# *Chapter 8*

## DISCUSSION

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The floristic diversity, richness and originality of the second smallest state of India, Sikkim, is well known (Lama, 2004; Lepcha, 2011; Lepcha & Das, 2012; Das, 2011, 2013; Das & Ghosh, 2007, 2011; Das et al., 2010).The state is experiencing almost all types of climatic conditions, except hot desert, starting from tropical to permanent snow covered areas with polar environmental conditions. The sharp change in altitude (284 to 8598) m within short distance is also important that is directly affecting the structure, function and composition of vegetation in different and innumerable ecological niches in the state. The multi-pronged progress of civilization at the, so far, fastest speed is seriously affecting the Sikkim's original green wealth. With this back ground, it is now prime time to understand (i) the pattern of distribution of biological elements, (ii) species richness areas, (iii) how different species respond to changes in temperature, precipitation and altitude, etc.

**8.1. Topology:** In East district of Sikkim the elevation is ranging from 340 m to 4649 m. For the present study an elevation sector of 500 – 3300m was taken, as 70% of the areas are covered under this range. The elevation wise geographical areas of East district of Sikkim has also been calculated using the GIS software in each 500m elevation band (Figure 8.1). Slope, Aspect and climatic parameters were also taken in the present study to understand the effect of other variables with species richness and biomass production along the change of altitude. The forest type map prepared as per Champion & Seth (1968) for forest classification was used as a base map to layout the quadrats in the field) Fig. 5.11.The landuse and Landcover maps prepared by Sharma and Das (2015) were used for final analysis (Fig. 8.2). The collected data was analyzed in Microsoft excel.

**8.2. Plant diversity:** The field data was collected mostly from non-disturbed forest areas using 224 nested quadrat samples in 28 elevation steps from where 664 vascular plant species covering 367 genera and 131 Families. A maximum number of 155 species recorded from the elevation of 2200 – 2300 m and minimum number of 60 species recorded from 3200 – 3300 m elevation steps. *Schima wallichii* contributed the maximum number stands amongst the recorded tree species. The elevation wise number species, Genus and Family has been given in Table 8.1.

**8.3. Dominance analysis:** The dominant trees recorded from this region include *Castanopsis hystrix, Engelhardtia spicata, Ostodes paniculata* and *Schima wallichii. Alnus nepalensis* and *Ostodes paniculata* are the dominant tree species of tropical and temperate forests and the similar observation has been reported by ISRO in 1994.

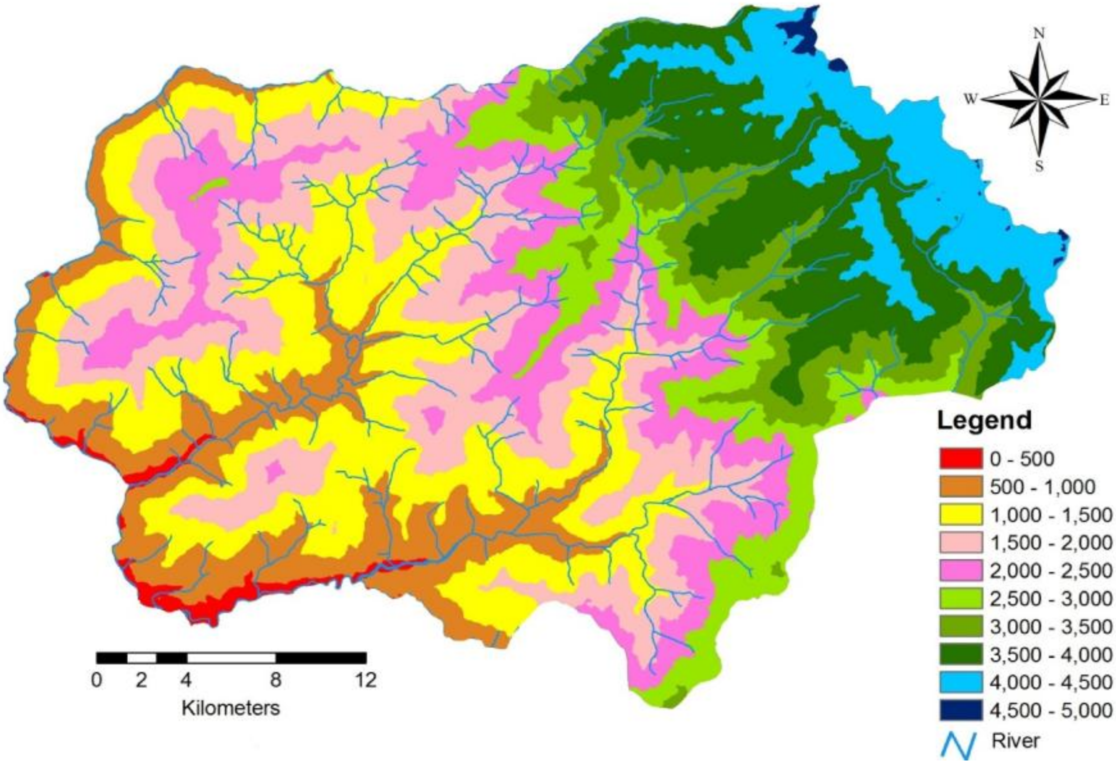


**Fig. 8.1.** Elevation wise geographical area distribution map of east district of Sikkim

**Table 8.1.** Detail of vascular plant species Genus and Family in each elevation steps

| Elevation Steps | Number Species | Number Genus | Number Family |
|---|---|---|---|
| 550 | 129 | 108 | 59 |
| 650 | 96 | 85 | 47 |
| 750 | 106 | 89 | 53 |
| 850 | 121 | 103 | 64 |
| 950 | 134 | 110 | 68 |
| 1050 | 134 | 110 | 63 |
| 1150 | 109 | 95 | 59 |
| 1250 | 126 | 104 | 56 |
| 1350 | 106 | 92 | 57 |
| 1450 | 128 | 105 | 70 |
| 1550 | 133 | 111 | 64 |
| 1650 | 122 | 95 | 64 |
| 1750 | 130 | 101 | 60 |
| 1850 | 134 | 106 | 69 |
| 1950 | 140 | 103 | 66 |
| 2050 | 109 | 90 | 56 |
| 2150 | 143 | 106 | 65 |
| 2250 | 155 | 121 | 69 |

