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Floristic inventory and diversity assessment - a critical review

S. Jayakumar[1], Seong Sam Kim[2], Joon Heo[2]

[1]Department of Ecology & Environmental Sciences, School of Life Sciences, Pondicherry University, Puducherry, India

[2]Geomatics and Remote Sensing (GRS) lab, School of Civil & Environmental Engineering College of Engineering, Yonsei University, Seoul, Korea

E-mail: jayakumar.eco@pondiuni.edu.in, s.jkumar1@gmail.com

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Abstract

Floristic inventory and diversity assessments are necessary to understand the present diversity status and conservation of forest biodiversity. Although, inventory and diversity studies are taken up at different levels all over the world by various research groups with available resources and to fill the gap in the biodiversity knowledge, there are variations in sampling methods/techniques, sample size, measurements taken in the field that hinder the compilation and comparison of results. This review discusses the problems and pitfalls in different sampling techniques, which are being followed in floristic inventory and diversity measurements.

Keywords floristic inventory; diversity measurement; forest biodiversity; sampling methods; measurement technique.

1 Introduction

Biodiversity is the totality of genes, species and ecosystem in a region. It is essential for human survival and economic well being and for the ecosystem function and stability (Singh, 2002). The total number of species available on the earth is not determined yet however, it is estimated that the total number of animal and plant species could be between 13 and 14 million (Heywood, 1995). Conservation biologists warn that 25 percent of all species could become extinct during the next twenty to thirty years (Khera et al., 2001). The cause for the loss of species is numerous but the most important is the loss and fragmentation of natural habitats. One of the foundations for conservation of biological diversity in forest landscapes is understanding and managing the disturbances regimes of a landscape (Spies and Turner, 1999).

Various programs namely, UNEP (United Nations Environmental Programme), IUBS (International Union of Biological Sciences, UNESCO (United Nations Educational Scientific and Cultural Organization), CITES (Convention on International Trade in Endangered Species) Global Biodiversity Strategy were set off for understanding and evaluating biodiversity. Global conservation of biodiversity will require efforts at multiple levels to be successful (Miller et al., 1999). More than 160 countries have ratified the Convention on Biological Diversity (CBD), and are expected to initiate inventory of various components of biodiversity and institute measures for *in situ* conservation and monitoring (Rawat, 2009). Forests are major stores of species, habitat, and genetic diversity (Noble and Dirzo, 1997) and activities on forest lands will have a significant impact on local, regional, and global diversity and the health and function of natural ecosystems (Kimmins, 1997). Many forests are under great anthropogenic pressure and require management intervention to maintain the overall biodiversity, productivity and sustainability (Kumar et al., 2002). Understanding species diversity and distribution patterns is important to evaluate the complexity and resources of these forests (Kumar et al., 2006). Floristic inventory is a necessary prerequisite for much fundamental research in tropical community ecology, such as modeling patterns of species diversity or understanding species distributions (Phillips et al., 2003). Many floristic diversity studies have been conducted in different parts of world. Majority of studies focus on inventory (Whittaker and Niering, 1965; Risser and Rice, 1971; Gentry, 1988; Linder et al., 1997; Chittibabu and Parthasarathy, 2000; Sagar et al., 2003; Padalia et al., 2004; Appolinario et al., 2005). Apart from inventory, disturbance intensity on regeneration, (Kennard et al., 2002; Denslow, 1995), phenological assessment (Frankie et al., 1974), comparison of tree species diversity (Pitman et al., 2002), monitoring (Sukumar et al., 1992), species area and species individual relationship (Condit et al., 1996) have also been studied through floristic analysis. Thus, it is clear that floristic studies are undertaken by many researchers worldwide in different levels following variety of sampling and measurement techniques based on their objectives. Comparable inventory dataset is required to locate areas for *in situ* conservation and to efficiently allocate available scarce resources. However, it is very difficult to use and to compare all the data that are available through inventory and diversity studies, because the sampling techniques, sample size and measurements taken in the fields vary considerably between studies. Therefore, this review discusses the issues in commonly followed floristic sampling methods and measurement techniques in floristic inventory and diversity studies. In this review, section 2 discusses the various sampling techniques, their advantages and pitfalls, section 3 discusses the issues related to field measurements, section 4 discusses the sample size in diversity measurements and section 5 discusses the applicability of remote sensing in floristic diversity measurements.

2 Sampling Techniques

Based on the literature survey, the sampling methods used for floristic diversity assessment could be broadly classified into 1) Plot sampling method, 2) Line transect method, 3) *k-tree* or fixed tree count sampling method and 4) *ad-hoc* method.

2.1 Plot sampling method

Majority of the inventory and floristic diversity studies have been done following plot sampling methods. However, from the literature review, the plot sampling could be divided into a) permanent plot technique, b) random plot technique and c) stratified random plot technique.

2.1.1 Permanent plot technique

Many studies (for e.g., Harms et al., 2001; Chittibabu and Parthasarathy, 2000; Phillips et al., 2003; Fashing et al., 2004; Proctor et al., 1983) have followed permanent plot sampling technique for floristic diversity analysis. However, the size of permanent plot varied from 1 ha to 50 ha (Table 1). The studies such as Proctor et al., (1983) in Gunung Mulu National Park, Sarawak, Parthasarathy and Karthikeyan (1997), Kadavul and Parthasarathy (1999) in Coromandal coast and Eastern Ghats respectively, Aldrich et al., (2002) in East central Indiana, Grau et al., (1997) in Tucuman, Argentina, Mani and Parthasarathy (2006) in Shevaroys, India, Bhat et al., (2000) in Uttara Kannada India have laid less than 10 ha plots to estimate the floristic diversity. Phillips et al., (2003) in Amazonian Peru, Pitman et al., (2002) in Ecuador and Peru have estimated with greater than 10 ha but less than 50 ha plots. Harms et al., (2001) in Barro Colorado, Panama Island, Nath et al. (2006) in Mudumalai Wildlife Sanctuary, India and He et al., (1996) in Negeri Sembilan, Malaysia have laid 50 ha plots in their studies. Though these studies have conducted big permanent plot estimation, for convenience the plots are divided into 10 x 10 m sub-plots (plots) (Chittibabu and Parthasarathy, 2000; Mani and Parthasarathy, 2005; Venkateshwaran and Parthasarathy, 2003), 20 x 20 m plots by Harms et al. (2001), He et al. (1996) and

Grau et al. (1997), 5 x 5 m plots by Franklin and Rey (2007), 2 x 50 m and 6 x 50 m by Gordon and Newton (2006a). Occasionally the plot dimension has also been changed to circular (20 m radius) in Linder et al., (1997) and rectangular (10 x 500 m) in Shankar (2001).

