Tree and Forestry Science and Biotechnology ©2012 Global Science Books

Community Classification and Species Assemblage Limit within the Forests of North Andaman Islands, India

P. Rama Chandra Prasad[1*] • C. B. S. Dutt[2]

[1] Lab for Spatial Informatics, International Institute of Information Technology, Gachibowli, Hyderabad- 500032, India
[2] Environmental Sciences and Applications Group, National Remote Sensing Centre, Balanagar, Hyderabad, 500 625, India

Corresponding author: * rcprasad@iiit.ac.in, rcpncmsl@gmail.com

ABSTRACT

In the present study, three large ecological plots of 3 ha each were surveyed in 3 different forest types of North Andaman Islands. Each 3-ha plot (30 sub-plots of 0.1 ha each) was classified into different classes based on site quality as either excellent, good, moderate or poor using an index developed by utilizing vegetation parameters such as species richness, diversity, density, among others. Analysis revealed most of the area to be under the good category in three forest communities, indicating that forests of North Andaman are potential sites of species richness and diversity. The "general limit of species assemblage" with respect to higher angiosperm taxa in North Andaman was observed based on two independent approaches of sampling: stratified random plots and the large area ecological plots. The general limit of species assemblage was in the range of 14-33 species. The present analysis provides a base for future investigations to identify subplot characteristics that provide variation in species dominance, richness and diversity within a small unit area, which has made it possible to classify the 3-ha plots into four classes.

Keywords: diversity, richness, self organizing maps, site quality index, tropical rainforest

Abbreviations: A&N, Andaman and Nicobar Islands; **EG**, evergreen; **IVI**, important value index; **MD**, moist deciduous; **NAI**, North Andaman Islands; **SEG**, semi-evergreen; **SOM**, self organizing maps; **SQI**, site quality index

INTRODUCTION

Tropical rainforests are the most complex ecological systems on earth that house greater species richness and wide-range diversity than other ecosystems on earth (Terborgh 1985; Adam 1998; Huang *et al*. 2003). The variation in diversity profiles of these rainforests is attributed mainly to spatial heterogeneity in geographical conditions (edaphic, topographic, climatic, etc.) (Ricklefs 1977; Rohde 1992; Stevens 1992; Clark and Clark 2000; Hill and Hill 2001; Wright 2002; Potts *et al*. 2002) which is one of the fundamental concepts in understanding complex ecosystems (Levin *et al*. 1997). Researchers across the world explored these forests to investigate richness, diversity, species behavior and their distributional patterns using either stratified random sampling by laying out quadrat or transect (Whittaker and Niering 1965; Huang *et al*. 2003; Hardy and Sonke 2004; Devi and Yadav 2006; Prasad *et al*. 2007a; Jayakumar *et al*. 2009) or by a systematic survey of a large area ecological plots or contiguous plots (Manokaran and La Frankie 1990; Chai 1995; Condit 1995; Harms *et al*. 2001; Gunatilleke *et al*. 2004; Faridah-Hanum *et al*. 2008; Prasad *et al*. 2009). Random sampling captures maximum diversity of the area compared to large contiguous plot inventory, where, in the former case, sampling is done at heterogeneous locations with varied biotic and abiotic environmental factors (Grubb 1977) while in the latter under relatively homogenous conditions.

Field inventories, either random or contiguous, not only provide information on the encompassed diversity (Phillips *et al.* 2003) but also vistas the number of species that can be accommodated in a given unit area. This number, which is generally termed as the optimal limit of species (Macarthur and Levins 1967; Sheil 1996) that can be supported by an ecosystem, varies with the region, topography and environmental conditions. Estimation of optimal species limit maintained by ecosystem also differs with respect to the sampling strategy adopted (Purvis and Hector 2000). The diversity assessment made by random inventory shows difference in values with the inventory done using large contiguous sampling for the same region or location (Jayakumar *et al.* 2009). However, if database about the species limit (minimum and maximum) from both the inventories is available for a region, it could help in estimating the lower and higher limits of species number that can be seized by a vegetation unit or plot of an area.

It is a common phenomenon to show variation in diversity values for quadrats studied in a random inventory as they are laid in different topographic gradients. However, during the systematic survey of a large area plot (divided into contiguous sub-plots), few sub-plots show high values for certain vegetation parameters such as species richness and diversity, while few other show low patterns (Prasad *et al*. 2009; Nesheim *et al*. 2010). This variation in relation to large plots is significant and should be considered since all the quadrats lie more or less in homogenous environmental conditions (Campbell *et al.* 1986; Newberry *et al*. 1996). This can be attributed to micro-site characteristics which plays an important role in showing distinct and different diversity patterns among the quadrats apart from species eco-physiological characters (Ayyappan and Parthasarathy 2001; Tuomisto *et al*. 2003). Even with respect to species dominance, this variation is noteworthy and some species dominate few plots with their population distribution and basal area occupancy. Though all the species exists within homogenous environmental conditions, disparities are prominent resulting in the dominance of a particular species (Hubbell *et al.* 1999).

