सत्यमेव जयते

Assessment of the Impact of Climate Change on Forests and Biodiversity of Meghalaya

A study for the

Government of Meghalaya

The Research Team

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Abbreviations

MtC - Million tonnes of carbon
FSI – Forest Survey of India
Mha - Million hectares
CO_2e - Carbon di-oxide equivalent
LPJ – Lund Postdam and Jena model
IPCC- Intergovernmetal panel on climate change
NDC – Nationally Determined Commitments to UNFCCC
RCP – Representative Concentration Pathways
CMIP5 – Coupled Model Intercomparison Project – phase 5
NPP – Net Primary Producity
NTFP - Non Timber Forest Product
NDVI – Normalized Difference Vegetation Index
MODIS - Moderate Resolution Imaging Spectroradiometer from NASA
DGVM – Dynamic Global Vegetation Model
CRU – Climate Research Unit, East Anglia, UK
FAO – Food and Agricuture Organization of the UN

SUMMARY FOR POLICY MAKERS

1. Forest ecosystems are intrinsically linked to climate, ongoing and projected changes in climate will have an impact on the forests and biodiversity of Meghalaya.
2. Meghalaya is a forest rich state as the state has a total of about 80% of its geographic area under forest and tree cover, which is more than three times higher than the national average of about 24% (FSI, 2017).
3. Meghalaya is part of the Indo-Myanmar global biodiversity hotspot and home to diverse plants and animal groups. Indo-Myanmar is one of the most threatened biodiversity hotspots, due to rapid resource exploitation and habitat loss.
4. This study aims to assess the current state of the structure and composition of Meghalaya forests and its floral biodiversity. The study further aims to assess the impacts of projected climate change on the state's forests.
5. Forests in Meghalaya are already experiencing a variety of stresses, for example, based on satellite data (NDVI analysis) we find that about 50% of the forests in Meghalaya have experienced negative change in NDVI (indicating increased disturbance) in the last 16 years (2000-2016)
6. Satellite based assessment of Net Primary Productivity (NPP) over the last 15 years (2000-2015) suggest that overall NPP has declined in the state over this period, indicating increased forest stress and disturbance
7. Despite significant increase in forest disturbance, Meghalaya continues to be one of the leaders in the country in terms of forest and tree cover (about 80% of the geographic area)
8. We collected field based measurements from about 180 plots across Meghalaya, the field based analysis suggests an average carbon density of about 55 tonnes carbon per hectare (tC/ha) in the state, which is much higher than the estimates published by forest survey of India for the state (17 tonnes C/ha)
9. The field study identified a total of 243 species in the state. Species richness in the sample plots showed a wide variation from single species per plot in

degraded forests to almost 30 species per plot in high dense evergreen forests, species richness is generally found to be high in West Garo hills and parts Jaintia Hills, and low in districts of West Khasi Hills and Ri-Bhoi

10. Inherent (or current) vulnerability of the Meghalaya forests is computed using the IPCC, 2014 methodology and by using the vulnerability assessment framework developed by the Indian Institute of Science. We estimate that about 25% of the total forested area in Meghalaya has high or very high inherent vulnerability. About 64% of the forested area in the state is estimated to have low inherent vulnerability, indicating higher resilience in these areas. Forests in the districts of North Garo Hills and Ri-Bhoi are the districts with most vulnerable forests in the state, while the forests from East Jaintia Hills and East Khasi Hills districts being the most resilient.
11. We project the impact of climate change in future by using a vegetation dynamics model Lund Postdam and Jena (LPJ) and high resolution multi-model climate change projections, we find that under the high emission scenario a large number of the forested grids (about half of the total forested grids in the state) may not remain suitable for the existing forest types. This may have implications for biodiversity loss and provisioning of the ecosystem services in the state.
12. Model based projections suggest that Climate change presents both an opportunity and a threat to the forests in the state. The opportunity arises from the projections of increased productivity, increased biomass and increased soil organic carbon in some parts of the state. However the threat comes from the projections of shifting vegetation boundaries. Shifting vegetation boundaries in combination with the lack of biodiversity, disturbed and fragmented habitats, poses serious threats to forest ecosystems.
13. This assessment suggests that vulnerability in future, considerably increases under climate change scenarios. For example, in high emission scenario (RCP 8.5) in 2080s about 70% forested grids in the state become extremely vulnerable, the districts of West Khasi Hills, South-West Khasi Hills, East Khasi Hills, East Jaintia Hills, West Jaintia Hills and Ri-Bhoi are assessed to be the most