Table 1 Sampling technique, plot dimension, sample size and measurement taken in various inventory, diversity and disturbance floristic studies around the world. PP: Permanent plot, RP: Random plot, SRP: Stratified random plot, Ht.: Height, Dia.: Diameter

Sl. No.	Study area	Quadrat/Plot Sampling technique			Plot dimension	No. plots	Sample size (ha)	Threshold of stem size		Ht. at which Girth/ Dia. is measured (m)	References
		PP	RP	SRP				Girth in cm	Dia. in cm		
1.	Tropical semideciduous forest in South-eastern Brazil	✓	-	-	0.18 ha subdivided by eight 15x15m subplots	3	0.54	-	≥5	-	Appolinario et al., 2005
2.	Mexican tropical deciduous forest of Baja California Sur	-	✓	-	$1000m^2$ $1200m^2$	2 2	0.2 0.24	-	-	-	Arriaga and Leon, 1989
3.	Tropical evergreen forest of Western Ghats, India	✓	-	-	600x500	1	30	≥30	-	-	Ayyappan and Parthasarathy, 2004
4.	Successional deciduous forest in Southern Illinois	-	✓	-	10x10	25	0.25	-	-	-	Bazzaz, 1975
5.	Eastern Himalayas, India	-	✓	-	20x20	88	3.52	≥15	-	-	Behera and Kushwaha, 2007
6.	Recovering forest stand, Eastern Ghats of India	-	✓	-	1x1	60	0.006	-	-	-	Behera and Misra, 2006
7.	Eastern Himalayas, India	-	-	✓	20x20	122	4.88	≥15	-	-	Behera et al., 2002
8.	Eastern Himalayas, India	-	-	✓	20x20	121	4.84	≥15	-	-	Behera et al., 2005
9.	Uttara Kannada of Western Ghats, India	✓	-	-	100x100	8	8	≥10	-	1.32	Bhat et al., 2000
10.	Arunachal Pradesh, India	-	✓	-	30x30 trees 10x10 seedlings	10	0.3	-	≥20	1.37	Bhuyan et al., 2003
11.	Fragmented littoral forest of southeastern Madagascar	-	✓	-	50x50	20	5	-	≥10	1	Cadotte et al., 2002
12.	West Kalimantan, Indonesia	-	✓	-	0.1ha plot	100	10	≥20	-	-	Cannon, 1998
13.	Tropical forest in Xishuangbanna, Southwest	-	-	-	-	17	-	-	≥5	-	Cao and Zhang, 1997

	China										
14.	Tropical deciduous forest of central Veracruz, Mexico	-	✓	-	10x10	60	0.6	-	-	-	Castillo-Campos et al., 2008
15.	Iringole Kave, S.N. Puram Kavu and Ollur Kavu in Kerala, India	-	✓	-	10x10 (Trees) 10x10 (Saplings) 1x1 (Seedlings)	300 75 60	3.81	≥30 10.1-30 ≤10	-	1.37	Chandrashekara and Sankar, 1998
16.	Tuscany, Italy	✓	-	-	50x50	1	0.25	-	-	-	Chiarucci et al., 2001
17.	Kolli hill, India	✓	-	-	100x200	4	8	≥30	-	1.3	Chittibabu and Parthasarathy, 2000
18.	Tropical semi-evergreen forest in Manipur, India	-	✓	-	10x10	20	0.2	≥30	-	1.37	Devi and Yadava, 2006
19.	Tropical semideciduous forest, Brazil	✓	-	-	280x320	1	8.96	-	-	-	Lima et al., 2008
20.	Northern Borneo, Indonesia	-	✓	-	Radius=2, 0.001ha Radius=5.64, 0.01 ha Radius=12.62, 0.05 ha	52	-	-	≥2	-	Foody and Cutler,2003
21.	Caribbean Semievergreen forest, St. John, United States Virgin Islands	✓	-	-	4 ha plot	1	4	-	>10	-	Forman and Hahn, 1980
22.	Tropical forest in Western Polynesia, Kingdom of Tonga	✓	-	-	0.45 ha plot	3	1.35	-	≥10	-	Franklin and Rey, 2007
23.	Upper Amazonian, Brazil-Venezuela border	✓	-	-	1ha plot	7	7	-	≥10	-	Gentry, 1988
24.	(1) Santa Rosa National Park, Costa Rica, (2)Palo Verde National Park, Costa Rica (3) La Flor Nature Reserve, Nicaragua (4) Chacocente Wildlife Refuge, Nicaragua (5) Reserve on the island of Ometepe, Nicaragua (6)	-	✓	-	2x50	80	8	-	≥2.5	-	Gillespie et al., 2000

	Masaya National Park, Nicaragua (7) Cosiguina Nature Reserve, Nicaragua										
25.	Tropical dry deciduous and gallery forests in Nicaragua	✓	-	-	1ha plot	1	1	-	≥10	-	Gonzalez-Rivas et al., 2006
26.	Coastal lowlands of Oaxaca, Mexico	-	✓	-	2x50 in 8 sites 10 plots in each site 6x50 in 8 sites 15 plots in each site	80 120	0.8 3.6	-	≥5	-	Gordon and Newton, 2006a
27.	Southern Mexico	-	✓	-	2x50 in 8 sites 15 plots in each site 6x50 in 8 sites 15 plots in each site	120 120	1.2 3.6	-	≥5	-	Gordon and Newton, 2006b
28.	Subtropical montane forest, Argentina	✓	-	-	1 ha plot	6	6	-	>10	-	Grau et al., 1997
29.	Tropical rain forest of Malaysia	-	-	-	20x20	1250	50	-	≥1	-	He et al., 1996
30.	Pasho, Malaysia	-	✓	-	20x20	1250	50		>1	-	Poore, 1968
31.	Tropical forest, Tanzanian	-	-	-	50x20 systematic plot	279	27.9	-	>10	1.3	Huang et al., 2003
32.	Sanyasimalai reserve forest of Shervaroys, Eastern Ghats, India	✓	-	-	100x100	4	4	≥30	-	1.3	Kadavul and Parthasarathy, 1999a
33.	Kalrayan Hill, Eastern Ghats, India	✓	-	-	100x100	4	4	≥30	-	1.3	Kadavul and Parthasarathy, 1999b
34.	Sacred groves of Manipur, northeast India	-	✓	-	10x10 trees 5x5 shrubs 1x1 herbs	160 80 80	1.6 0.2 0.008	-	-	-	Khumbongmayum et al., 2005
35.	Tropical semideciduous forest in the Chiquitania region of Santa Cruz, Bolivia	-	-	✓	50x20	100	10	-	-	1.3	Killeen et al., 1998
36.	Barro Colorado Island, Panama	-	✓	-	10x20	13	0.26	-	≥2.5	-	Knight, 1975
37.	Tropical forest, Costa Rica	✓	-	-	1 ha plot	11	11	-	≥10	-	Lieberman et al., 1996
38.	Virgin Boreal forest, Sweden	-	✓	-	Circular plot of 20m radius (0.1257 ha)	12	1.51	-	≥10	1.3	Linder et al., 1997