The dynamic growth and population stability of a species mainly depends on the site or habitat where it occupies the space for resource accessibility (Silvertown and Lovett Doust 1993). This habitat or site which is generally referred

Received: 18 May, 2011. Accepted: 20 July, 2011.

Original Research Paper

as 'species niche', shows a set of environmental parameters required for its survival and reproduction (Hutchinson 1957; Kohyama 1997) and is representative indicator to analyze the characteristics and dominance of species (Tilman and Pacala 1993). In general, the niche of a species can be defined as the range and selection of resources exploited by the species (Waite 2000). Further, the ecological success of species depends upon its capacity to cope up with the physical environment and also on its ability to adjust to the intra-specific and inter-specific resource competition and association (Odum 1959; Pontin 1982). Species can have either broad or narrow niche depending on the resource quality of the site in which they occur and different indices (e.g. Levin's Index, Freeman-Turkey Index) were used to measure these variations among the species. Since the site characteristics influence this dissimilarity, in the present study an attempt has been made to classify the large contiguous plot (3-ha) into different classes taking into the consideration of species vegetation parameters that has dominated the site. This analysis perhaps forms one of the new approaches in ecosystem research as well as first for the Andaman and Nicobar (A&N) Islands with reference to forest community classification.

The objectives of the present study are to: (i) classify the large plot (3-ha) and evaluate the contiguous subplots of large plot into different sites of quality, with the help of an Index developed using vegetation parameters *viz*., species richness, diversity, density, basal area and height; (ii) describe association pattern of dominant species within the forest community; (iii) investigate the species assemblage limit (lower and higher) that can be encountered within the forests of North Andaman.

Study area

North Andaman Islands (NAI) are one of the major group of islands in the Andaman district of the Andaman and Nicobar archipelago. The varied edaphic and climatic conditions along with isolation from the mainland have resulted in the formation of unique vegetation types in these islands. The flora of Andaman differs with that of Nicobar Islands, though both belong to a single stretch of the archipelago. NAI contributes a share of species richness, diversity and endemicity (Reddy *et al*. 2004; Prasad *et al*. 2007a, 2008, 2009, 2010) that makes these islands distinctive of their own.

MATERIALS AND METHODS

The vegetation map derived from the satellite data (details in Prasad *et al*. 2007b) was used as a base for carrying out random (Prasad *et al*. 2007a) and large plot sampling (Prasad *et al*. 2009). The inventory was carried out in three predominant inland forest types *viz*., Evergreen (EG), Semi-Evergreen (SEG) and Moist Deciduous (MD). Forest patch of 3-ha size was selected in each forest type as large plot sampling for community classification, while the randomly surveyed plot data (100 plots of 0.1 ha) was used as an addition to the large plot sampling to assess the optimal species assemblage limit within the NAI forest. In large plot sampling, each 3-ha plot was divided into 30 subplots of 0.1-ha size (Prasad *et al.* 2009a). Both in random and large plot, phytosociological attributes were collected at 0.1-ha plot. The field attributes collected during the inventory includes identification of species with their girth (> 30 cm at gbh) and height measurements. These attributes were later used to derive primary information about the species such as their number, density, basal area and height. Further, secondary information was obtained using the indices for diversity (Shannon-Wiener 1963) and dominance (Important Value Index - Cottam and Curtis 1956). Based on these parameters, subplots (0.1 ha) were categorized into different classes and ranks were assigned as follows (**Table 1**).

Species richness and diversity

A good index of species variability within the community is species richness (Spies and Turner 1999) which is the sum of the number of species encountered within the sampled area and species diversity, an indicator of relative abundance of species (Magurran 1988) packed in an area. For each subplot (30) both richness (count of species) and diversity values were calculated. These values based on minimum and maximum were scaled with equal class intervals and the subplots were grouped into four classes as *high*, *moderate*, *low* and *very low* to assign the ranks.

Density

Density is the representative numerical strength of species packed in an area (Sigdel 2008). This is obtained by counting the number of individuals of species in the sampled area divided by total area sampled (Verma 1981). Based on the density, subplots were grouped as *high*, *moderate*, *low* and *very low* density classes and subsequently ranked.

Species basal area

The tree's basal area is an indication of volume occupied by the aerial parts of the species on ground (Verma 1981). Depending on the basal area (m^2) of species, subplots were grouped as *Mature*, *Pre-mature*, *Transitional* and *Pioneer* followed by their ranking accordingly.