vulnerable and the forests in the district of South West Garo Hills and West Garo Hills are assessed to be the most resilient.

14. While we have used the best available downscaled climate projections and most advanced dynamic vegetation model, still we note that climate change projections especially rainfall projections are generally associated with high levels of uncertainty at local levels, especially in a hilly state like Meghalaya. Hence, inherent vulnerability should be given preference in planning current adaptation actions in the state
15. This study finds that the current vulnerabilities of the forest systems in Meghalaya arise from forest disturbances, fragmentation, patchiness, low biodiversity, and precarious mountain slopes. This study further finds that the fragmented and isolated forests in low biodiversity areas are especially vulnerable to the impacts of climate change as well
16. Thus we argue that management interventions required to address the current vulnerabilities and climate change vulnerabilities are identical and synergistic. Strengthening the structure and composition of forests, and augmenting the biodiversity in the state, will not only manage current vulnerabilities and weaknesses of the forest systems in the state but at the same time will also make the forests more resilient to future climatic stresses
17. We recommend that the impact and vulnerability information must be used in development of the working plans, in planning of afforestation programmes in the state, and in forest management in general.
18. Given the importance of the forest sector for the state, long-term forest monitoring programmes must be initiated in the state to periodically assess the structure and composition of the state’s forests.

Photo Credit: Meghalaya climate Change Centre

CHAPTER 1

Introduction

According to the Forest Survey of India (FSI) State of the Forest Report (FSI, 2017), Meghalaya state has a total of about 80% of its geographic area under forest and tree cover, which is more than three times higher than the national average of 24%. Meghalaya is part of the Indo-Myanmar global biodiversity hotspot and home to several plants and diverse animal groups. Indo-Myanmar is one of the most threatened biodiversity hotspots, due to the rate of resource exploitation and habitat loss. According to the estimate by FSI the distribution of forest area under different forest types (FSI, 2013) in Meghalaya is largely covered by five forest type groups, with the dominating contribution coming from the 'tropical moist deciduous forests', which account for more than 60% of the area under forests in the state, followed by sub-tropical broadleaved hill forests (17.7%), tropical wet evergreen forests (10.45%), sub tropical pine forests (8.3%), and tropical semi evergreen forests (1.9%).

In this study we aim to understand the current state of the forests in Meghalaya in terms of forest structure, composition, biomass, vegetation productivity and the distribution of biodiversity across the state. In this study we also try to understand as to how the forest ecosystems in the state are changing in the last decade and how could the projected climate change scenarios may further impact these forests. Based on the state of the current forest structure, composition and biodiversity across the state we attempt to identify vulnerable forest areas for conservation priorities and further we are interested in understanding how the current vulnerability (vulnerability refers to the degree to which a system is susceptible to, or unable to cope with, adverse effects climate variability, climate extremes and climate change) of the forests in Meghalaya may get impacted in future climate scenarios.

Mean annual temperature in Meghalaya has witnessed an increasing trend since 1950, more specifically the mean winter temperature in the state has increased by 0.6°C over the period 1951 to 2010, and post monsoon temperature has increased by 1.2°C over the same period (IMD, 2013). Annual mean minimum temperature has increased by 0.6°C and the minimum temperatures in the seasons of winter, monsoon and post monsoon has increased by 1.2°C, 0.6°C and 1.2°C respectively, over the period 1951-2010.