39.	Pudukkotai, India	✓	-	-	100x100	5	5	≥10	-	1.3	Mani and Parthasarathy, 2005
40.	Caetetus E.S., Brazil	✓	-	-	320x320	1	10.24		>20	-	Martini et al., 2008
41.	Meghalaya, Northeast India	-	✓	-	10x10 trees 5x5 shrubs 1x1 seedlings	-	0.25	≥15	-	-	Mishra et al., 2004
42.	Western Ghats, India	-	✓	-	20x20	20	0.8	>30	-	1.3	Muthuramkumar et al., 2006
43.	Neotropical cloud forest, Monteverde, Costa Rica	✓	-	-	200x200	1	4	-	≥1	-	Nadkarni et al., 1995
44.	Namdapha National Park, India	-	✓	-	25x25 trees 15x15 trees 10x10 trees 10x10 saplings 5x5 seedlings 1x1 herbs	40 20 20 20 20 20	2.5 0.45 0.2 0.2 0.05 0.002	>30	-	1.37	Nath et al., 2005
45.	Andaman, India	-	-	✓	-	462	12.52	≥17	-	-	Padalia et al., 2004
46.	Tropical rain forest in New Guinea	-	-	✓	80x100 and 40x200	4	3.2	≥30	-	-	Paijmans, 1970
47.	Managed sal forests of Gorakhpur, India	✓	-	-	100x100	24	24	≥30	-	-	Pandey and Shukla, 2003
48.	Kalakad National Park South Western Ghats, India	✓	-	-	100x100	3	3	≥30	-	1.3	Parthasarathy, 1999
49.	Coromandel coast of Tamil Nadu, India	✓	-	-	100x100	2	2	≥30	-	1.3	Parthasarathy and Karthikeyan, 1997
50.	Colorado Frant range	-	✓	-	50x20	305	30.5	-	-	-	Peet, 1978
51.	Amazonian Peru	-	✓	-	1ha 0.1 ha	16 128	16 12.8	-	≥10	1.3	Phillips et al., 2003
52.	Tripical riparian forest in Belize, Central America	-	✓	-	500x10	11	11	-	≥5	-	Pither and Kellman, 2002
53.	Yasuni National park, Ecuador and Manu National Park, Peru	-	✓	-	0.875 to 2 ha = in Manu, 1 ha plot in Yasuni,	9 15	13.875 15	-	≥10	-	Pitman et al., 2002
54.	Lowland Amazonian forest of Andean foothill to Brazil	✓	-	-	100x100 10x1000	54	54	-	≥10	-	Pitman et al., 2008
55.	Lowalnd Rain forest of	✓	-	-	100x100	4	4	-	>10	-	Proctor et al., 1983

	Gunung Mulu National Park, Sarawak										
56.	In two sites of South-eastern coastal of India	-	✓	-	20x20	50	2	≥20	-	-	Ramanujam and Kadamban, 2001
57.	Upland forest of Oklahoma	-	✓	-	0.01 acre rectangular plot	61	0.243	-	-	-	Risser and Rice, 1971
58.	Riparian forest of lower Caura River, Venezuela	-	✓	-	20x50	54	5.4	-	≥10	-	Rosales et al., 2001
59.	Tropical dry deciduous forest, Northern India	✓	-	-	100x100 trees 2x2 saplings & seedlings	3	3	-	≥9.6	1.37	Sagar and Singh, 2005
60.	Vindhyan dry tropical forest of India	✓	-	-	100x100	15	15	-	>9.6	1.37	Sagar and Singh, 2006
61.	Vindhyan Hill ranges, India	✓	-	-	100x100	3	3	≥30	-	-	Sagar et al 2003
62.	Gola River, Kumaun Himalaya	-	✓	-	10x10 trees 5x5 for saplings	-	1.68	-	≥31.5	1.37	Saxena and Singh, 1982
63.	Mahananda Wildlife Sanctuary in Darjeeling, Eastern Himalaya, India	-	-	-	4 Belt transects of 10x500	4	2	≥30 ≥10 <10	-	1.3	Shankar, 2001
64.	Veerapuli and Kalamalai forest reserve, of Agasthyamalai hills, South India	-	-	-	9 Line transects of 1km distance, 10x10m plot at 100m interval	90	0.9	-	>10	-	Swamy et al., 2000
65.	Oregon, USA	-	✓	-	circular 0.1 ha circular 0.025ha	4-6 3 or 4	-	-	≥10	≥50 ≥75	Tappeiner et al, 1997
66.	Naintia hills in Meghalaya, India	-	✓	-	100 m^2 plot	100	1	-	≥5	-	Upadhaya et al., 2003
67.	Amazon, eastern Ecuador	✓	-	-	100x100	1	1	-	≥5	-	Valencia et al., 1994
68.	Tropical dry evergreen forest, Coromandel coast India	✓	-	-	100x100 200x25	2	2	≥10	-	1.3	Venkateswaran and Parthasarathy, 2003
69.	Tropical evergreen forest at Puthupet in Pondicherry, India	✓	-	-	100x100	2	2	≥10	-	1.3	Venkateswaran and Parthasarathy, 2005
70.	Santa Catalina Mountatin, Arizona	-	✓	-	10x50	350	17.5	-	>1	-	Whittaker and Niering, 1965

Floristic diversity analysis of ≥ 1 ha plot is very popular because it is widely being used in many studies and it is suited to a variety of additional purposes such as monitoring forest dynamics as well as phenological and ethnobotanical research (Condit et al., 1996). Phillips et al. (2003) have compared the suitability of 0.1 ha and 1 ha plots for floristic studies. They have concluded that the 0.1 ha inventory method achieves a greater gain in floristic knowledge and understanding and in detecting significant habitat–species associations than the 1 ha inventory method. Moreover, the 1 ha method also demands more man power and time than 0.1 ha plot. The permanent plots require regular monitoring and assessment. However, in many studies the plots are abandoned after yielding the inventory data. For e.g., in western Amazonia the failure rate is estimated as > 50% (Phillips et al., 2003). The reasons could be inadequate funds to re-census, impossibility of relocating the plot's position, disturbance from the local residents in terms of commercial logging and removal of tags, natural disturbances such as rapid radial tree growth 'swallowing' tags, inaccessibility due to over growth of liana and moreover, conversion to permanent plot status is expensive, time-consuming and uncertain. Temporary and inadequate funding is the main reason that most 1 ha plots remain simply temporary floristic samples. Therefore Phillips et al., (2003) suggest that it is advisable to install 1 ha plots only with long term funding programmes. Condit et al., (1996) verified that the plots of small area tended to have fewer species than plots of a larger area with the same number of individuals, but the differences were slight and sometimes nonexistent. In many cases plots of larger size did not have more species. They also suggested that rectangular plots recorded 10% more species than square plots.