Species mean height

Physiognomy, which refers to the external appearance (Leslie 1929) of the forest structure, basically depends on the height of the plant species. The total tree height is a good indicator of site suitability and is extensively used in forest management (Bettinger *et al*. 2009) and ecological purpose (Verma 1981). Based on the average species height, the subplots were again grouped into four classes as Light Demanding Canopy (LDC), Light Demanding Under Storey (LDU), Half Tolerant (HT) and Shade Tolerant Canopy (STC).

Site quality index (SQI)

In order to classify each 3-ha plot into different sites of potentiality, it is necessary to identify the quality of each subplot based on the five vegetation parameters, discussed earlier. To achieve this, we have proposed a measure of Index called "Site Quality Index (SQI)", which is calculated in two steps (a) Assigning ranks to each class after classifying each parameter into four classes (b) These ranks are further weighted depending on the correlation and dependency between the parameters to a scale of 1. The values thus obtained from SQI for each subplot are subsequently used to classify the large plot into four categories as *Excellent*, *Good*, *Moderate* and *Poor* sites. The higher the SQI, the better is the site quality.

As all the five parameters are equally important to quantify the site quality, it is mandatory to give equal weights to all the five parameters. However, an experimental analysis of correlation among the five parameters in the present study illustrated high correlation between species richness and diversity in three forest types, while it was least for parameters of density, basal area and height. So while calculating the Index, species richness and diversity shared half of the weight that is assigned to each of the other three parameters. Overall the Index is calculated as follows:

$$SQI = \sum_{i=1}^{5} w_i R_i$$

$$\sum_{\forall i} w_i = 1$$

$$w_{1,2} = 0.125, w_{3,4,5} = 0.25$$

where R is rank (1-4) for the classes of parameters (R_1 = Species richness; R_2 = Species diversity; R_3 = Density; R_4 = Basal area; R_5 = Average height) and w, weight assigned for each rank.

Modeling of species for spatial pattern analysis (Association of dominant species)

Analysis of phytosociological data provided the maximum IVI representing species as the dominant species in each forest type, confirming to the identity of community structure. Based on the enumerated species, an effort has been made to quantitatively represent the patterns of species community occurrence based on the selected ten predominant taxa. Towards this, during the current investigation Self Organizing Maps (SOM) [module of Modeling Patterns in Environmental Data "MOPED" 1.10 a software package (Jowett 2001)] were used to characterize the ten representative taxa in each forest type. Kohonen's SOM uses a neural network approach of grouping similar data together in a rectangular pattern with a series of bins into which data items are placed in an iterative process, similar to k-means. SOM are prepared using mean & standard deviation transformation with exponential Bray-Curtis distance measures for 10 dominant species in three 3-ha plots. The Bray-Curtis coefficient was originally applied to presence-absence data, but it works equally well with quantitative data and compared to Euclidean distance it retains sensitivity in more heterogeneous data sets and gives less weight to the outliers (Adopted from Jowett 2001).

Species assemblage limit within NAI

The stratified random allocation of sample plots (100) in the three forest types was primarily intended to address the spatial heterogeneity and to account species richness representative to NAI phytodiversity. Using 100 random plots, the number of species occurring in the number of plots (frequency) have been computed and plotted. Similarly, the 90 sub plots, obtained by pooling the three 3-ha forest types were plotted with their respective number of species and the number of plots of occurrence. A combination of both the analysis was used to estimate the possible optimal species assemblage limit of NAI forests.

RESULTS AND DISCUSSION

Forest communities are generally classified using clustering techniques (single to complete linkage) which take into account one parameter (e.g., species, basal area) at a time to classify the set of observations into different groups based on the similarity or the linkage distance. However in the current investigation application of Index derived from multiple vegetation parameters provided a different type of classification and was able to classify the large area plot into defined classes of site quality. The study was a novel approach of classifying forest community and no similar work has been carried out of this type to draw comparative conclusions. Also as mentioned by Jayakumar *et al.* (2009) comparing studies of different regions with respect to the floristic attributes may not be coherent since the type of sampling strategy adopted is different along with the dissimilar geographical parameters.

Community classification

With respect to species richness, EG and MD showed higher area under moderate class (43%, 60%) while SEG reflected high species richness (70%). Also the very low class (<10) was absent in both SEG and MD and minimum species value of 12 was recorded in both the forest types. With reference to species diversity, majority of the area in EG (36.7%) fell under low class and MD under moderate (43.3%) while SEG was under high diversity group (66.7%) with the absence of very low diversity class (<3). The high species richness and diversity observed in SEG is mainly due to its existence as intermix of forest patches in between EG and MD with species contribution from both the forest types. The low range found in EG is attributed to their location at inaccessible and isolated locations with wide canopy and large girth trees that does not allow the growth and survival of new species, thus maintaining old community of mature trees. In case of MD, observation of high area under moderate species richness and diversity is due to their distribution at low altitudinal levels with frequent disturbances which favors immigration of new species.