Meghalaya literally means 'the abode of clouds' and the annual rainfall in the state varies from 4000mm to 11436mm. 'Cherrapunjee' and 'Mawsynram' located in the southern part of the state receive the highest rainfall in the World. India Meteorological Departments based on the observations of rainfall over the period 1951 to 2010 over whole of India concluded that Meghalaya witnessed the highest increase in annual rainfall in the country at 14.68 mm/year since 1960 (IMD, 2013). Further, an analysis of the observations of monsoon rainfall statistics from the three stations of Shillong, Cherrapunji and Guwahati over the last 150 years suggests that much of the increase in annual rainfall comes in the form of extreme rain events, while more beneficial low and moderate rain events have experienced a declining trend over this period (Prokop and Walnus, 2014). In recent years monsoon rainfall pattern in the state has witnessed erratic departures from its long term mean. Further, It is projected that under business-as-usual climate change scenario mean annual temperature in India increases by 3.3°C (RCP6.0) to 4.8°C (RCP8.5) and the all India annual rainfall is projected to increase by 6-14 % towards the end of the 21st century (Chaturvedi et al 2012). For the North-east India, including Meghalaya, Ravindranath et al (2011) estimated the climate change vulnerability using the IPCC climate scenarios. It is important to understand as to how these projected changes in climate could potentially affect the forest productivity and the distribution of different forest types in the state. Figure 1 shows the conceptual framework for climate risk assessment.

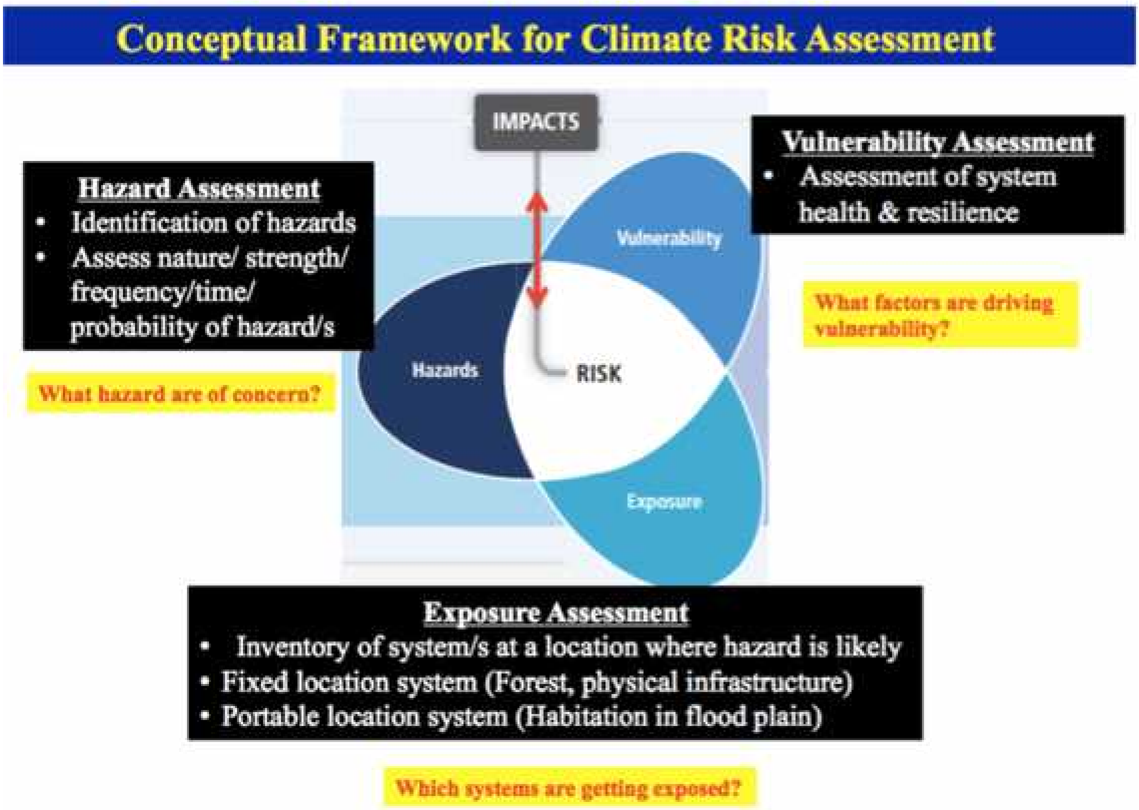


Figure 1.1: Conceptual framework of climate risk assessment (Source: IPCC, 2014)

Figure 1 suggests that the climate risk comprises of a triad of Hazard, Exposure and Vulnerability.