2.1.2 Random plot technique

According to random sample technique, plots are laid in the field randomly to represent the entire floristic region in order to avoid bias sampling (Magurran, 1988; Zhang and Wei, 2009; Zhang, 2010, 2011). When compared to big permanent plot studies, the random plot studies are very limited in the literature (Table 1). The size of the plot/quadrat varies from 1 x 1 m to 20 x 50 m (Zhang and Barrion, 2006; Zhang et al., 2008). Gordon and Newton (2006b) have conducted random plot analysis in Huatulco, Mexico with 2 x 50 and 6 x 50 m size. Knight (1975) has investigated the floristic diversity in Barro Colorado Island, Panama with 10 x 20 m plots. In Santa Catalina Mountain, Arisona, Wittakar and Niering (1965), Swamy et al. (2000) in Agasthyamalai hills of South India, Sagar and Singh (2006) in Vindhyan dry tropical forest of India have estimated the diversity of forest using 10 x 10 m plots. Ramanujam and Kadamban (2001) in South eastern coastal of India have used 25 plots of 20 x 20 m. Huang et al. (2003) in the East Usambara Mountains of Eastern Arc Africa and Kalacska et al. (2004) in Parque National Santa Rosa in the Province of Guanacaste have conducted floristic studies with 20 x 50 m random plots. Bazzaz (1975) in Southern Illinois have used 40 plots of 2 x 1 m size and 25 plots of 4 x 4 m size in his diversity studies. Rarely the dimension of plot is circular (Linder et al., 1997) with 20 m radius. However, they have not mentioned the reason for the circular plot and its significance. Gordon and Newton (2006b) have recommended that randomized selection of site for sampling would ideally assess the diversity in any locality. As far as shape of plot is concerned, Condit et al., (1996) confirmed that very narrow rectangular plots, 1000 m x 1m, were more diverse (18% to 27%) than square plots.

2.1.3 Stratified random plot technique

Stratified random sample is a technique by which the floristic area is first divided into homogenous vegetation group based on type or density (Forest cover / type classification) using satellite data and then samples are distributed to each vegetation group proportionately based on their aerial extent (NRSA, 1998). In the early 70s, Paijmans (1970) has estimated the floristic diversity of tropical rain forest in New Guinea following SRP technique, where he used aerial photos to classify the forests. In India, Behera et al., (2002, 2005) in the eastern Himalayas, Balaguru et al. (2006) in the Eastern Ghats have estimated the floristic diversity by SRP method using 20x20m plots. Padalia et al., (2004) have conducted floristic study in Andaman Islands of India adopting SRP technique with 462 samples of various plot size covering 12.52 ha totally. In Bolivia, Killeen et al. (1998) assessed the tropical semideciduous forest in the Chiquitania region of Santa Cruz following SRP method. However, this method is also limited in the literature.

2.2 Line transect method

In this method, a line transect is formed in the field to a specific distance and then those species, which are touching the line will be measured. This method, for floristic inventory, is not popular among ecologist (Zhang and Wei, 2009). Frankie et al. (1974) have adopted this technique in Lowlands of Costa Rica. They made seventeen line transects of 200 m each through aerosol paint. But the main objective of their study was phenological variation between wet and dry forest. This method is popular in animal diversity studies. For example, Shahabuddin and Kumar (2006) have studied the bird communities in tropical dry forest of Sarika Tiger Reserve in Rajasthan, India in connection with vegetation structure and anthropogenic disturbance using five hundred meter line transect. In Tanzania, Rovero and Marshall (2005) have studied the forest antelopes using two line transects of about 3100 m long. Although line transect is easy to follow, the inability of the resulting datasets to estimate various diversity indices based on area made it unpopular.

2.3 *k-tree* sample/fixed tree count

k-tree or fixed tree count plot is synonymous with point samples or variable area plot, required no plot demarcation but only a fixed number of trees will be measured per point sample (Gordon and Newton, 2006a; Sheil et al., 2003). The advantage of *k*-tree sampling method is that it is plot less (Engeman et al., 1994) and same number of trees is measured in all sampling. In Miombo woodlands of Northern Zambia, Kleinn and Vilcko (2006) have conducted floristic diversity studies with *k-tree* sampling method. Gordon and Newton (2006a) in Southern Mexico have also conducted *k-tree* sampling at 8 sites. Hall (1991) has attempted to effectively survey montane forest in Africa adopting fixed tree counts, but provided no direct comparison of its efficiency with other methods. Condit et al. (1996) have supported fixed tree count methods on statistical grounds. They have argued that by comparing equal number of stems, the resulting diversity indices would be unbiased. As the number of studies following this method is very limited, comparison of results with other studies is also very limited.

2.4 a*d-hoc* method

This method is deliberately informal, the sampling is started from the perimeter and circling inwards until the team decides, subjectively, that no more new species are like to be found. Gordon and Newton (2006a) have adopted this method in their study and concluded that the *ad- hoc* protocol is the most efficient protocol in accumulating new species during sampling. They have also recommended that this method is highly efficient and simple, where the resources are limited and statistical analysis is not considered. However, Nelson et al. (1990) argued that this method is of limited value to ecologists as it is subjective to various forms of sampling bias.

In conclusion, careful matching of inventory purpose to method has always been important for ecologists, and is especially so now in the tropical context of rapid environmental change. The need for efficient sampling is a dominant factor determining methodological decisions, but comparative analysis of efficiency has been lacking in the tropical eco-floristic literature.

3 Field Measurements

In all sampling techniques, the important measurement made in the field with reference to trees and lianas is the girth at breast height (GBH) (Chittibabu and Parthasarathy, 2000; Shankar, 2001; Kumar et al., 2006). In some studies the diameter at breast height (DBH) (Pitman et al., 2002; Knight, 1975; Gillespie et al., 2000) or circumference at breast height (CBH) (Padalia et al., 2004) or diameter at base trunk (DBT) (Appolinario et al., 2005) are also considered (Table 1). CBH and GBH represent same meaning whereas the DBH is different. Variations are noted in many studies in measurements irrespective of GBH, CBH, DBH and DBT. From the literature survey, the GBH measurement is taken at 10 and 30 cm, the CBH is measured at 10, 17 and 30 cm, DBH is measured from 1 to 10.2 cm and DBT is measured at 5 cm. Because tree stems taper, 'breast height' (BH), the height above ground where diameter is measured, should influence DBH recorded (Brokaw and Thomson, 2000). Using a BH of 130 cm was customary in continental Europe (Robbie, 1955), whereas the seemingly odd value of 137 cm (4.5 feet) the usual BH where English units were employed (Grubb et al., 1963). The present literature review and the study made by Brokaw and Thomson (2000) reveal two important information, a) More than 50% of the studies did not mention the height at which the measurement was taken in units, i.e., breast height and b) Of those that did report BH used, ranged from 120 cm to 160 cm.

It is very important to note that the basal area, biomass and growth of standing trees in many studies (Pitman et al., 2002; Parthasarathy, 1999; Linder et al., 1997; Kalacska et al., 2004) and sometime lianas in few studies (Reddy and Parthasarathy, 2003, Parthasarathy and Sethy, 1997) are represented per hectare and it has also been compared to other studies. As basal area and biomass are exponential functions of diameter, consistency should be maintained when measuring DBH, because, using different values of BH may lead to erroneous comparisons of diameter-class distributions, growth, basal area, or biomass (Brokaw and Thomson, 2000).