Table 1 Community classification using different species parameters.

	Range	Rank	EG	SEG	MD
			% of area		
Classes / Parameters			***Species richness***		
High	>20	4	20.0	70.0	26.7
Moderate	15-20	3	43.3	23.3	60.0
Low	10-15	2	30.0	6.7	13.3
Very low	<10	1	6.7	0.0	0.0
			Species diversity		
High	>4.0	4	10.0	66.7	23.3
Moderate	3.5-4.0	3	30.0	23.3	43.3
Low	3.0-3.5	2	36.7	10.0	26.7
Very low	<3	1	23.3	0.0	6.7
			Density		
High	>60	4	20.0	20.0	23.3
Moderate	50-60	3	30.0	30.0	40.0
Low	40-50	2	46.7	30.0	23.3
Very low	<40	1	3.3	20.0	13.3
			Basal area (m^2)		
Climax	>5	4	30.0	20.0	10.0
Pre-climax	4-5	3	20.0	20.0	30.0
Transitional	3-4	2	30.0	33.3	26.7
Pioneers	<3	1	20.0	26.7	33.3
			Average height (m)		
LDC	>11	4	33.3	0.0	3.3
LDU	10-11	3	20.0	16.7	16.7
HT	9-10	2	20.0	50.0	36.7
STC	<9	1	26.7	33.3	43.3
Site categories			***SQI (% of area)***		
Excellent	>3.5		13	10	0
Good	2.5-3.5		47	57	53
Moderate	1.5-2.5		33	30	47
Poor	<1.5		7	3	0

Tree density wise much of the area in MD is classified under moderate density (40%) and EG under very low density (46.7%) while SEG had equal area (30%) in both moderate and low density classes. Among the three communities EG showed majority of the area (30%) under mature and transitional classes, SEG under transitional (33%) and MD under pioneer (33.3%) class. Within EG, older trees with large girth contributed for the representation of higher mature class, while in MD the younger stems with small girth occupied greater part of the 3-ha plot. This observation, indicates the undisturbed and dense nature of EG and open and scattered nature of MD communities respectively.

Height classes are the indicative of active photosynthetic zones, related with community productivity and with respect to this parameter, EG showed much area under LDC (33.3%), SEG under HT (50%) and MD under STC (43.3%). Height representation among the three forest communities depicted a typical stratified tropical forest scenario with majority of the area showing tall emergent (LDC) species in EG. Absence of LDC in SEG indicates that the site (3 ha) selected for investigation is mostly represented or dominated by MD species.

Finally, scaling of SQI made it possible to classify the community into four categories of site potentiality within each forest community, and in three forest types, majority of the area (EG – 47%; SEG – 57%; MD – 53%) was categorized as good quality site supporting the species growth and survivability (**Fig. 1; Table 1**). Within MD, neither poor nor excellent class was encountered and half of the plots were categorized as good with the remaining half being moderate.

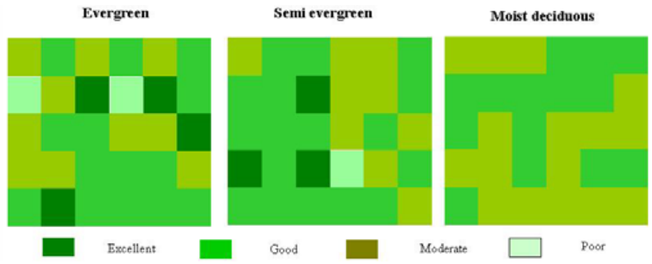

Fig. 1 Classification of large ecological plot into "sites" based on SQI in three forest communities.

Species associations and community delineation

The SOM obtained, showed different colour patterns representing the average density of each species, with red indicating high and blue low density respectively. The various colour (between red and blue) patterns are indicative of the species occurrence and densities in the community. If same locations in the two maps are red then those species occur together. The composition of the SOM cells reflects the mean value of the SOM variables for each bin in the plot (**Fig. 2**).

SOM showed three main associations within the EG community *viz.*, *Myristica andamanica* – *Xanthophyllum andamanicum* – *Pometia pinnata* (top right bins of the map), *Tetrameles nudiflora* - *Pterospermum acerifolium* – *Pterygota alata* (left side lower bins) and *Myristica glaucescens* – *Dipterocarpus gracilis* (bottom right bins). In SEG two predominant associations were observed as *Pterocarpus dalbergoides* – *Pterygota alata* – *Artocarpus chaplasha* – *Dolichondrone rheedi* – *Pterospermum acerifolium* – *Tetrameles nudiflora* (right lower and side bins) and *Dipterocarpus gracilis with Doliochondrone rheedi* (top left bins). Within MD, *Celitis wightii* forms association with *Tetrameles nudiflora*, *Diospyros oocarpa*, *Streblus asper* (top left corner bins), *Diospyros kurzi* with *Pterocarpus dalbergoides*, *Terminalis bialata*, *Mitragyan rotundifolia* (lower left corner bins) and *Sagereae elliptica* with *Lannea coromandelica* (top bins).