- Hazard is defined as "*The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts".*
- The exposure is defined as *"The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected". And*
- The Vulnerability is defined as *"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements*

including sensitivity or susceptibility to harm and lack of capacity to cope and adapt"

It has been argued that since Hazard is an externality, exposure is a situational aspect, both these components are less manageable. Whereas, Vulnerability being a systems' property can effectively be addressed and has a much larger manageability compared to the other components of the risk management framework. It is clear that by managing vulnerability climate risk (present and future) could be managed (Sharma et al 2013).

Provided this context, this study aims to:

1) Study the state of forests in Meghalaya and changes in the Meghalaya forest in the last two decades
   a) Document the key characteristics of the Meghalaya forests such as, forest composition and structure, forest productivity, forest biomass and its biodiversity based on satellite based assessments and field measurements
   b) Study the changes in Meghalaya forests and biodiversity based on satellite based assessments and field measurements

2) Assess the inherent (current) vulnerability of the forests in Meghalaya based on the Current state of the Meghalaya forests represented by its structure and composition as well as changes in the structure and composition of the forests in the last two decades.

3) Study the impact of projected climate change on the forests and biodiversity of Meghalaya using the dynamic vegetation model LPJ and an ensemble of dynamically downscaled CORDEX based climate projections
   a) Project the impact of climate change on the distribution and range shift of important forest types in the state
   b) Project the impact of climate change on the forest productivity and net primary productivity in the forests of Meghalaya

c) Project the impact of climate change on the soil carbon dynamics in the forests of Meghalaya

4) Assess the overall vulnerability of the forests of Meghalaya including the inherent vulnerability and climate change vulnerability
5) Identify critical and vulnerable forest areas in Meghalaya and suggest adaptation strategies for the state forests

Table 1.1: Key objectives of the study and the suggested methodology

S. No.	Objective	Methodology
1	Assess the state of the forests and floral biodiversity in Meghalaya	State of forests and biodiversity is assessed based on satellite data (MODIS) and field sampling from about 180 plots across the state
2	Assess the change in forests in the last decade in Meghalaya	The change in forests is assessed based on high-resolution satellite data for the state of Meghalaya over the period 2000-2016.
3	Assess the current/inherent vulnerability of the forests in Meghalaya	Inherent vulnerability of the forests in Meghalaya is assessed using the IPCC 2014 methodology, following the approach developed by Sharma et al 2017. This study uses: Biodiversity Index, disturbance index, canopy and biomass index and & slope as indicators for inherent vulnerability
4	Assess the impact of projected climate change on the forests and biodiversity of Meghalaya	We used high resolution multi-model ensemble to force the LPJ model to project climate change impacts on NPP, Vegetation distribution, biomass, and soil carbon
5	Identify critical and vulnerable forest areas in Meghalaya	We identify vulnerable forest areas in the state of Meghalaya based on the results of the inherent vulnerability analysis and projected climate change impacts

Organization of this Report

Chapter 1 Introduces the forests of Meghalaya its relation on climate change and the motivation and broad objectives of this report.

Chapter 2 Presents an up-to-date state of the forest of Meghalaya based on the data available with the Meghalaya Government, field and satellite data sets as collected by the Indian Institute of Science team

Chapter 3 presents an inherent vulnerability map of the state of Meghalaya using the IPCC 2014 methodology, following the vulnerability assessment process as developed by the Indian Institute of Science, Bangalore. We present a tier III inherent vulnerability mapping for the state to help develop adaptation and forest conservation interventions in the state's forests

Chapter 4 projects the impact of climate change on the forest ecosystems of Meghalaya using the state of the art LPJ vegetation dynamic model and regionally downscaled climate change projections from NASA/NEX. The chapter projects the impact of climate change on vegetation distribution, net primary productivity and soil organic carbon in the state under RCP scenarios of RCP4.5 and RCP8.5 in short term and long-term compared to the baseline of 1975-2005.

