

## FOREST FRAGMENTATION AND TREE DIVERSITY IN KHANGCHENDZONGA BIOSPHERE RESERVE, SIKKIM

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### Introduction

Fragmentation of continuous forests into smaller patches has serious consequences on the survival of species and ecosystems. Forest fragmentation alters forest microenvironment and increases the vulnerability of the forest communities (Lovejoy *et al.*, 1984, 1986; Lord and Norton, 1990; Robinson *et al.*, 1992; Matlack, 1994). Fragmentation caused by natural as well as anthropogenic forces, is a dynamic process in which the habitat is progressively reduced into smaller patches that becomes more isolated and increasingly affected by edge effects (Forman and Godron, 1986; Reed *et al.*, 1996; Franklin, 2001; McGarigal, 2002). The fragments of irregular shape tend to have increased edge lengths (Echeverria *et al.*, 2007) and therefore, total species richness in smaller fragments is significantly lower than the larger ones (Metzger *et al.*, 1997). Thus, conversion of continuous forests into forest fragments and large fragments into smaller fragments has been attributed as the most important factor of species and ecosystem loss in tropics (Turner, 1996).

Khangchendzonga Biosphere Reserve (KBR) in Eastern Himalayas is extremely rich in biodiversity. At least 1,225 species of angiosperms have been reported from

the Biosphere Reserve by Maity and Chauhan (2002). However, of late, the increasing incidences of grazing, landslide, forest fire and wind throw have brought about discontinuity in forest cover in many parts of the Biosphere Reserve, thereby fragmenting the natural habitats of several species. This paper analyses the forest fragmentation pattern in the Biosphere Reserve and evaluates its effect on tree species diversity.

### Material and Methods

The study was carried out in Khangchendzonga Biosphere Reserve (27°06' - 28°05' N latitudes and 88°02' - 88°47' E longitudes) in the Eastern Himalayas. The KBR is situated in the state of Sikkim in North-East India and has an elevation range of 1,200 m to >4,500 m. The core zone consists of temperate, subalpine and alpine forests, i.e. mostly at higher elevations ranging from 2,500 m to >4,500 m a.s.l., while the buffer zone encompasses the sub-tropical and temperate forests at mid-elevation zone, altitude ranging from 1,200 m to 2,500 m. The study sites represented sub-tropical, temperate and sub-alpine forests both in core and buffer zones of the Biosphere Reserve in West and North districts of Sikkim along an altitudinal gradient of 1,700-4,000 m.

The vegetation of Sikkim Himalaya is broadly classified into six types (Champion and Seth, 1968), viz.:

- (i) tropical mixed deciduous to semi-evergreen forest,
- (ii) sub-tropical broad leaved hill forest,
- (iii) temperate forest,
- (iv) temperate to subalpine forest,
- (v) sub-alpine forest, and
- (vi) alpine moorland forest.

The climate of Sikkim is monsoonic. Because of its proximity to the Bay of Bengal and direct exposure to the effect of moisture laden South-West monsoon, the state receives very high rainfall. Four seasons are distinguishable in a year viz. Cold winter season (mid October-March), Pre-monsoon season (March-May), Monsoon season (June-mid September) and Post-monsoon season (mid September-mid October). However, the climatic conditions within KBR vary greatly from one place to the other due to wide topographic and altitudinal variations.

The forest fragments were surveyed during 2005-2006 in sub-tropical, temperate and subalpine forests both in core and buffer zones of KBR. In total, 23 fragments were identified and permanently demarcated for detailed study. Ten random quadrats of 10 x 10 m<sup>2</sup> were laid for sampling of tree species in each of the 22 fragments, having area of >1 ha and also in the adjacent continuous forests for all the 23 fragments. The tree species were enumerated by direct counting in fragment FF17, which had <1 ha area. The altitude, area, latitude and longitude of each fragment were recorded using a GPS (GARMIN model Map 76), and the angle and aspect of the slope were estimated using a Clinometer. The density, basal cover frequency, IVI, and species

diversity indices such as Fisher's diversity, Shannon's index, and evenness index were computed to compare tree diversity in different fragment sizes with continuous forests following Barik *et al.* (1992), Magurran (1988) and Rao *et al.* (1990).

## Results

**Forest fragmentation pattern :** Out of the total 23 forest fragments located, 10 fragments were identified in temperate forest, 12 fragments in subalpine forest and only one in subtropical forest (Table 1). The size of the forest fragments varied between 0.1 and 9.92 ha. At least seven of the fragments were situated on the steep slopes. When segregated into three different fragment size classes, viz., < 2 ha area, 2-6 ha and > 6 ha fragment area, the maximum proportion of fragments were in 2-6 ha size classes (Fig. 1).