Similar species exhibit different kind of associations with different forest types, e.g., *Pterocarpus dalbergoides* within SEG showed association with evergreen species like *Artocarpus chaplasha*, *Dolichondrone rheedi* while when present in MD form groups with deciduous species like *Diospyros kurzi*, *Terminalia bialata*, etc. Some species within the same forest type showed two kinds of association like *Dolichondrone rheedi* within SEG associated with *Pterygota alata* group and also formed a different community with *Dipterocarpus gracilis*.

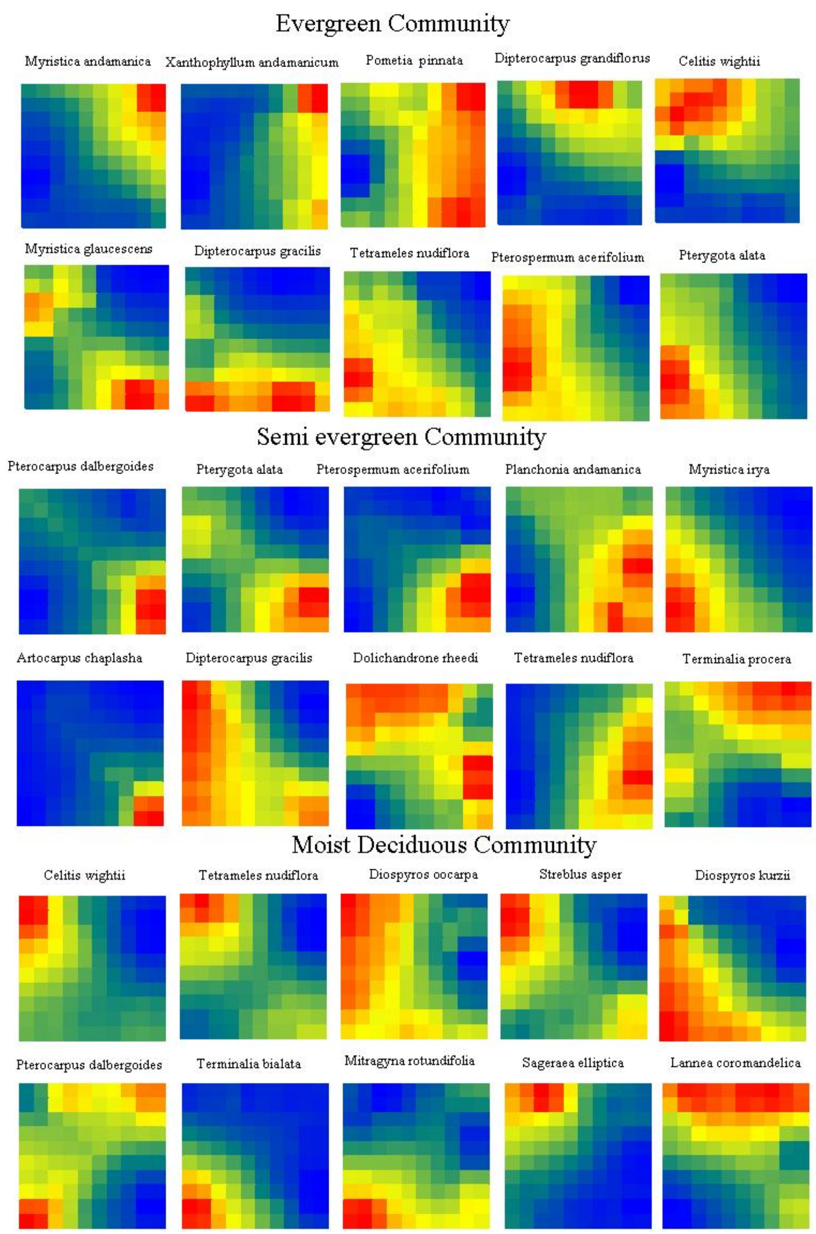

Fig. 2 Dominant species (IVI based) distribution and association in EG, SEG and MD forest communities.