Chapter 5 combines the climate change projection scenarios in to the inherent vulnerability analysis to give an idea about the vulnerable areas in a climate change scenario.

Finally, **Chapter 6** summarizes the key policy relevant findings and subsequently concludes the report in the light of adaptation planning in the state.

CHAPTER 2

State of the forests and biodiversity in Meghalaya

This section documents the state of the forests in Meghalaya. This section also documents the recent changes in the structure, composition, productivity and biodiversity of the Meghalaya forests. Much of the spatial information shown here is used for constructing the current (inherent) vulnerability analysis for the forests of Meghalaya. The spatial datasets presented here are obtained from satellite platforms, field works and modeling (methodological details for which are provided in Chapter 3).

Figure 2.1 shows the spatial distribution of canopy cover in Meghalaya. The figure suggests that while around 80% of the state's geographic area accounts for forest and tree cover, much of it comprises of moderately dense and open forests.

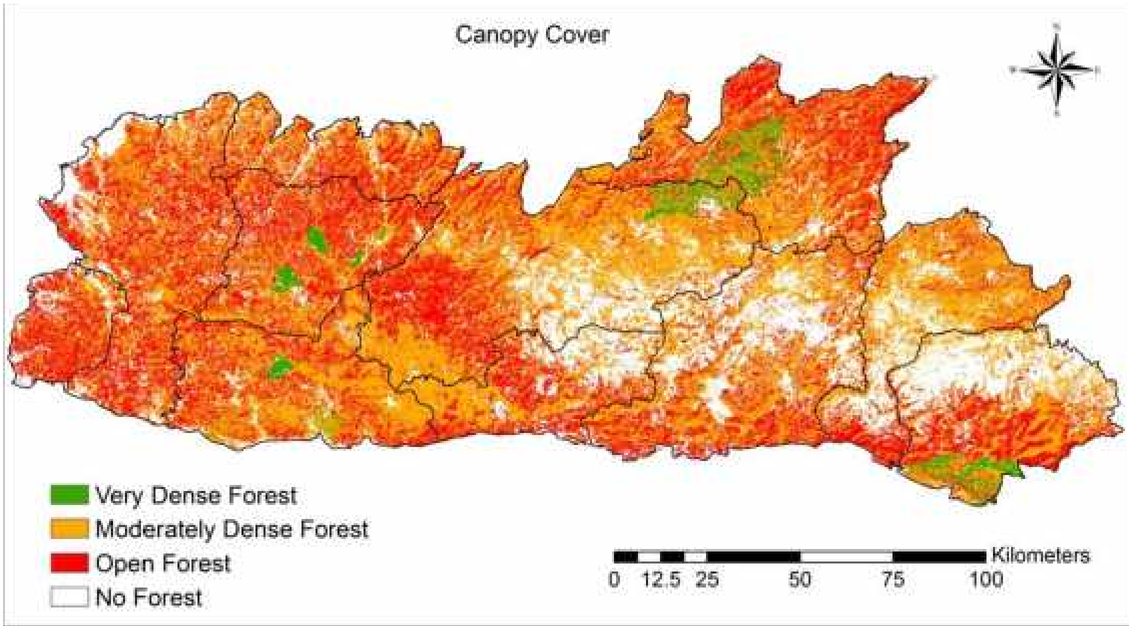


Figure 2.1: Spatial distribution of Canopy Cover in Meghalaya (FSI, 2013)

Figure 2.2 documents the spatial distribution of the key forest types in Meghalaya