Another important issue with reference to the girth measurement is that it is also responsible for including and excluding the tree species while taking measurements. For example in a study, if the girth threshold for tree is fixed as ≥ 30 cm, then the girth of tree stems equal and above the threshold will be considered as the trees. In such cases, the girth of tree stems lesser than this threshold will not be considered as trees. Then automatically, those species which failed to reach 30 cm girth will be omitted from the sampling resulting in poor species richness and stand density. We argue that this will affect the total number of species, stand density and basal area of the study. For e.g., the inventory study by Shankar (2001) in the Eastern Himalaya, apart from adult trees (≥ 30 cm girth), the saplings and seedlings (<30 cm girth) were also enumerated. As a result, the number of species, stand density and basal area increased considerably. As evidenced from literature, there is no strict rule or threshold value for the girth of tree stems. The girth threshold varies considerably from ≥1cm - 30cm. The girth threshold set in each study is based on the author's discretion not based on any rationality. Especially in the inventory studies, all the species inside the plot should be considered such as (Guariguata et al., 1997) where, they enumerated all the species inside the study plot. For better understanding they classified the stems into (1) trees (stems ≥10 cm DBH), (2) treelets (stems ≥ 5 cm DBH and < 10 cm DBH), (3) saplings (stems ≥ 1 m tall and < 5 cm DBH: stem diameter at 1.3 m), and (4) seedlings (stems ≥ 0.2 m tall and < 1 m tall). According to this grouping all the stems will be enumerated. Although Ferreira and Prance (1998) suggested that minimum recommended DBH for tree is 10 cm, as it is becoming standard for quantitative inventories for many ecologists, but again, if resources permit a smaller minimum DBH should be included for a subsample in any floristic inventory (Cambell, 1990, cited in Ferreira and Prance, 1998).

4 Sample Size

Sample size plays a major role in determining the total diversity of a region. However, the sample size varies among studies considerably. For example in PP, RP and SRP the minimum and maximum sample size based on the literature survey are 0.54-54 ha, 0.2-50 ha and 3.2-12.52 ha respectively (Table 1). These variations prove the assumption that the sample size is determined mainly based on time, money and man power availabilities (Phillips et al., 2003). These drawbacks hinder the biodiversity studies proportionately. All the diversity studies aim to bring out the species diversity of any region, but it is doubtful that whether the studies estimate full diversity or not, because, the sample size may be insufficient in many studies to derive the floristic pattern of a region. For example the study at Jau National park of Central Amazonia with 4 ha of sample size (Ferreira and Prance, 1998) concluded that it is difficult to elucidate major floristic patterns at regional and local scales with this sample size. They also suggested that the sampled area should be of at least one hectare or more and the sampling should be from independent replicated samples. Diversity studies may underestimate the species richness in tropical forests when the stem counts are < 1000 (Condit et al., 1996).

However, it is important for a study, to make ample biodiversity measurement, to determine the sample size based on species area curve/asymptotic curve. These methods are widely accepted among biodiversity measurements, but are available in few studies to check whether the samples size of respective studies sufficient enough to represent the true biodiversity profile of the region or not. Therefore, every biodiversity study should give more importance to the sample size before concluding the study. Otherwise the results and conclusions made in a study may not be a true representative and moreover may give a false impression on the biodiversity status of the respective regions.

5 Remote Sensing and Floristic Diversity Assessment

Application of remote sensing in biodiversity assessment and characterization is limited in the literature. Remote sensing technique has been used to demarcate the biotype of a region so far. The dream of species characterization in biodiversity assessment using remote sensing is yet to be achieved (Turner et al., 2003). Though Van-Aardt and Wynne (2001) have demonstrated the discrimination of tree species through remote sensing in temperate forest, it is still at developmental stage (Foody and Cutler, 2003) because, it will be very difficult in the tropics where occur heterogeneous forest covers with variety of species (Boyd and Danson, 2005). Debinski and Humphrey (1997) suggested that if the relationship between species distribution pattern and remote sensing data is known then it is possible to predict single or group of species. Tropical evergreen forest along with other phonological types and major disturbed habitats (grassland, orchards, mangroves, Myristica swamps and Ochlandra) were mapped using various remote sensing data (Murthy et al., 2003). Datasets from IRS 1C/1D LISS III have been used effectively in mapping the pure, plant colonies of *Hippophae rhamnoides* in the Spiti region of India with prior knowledge of their occurrence and vegetation types of the area by using remote sensing (Roy et al., 2001). IRS 1C/1D LISS-III FCC has been used for stratification of *Ephedra gerardiana* in complex terrain conditions of Lahul and Spiti district (Porwal et al., 2003). However, they have just demarcated the species occurrence not the biodiversity value of that species. The other study in genus level mapping of *Pinus* and *Abies* by White et al. (1995), has achieved only 63% accuracy. Hence, the details such as the species composition and stand density of forests could be obtained only through field floristic sampling studies.

As far as field biodiversity measurement is concerned, the remote sensing technique has much been used to carry out the stratified random sampling, in which the vegetation is grouped into various categories according to the vegetation types and densities. This demarcation of vegetation types helps in two important ways: a) Helping to get clear picture of the total vegetation area in a study and b) Distributing the samples efficiently and proportionately to each vegetation group, which helps to cover all vegetation types. Few studies (Padalia et al., 2004; Jayakuamr et al., 2000; Balaguru et al., 2006; Nagendra and Gadgil, 1999) have followed stratified random sampling technique incorporating remote sensing data as a source of information for vegetation characterization before conducting the study. However, the efficiency of using remote sensing technique over other biodiversity measurement technique is not available in the literature. The major problem with the use of remote sensing in biodiversity characterization is the identification species, as we could see only the crown in the air borne/space borne data. The crown pattern varies species to species and it is impossible to predict the crown pattern in the tropics as many number of tree species show enormous variations in phenology under various edapho-climatic conditions. Although with the high resolution Quickbird satellite data, very few species could be identified, it is impossible to count the stems and diameter measurement, which are very important to calculate the biodiversity indices. Even satellite data with 0.5 m pixel resolution are not able to identify individual species (Biging et al., 1995). In the natural landscape with several species, the chance of application of remote sensing to identify individual species correctly is rare (Nagendra, 2001). Thus remote sensing of biodiversity assessment and characterization are still a long way to go.

6 Conclusion

Florist diversity assessment is tried at local and regional levels to understand the present status and to make effective management strategies for conservation. In this regard, various sampling techniques and measurements methods are followed based on objectives of the studies and in majority of the studies, the availability of time, money and manpower is the major constrain. Several issues discussed in this review in relation to sampling techniques, measurements, sample size and possibility of incorporating other techniques in floristic diversity studies such as remote sensing. To summarize, the sampling methods should satisfy the objective of the study and also to bring out the inherent diversity status of a region of investigation. The measurement of stem size in the field is the major issue in diversity studies where, unanimous decision should be achieved among the studies in relation to the threshold of girth of stem considered to be a tree and the height at which it is to be taken from the ground. Sample size in floristic diversity study is an important issue, which determines the success and failure of a diversity study to bring out the true diversity status. Much attention should be paid in this issue in determination of the sample size, and distribution of the samples. Although remote sensing is a handy tool to study the vegetation at community level, applicability of the same at species level is impractical at the present context with available advancements. Much advancements and researches should be made in this line to apply this technology at species level characterization.