Natural causes such as landslide and wind-throw, and anthropogenic causes such as grazing, tourist trekking and forest fire are responsible for forest fragmentation in the KBR (Table 2). Even the forests in the core area were also affected by grazing, trekking activity and forest fire in the past.

The forest fragments in temperate forest represent the patches, which are incompletely fragmented and are connected to the continuous forest by forest corridors. On the other hand, the fragments in sub-alpine forest occur as isolated patches. Although many fragments were identified in the subtropical forest, most of them were outside the boundary of KBR. As only one subtropical fragment was present within the KBR boundary that was included in

**Table 1**

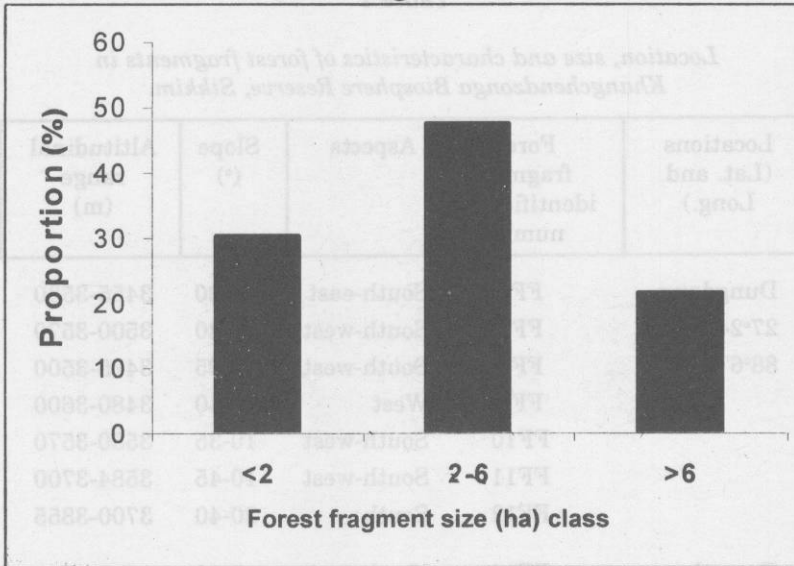
*Location, size and characteristics of forest fragments in  
Khangchendzonga Biosphere Reserve, Sikkim.*

Forest type	Locations (Lat. and Long.)	Forest fragment identification number	Aspects	Slope (°)	Altitudinal range (m)	Fragment size (ha)	
Sub-alpine	Dungdang 27°24' N 88°6' E	FF6	South-east	5-20	3455-3530	7.68	
		FF7	South-west	10-20	3500-3570	3.04	
		FF8	South-west	10-25	3485-3500	6.72	
		FF9	West	20-40	3480-3600	3.84	
		FF10	South-west	10-35	3530-3570	6.72	
		FF11	South-west	10-45	3584-3700	6.40	
	Gomathang 27°27' N 88°06' E	FF12	South	20-40	3700-3855	2.57	
		FF18	North-east	5-10	3800-3840	3.10	
		FF19	South-east	15-20	3770-3790	3.78	
		FF20	West	20-25	3830-3930	4.47	
		Kalep 27°45' N 88°32' E	FF21	South	25-35	3125-3139	1.02
			FF22	East	30-40	3088-3117	2.07
Temperate	Ngom-Phedi 27°23' N 88°07' E	FF1	West	5-10	2525-2550	3.20	
		FF2	East	10-25	2560-2565	1.92	
		FF3	East	15-30	2740-2770	1.60	
		FF4	East	10-20	2800-2900	1.99	
		FF5	South-east	30-50	3018-3600	9.92	
	Tshoka-Kibek 27°6' N 88°11' E	FF13	South-east	10-20	2545-2552	1.60	
		FF14	East	10-35	2709-2725	2.93	
		FF15	South	10-40	2900-2930	5.86	
		FF16	South	15-20	2940-2985	1.90	
		FF17	South-east	10-15	3283-3290	0.10	
Sub-tropical	Topung 27° 19' N 88° 09' E	FF23	South	30-45	1700-1760	4.00	

the study. This fragment was separated from the continuous forest by an agricultural land.