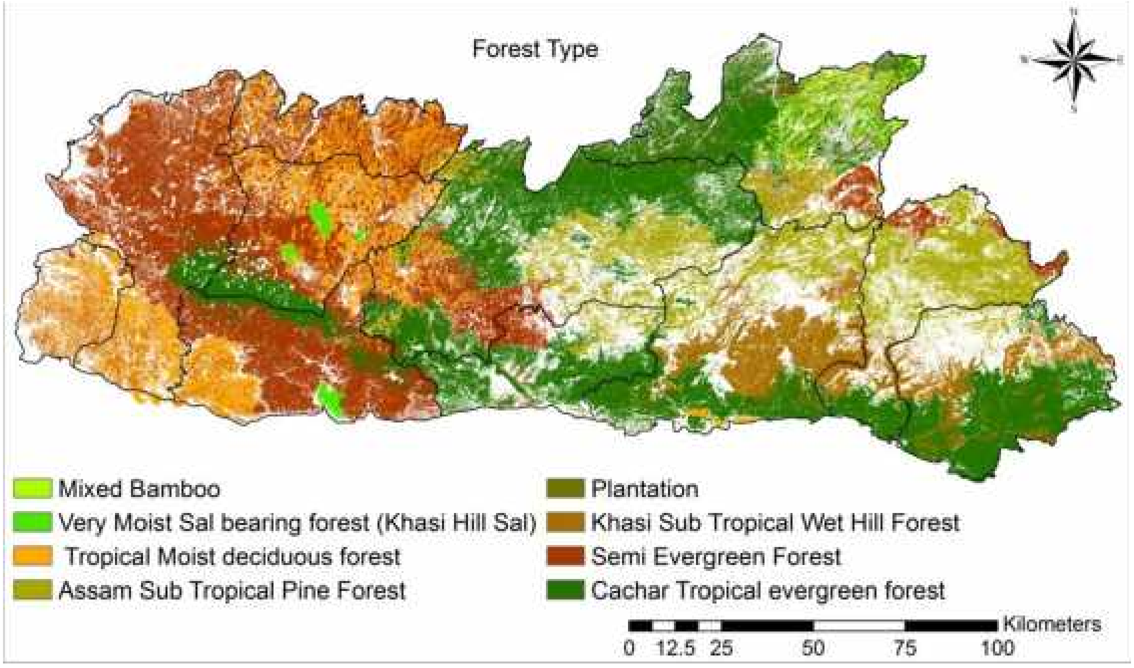


Figure 2.2: Key forest types in Meghalaya (Source: NESAC, 2017)

Species diversity is an important attribute of a natural community that influences functioning of an ecosystem (Hengeveld, 1996) and greater diversity may lead to higher stability of the community (MacArtur, 1955). Species richness, is defined as the number of species per unit area (Rebecca et al 2016). It is simply a count of species in an ecological community, landscape or region, and it does not take into account the abundances of the species or their relative abundance distributions

Species richness is computed based on the field data collection from 84 locations comprising of 182 plots across the state. Location of sampling plots and methodology is described in Chapter 3. Figure 2.3 shows the spatial distribution of species richness across Meghalaya. A total of 243 species were identified from sampling plots covering area of 7.3 ha across the state. Species richness showed wide variation from single species per plot in non-forest category to almost 30 species per plot in high dense evergreen forest