| Elevation Steps | Number Species | Number Genus | Number Family |
|---|---|---|---|
| 2350 | 109 | 86 | 57 |
| 2450 | 146 | 106 | 63 |
| 2550 | 119 | 87 | 53 |
| 2650 | 142 | 99 | 56 |
| 2750 | 124 | 93 | 51 |
| 2850 | 102 | 84 | 48 |
| 2950 | 112 | 85 | 48 |
| 3050 | 86 | 60 | 36 |
| 3150 | 80 | 54 | 36 |
| 3250 | 60 | 46 | 33 |

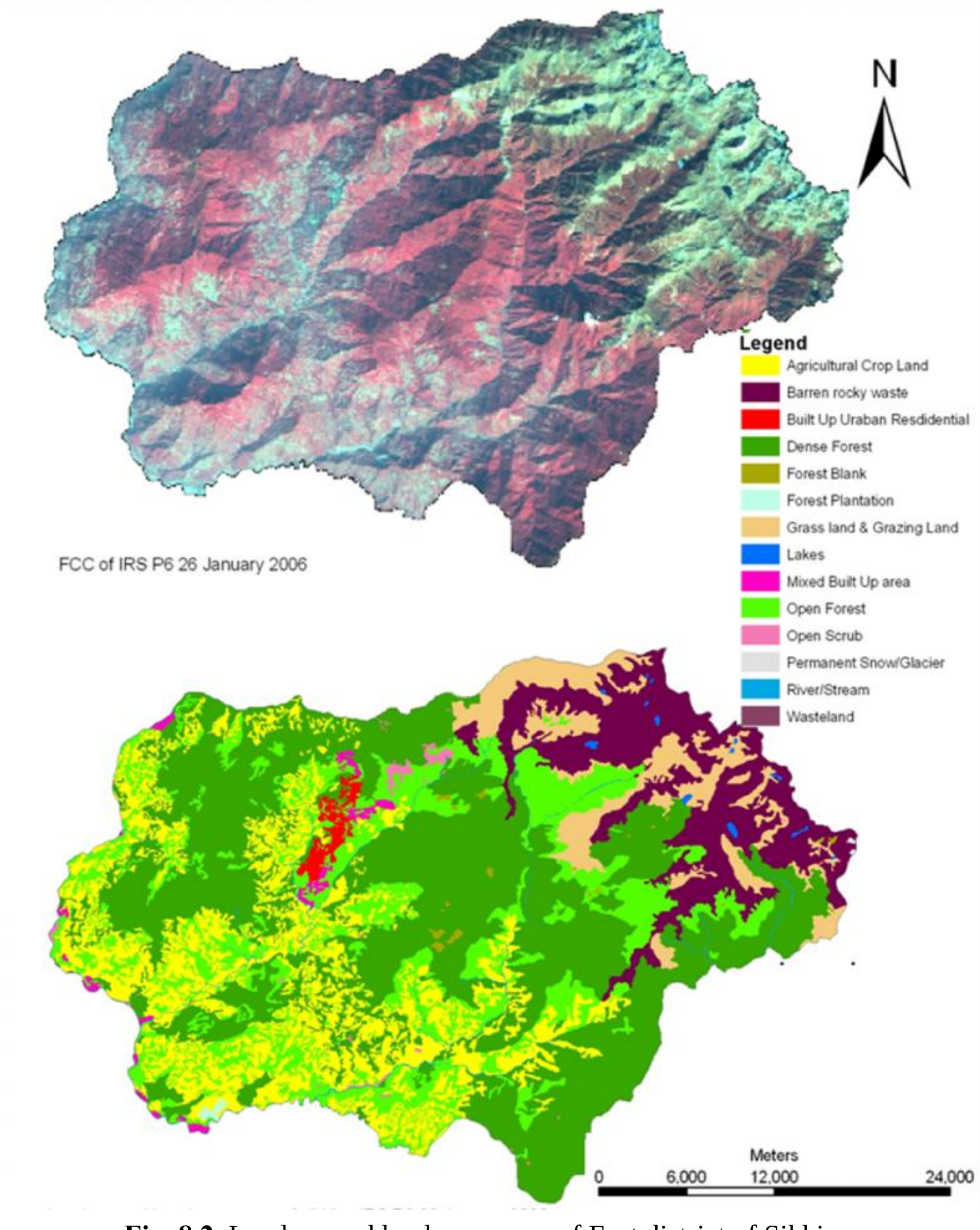


**Fig. 8.2.** Landuse and landcover map of East district of Sikkim

The Frequency, Relative Frequency, Density, Relative Density, Abundance, Relative Abundance and Importance value Index were also determined for the East district of Sikkim, where *Pteridium aquilinum* is recorded with 100 % frequency but *Schima wallichii* contributed maximum density with highest IVI score of 12.19 followed by *Ostodes paniculata* with IVI score of 4.64.The highest IVI scores of 10 top vascular plant with the IVI is given in Table 8.2.