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References

Aldrich PR, Parker GR, Ward JS, et al. 2002. Spatial dispersion of trees in an old-growth temperate hardwood forest over 60 years of succession. Forest Ecology and Management, 180: 475-491

Appolinario V, Filho ATO, Guilherme FAG. 2005. Tree population and community dynamics in a Brazilian tropical semideciduous forest. Revista Brasil, 28: 347-360

Arriaga L, León JL. 1989. The Mexican tropical deciduous forest of Baja California Sur: a floristic and structural approach. Plant Ecology, 84: 45-52

Ayyappan N, Parthasarathy N. 2004. Short-term changes in tree populations in a tropical evergreen forest at Varagalaiar, Western Ghats, India. Biodiversity and Conservation, 13: 1843-1851

Balaguru B, Britto, SJ, Nagamurugan N, et al. 2006. Identifying conservation priority zones for effective management of tropical forests in Eastern ghats of India. Biodiversity and Conservation, 15: 1529-1543

Bazzaz FA. 1975. Plant species diversity in old-field successional ecosystems in southern Illinois. Ecology, 56: 485-488

Behera MD, Kushwaha SPS. 2007. An analysis of altitudinal behavior of tree species in Subansiri district, Eastern Himalaya. Biodiversity and Conservation, 16: 1851-1865

Behera MD, Kushwaha SPS, Roy PS. 2002. High plant endemism in an Indian hotspot – eastern Himalaya. Biodiversity and Conservation, 11: 669-682

Behera MD, Kushwaha SPS, Roy PS. 2005. Rapid assessment of biological richness in a part of Eastern Himalaya: an integrated three-tier approach. Forest Ecology and Management, 207: 363-384

Behera SK, Misra MK. 2006. Floristic and Structure of the Herbaceous Vegetation of Four Recovering Forest Stands in the Eastern Ghats of India. Biodiversity and Conservation, 15: 2263-2285

Bhat DM, Naik MB, Patagar SG, et al. 2000. Forest dynamics in tropical rain forests of Uttara Kannada district in Western Ghats, India. Current Science, 79: 975-985

Bhuyan P, Khan ML, Tripathi RS. 2003. Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. Biodiversity and Conservation, 12: 1753-1773

Biging GS, Dobbertin M, Murphy EC. 1995. A test of airborne multispectral videography for assessing the accuracy of wildlife habitat maps. Canadian Journal of Remote Sensing, 21: 357–366

Boyd DS, Danson FM. 2005. Satellite remote sensing of forest resources: three decades of research development. Progress in Physical Geography, 29: 1-26

Brokaw N, Thompson J. 2000. The H for DBH. Forest Ecology and Management, 129: 89-91

Cadotte MW, Franck R, Reza L, et al. 2002. Tree and shrub diversity and abundance in fragmented littoral forest of southeastern Madagascar. Biodiversity and Conservation, 11: 1417-1436

Cao M, Zhang J. 1997. Tree species diversity of tropical forest vegetation in Xishuangbanna, SW China. Biodiversity and Conservation, 6: 995-1006

Castillo-Campos G, Halffter G, Moreno CE. 2008. Primary and secondary vegetation patches as contributors to floristic diversity in a tropical deciduous forest landscape. Biodiversity and Conservation, 17: 1701-1714

Chandrashekara UM, Sankar S. 1998. Ecology and management of sacred groves in Kerala, India. Forest Ecology and Management, 112: 165-177

Chiarucci A, Dominicis VD, Wilson JB. 2001. Structure and floristic diversity in permanent monitoring plots in forest ecosystems of Tuscany. Forest Ecology and Management, 141: 201-210

Chittibabu CV, Parthasarathy N. 2000. Attenuated tree species diversity in human-impacted tropical evergreen forest sites at Kolli hills, Eastern Ghats, India. Biodiversity and Conservation, 9: 1493-1519

Condit R, Hubbell SP, Lafrankie JV, et al. 1996. Species-area and species-individual relationship for tropical trees: A comparison of three 50-ha plots. Ecology, 84: 549-562

Debinski DM, Humphrey PS. 1997. An integrated approach to biological diversityassessment. Natural Areas Journal, 17(4): 355-365

Devi LS, Yadava PS, 2006. Floristic diversity assessment and vegetation analysis of tropical semievergreen forest of Manipur, northeast India. Tropical Ecology, 47: 89-98

Denslow JS. 1995. Disturbance and diversity in tropical rain forests: The density effect. Ecological Applications, 5: 962-968

Engeman RM, Sugihara RT, Pank LF, et al. 1994. A comparison of plotless density estimators using Monte Carlo simulation. Ecology, 75: 1769–1779

Fashing JP, Forrestel A, Scully C, et al. 2004. Long-term tree population dynamics and their implications for the conservation of the Kakamega Forest, Kenya. Biodiversity and Conservation, 13: 753-771

Ferreira LV, Prance GT. 1998. Species richness and floristic composition in four hectares in the Jau National Park in upland forests in central Amazonia. Biodiversity and Conservation, 7: 1349–1364

Foody GM, Cutler MEJ. 2003. Tree biodiversity in protected and logged Bornean tropical rain forests and its measurement by satellite remote sensing. Journal of Biogeography, 30: 1053-1066

Forman RTT, Hahn DC. 1980. Spatial patterns of trees in a Caribbean semievergreen forest. Ecology, 61: 1267-1274

Frankie GW, Baker HG, Opler PA. 1974. Comparative phenological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. The Journal of Ecology, 62: 881-919

Franklin J, Rey SJ. 2007. Spatial patterns of tropical forest trees in Western Polynesia suggest recruitment limitations during secondary succession. Journal of Tropical Ecology, 23: 1-12

Gentry AH. 1988. Tree species richness of upper Amazonian forests. Proceedings of the National Academy of Science of U.S.A., 85: 156– 159

Gillespie TW, Grijalva A, Farris CN. 2000. Diversity, composition, and structure of tropical dry forests in Central America. Plant Ecology, 147: 37-47

González-Rivas B, Tigabu M, Gerhardt K, et al. 2006. Species composition, diversity and local uses of tropical dry deciduous and gallery Forests in Nicaragua. Biodiversity and Conservation, 15: 1509-1527

Gordon JE, Newton AC. 2006a. Efficient floristic inventory for the assessment of tropical tree diversity: A comparative test of four alternative approaches. Forest Ecology and Management, 237: 564-573

Gordon JE, Newton AC. 2006b. The potential misapplication of rapid plant diversity assessment in tropical conservation. Journal for Nature Conservation, 14: 117-126

Grau HR, Arturi MF, Brown AD, et al. 1997. Floristic and structural patterns along a chronosequence of secondary forest succession in Argentinean subtropical montane forests. Forest Ecology and Management, 95: 161-171

Grubb PJ, Lloyd JR, Pennington TD, et al. 1963. A comparison of montane and lowland forests in Ecuador I. The forest structure, physiognomy, and floristic. Journal of Ecology, 51: 567-601