*Tree species diversity in forest fragments :*  
In temperate forest fragments, a total of 49 species of trees representing 33 genera

Fig. 1



Distribution of forest fragments in three size classes in KBR.

Table 2

*Details of causes of forest fragmentation and tree density in Khangchendzonga Biosphere Reserve, Sikkim.*

Forest type	Forest fragment identification number	Tree density (mean $\pm$ SE)	Causes of fragmentation and characteristics
1	2	3	4
Sub-alpine	FF6	70.0 $\pm$ 10.0	Fragment caused by forest fire
	FF7	60.0 $\pm$ 13.0	Fragment connected by large corridors, gentle terrain
	FF8	80.0 $\pm$ 12.1	Gentle terrain
	FF9	75.7 $\pm$ 4.2	Steep; fragment caused by landslides
	FF10	64.0 $\pm$ 12.8	Large fragment, juniper scrub dominated
	FF11	70.0 $\pm$ 12.2	Caused by grazing and river boundary to the West, North boundary represents tree-line
	FF12	77.5 $\pm$ 11.3	Isolated fragment, north boundary represents tree-line
	FF18	48.0 $\pm$ 7.1	Fragment is human induced, presence of narrow corridor

Contd...

1	2	3	4
	FF19	62.0 ± 5.1	Caused by anthropogenic disturbances, presence of narrow corridor
	FF20	66.4 ± 6.4	Medium isolated fragment, caused by human disturbances and wind throw
	FF21	28.0 ± 2.9	Isolated fragment, caused by landslide and road construction
	FF22	30.9 ± 9.1	Steep fragment caused by landslide and road construction
Temperate	FF1	32.4 ± 3.8	Connected to continuous forest through narrow forest corridors in the east and west direction
	FF2	24.3 ± 7.1	Most part connected to main forest; fragment caused by gaps; has thick bamboo brake
	FF3	25.5 ± 5.5	Connected to main forest, fragment caused by gaps
	FF4	30.0 ± 3.9	Connected to main forest, fragment caused by gaps, relatively on flat terrain
	FF5	58.7 ± 6.6	Steep fragment largely connected to main forest, has dense bamboo brakes
	FF13	35.0 ± 5.0	Small fragment caused by treefall gaps, corridor present; parcelized area
	FF14	42.2±2.2	Forest fragment caused by tree fall gaps; parcelized area
	FF15	36.0±4.3	Fragment caused by parcelization
	FF16	31.4±8.6	Small forest fragment caused by parcelization, has dense bamboo brake
	FF17	40.0±13.4	Small fragment occurred as narrow belt across the trekking path
Sub-tropical	FF23	62.0±7.6	Forest fragment separated from main forest by agricultural land

and 21 families were recorded. Taxonomically, the well represented families include Aceraceae, Ericaceae, Fagaceae, Rosaceae and Theaceae. The maximum species diversity was found in FF1 (25 species, 22 genera and 17 families) and the least was in FF17 (5 species, 4 genera and 4 families). In subalpine forest fragments, 27 species belonging to 14 genera and 8 families were represented. The dominant families include Aceraceae,

Ericaceae, Pinaceae and Salicaceae. In the subtropical forest, only one fragment was located having 15 species belonging to 12 genera and 10 families. The dominant families are Aceraceae, Juglandaceae and Fagaceae.

The highest mean tree density was in FF8 (80±12.1) having the fragment size of 6.72 ha, and is the second largest fragment in subalpine region after FF5 (Table 2).

Lowest mean density was in FF2 ( $24.3 \pm 7.1$ ) with the fragment size of 1.9 ha in temperate region (Buffer zone). The highest basal area measured was in FF13 ( $3.23 \text{ m}^2/\text{ha}$ ) in subtropical fragment followed by FF1 in temperate forest fragment and the lowest was in FF4 ( $0.75 \text{ m}^2/\text{ha}$ ) (Table 3).

The correlation between mean tree density and fragment size depicted a significant positive correlation ( $p < 0.002$ ) (Fig. 2). The species richness did

not show significant correlation with fragment size (Fig. 3). The Shannon-Weiner index varied among the forest fragments and it was higher in the larger fragments than the smaller ones within a forest type. The highest Shannon index was shown by FF1 (1.31) and lowest was in FF9 (0.74). Evenness index among the forests fragments also varied significantly. It ranged between 0.97-0.79. The larger fragments had higher evenness index value than the smaller fragments (Table 3).