**Table 8.2.** List of the highest IVI scores of 10 vascular plants

| Sl No. | Botanical Name | F | D | A | RF | RD | RDM | IVI |
|---|---|---|---|---|---|---|---|---|
| 1 | *Schima wallichii* | 50.000 | 44.500 | 89.000 | 0.420 | 7.830 | 3.941 | 12.190 |
| 2 | *Ostodes paniculata* | 42.857 | 15.357 | 35.833 | 0.360 | 2.702 | 1.587 | 4.649 |
| 3 | *Alnus nepalensis* | 57.143 | 12.607 | 22.063 | 0.480 | 2.218 | 0.977 | 3.675 |
| 4 | *Castanopsis hystrix* | 71.429 | 11.607 | 16.250 | 0.600 | 2.042 | 0.719 | 3.362 |
| 5 | *Engelhardtia spicata* | 53.571 | 11.214 | 20.933 | 0.450 | 1.973 | 0.927 | 3.350 |
| 6 | *Nephrolepis cordifolia* | 82.143 | 10.786 | 13.130 | 0.690 | 1.898 | 0.581 | 3.169 |
| 7 | *Symplocos lucida* | 39.286 | 8.071 | 20.545 | 0.330 | 1.420 | 0.910 | 2.660 |
| 8 | *Eupatorium adenophorum* | 75.000 | 8.607 | 11.476 | 0.630 | 1.514 | 0.508 | 2.652 |
| 9 | *Dryopteris sikkimensis* | 64.286 | 8.286 | 12.889 | 0.540 | 1.458 | 0.571 | 2.568 |
| 10 | *Selaginella ciliaris* | 64.286 | 7.893 | 12.278 | 0.540 | 1.389 | 0.544 | 2.472 |

**8.4. Diversity Indices:** Different vascular plant species recorded in different elevation gradient of East district of Sikkim are not with uniform pattern of distribution. This is influencing the changes in diversity indices in different locations and in different vegetations. To know the plant diversity *viz*. richness, dominance, evenness, etc., the diversity indices like Margalef Index (MI), Simpson's Index (D), Shannon-Wiener Index (H) and Pielou's Index (J) also analysed. The Margalef diversity index showed very high values at all elevation bands with the highest reaching at 2200 – 2300 m; whereas Shannon Weiner Diversity Index values varied between 3.4 and 4.4 [except at the highest elevation band, where the values was the lowest (1.9)] with the highest value of 4.4 at 2200 – 2300 m. Through this the highest species richness was observed at 950 m elevation. The values of different diversity indices in different altitudinal bands has been presented in (Fig. 5.14 to 5.17) which shows the diversity is higher in the elevation at 1050 m, 1850 m and 2250 m, then decrease slowly. This indicate that the diversity is more in the ecotonal regions. The value each indices is given in the Table 5.4.

## 8.5. Species Richness and Elevation

Maximum area spread is found to be in 1100 – 1500 m elevation range, especially at 1300 – 1400 m band; whereas the north-eastern aspect occupies minimum area with north western aspect occupying maximum area in East district of Sikkim. *Schima wallichii* is found to be occurring abundantly in sub-tropical belt of the district with 1246 counts. A minimum of 60 and maximum of 155 species were noted in 3200 – 3300 m and 2200 – 2300 m elevation bands. At 1800 – 1900 m elevation band a minimum of 29 and maximum of 63 species were noted pointing to an intermediate minima. At 600 – 700 m elevation band, the standard deviation of species range is found to be below 5 indicating greater abundance of species. In general, the number of shrub, herb and lianas decreased from lower to higher elevations with lianas almost absent beyond 3200m elevation. The number of tree species was found to follow a mixed trend, coinciding to the level of disturbance and other abiotic factors. *Pteridium quilinum* is found in all elevation bands indicating maximum tolerance and adaptability, whereas 190 species found with single appearance in one elevation band have narrow tolerance and adaptability range.

A study conducted by Behera and Kushwaha (2007) in Arunachal Pradesh of Eastern Himalaya using data on the tree species (cbh e" 15 cm) gathered at every 200 m steps between 200 m and 2200 m gradients. Tree diversity demonstrated a greater variation along the gradients with a total of 336 species belonging to 185 genera and 78 families. While studying in Helan Mountain, China, Jiang *et al.* (2007) found that the number of species initially increased and then declined, and the curve was markedly 'humped'. They observed richness was the highest between 1800 and 2000 m amsl.

**8.5.1. Species richness:** In any biodiversitically rich vegetation and flora occurrence and distribution of different species can't be uniform. It certainly respond to different prevailing factors in the habitat. From a study in the 500 – 3300 m elevational range of habitat in the East district of Sikkim led to the record of 664 species of vascular plants. This include almost all habit groups, harbs, shrubs, climbers, lianas, trees, and epiphytes. Major part of the natural vegetation, especially in the tropical to warm temperate belt is dominated by trees. It was noted that at least 158 species of trees, 197 species of Shrubs 91 species of lianas and 304 species of herbs are growing in the study area. To understand the scaling effect the field data is divided into three different scale viz. 100 m elevation steps 200 m elevation steps and 300 m elevation steps. The species richness along the 100 m elevation gradient shown in figure. 8.3.