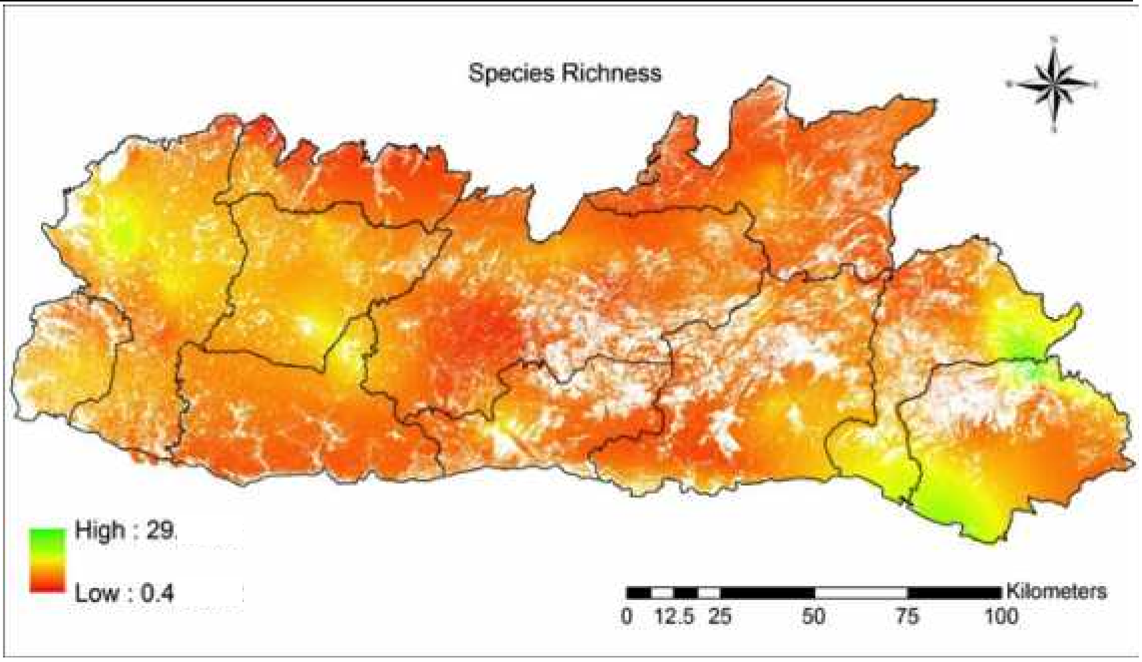


Figure 2.3: Spatial distribution of species richness in Meghalaya

Shannon Diversity index provides a quantitative measure of how many different species are present in a community (sample plot), while simultaneously considering as to how evenly the individuals are distributed among these species groups. Figure 2.4 shows the Shannon Wiener diversity index to vary from almost zero to 3 across the sample plots in the state. Further the distribution of the diversity index across is also shown in figure 2.4.