Table

*Consolidated details of tree species inventory in the 23 forest fragments*

Parameters	Sub-alpine									
	6	7	8	9	10	11	12	18	19	20
Forest fragment identification number										
Species richness	10	9	7	7	10	9	8	10	10	11
No. of genera	6	6	4	6	9	7	4	8	8	8
No. of families	4	5	4	6	7	6	4	8	8	8
Shannon-Weiner index	0.95	0.82	0.82	0.74	0.95	0.89	0.78	0.92	0.94	0.97
Evenness index	0.95	0.86	0.97	0.87	0.95	0.93	0.87	0.92	0.94	0.94
Basal area ( $\text{m}^2/\text{ha}$ )	1.17	1.05	1.87	1.79	0.97	1.66	1.13	0.78	0.97	1.38
Fisher's index	2.59	2.26	1.74	1.76	2.4	2.17	1.94	2.58	2.42	2.56

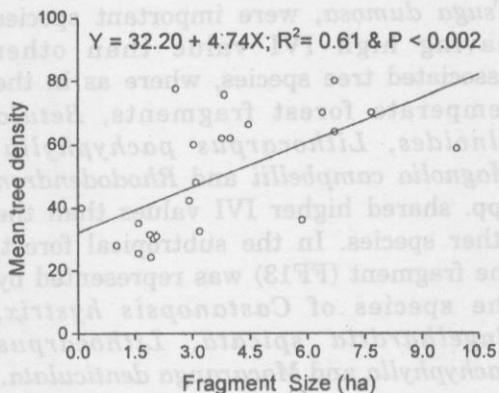
The species represented by a single individual were much more numerous than the species with high abundance (i.e. high IVI), that represented a small number of total species (Fig. 4). The sub-alpine forest fragments in KBR exhibited short tails at the end of the curves, indicating low species richness and IVI was distributed among a few species only. In contrast in sub-tropical and temperate forest fragments, the IVI was more equitably distributed among many species. In the subalpine forest fragments, *Abies* spp.,

*Picea spinulosa*, *Rhododendrons* spp. and *Tsuga dumosa*, were important species having high IVI value than other associated tree species, where as in the temperate forest fragments, *Betula alnoides*, *Lithocarpus pachyphylla*, *Magnolia campbellii* and *Rhododendron* spp. shared higher IVI values than the other species. In the subtropical forest, the fragment (FF13) was represented by the species of *Castanopsis hystrix*, *Engelhardtia spicata*, *Lithocarpus pachyphylla* and *Macaranga denticulata*.

3  
of different sizes in three forest types in KBR, Sikkim

Sub-tropical			Temperate									
21	22	23	1	2	3	4	5	13	14	15	16	17
10	11	15	25	14	11	10	15	8	9	15	7	5
9	10	12	22	11	9	8	10	8	9	13	6	4
6	6	11	17	10	8	7	8	6	8	9	4	4
0.95	1.00	1.10	1.31	1.12	1.02	0.97	1.12	0.84	0.93	1.13	0.76	0.53
0.95	0.96	0.93	0.94	0.98	0.98	0.97	0.95	0.93	0.97	0.96	0.89	0.75
0.95	3.00	5.60	3.23	1.71	0.86	0.75	1.88	2.63	2.19	2.06	0.97	1.24
3.00	1.49	3.31	5.69	3.97	3.6	3.00	3.35	2.40	2.47	3.76	2.26	1.67

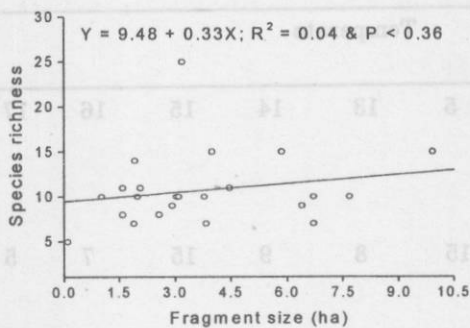
**Fig. 2**



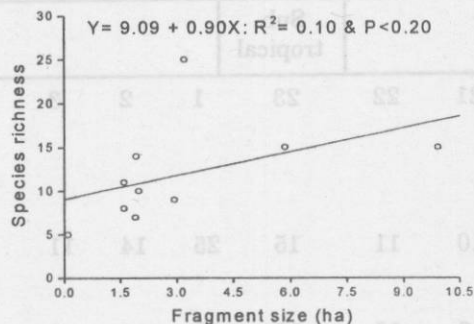
Mean tree density and fragment size relationship across 23 forest fragments in KBR.