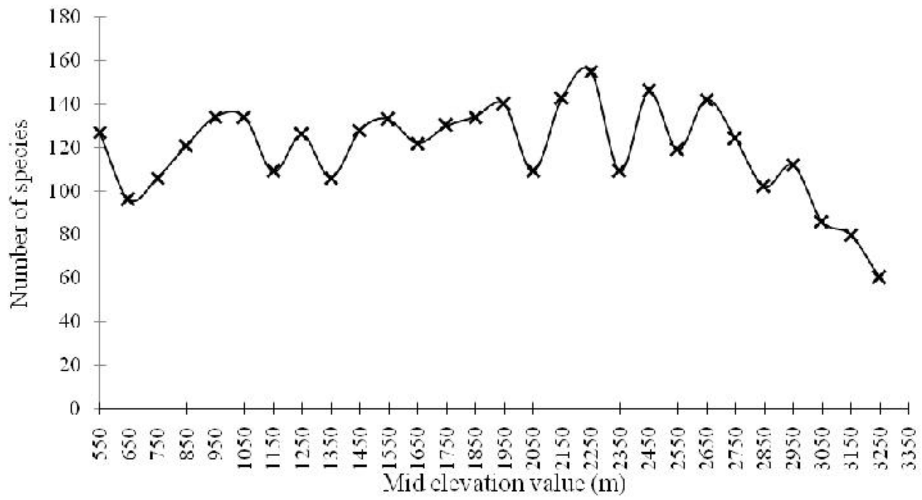


**Fig. 8.3.** Species richness along the 100m elevation steps

**8.6. Distribution of Trees Shrubs and Herbs along the altitude:** A total of 664 species of vascular plants were recorded from the East district of Sikkim, out of which only *Pteridium aquilinum* has been found in all the elevation steps, 8 species are found in more than 20 elevations steps and 25 species are found in more than 15 elevations steps and 195 species are found in only single elevation step **(Annexure-V).** In general, 24 tree species are found only in single elevation band, whereas *Acer campbellii* and *Schima wallichii* are found in more than 14 elevation steps and *Albizia chinensis*, *Macaranga indica* are found in more than 10 elevation steps of the study area. It was also observed that 14 species of shrubs were found in more than 10 elevation steps, whereas 59 species of shrubs occurs only in single elevation step. Similarly, 21 species of herbs are recorded in more than 15 elevation steps and 79 species of herbs are found only in single elevation steps. Table 8.3 showing the list of all vascular plant recorded from each elevation band of East district of Sikkim.

**Table 8.3.** List of tree, shrubs, herbs and epiphyte of the study area

| Elevation Steps | Number of Tree | Number of Shrubs | Number of Herbs | Number of Epiphyte |
|---|---|---|---|---|
| 550 | 20 | 34 | 57 | 25 |
| 650 | 18 | 16 | 52 | 14 |
| 750 | 18 | 21 | 59 | 12 |
| 850 | 28 | 34 | 56 | 8 |
| 950 | 36 | 40 | 61 | 8 |
| 1050 | 30 | 35 | 65 | 12 |
| 1150 | 24 | 28 | 54 | 6 |
| 1250 | 27 | 31 | 61 | 13 |
| 1350 | 18 | 23 | 58 | 9 |
| 1450 | 21 | 33 | 69 | 8 |
| 1550 | 22 | 43 | 59 | 13 |
| 1650 | 25 | 26 | 63 | 10 |
| 1750 | 19 | 38 | 68 | 12 |
| 1850 | 31 | 28 | 69 | 11 |
| 1950 | 19 | 41 | 69 | 13 |
| 2050 | 21 | 38 | 42 | 13 |
| 2150 | 42 | 30 | 63 | 11 |
| 2250 | 33 | 30 | 82 | 15 |
| 2350 | 16 | 27 | 65 | 10 |
| 2450 | 30 | 28 | 86 | 10 |
| 2550 | 24 | 17 | 69 | 9 |
| 2650 | 33 | 23 | 84 | 8 |
| 2750 | 28 | 19 | 75 | 9 |
| 2850 | 12 | 18 | 68 | 10 |
| 2950 | 34 | 17 | 59 | 8 |
| 3050 | 28 | 19 | 38 | 8 |
| 3150 | 21 | 17 | 47 | 0 |
| 3250 | 15 | 15 | 35 | 0 |

## 8.7. Species richness along elevation gradient

In general, the species richness showed a gentle mid-elevation peak with a fast declining trend beyond mid-elevation. The pattern became prominent when adjudged from 100 m to 200 m and 300 m elevation bands with $R^2$ values of 0.502, 0.553 and 0.743 respectively; indicating realisation of scale effect. Similarly, the genera and family richness pattern followed the mirror image of species with mid-elevation peak. The $R^2$ values increased when plotted from100 m to 200 m and 300 m elevation bands for genera (0.657, 0.764 and 0.862) and families (0.765, 0.875 and 0.907). Though, the species richness pattern along elevation gradient non-linear polynomial relationship, it clearly confirmed the pattern of mid-elevation peak across the taxonomic spectrum (i.e., species, genera and families), and grain size (100 m, 200 m and 300 m elevation bands).

This pattern is in contrast to a hump-shaped pattern found by Vetaas and Grytnes (2002), while studying the distribution of vascular plant species richness along the elevation gradient of Nepal Himalaya, between 1000 to 5000 m and found a hump-shaped pattern. Another study by Bhattarai and Vetaas (2006) showed drastic decrease in tree species richness up to 4000 m elevation in central Himalaya. Behera and Kushwaha (2007) in Arunachal Pradesh of Eastern Himalaya found that the alpha diversity demonstrated a decreasing pattern with two maxima (i.e., elevational peaks) along the gradients; one in 601–1000 m and the other in 1601–1800 m, corresponding to transition zones between tropical-subtropical and subtropical-temperate forests. Acharya *et al*., (2011) observed increase in tree species richness pattern till 1500 m and drastic decrease beyond till 3800 m in Sikkim state. However, the pattern differs once the other life-forms such as shrubs, herbs and lianas are considered. Namgail *et al*. (2012) while analysing the dry alpine communities between 4500 m and 5500 m in Ladakh of Western Himalaya found unimodal relationship between plant species-richness and Elevation between 5,000 and 5,200 m, while it peaked between 3,500 and 4,000 m at entire Ladakh level. In south west Saudi Arabia, the species richness increased from lower elevation to higher elevation up to 2000 m highest in 2000-2500 m, then the species diversity decreased while increasing elevation there is a remarkable change in vegetation species diversity and floristic relation (Hegazy *et al*., 1998). In Costa Rica, Kluge *et al*. (2006) observed that the species richness of the 484 recorded species showed a hump-shaped pattern with elevation (with a richness peak at mid-elevations at 1700 m) related strongly with climatic variables, especially humidity and temperature; while area and species pool were associated less strongly.

