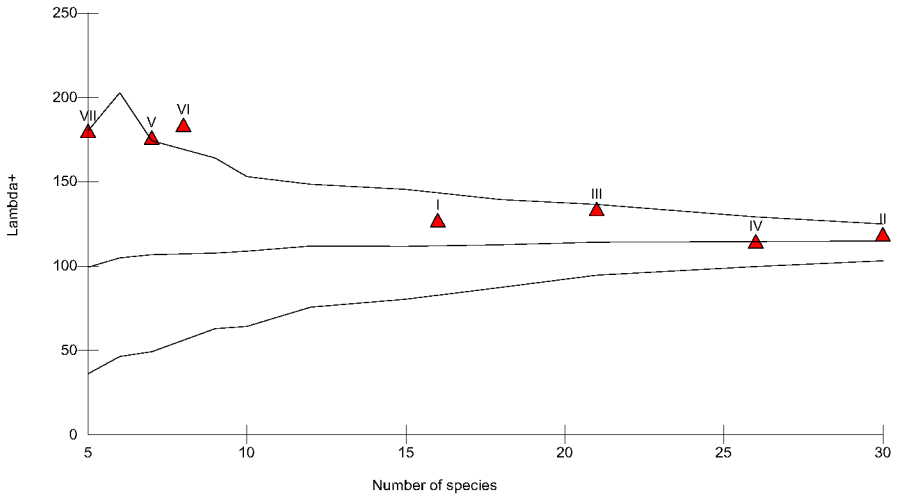

Figure 6. The 95% confidence funnel for variation in taxonomic distinctness values (lambda+) showing lower diversity of crabs and deviation from the normal distribution (sample VI) in Vellar mangroves and higher diversity and no deviation from the normal distribution in Pitchavaram mangroves.

and it is attributed to the higher evenness values recorded here[13]. However, the Margalef index, which has a good discriminating ability, clearly brought out the variation in species richness between the two habitats (2.3352–4.2816 in Pitchavaram mangroves and 0.7569–1.3186 in Vellar mangroves). The conventional indices are much influenced

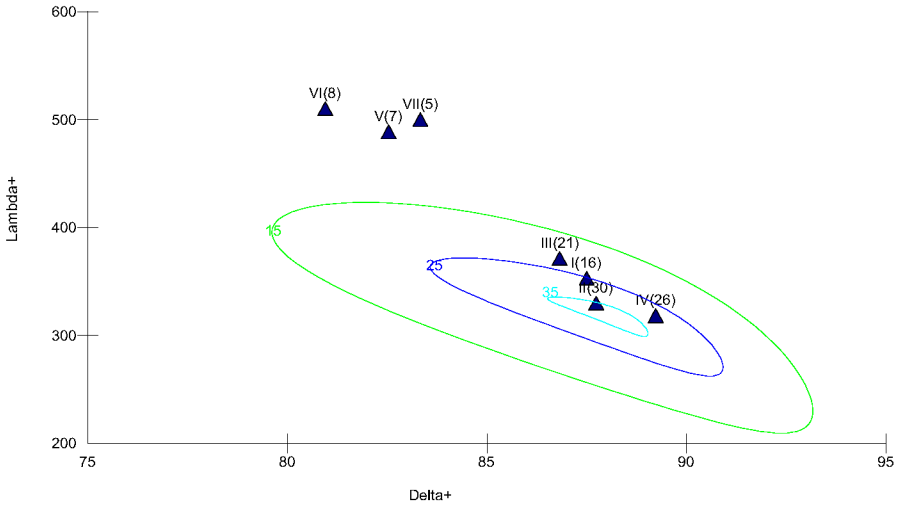

Figure 7. Fitted 95% probability contours of average taxonomic distinctness (delta+) and variation in taxonomic distinctness (lambda+), showing statistically significant deviation in crab diversity between Pitchavaram and Vellar mangroves.

by the sampling effort and evenness property. These indices can only be used with quantitative data. They also lack the statistical framework for comparison of one sample with another. Therefore diversity indices based on relatedness of species have been introduced such as taxonomic diversity index, average taxonomic distinctness index, variation in taxonomic distinctness index and phylogenetic diversity index by Clark and Warwick[13]. These indices were used in the present study with the view to finding out the statistical significance of the difference in diversity between the two mangrove forests. Even though the taxonomic diversity index was more in Pitchavaram mangroves (60.7382–70.6842) than in Vellar mangroves (45.9062–60.9411), the more or less similar taxonomic diversity values for station I in Pitchavaram mangroves (60.7382) and station VI in Vellar mangroves (60.9411) having 16 and 8 species of crabs respectively, indicate the inadequacy of this index also in discriminating these two stations. This is mainly due to the similarity in the Linnean taxonomic tree of these stations. True to the fact that samples from biodiversity-rich areas have more stability and less variation than others, the variation in taxonomic diversity index was comparatively low in the range of 318.2117–371.4034 in Pitchavaram mangroves than in Vellar mangroves (488.788–510.2041). The total phylogenetic diversity index, which vouches safe for the taxonomic breadth of the biota[14], also clearly showed the highly diverse nature of the Pitchavaram mangroves (1100–1533.3330) compared to the Vellar mangroves (36666.67–500).