Guariguata MR, Chazdon RL, Denslow JS, et al. 1997. Structure and floristics of secondary and old-growth forest stands in lowland Costa Rica. Plant Ecology, 132: 107-120

Hall JB. 1991. Multiple-nearest-tree sampling in an ecological survey of Afromontane catchment forest. Forest Ecology and Management, 42: 245–299

Harms K, Condit R, Hubbell SP, et al. 2001. Habitat associations of trees and shrubs in a 50-ha neotropical forest plot. Journal of Ecology, 89: 947-959

He F, Legendre P, Lafrankie JV. 1996. Spatial pattern of diversity in a tropical rain forest in Malaysia. Journal of Biogeography, 23: 57-74

Heywood VH. 1995. Global Biodiversity Assessment. Cambridge University Press, Cambridge, UK

Huang W, Pohjonen V, Johansson S, et al. 2003. Species diversity, forest structure and species composition in Tanzanian tropical forests. Forest Ecology and Management, 173: 11-24

Jayakumar S, Samy DIA, Britto SJ. 2000. Estimates of current states of forest types in Kolli hill using remote sensing. Journal of Indian Society of Remote Sensing, 28: 141–151

Kadavul K, Parthasarathy N. 1999. Plant biodiversity and conservation of tropical semo-evergreen forest in the Shervarayan hills of Eastern Ghats, India. Biodiversity and Conservation, 8: 421-439

Kalacska M, Sanchez-Azofeifa GA, Calvo-Alvarado JC, et al. 2004. Species composition, similarity and diversity in three successional stages of a seasonally dry tropical forest. Forest Ecology and Management, 200: 227-247

Kennard DK, Gould K, Putz FE, et al. 2002. Effect of disturbance intensity on regeneration mechanisms in a tropical dry forest. Forest Ecology and Management, 162: 197-208

Khera AN, Kumar A, Ram J, et al. 2001. Plant biodiversity assessment in relation to disturbances in midelevational forest of Central Himalaya, India. Tropical Ecology, 42: 83-95

Khumbongmayum D, Khan ML, Tripathi RS. 2005. Sacred groves of Manipur, northeast India:biodiversity value, status and strategies for their conservation. Biodiversity and Conservation, 14: 1541-1582

Killeen TJ, Jardim A, Mamani F, et al. 1998. Diversity, composition and structure of a tropical semideciduous forest in the Chiquitanía region of Santa Cruz, Bolivia. Journal of Tropical Ecology, 14: 803-827

Kimmins JP. 1997. Biodiversity and its relationship to ecosystem health and integrity. Forest Chronicle, 73: 229-232

Kleinn C, Vilcko F. 2006. A new empirical approach for estimation in k-tree sampling. Forest Ecology and Management, 237: 522-533

Knight DH. 1975. A phytosociological analysis of species-rich tropical forest on Barro Colorado Island, Panama. Ecological Monographs, 45: 259-284

Kumar A, Gupta AK, Marcot BG, et al. 2002. Management of forests in India for biological diversity and forest productivity, a new perspective. Volume IV: Garo Hills Conservation Area (GCA). Wildlife Institute of India – USDA Forest Service collaborative project report, Wildlife Institute of India, Dehra Dun, India, 206

Kumar A, Marcot BG, Saxena A. 2006. Tree species diversity and distribution patterns in tropical forests of Garo Hills. Current Science, 91: 1370-1381

Lieberman D, Lieberman M, Peralta R, et al. 1996. Tropical forest structure and composition on a large-scale altitudinal gradient in Costa Rica. Journal of Ecology, 84: 137-152

Lima DAF, Martini AMZ, Gandolfi S, et al. 2008. Repeated disturbances and canopy disturbance regime in a tropical semi-deciduous forest. Journal of Tropical Ecology, 24: 85-93

Linder P, Elfving B, Zackrisson O. 1997. Stand structure and successional trends in virgin boreal forest reserves in Sweden. Forest Ecology and Management, 98: 17-33

Magurren AE. 1988. Ecological Diversity and its Measurement. Princeton University Press, Princeton, NJ, USA

Mani S, Parthasarathy N. 2005. Biodiversity assessment of trees in five inland tropical dry evergreen forests of peninsular India. Systematic and Biodiversity, 3: 1-12

Mani S, Parthasarathy N. 2006. Tree diversity and stand structure in inland and coastal tropical dry evergreen forests of peninsular India. Current Science, 90: 1238-1246

Martini AMZ, Lima RAF, Francoc GADC, et al. 2008. The need for full inventories of tree modes of disturbance to improve forest dynamics comprehension: An example from a semideciduous forest in Brazil. Forest Ecology and Management, 255: 1479-1488

Miller JH, Byod RS, Edwards MB. 1999. Floristic diversity, stand structure, and composition 11 years after herbicide site preparation. Canadian Journal of Forest Research, 29: 1073-1083

Mishra BP, Tripathi OP, Tripathi RS, et al. 2004. Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. Biodiversity and Conservation, 13: 421-436

Murthy MSR, Giriraj A, Dutt CBS. 2003. Geoinformatics for biodiversity assessment. Biological Letters, 40: 75-100

Muthuramkumar S, Ayyappan N, Parthasarathy N, et al. 2006. Plant community structure in tropical rain forest fragments of the Western Ghats, India. Biotropica, 38: 143-160

Nadkarni NM, Matelson TJ, Haber WA. 1995. Structural characteristics and floristic composition of a Neotropical cloud forest, Monteverde, Costa Rica. Journal of Tropical Ecology, 11: 481-494

Nagendra H. 2001. Using remote sensing to assess biodiversity. International Journal of Remote Sensing, 22: 2377-2400

Nagendra H, Gadgil M. 1999. Biodiversity assessment at multiple scales: linking remotely sensed data with field information. Proceedings of the National Academy of Sciences of U.S.A., 96: 9154–9158

Nath CD, Dattaraja HS, Suresh HS, et al. 2006. Patterns of tree growth in relation to environmental variability in the tropical dry deciduous forest at Mudumalai, southern India. Indian Academy of Sciences, 31: 651-669

Nelson BW, Ferreira C, Da Silva M, et al. 1990. Endemism centers, refugia and botanical collection density in Brazilian Amazonia. Nature, 345: 714–716

Noble IR, Dirzo R. 1997. Forests as human-dominated ecosystems. Science, 277: 522-525

NRSA. 1998. Biodiversity Characterization at landscape level Using Remote Sensing and GIS. Field Manual, National Remote Sensing Agency, Hyderabad, India

Padalia H, Chauhan N, Porwal MC, et al. 2004. Phytosociological observations on tree species diversity of Andaman Islands, India. Current Science, 87: 799-806

Paijmans K. 1970. An analysis of four tropical rain forest sites in New Guinea. Journal of Ecology, 58: 77-101

Pandey SK, Shukla RP. 2003. Plant diversity in managed sal (*Shorea robusta* Gaertn.) forests of Gorakhpur, India: species composition, regeneration and conservation. Biodiversity and Conservation, 12: 2295-2319

Parthasarathy N, Karthikeyan R. 1997. Plant biodiversity inventory and conservation of two tropical dry evergreen forests on the Coromandel coast, south India. Biodiversity and Conservation, 6: 1063-1083