In present studies showed that quadrats falling in the transition zones between two forest types possess significantly larger number of species than other steps (Fig. 5.18) with elevations of 900 m, 1800 m and 2200 m. This corresponds to the transition zones between tropical-subtropical and temperate and sub-temperate zone. The 100 m elevation steps there is no direct correlation of elevation with the richness of different ranks of taxa, namely species, genus and family. This may be due to the impact of scale factor. In general, there is no clear idea regarding the species richness along the 100 m elevation gradient (Fig. 5.18).The $R^2$ value was 0.50 in second order polynomial, but the relation seen increasing in the initial stage but it decreases with the increase of elevation from temperate forest transition zone, which is located at around 2200 m altitude in the East district Sikkim.

Through this study, species richness found increasing along the altitudinal gradient of lower elevation from tropical forest and up to the sub-tropical forest, i.e. up to 1900 – 2000 m elevation. In the temperate zone the number of species decreases with an increase in elevation. List of vascular in each elevation band is presented in Table 8.4.

**Table 8.4.** List of the number vascular plant species in each 100 m 200 m, and 300 m elevation steps.

<table>
<tr><th>Elevation step (m)</th><th>No. of Species (100 m)</th><th>No. of Species (200 m)</th><th>No. of Species (300 m)</th></tr>
<tr><td>550</td><td>127</td><td rowspan="2">163</td><td rowspan="3">204</td></tr>
<tr><td>650</td><td>96</td></tr>
<tr><td>750</td><td>106</td><td rowspan="2">167</td></tr>
<tr><td>850</td><td>121</td><td rowspan="3">227</td></tr>
<tr><td>950</td><td>134</td><td rowspan="2">194</td></tr>
<tr><td>1050</td><td>134</td></tr>
<tr><td>1150</td><td>109</td><td rowspan="2">166</td><td rowspan="3">196</td></tr>
<tr><td>1250</td><td>126</td></tr>
<tr><td>1350</td><td>106</td><td rowspan="2">245</td></tr>
<tr><td>1450</td><td>128</td><td rowspan="3">224</td></tr>
<tr><td>1550</td><td>133</td><td rowspan="2">163</td></tr>
<tr><td>1650</td><td>122</td></tr>
<tr><td>1750</td><td>130</td><td rowspan="2">187</td><td rowspan="3">242</td></tr>
<tr><td>1850</td><td>134</td></tr>
<tr><td>1950</td><td>140</td><td rowspan="2">203</td></tr>
<tr><td>2050</td><td>109</td><td rowspan="3">249</td></tr>
<tr><td>2150</td><td>143</td><td rowspan="2">194</td></tr>
<tr><td>2250</td><td>155</td></tr>
<tr><td>2350</td><td>109</td><td rowspan="2">206</td><td rowspan="3">227</td></tr>
<tr><td>2450</td><td>146</td></tr>
<tr><td>2550</td><td>119</td><td rowspan="2">198</td></tr>
<tr><td>2650</td><td>142</td><td rowspan="3">150</td></tr>
<tr><td>2750</td><td>124</td><td rowspan="2">166</td></tr>
<tr><td>2850</td><td>102</td></tr>
<tr><td>2950</td><td>112</td><td rowspan="2">150</td><td rowspan="4">108</td></tr>
<tr><td>3050</td><td>86</td></tr>
<tr><td>3150</td><td>80</td><td rowspan="2">108</td></tr>
<tr><td>3250</td><td>60</td></tr>
</table>

**8.7.1. Along 100 m elevation step:** Statistical test has been carried out targeting the elevation bands of 100 m, 200 m and 300 m to find out the species richness in three different classes at species, genus and family levels. In every 100 m elevation steps there are eight sample plots which seems less to see the pattern of species richness curve. The species richness pattern in 100 m elevation band is statically not significant ($R^2$ Value is 0.502) owing to the effects of local factors in the Eastern Himalayan region as well as topographic factors (steep slope/shortest elevation zone) along this elevation band.

**8.7.2. Along 200 m and 300 m elevation steps:** Additionally, statistical tests have been carried out targeting the elevation bands of 200 m and 300 m with 16 sample plots and with 24 sample plots of 20 x 20 m, respectively. In the second polynomial regression equation, the relation between species richness in 200 m is $R^2 = 0.553$ and $p<0.01$ and for 300 m it is $R^2=0.73$ and $P<0.01$, which are statically significant and express that the relation between species richness and elevation is improving in the combined data set or in courser resolution or number of sample size may be increased to produce the better result. Behera and Kushwaha (2007) discussed that the fine resolution data may improve the result in the eastern Himalaya. It can been seen that along 100 m elevation step, data set of eight plots of 20 x 20 m are not sufficient to understand the actual relationship between species richness along the elevation step of 100 m in the Eastern Himalaya Sikkim. The list of number vascular plant species in each 100 m, 200 m, 300 m elevation steps are given in Table 8.4.

Though the species richness followed the hump-shaped relationship with elevation showing a peak in between 1500 – 1800 m for species genera and families (Fig. 5.19 & Fig. 5.20).