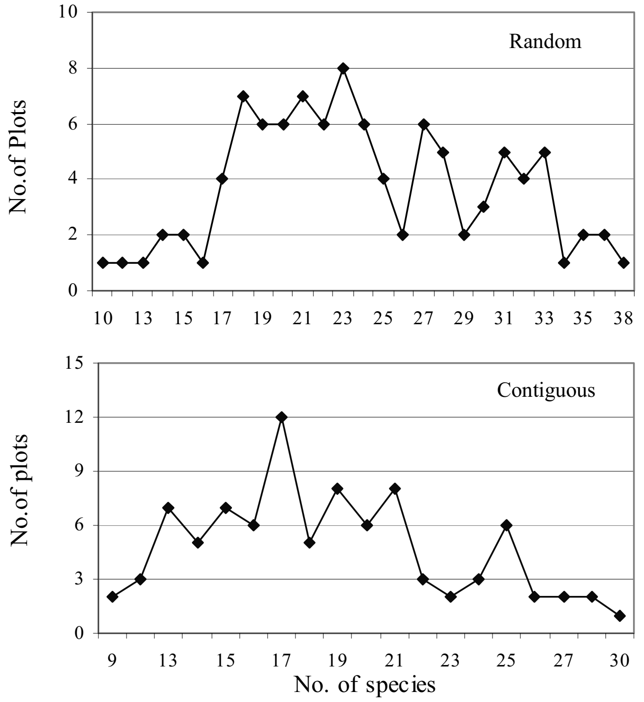

Fig. 3 Species and number of plots observed in different sampling types.

Resource optimality and species assemblage

The graph (**Fig. 3**), depicting the species and the number of plots in the random survey has distinctly showed that for the lower as well as higher number of species, the number of plots occurrence is limited to 2-4 plots only. The graph (**Fig. 3**) in the lower end showing 10-16 species and in the upper end 34-38 species is contrastingly represented in only 2-3 plots. In the present investigation, we conjecture that in the island vegetation of NAI there is specific organization of species distribution clearly indicating the ecological limit of species assemblage in a unit area. In the analysis it was observed that most of the plots showed 18-33 species as upper limit and beyond 34th species perhaps the ecosystem is competing for resources and attaining optimality. This is clearly observed in the graph where beyond 34th species, the plots are again restricted to lesser number.

We have also observed the general envelope over 18-33 species where both the tails of the plots represented less number of plots. This observation in NAI supports our contention, as there is "general limit of species assemblage" in the forest of NAI. However this observation is in respect to 100 random plots representing all the forest types. The 90 sub-plots species *versus* number of plots has also shown general behavior of less number of species having 9-12 and 26-30 species in the upper range, represented in only two plots each. Once again the "general limit of species assemblage" is also visible through analysis of large plot sampling which indicates the number of species having 14-25 occupied in maximum number of plots.

The present investigation substantially accounted the "general limit of species assemblage" through two different comprehensive phytosociological surveys represented by sufficiently large field sampling. Thus, the observations of these studies indicate maximum tree species packing of 14-25 in respect of large area field sampling and 18-33 in respect of stratified random plots. However, considering both the ranges, the study proposes the general possible optimal limit of tree diversity (> 30 cm gbh) packing may be between 14-33 species. This could be the "general limit of species assemblage" in the present state of NAI vegetation with respect to angiosperm tree diversity.

CONCLUSIONS

The variation in species richness and diversity is mainly attributed to climatic and edaphic factors in case of large contiguous heterogeneous landmasses. But in areas where homogenous conditions prevail, it is difficult to assign or identify the factors that enhance the floristic diversity, as is the case with NAI. The present analysis provides an evidence for future investigations to identify the plot characteristics that brings variation in species dominance, richness and diversity within a small unit area, which has made it possible to classify the 3 ha plot into four groups of site potentiality using SQI.

The presence of peculiar site-specific features within the subplot makes the species to exhibit extraordinary features when compared to their associated similar or dissimilar companion species. There exists a reciprocal relationship between the dynamic subplots and dominant species. The subplots were treated as dynamic because of the presence of dominant species and species are exhibiting dominating features based on the subplot characters. Analysis of results showed much of the area under good category in three forest communities and this indicates that the forests of NAI are potential sites of species richness and diversity.

The "general limit of species packing" in respect of higher angiosperm taxa in NAI has been observed based on two independent approaches of sampling stratified random plots and large area ecological plots. The investigation found the possible limit of 14 –33 species is the maximum presently the NAI vegetation is holding in respect of tree diversity. Any number on either side interestingly is observed to be having present in only limited number of plots.

ACKNOWLEDGEMENTS

The study was carried out as part of project - Biodiversity characterization at landscape level in Andaman and Nicobar Islands using remote sensing and GIS under Jai Vigyan Science and Technology Mission Project. Thanks are due to Dr. Sudhakar Reddy, Scientist, NRSC, Hyderabad, for his help during field visits.