The similarity coefficient is extensively used to find out the degree of relationship (in species composition and abundance) between samples collected from various places. Among the numerous similarity measures that have been suggested over the years, the commonly used one is the Bray–Curtis similarity[15]. Therefore, in the present study, this measure was used. This coefficient varies from 0 to 100%, with the ends of the range representing the extreme possibilities. The similarity is 100% if the two samples are totally similar and it is 0 if the two samples are totally dissimilar. The converse concept of similarity is that of dissimilarity, the degree to which two samples are unlike each other. However, similarity and dissimilarity are just opposite sides of the same coin. In the present study, similarity was used to find out the degree of relationship among the stations of Pitchavaram mangroves so also among the stations of Vellar mangroves, while the dissimilarity was used to know the degree of difference between the two habitats. The stations studied in Pitchavaram mangroves showed higher similarity (68.6951–74.2139%) and the average similarity was 71.56%. The distribution of crabs varied in relation to the mangrove vegetation with more number of species associated with *Avicennia* spp. followed by *Rhizophora* spp. compared to other species of plants. The stations in Vellar also showed good similarity (52.1375–76.4027%) among themselves, with an average similarity of 66.95%. As the diversity of crabs was low in the Vellar mangroves, dissimilarity with Pitchavaram mangroves was about of 66.32%.

Cluster analysis (or classification) is helpful in finding natural groupings of samples, such that samples within a group are more similar to each other than samples in different groups. It is also used to define species assemblages, i.e. groups of species that tend to co-occur in a parallel manner across sites. In the present study the samples from Pitchavaram, which showed more similarity among themselves than those in Vellar mangroves, were grouped together. In the same way samples from Vellar, which showed more similarity among themselves than those in Pitchavaram, were grouped together. However, as cluster analysis has the inherent disadvantage of linking ultimately the dissimilar groups also, ordination of the samples was done using MDS. The purpose of using this is to represent the

samples collected as points in a map (low-dimensional space, usually 2D). Samples lying closer have more similarity in species composition and abundance, while samples lying far apart have more dissimilarity in species composition and abundance. As noticed in the cluster pattern, here also the samples from Pitchavaram and Vellar occurred separately. On this map, the abundance of species, which vouched safe for the dissimilarity between the two habitats, was superimposed as circles of different sizes. This is called the bubble plot. Larger the bubble size, greater is the value of the superimposed variable – here abundance of the crab species. The bubble plots clearly showed the higher abundance of discriminating species in the Pitchavaram mangroves.

Variability is more among the less diverse areas and less among the highly diverse areas. Variability can be compared through tests for taxonomic distinctness, which are helpful in checking the null hypothesis that a species list from one locality (or time), has the same taxonomic distinctness structure as the master list (of all species in that biogeographic region – Pitchavaram mangrove). Given the number of species observed in a sample, the test makes repeated drawings at random from the full master list and computes the average taxonomic distinctness and variation in taxonomic distinctness values for each drawing, building up a 95% probability range of possible values of average taxonomic distinctness and variation in taxonomic distinctness values under the null hypothesis. The true values of average taxonomic distinctness and variation in taxonomic distinctness can then be compared with the 95% level of probability distribution, and values away from the 95% limit do indicate a significant deviation from the normal situation[13]. This computation can be performed for a range of sublist sizes (5, 15, 25 and 30 presently) noticed in various habitats and the 95% limits plotted against that size to give a 95% funnel. The advantage of this 95% funnel is that all the samples can be plotted in the same funnel. In the present study, the 95% funnel drawn for the variation in taxonomic distinctness not only separated the stations of Pitchavaram and Vellar mangroves, but also showed the significant deviation of a sample (station VI) from Vellar mangroves. Stations from the Pitchavaram mangroves conformed to the normal distribution. Tests combining average taxonomic distinctness and variation in taxonomic distinctness involve plotting of the combination of these values by drawing the 95% probability contours (ellipse), which are advantageous in testing under the usual null hypothesis of random sampling from the master species list and superimposing the real values. The ellipse plot also clearly separated the samples of Pitchavaram mangroves from the Vellar mangroves. The samples of Pitchavaram mangroves with higher crab diversity fell within the 95% contours and those of Vellar mangroves with less crab diversity fell away from the 95% contours, showing significant statistical deviation.

The Pitchavaram mangrove forest has been in existence since 1600 to 1700 years (K. Kathiresan, pers. commun.). In the Vellar estuary, the mangrove was established only 13 years ago. The mangroves with a vast network of roots and trunks, offer a good niche for the brachyuran crabs. Due to its age and vast extent, the Pitchavaram mangrove forest has higher brachyuran crab diversity. When the mangroves were established in the Vellar estuary, mangrove-associated crabs were not present. Subsequently, due to their extended breeding period, high fecundity, higher survival rate of larvae, larval transport from the Pitchavaram mangroves and colonizing effect, few species got established. The remaining species may also get established in due course of time. But how much time will it take? This question is worth investigating. Continuous monitoring of brachyuran crab diversity may provide the answer.

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