*Tree species diversity in continuous forests* : Shannon's diversity index for trees was highest in the sub-tropical forest and it decreased sharply in the higher altitude forest ecosystems. The species evenness index was lower in the sub-tropical and sub-alpine forest than the temperate forest. The alpha diversity of plants ranges from 0.580 in sub-tropical forest to 0.14 in the subalpine forest (Table 4). Tree density was highest in the subtropical forest with 900 trees per ha followed by temperate forest with 536 trees per ha and lowest in alpine forest with 324 trees per ha.

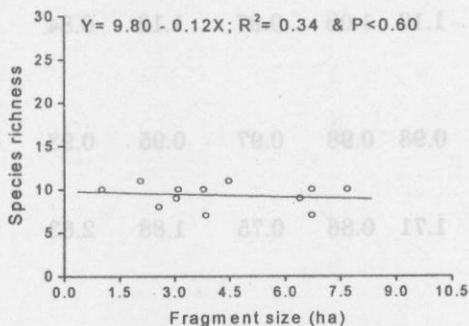
**Fig. 3**



Across the forest



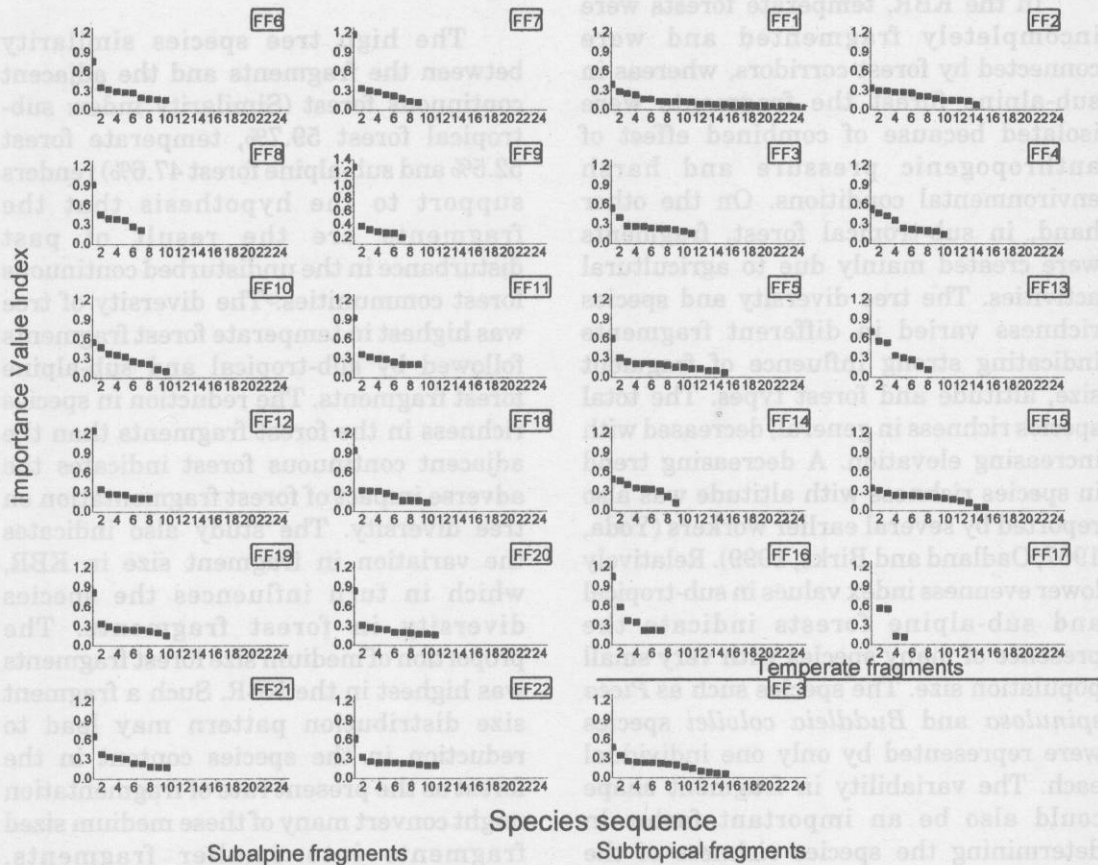
Temperate forest



Sub-alpine forest

Tree species richness and fragment size relationship in KBR

Fig. 4



Tree species-abundance curves for 23 forest fragments (FF1-FF23) in KBR, Sikkim.