REFERENCES

Ayyappaan N, Parthasarathy N (2001) Patterns of tree diversity within a large-scale permanent plot of tropical evergreen forest, Western Ghats, India. *Ecotropica* **7**, 61-76

Bettinger P, Boston K, Siry J, Grebner DL (2009) *Forest Management and Planning*, Academic Press, New York, 360 pp

Campbell DG, Daly DC, Prance GT, Maciel UN (1986) Quantitative ecological inventory of terra firme and varzea tropical forest on the Rio Xingu, Brazilian Amazon. *Brittonia* **38**, 369-393

Chai EOK, Lee HS, Yamakura T (1995) Preliminary results from the 52-hectare long term ecological research plot at the Lambir National Park, Sarawak, Malaysia. In: Lee HS, Ashton PS, Ogino K (Eds) *Long Term Ecological Research of Tropical Rain Forest in Sarawak*, Ehime University, Ehime, pp 42-60

Condit R (1995) Research in large, long-term tropical forest plots. *Trends in Ecology and Evolution* **10**, 18-22

Clark DB, Clark DA (2000) Landscape-scale variation in forest structure and biomass in a tropical rain forest. *Forest Ecology and Management* **137**, 185-198

Cottam G, Curtis JT (1956) The use of distance measurement in phytosociological sampling. *Ecology* **37**, 451-460

Devi LS, Yadava PS (2006) Floristic diversity assessment and vegetation analysis of tropical semi-evergreen forest of Manipur, north east India. *Tropical Ecology* **47**, 89-98

Faridah-Hanum I, Philip L, Awang Noor AG (2008) Sampling species diversity in a Malaysian rain forest: The case of a logged-over forest. *Pakistan Journal of Botany* **40 (4)**, 1729-1733

Grubb P (1977) The maintenance of species richness in plant communities: the importance of the regeneration niche. *Biological Reviews* **53**, 107-145

Gentry AH, Dodson C (1987) Contribution of non-trees to species richness of a tropical rain forest. *Biotropica* **19 (2)**, 149-156

Gunatilleke CVS, Gunatilleke IAUN, Ethugala AUK, Esufali S (2004) Ecology of Sinharaja rain forest and the forest dynamics plot in Sri Lanka's Natural World Heritage Site, WHT Publications, Colombo, 221 pp

Hardy OJ, Sonke B (2004) Spatial pattern analysis of tree species distribution in a tropical rain forest of Cameroon: Assessing the role of limited dispersal and niche differentiation. *Forest Ecology and Management* **197 (1-3)**, 191-202

Harms K, Condit R, Hubbell SP, Foster RB (2001) Habitat associations of trees and shrubs in a 50-ha neotropical forest plot. *Journal of Ecology* **89**, 947-959

Hill JL, Hill RA (2001) Why are tropical rain forests so species rich? Classifying, reviewing and evaluating theories. *Progress in Physical Geography* **25**, 326-354

Huang W, Pohjonen V, Johansson S, Nashanda M, Katigula MIL, Luukkanen O (2003) Species diversity, forest structure and species composition in Tanzanian tropical forests. *Forest Ecology and Management* **173**, 11-24

Hubbell SP, Foster RB, OBrien ST, Harms KE, Condit R, Wechsler B, Wright SJ, Loo de Lao S (1999) Light-gap disturbances, recruitment limitation and tree diversity in a neotrpical forest. *Science* **283**, 554-557

Hutchinson GE (1957) Concluding remarks. Cold Spring Harbor Symposium on Quantitative Biology **22**, 415-427

Jowett IG (2001) Modeling Patterns in Environmental Data "MOPED" 1.10 a software package

Jayakumar S, Ramachandran A, Heo J (2009) Comparison of floristic diversity of evergreen forest inferred from different sampling approaches in the Eastern Ghats of Tamil Nadu, India. *Current Science* **96 (4)**, 575-581

Kohyama T (1997) The role of architecture in enhancing plant species diversity. In: Abe T, Levin SA, Higashi M (Eds) *Biodiversity: An Ecological Perspective*, Springer, New York, pp 21-55

Levin SA, Grenfell BT, Hastings A, Perelson AS (1997) Mathematical and computational challenges in population biology and ecosystem science. *Science* **275**, 334-343

MacArthur RH, Levins R (1967) The limiting similarity, convergence and divergence of coexisting species. *American Naturalist* **101**, 377-385

Magurran AE (1988) *Ecological Diversity and its Measurement*, Princeton University Press, Princeton, NJ, 192 pp

Manokaran N, La Frankie Jr. JV, Kochummen KM, Quah ES, Klahn JE, Ashton PS, Hubbell SP (1990) *Methodology for the Fifty Hectare Research Plot at Pasoh Forest Reserve*, Forest Research Institute Malaysia, Research Pamphlet No. 104, pp 1-69

Nesheim I, Halvorsen R, Nordal I (2010) Plant composition in the Maya Biosphere Reserve: Natural and anthropogenic influences. *Plant Ecology* **208**, 93-122