Obviously, a few studies have assumed that a species with particular altitudinal range will be present within each 100 m band of that range and thus interpolation violates control over sampling area and intensity. Such type of studies have clearly ignored the local ecological factors those might have significant impact on the alpha as well as beta diversity of a place. Furthermore, the magnitudes of change of microclimatic conditions in the 100 m bands are not remarkable compared to that of an individual plot. According to (Ricklefs, 2004; Whittaker*et al*., 2001) the characteristics of biodiversity generally result from two factors, evolutionary history and contemporary ecological conditions. If it assume that evolutionary history is identical, it can understand that the species groups that have the same or similar ecological requirement and ways of adapting or responding to the environment may also exhibit the same or similar distribution of diversity in space. Conversely, Whittaker *et al.* (2010) and Meentemeyer (1989) opined that ecological phenomena are hierarchically structured, which are related closely to the scale of observation. The challenge to contemporary ecology and biogeography is to document scale dependence or independence in different systems. The species pool is regarded as an important factor in determining community richness (Eriksson, 1993). This was seen in the elevation of 950 m where number of individual is less but numbers of species are more as compared to other bands.

The low elevation sites were relatively densely populated probably because of human interferences in these areas facilitates the introduction and establishment of non-native species (Rawal & Pangtey, 1994). These spaces may intensify the establishment of shade intolerant species and enhance the regeneration of mixed pine-broadleaved forests (Wangda & Ohsawa, 2006). As a result of which the maximum species were encountered at lower elevation compared to higher elevation sites. The human impact at lower altitudes was evident in the form of open spaces left after felling of selective species.

### 8.8. Effect of the forest ecotone

Lomolino, (2001) has studies an ecotone effect (high diversity in the ecotone due to significant overlap between communities) in the context of elevational gradients and source-sink dynamics. The proportion of species shared and the amount of overlap between communities can play a significant role in determining the unimodal pattern of species richness by shifting of species to ecotone zones, which can also be explored further by looking at the contribution of marginal/sink species to the richness dynamics in the zones of overlap. Along a local gradient, richness in the ecotone was likely to be composed of ecotone specialists and a number of low abundance sink species contributed by spill over from adjoining biomes as shown by rescue effect as reported by Brown & Brown (1977) .

Similarly, the floristic and ecological importance of the forest in phytogeographical zonation has remained unquestioned (Odland & Birks, 1999). The plant species richness with the distance is often associated with abrupt change in climatic and other environmental conditions (Kirkpatrick & Brown, 1987).

The Himalayan region is a unique physiogeographical region with an average elevation above 4000 m. Zheng *et al*. (1981) reported that the monsoon and westerly are strongly influenced by climatic zones. The topographic configuration and atmospheric circulation determine the horizontal separation of natural vegetation segments. The vegetation changes successively from southeast to northwest with decreasing moisture from montane forest, are gradually changing through high-altitude scrubs, alpine meadows, and alpine steppes to alpine deserts.

### 8.9. Species Richness and Environmental Parameters

A main aim of this study was to investigate the evident incompatibility between the need for implements that correctly predict ecological consequences of forest management and the current ecological knowledge and available environmental data. The approach taken in this study is experiential and uses observed environmental and altitudinal distribution patterns as a starting point for generating maps for such studies. This method requires accurate maps of species richness parameters in high resolution. Altitude itself is not an environmental gradient and therefore, is itself virtually nothing to life (Kroner, 2000; Brown, 2001). However, several environmental gradients, either singly or in inter-correlations, act significantly along the changing elevation and therefore, it represents a composite gradient of those environmental variables. It is very difficult to explore the drivers of the complex biological patterns seen along the elevation gradients from the independent effects of single overriding forces (Lomolino, 2001). However, many studies have explored plausible driving factors for the prevailing patterns (Grime, 1997).

This study was undertaken along the high elevation range of East district of Sikkim focusing upon prevailing species richness and production of biomass. Anthropogenic and natural factors (e.g., wild fire, landslide, trekking, tourism, cattle grazing, strong wind, snow avalanche, etc.) responsible for disturbance of forest ecosystem have been identified through field survey. Bedsides, other factors may also have a bearing on sampling effect, facilitation and complementarily.

Total species richness, i.e. of all life-forms or habit-groups, has a significant hump-shaped pattern along the altitudinal gradient (elevation). Maximum species richness occurs at optimal elevation of 2100 – 2200 m, which is the trans-ecotone zone of two type of forests or vegetation. It has been observed that species richness varies in elevation between 1100 – 1200 m and 1300 – 1400m owing to human interference as well as changing climatic conditions. It has been reported that in Sikkim Himalaya, the species decreases along the altitude starting from the elevation range of 2400 – 2600m (Acharaya *et al.*, 2011). As per field observation, the north facing slopes have more species compared to the south facing slopes. Shrubby species decreases after 1800 – 1900 m as the area above 2000 m are mostly covered with different species of bamboos like *Arundinaria acerba*, *Chimonocalamus griffithianus* and *Arundinaria racemosa*. Owing to the dense population of these species in this region there is a less regeneration of other tree and shrub species. In majority of the cases, not a single shrub has been found in 20 x 20 m plots were these species were dominated. The variation of herbs in the region is attributed to the increasing anthropogenic activities or with the aggressive bamboo cover and it may also be due to changing climatic conditions.

Further, studies were also conducted the on geographical area and the species richness along the elevation was observed that the geographical area can play the major role for species richness along the elevation gradient in the Sikkim Himalaya, but further research needed to conclude the relation between geographical area and species richness in such mountainous regions.

### 8.10. Biomass along altitudinal (Elevation) gradient

Biomass is described as the plant material produced as a result of photosynthesis and its accumulation in different forms in the plant body. Its measurement is based on commonly accepted principles of forest inventory and ecological survey. Good estimation of stem volume forest biomass on account of its ever changing nature remains an interesting and challenging task for the researchers. The field data like forest type, density, stem diameter at breast height and the tree height are normally collected to calculate the biomass. The field inventory is not only a tedious and time consuming task, it becomes too complicated to carry out field survey manually in heterogeneous forests as the number of species within the stand increases.

Biomass has been calculated using the volume of different tree species in the study area using the FSI-2006 volume equation. After calculating the volume of each species, the specific gravity of the tree has been used to calculation the biomass. The general volume equation was used for the trees whose volume formula was not available. The biomass also shows the unimodal relationship along the altitudinal gradient in the study sites.