Table 4

Species richness, diversity and evenness index of trees in the adjacent continuous forest

Community characteristics	Sub-tropical	Temperate	Sub-alpine
Species richness	218	159	73
Shannon's Diversity Index	3.54	3.15	1.54
Alpha-diversity	0.58	0.367	0.141
Evenness Index	0.887	0.916	0.792

## Discussion

In the KBR, temperate forests were incompletely fragmented and were connected by forest corridors, whereas in sub-alpine forest the fragments were isolated because of combined effect of anthropogenic pressure and harsh environmental conditions. On the other hand, in sub-tropical forest, fragments were created mainly due to agricultural activities. The tree diversity and species richness varied in different fragments indicating strong influence of fragment size, altitude and forest types. The total species richness in general, decreased with increasing elevation. A decreasing trend in species richness with altitude was also reported by several earlier workers (Yoda, 1967; Oadland and Birks, 1999). Relatively lower evenness index values in sub-tropical and sub-alpine forests indicate the presence of many species with very small population size. The species such as *Picea spinulosa* and *Buddleia colvilei* species were represented by only one individual each. The variability in fragment shape could also be an important factor in determining the species richness of the fragments (Game, 1980; Formann, 1995). The difference in tree species diversity between small and large fragments was significantly greater than that between medium and large fragments, indicating

the decline of species diversity due to creation of small fragments.

The high tree species similarity between the fragments and the adjacent continuous forest (Similarity index: sub-tropical forest 59.7%, temperate forest 52.5% and sub-alpine forest 47.6%) renders support to the hypothesis that the fragments are the result of past disturbance in the undisturbed continuous forest communities. The diversity of tree was highest in temperate forest fragments followed by sub-tropical and sub-alpine forest fragments. The reduction in species richness in the forest fragments than the adjacent continuous forest indicates the adverse impact of forest fragmentation on tree diversity. The study also indicates the variation in fragment size in KBR, which in turn influences the species diversity in forest fragments. The proportion of medium size forest fragments was highest in the KBR. Such a fragment size distribution pattern may lead to reduction in the species content in the forest as the present rate of fragmentation might convert many of these medium sized fragments into smaller fragments. Therefore, the Biosphere Reserve management must take immediate measures to halt the further forest fragmentation to avoid decline in tree species diversity in the forests of KBR.

## Acknowledgement

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## SUMMARY

The pattern of forest fragmentation was studied in Khangchendzonga Biosphere Reserve, Sikkim (KBR) and tree diversity was correlated with fragment size. A total of 23 forest

fragments were identified in the KBR after intensive survey, of which ten fragments were in temperate forest, 12 in sub-alpine forest and one in sub-tropical forest. Maximum numbers of fragments were in 2-6 ha size classes. Landslide, wind storm and grazing by livestock herds were identified as the causes of forest fragmentation in KBR. The fragmentation of forest significantly impacted species composition, and community structure of trees in the forest, as evidenced from the differences in these attributes between the fragments and adjacent continuous forests.

**Key words :** Forest Fragmentation, Tree Diversity, Khangchendzonga Biosphere Reserve, Sikkim.

कांचनजंघा में वन विखण्डक और उनकी वृक्ष विविधता

ए० छेत्री, एस०के० बारिक, एच० एन० पाण्डेय व एम०के० लिंगदोह

सारांश

कांचनजंघा जीवमण्डल आरक्षित क्षेत्र, सिक्किम में वन विखण्डन रूपसज्जा और खण्डों के आकार को वृक्ष विविधता से सह संबंधित किया गया। जीवमण्डल क्षेत्र में कुल मिलाकर 23 वन टुकड़ों की पहचान सघन सर्वेक्षण के उपरान्त की गई जिनमें से दस टुकड़े समशीतोष्ण वनों में 12 टुकड़े उपात्पीय वनों में तथा 1 टुकड़ा उपोष्ण वन में आता है। टुकड़ों की अधिकतम संख्या 2-6 हेक्टे० आकार वर्ग की है। भूस्खलन, आंधियां और पशुझुण्डों द्वारा चराई किए जाने को कांचनजंघा जीवमण्डल आरक्षित-क्षेत्र में वन विखण्डन होने के कारणों में पहचाना गया है। वन विखण्डन का वनों की वृक्षजाति रचना और उनकी समुदाय संरचना पर भी प्रभाव पड़ा है जैसा कि टुकड़ों और उनके साथ-साथ लगते सतत वनों की विशेषताओं में मिलते अंतर से प्रकट हो जाता है।

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