Newberry DMcC, Campbell EJF, Proctor J, Still MJ (1996) Primary lowland forest at Danum valley, Sabah, Malaysia. Species composition and patterns in the under storey. *Vegetatio* **122**, 193-220

Odum EP (1959) *Fundamentals of Ecology* (2nd Edn), Saunders, Philadelphia, 546 pp

Paul Adam (1998) History and ecology of rainforest diversity. *Trends in Plant Science* **3 (8)**, 287-288

Phillips OL, Martinez RV, Vargas PN, Monteagudo AL, Zans MEC, Galiano WG, Yli-Halla M, Rose S (2003) Efficient plot-based floristic assessment of tropical forests. *Journal of Tropical Ecology* **19 (6)**, 629-645

Pontin AJ (1982) *Competition and Coexistence of Species*, Pitman, London, 102 pp

Potts MD, Ashton PS, Plotkin JB, Kaufman LS (2002) Habitat patterns in tropical rainforests: A comparison of 105 plots in Northwest Borneo. *Ecology* **83**, 2782-2797

Prasad RCP, Reddy CS, Dutt CBS (2007a) Phytodiversity assessment of tropical rainforest of North Andaman Islands, India. *Research Journal of Forestry* **1 (1)**, 27-39

Prasad RCP, Reddy CS, Rajasekhar G, Dutt CBS (2007b) Mapping and analyzing vegetation types of North Andaman Islands, India. *GIS Development* **3 (1)** Available from: http://www.geospatialworld.net

Prasad RCP, Reddy CS, Dutt CBS (2008) Phytodiversity zonation in North Andaman Islands, India using remote sensing, GIS and phytosociological data. *Research Journal of Environmental Sciences* **2 (1)**, 1-12

Prasad RCP, Sringeswara AN, Reddy CS, Vijayakumari P, Varalakshmi RK, Raza SH, Dutt CBS (2009a) Vegetation structure and ecological characteristics of North Andaman Forest, India. *Biological Letters* **46 (2)**, 105-121

Prasad RCP, Rajan KS, Dutt CBS, Roy PS (2010) A conceptual framework to analyse the land-use / land-cover changes and its impact on phytodiversity – A case study of North Andaman Islands, India. *Biodiversity and Conservation* **19 (11)**, 3073-3087

Purvis A, Hector A (2000) Getting the measure of biodiversity. *Nature* **405**, 212-219

Reddy CS, Prasad RCP, Murthy MSR, Dutt CBS (2004) Census of endemic flowering plants of Andaman and Nicobar Islands. *Journal of Economic and Taxonomical Botany* **28 (3)**, 712-728

Ricklefs RE (1977) Environmental heterogeneity and plant species diversity: A hypothesis. *American Naturalist* **111**, 376-381

Rohde K (1992) Latitudinal gradients in species diversity: The search for the primary cause. *Oikos* **65**, 514-527

Shannon CE, Weiner W (1963) *The Mathematical Theory of Communication*, University of Illinois Press, Urbana, USA, 117 pp

Sheil D (1996) Species richness, tropical forest dynamics and sampling: Questioning cause and effect. *Oikos* **76**, 587-590

Sigdel SR (2008) Altitudinally coordinated pattern of plant community structure in the Shivapuri National Park, Nepal. *Banko Janakari* **18 (1)**, 11-17

Silvertown JW, Lovett Doust J (1993) *Introduction to Plant Population Biology*. Blackwell Scientific, Oxford 210 pp

Spies TA, Turner MG (1999) Dynamics forest mosaics. In: Hunter Jr. ML (Ed) *Maintaining Biodiversity in Forest Ecosystems*, Cambridge University Press, Cambridge, pp 95-160

Stevens GC (1992) The elevation gradient in altitudinal range: an extension of Rapport'slatitudinal rule to altitude. *American Naturalist* **140**, 893-911

Tilman D, Pacala S (1993) The maintenance of species richness in plant communities. In: Ricklefs RE, Schluter D (Eds) *Species Diversity in Ecological Communities*, University of Chicago Press, Chicago, pp 13-25

Terborgh J (1985) The vertical component of plant species diversity in temperate and tropical forests. *American Naturalist* **126**, 760-776

Verma V (1981) *A Text Book of Plant Ecology*, Emkay Publications, New Delhi, India, 345 pp

Waite S (2000) *Statistical Ecology in Practice. A Guide to Analysing Environmental and Ecological Field Data*, Pearson Education, Prentice Hall, Harlow, 414 pp

Whittaker RH, Niering WA (1965) Vegetation of the Santa Catalina Mountains, Arizona: A gradient analysis of the south slope. *Ecology* **46**, 429-452

Wright SJ (2002) Plant diversity in tropical forests: A review of mechanisms of species coexistence. *Oecologia* **130**, 1-14