The biomass of herbs, shrubs and epiphytes were also calculated using the percentile factor among different forest types ( Chaturvedi & Singh, 1987; Rawat & Singh, 1988; Singh & Singh, 1991). Data has tested at different elevation bands with 100 m, 200 m and 300 m elevation steps to see the effect of scale. The relationship between biomass along the altitude in different elevation bands were shown in Figs. 5.27, 5.28 & 5.29.

The biomass ranging from 6.3 t/ha at 3150m and 68.6t/ha at 2650m in different elevation range of Sikkim Himalaya. Sundriyal and Sharma (1996) recorded 8.32 t/ha woody biomass from Mamlay watershed in South Sikkim. In the present investigation, the average biomass of East Sikkim was determined to 38.8t/ha, whereas Chhabra *et al*. (2002) reported that Sikkim contributes 48.1Mt/ha.

The above ground (AG) biomass distribution pattern showed alternate increasing and decreasing pattern along the elevation gradient. In general, the AG biomass showed a smooth increase up to mid-elevation and decrease further. The $R^2$ values increased (i.e., 0.28, 0.41 and 0.58) when plotted from 100 m to 200 m and 300 m elevation bands. The AG biomass pattern along elevation gradient showed non-linear polynomial relationship, where in it confirmed the pattern of mid-elevation peak in the East district. Here, the primary productivity measured by the AG biomass is found to be positively correlated with plant species diversity as the productive forest ecosystems have more species, there by more productivity (Huston, 1994).

Bhattarai *et al*., (2004) observed a significant unimodal relationship between species richness and biomass in an arid sub-alpine grassland of the Central Himalayas, Nepal. They observed lower turnover in the old field than in the common pasture. Namgail *et al*., (2012) while analyzing the dry alpine communities between 4500 m and 5500 m in Ladakh of Western Himalaya reported a hump shaped relationship between aboveground phytomass and Elevation between 5,000 and 5,200 m, while it peaked between 3,500 and 4,000 m at entire Ladakh level. Benito et al., (2014) used 54,000 plots of the Spanish Forest

Inventory and maximum likelihood techniques to quantify how climate, stand structure and diversity shape carbon storage and tree productivity. They found a consistent positive effect of functional diversity on carbon storage and tree productivity was observed in all seven forest types studied. This relationship was not linear, and the largest changes in carbon storage and tree productivity were observed at low levels of functional diversity. They also found a generally positive effect of diversity on carbon storage and tree productivity, supported by both complementarity and selection mechanisms (Benito *et al*., 2014).

Relationship between biomass along the 100 m elevation step has been presented in Fig. 5.27.As it was seen, the pattern of biomass along the altitude in the lower elevation of 500 – 600m starts from 29.1 t/ha. It increases slowly and has reached around 40.0 t/ha in the elevation of step of 800 – 900m which represent the ecotone region of tropical and sub-tropical forest and again it decreases with increasing the elevation zone at 1400m. Between 1000m to 1500m there are major human habitations in East district. And, the decrease of biomass has been attributed to the anthropogenic activities in this eco-region. Besides, there are limited numbers of big trees in this eco-region as most of the trees were harvested for human consumption. The biomass, t/ha, again increases and reached to around 60.0t/ha at the elevation step of 1600 – 1700m which is the second ecotone for sub-tropical and temperate forests. Again, the biomass decreases down to 35.0t/ha at the elevation step of 1900 – 2000 m and then starts increasing with the increase of elevation and it reached around 69.0t/ha at the elevation step of 2600 – 2700 m which is the highest pick of biomass production. After the elevation step of 2700 m the biomass production decreases and it becomes less than 10.0t/ha in the elevation step of 3100 – 3200 m. The overall pattern indicated that the biomass decreases with increase in the elevation excluding the ecotone areas. Similar observation was also reported by Wang *et al.* (2014) who have conducted study above 3100 m ranging up to 4300 m in the elevation gradient on the Tibetan Plateau.

## 8.11. Satellite based correlation

Geometric and radiometric corrected optical data was procured for the present experiment. The processed data were further used for the assessment of EVI2 (a proxy for biomass).The data was tested in simple linear equation, the pattern of field derived biomass and EVI2 derived from Landsat, shows the positive relationship with $R^2 = 0.5$ as shown in figure 4.31. Similar result was found by Tan *et al*. (2007) during their study on satellite based estimation of biomass for north-east china. They tested their finding using the regression model for NDVI and field based biomass. But, Devagiri *et al.* (2013) and Zheng *et al.* (2004) found the NDVI and area weighted above ground biomass (AGB) $R^2$=0.8. The presently collected data was segregated in three different categories or classes: (a) EVI and field derived biomass in 100 m elevation steps, where the $R^2$ value was 0.32; (b) present data for above subtropical forest to subalpine forest were tested to see relationship and that was found to be $R^2$= 0.31; (c) such data was again tested for the relation between temperate forest to subalpine forest that showed $R^2$=0.80. This result shows even the fragmented data from different forest zones, the relation of biomass and EVI showed no any recognizable difference. But, if moved further towards the higher elevation the relation shows significant result. This may be due to the high moisture contents in the un- or low disturbed forests of high altitude areas. In such areas disturbances are caused mostly by the large number of visiting tourists and the activities of plant hunters. The field derived biomass production and MODIS productivity (1km x1km) was not found good relationship, it may due to the scale effect (i.e. the total geographical area of the study are is very small 954 sq km)

To understand the better relationship the further extensive research is needed to evaluate the climate change related studies in different sectors of the Sikkim Himalayan regions.