Parthasarathy N, Sethi P. 1997. Trees and liana species diversity and population structure in a tropical forest in south India. Tropical Ecology, 38: 19-30

Parthasarathy N. 1999. Tree diversity and distribution in undisturbed and human-impacted sites of tropical wet evergreen forest in southern Western Ghats, India. Biodiversity and Conservation, 8: 1365-1381

Peet RK. 1978. Forest vegetation of the Colorado front range: Patterns of species diversity. Vegetatio, 37: 65-78

Phillips OL, Martinez RV, Vargas PN, et al. 2003. Efficient plot-based floristic assessment of tropical forests. Journal of Tropical Ecology, 19: 629-645

Pither R, Kellman M. 2002. Tree species diversity in small, tropical riparian forest fragments in Belize, Central America. Biodiversity and Conservation, 11: 1623-1636

Pitman CA, Mogollon H, Davila N, et al. 2008. Tree community change across 700 km of lowland amazonian forest from the Andean Foothills to Brazil. Biotropica, 40: 525-535

Pitman NCA, Terborgh JW, Silman MR, et al. 2002. A comparison of tree species in two upper Amazonian forests. Ecology, 83: 3210-3224

Poore MED. 1968. Studies in Malaysian Rain Forest: I. The forest on triassic sediments in Jengka Forest Reserve. Journal of Ecology, 56: 143-196

Porwal MC, Sharma L, Roy PS. 2003. Stratification and mapping of *Ephedra gerardiana* Wall. in Poh (Lahul and Spiti) using remote sensing and GIS. Current Science, 84(2): 208 - 212

Proctor J, Anderson JM, Chai P, et al. 1983. Ecological studies in four contrasting lowland rain forests in Gunung Mulu national park, Sarawak: I. Forest Environment, Structure and Floristics. Journal of Ecology, 71: 237-260

Ramanujam MP, Kadamban D. 2001. Plant biodiversity of two tropical dry evergreen forests in the Pondicherry region of South India and the role of belief systems in their conservation. Biodiversity and Conservation, 10: 1203-1217

Rawat GS. 2009. Current trends in tropical biodiversity research and conservation. Tropical Ecology, 50: 5-6

Reddy MS, Parthasarathy N. 2003. Liana diversity and distribution in four tropical dry evergreen forests on the Coromandel coast of south India. Biodiversity and Conservation, 12: 1609–1627

Risser P, Rice EL. 1971. Diversity in tree species in Oklahoma upland forest. Ecology, 52: 876-880

Robbie TA. 1955. Teach Yourself Forestry. English Universities Press, London, UK

Rosales J, Petts G, Knab-Vispo C. 2001. Ecological gradients within the riparian forests of the lower Caura River, Venezuela. Vegetatio, 152: 101-118

Rovero F, Marshall AR. 2005. Diversity and abundance of diurnal primates and forests antelopes in relation to habitat quality: a case study from the Udzungwa mountains of Tanzania (Huber BA et al., eds). African Biodiversity, 297-304

Roy PS, Porwal MC, Sharma L. 2001. Mapping of Hippophae rhamnoides Linn. in the adjoining areas of Kaza in Lahul and Spiti using remote sensing and GIS. Current Science, 80: 1107-1111

Sagar R, Singh J. 2005. Structure, diversity, and regeneration of tropical dry deciduous forest of northern India. Biodiversity and Conservation, 14: 935-959

Sagar R, Singh JS. 2006. Tree density, basal area and species diversity in a disturbed dry tropical forest of northern India: implications for conservation. Environmental Conservation, 33: 256-262

Sagar R, Raghubanshi AS, Singh JS. 2003. Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. Forest Ecology and Management, 186: 61-71

Saxena AK, Singh JS. 1982. A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. Plant Ecology, 50: 3-22

Shahabuddin G, Kumar R. 2006. Influence of anthropogenic disturbance on bird communities in a tropical dry forest: role of vegetation structure. Animal Conservation, 9: 404-413

Shankar U. 2001. A case of high tree diversity in a sal (*Shorea robusta*)-dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation. Current Science, 81: 776- 786

Sheil D, Ducey MJ, Samsoedin I. 2003. A new type of sample unit for the efficient assessment of diverse tree communities in complex forest landscapes. Journal of Tropical Forestry Science, 15(1): 117–135

Singh JS. 2002. The biodiversity crisis: a multifaceted review. Current Science, 82 : 638–647

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

Sukumar R, Dattaraja HS, Suresh HS, et al. 1992. Long-term monitoring of vegetation in a tropical deciduous forest in Mudumalai, southern India. Current Science, 62: 608-613

Swamy PS, Sundarapandian SM, Chandrasekar P, et al. 2000. Plant species diversity and tree population structure of a humid tropical forest in Tamil Nadu, India. Biodiversity and Conservation, 9: 1643-1669

Tappeiner JC, Huffman D, Marshall D, et al. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. Canadian Journal of Forest Research, 27: 638-648

Turner W, Spector S, Gardiner N, et al. 2003. Remote sensing for biodiversity science and conservation. Trends in Ecology and Evolution, 18: 306 – 314

Upadhaya K, Pandey HN, Law PS, et al. 2003. Tree diversity in sacred groves of the Jaintia hills in Meghalaya, northeast India. Biodiversity and Conservation, 12: 583-597

Valencia R, Balslev H, Miño GPY. 1994. High tree alpha-diversity in Amazonian Ecuador. Biodiversity and Conservation 3: 21-28

Velencia R, Foster RB, Villa G, et al. 2004. Tree species distributions and local habitat variation in the Amazon: large forest plot in eastern Ecuador. Journal of Ecology, 92: 214-229

Van-Aardt JAN, Wynne RH. 2001. Spectral separability among six southern tree species. Photogrammetric Engineering and Remote Sensing, 67: 1367-1375

Venkateswaran R, Parthasarathy N. 2005. Tree population changes in a tropical dry evergreen forest of south India over a decade (1992-2002). Biodiversity and Conservation, 14: 1335-1344

White JD, Kroh GC, Pinder JE. 1995. Forest mapping at Lassen Volcanic National Park, California, using Landsat TM data and Geographical Information System. Photogrammetric Engineering and Remote Sensing, 61: 299-305

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

Zhang WJ. 2011. Simulation of arthropod abundance from plant composition. Computational Ecology and Software, 1(1): 37-48

Zhang WJ, Barrion AT. 2006. Function approximation and documentation of sampling data using artificial neural networks. Environmental Monitoring and Assessment, 122: 185-201

Zhang WJ, Wei W. 2009. Spatial succession modeling of biological communities: a multi-model approach. Environmental Monitoring and Assessment, 158: 213-230

Zhang WJ, Zhong XQ, Liu GH. 2008. Recognizing spatial distribution patterns of grassland insects: neural network approaches. Stochastic Environmental Research and Risk Assessment, 22(2): 207-216

Zhang WJ. Computational Ecology: Artificial Neural Networks and Their Applications. World Scientific, Singapore, 2010