**8.12. Relationship between Species Richness and Biomass Production along the altitude**

The relationship between species richness and biomass is tested in three different scales, as it was discussed above. It has been observed that there was a better relation in regional scale as compared to the local scale. In first 8 nested quadrats in each of the 28 different elevation steps the $R^2$ is less than 40%. But, if another eight quadrat in the same points are added the relation becomes more than 50 %. Similarly, if further 8 quadrats are added then the relation between biomass and species richness increases to over 80 %. This shows that there is major role of scale between biomass and species richness in determining the relationship, which can be referred as multi-scale dependant mechanism (Simova *et al*. 2013). They found that, at the smaller spatial scale of individual plots, there was significant curve that shows linear negative relationship between species richness and productivity. Whereas, at the larger site scale it is turning into a non-significant relationship.

The relation between species richness and biomass along the elevation gradient has also been tested using the second order polynomial regression equation, and the determined relation is 27 %, 30 % and 58 % respectively for 100 m, 200 m and 300 m elevation steps.

The result has also been tested with different environmental variables. It was observed that there is a positive relationship of species richness and biomass along the altitude, as it was tested along the 100 m, 200 m and 300 m elevation gradients.

The data has been tested in the GLM model with seven variables. It was found that temperature plays the most important role for the relationship between species richness and biomass accumulation along the elevation gradient. Similar observation has been reported by Bhattarai in 2004. There are several ecological factors those might different types of impacts on different relationships. The relationship between diversity and productivity is based on the ecological effects of complementarity and ‘sampling’.complementarity suggests that species richness enhances productivity because of niche differentiation (for example, complementarity) or positive interactions (for example, facilitation) between species and therefore more of the available resources can be exploited. ‘Sampling’ means that more-diverse communities are, by chance, more likely to contain species with higher average productivity than are with low diverse communities (Venail1 *et al*., 2008).

Both species richness and AG biomass co-vary along elevation gradient showing strongly positive relationships. The relationship became prominent with increasing elevation and grain size of elevation bands i.e., from 100 m to 200 m and 300 m (with $R^2$ value increase i.e., 0.31, 0.53 and 0.80). Hence, productivity, one of the important factors is found to be correlated with elevation gradient potentially influencing species diversity.

**8.13. Relation of diversity with Temperature, Precipitation and Area**

The effect of area was highly conspicuous which supports the geographic area hypothesis that in higher areas availability facilitates more species to co-exist. Simultaneously, the crucial impact of precipitation and temperature, both at individual and combined conditions, explain the local effect of climate on species diversity. The non-linear spatial distribution of precipitation greatly affects moisture gradient characterise species diversity along the elevation in tropical areas (Brown, 1988). The precipitation that affects the moisture gradient, influencing high species diversity for epiphytes in tropical Andes (Gentry & Dodson, 1987), in moist temperate forests of Pakistan (Shaheen *et al*., 2012) and in the grasslands (Cornwell & Grubb, 2003) have been reported. Since, the study was within elevational range of 500 to 3300m, the influence of temperature was comparatively less significant. At higher elevation, the effect of temperature is significant as adiabatic lapse rate becomes lethal to plant physiology. It was assumed that the effect of candidate variables along elevation behave in non-linear fashion was substantiated by the curve pattern. Additionally, heteroscedasticity could be accounted by choosing appropriate poisson error distribution.

Despite combined effects of direct or indirect environmental variables no single parameter could explain the species richness pattern along the elevation (Whittaker, 1972). The more detailed study involving a wide range of ecologically significant variables can provide better explanations to the observed conditions of species richness along the gradients of elevation.

## 8.14. Status of Conservation in the Study area

Protected Areas (PA) are, and have been, the cornerstones of biodiversity conservation in the present era. Following IUCN guideline (Dudley, 2008) the Govt. of India has recently taken up some serious measures for the conservation of biodiversity by declaring many biodiversity rich areas as Protected or Reserve Areas for *in situ* conservation. As such, the proper management of these PAs, after notification, needed to be maintained with effective monitoring and strong enforcement of laws. Considering this fact, Govt. of Sikkim has declared (i) 01 Biosphere Reserve,(ii) 01 National Park, (iii) 06 Wildlife Sanctuaries and (iv) 01 Bird Sanctuary (Table 8.5).

**Table 8.5.** Protected area networks in Sikkim

| Name of the protected area | Location and district | Area ($km^2$) | Biogeographic Province | Altitude (m) | Year of Notification |
|---|---|---|---|---|---|
| Kanchendzonga National Park | North and West | 1784 | 1B | - | 1977 |
| Fambong Lho Wildlife Sanctuary | East Sikkim | 51.76 | 2C | 1524-2749 | 1984 |
| Shingba Rhododendron Sanctuary | North Sikkim | 43 | 1B | 3048-4575 | 1992 |
| Kyongnosla Alpine Sanctuary | East Sikkim | 31 | 2C | 3292-4116 | 1993 |
| Maenam Wildlife Sanctuary | South Sikkim | 35.34 | 2C | 2300-3263 | 1987 |
| Barsey Rhododendron Sanctuary | West Sikkim | 104 | 2C | 2200-4100 | 1996 |
| Pangolakha Wildlife Sanctuary | East Sikkim | 128 | 2C | | 2000 |
| Kitam Bird Sanctuary | South Sikkim | 6 | - | 320-875 | 2005 |
| Kanchendzonga Biosphere Reserve | North and West | 2620 | 1B &1C | 2725-5537 | 1997 |

*Source*: Lepcha & Das, 2012

Apart from these, many small pockets of forests, mostly located around the monasteries, village herbal gardens are forming part of traditional biodiversity conservation system in Sikkim. There are three sanctuaries [*viz.* Pangolakha Wildlife Sanctuary, Fambong Lho Wildlife Sanctuary and Kyongnosla Alpine Sanctuary] and some botanical and herbal gardens present in the East district of Sikkim for the conservation of biodiversity of the area.