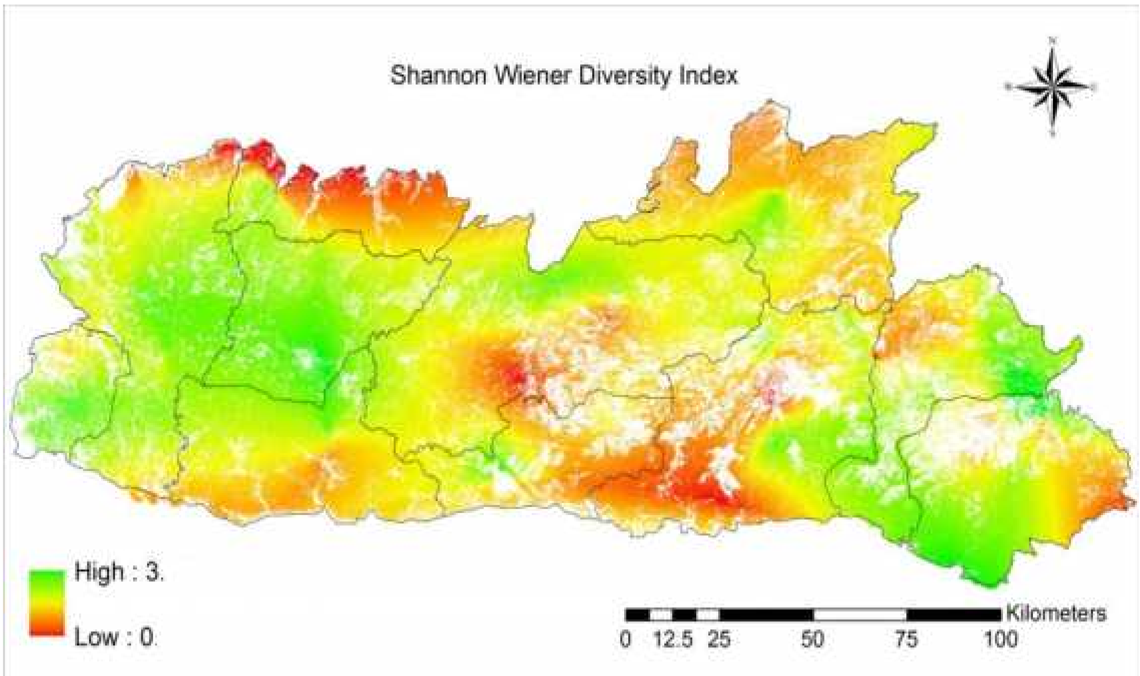


Figure 2.4: The Shannon Wiener diversity index of forests in Meghalaya

Species Importance Value is a measure of how dominant a species is in a given forest area. Importance value is the sum of the following three measures: relative frequency, relative density and relative basal area, each of these values is expressed as a percent, and ranges from 0 to 100. Since the Importance Value is a sum of these three measures, it can range from 0 to 300. The distribution of species importance value in Meghalaya is shown in figure 2.5 and in the state it varies from near zero to 16.

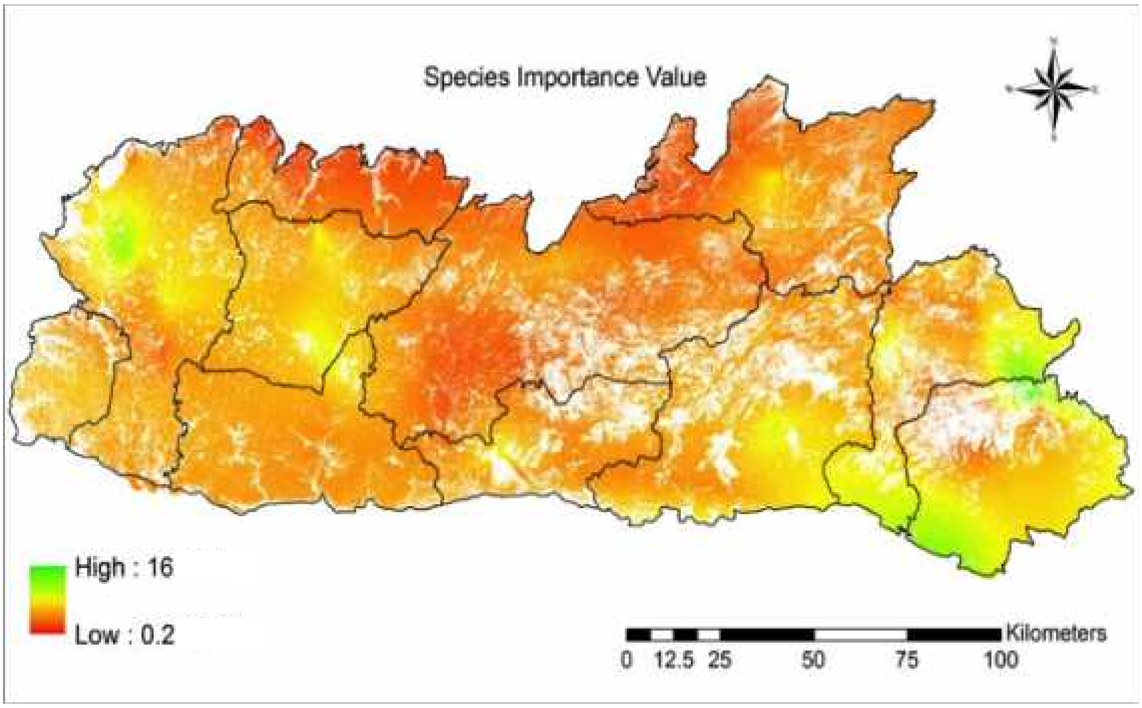


Figure 2.5: Spatial distribution of species importance value in the forests of Meghalaya

This field based analysis suggests a biomass density of about 110 tonnes per hectare in the state. Figure 2.6 shows the spatial distribution of biomass distribution in the state of Meghalaya.

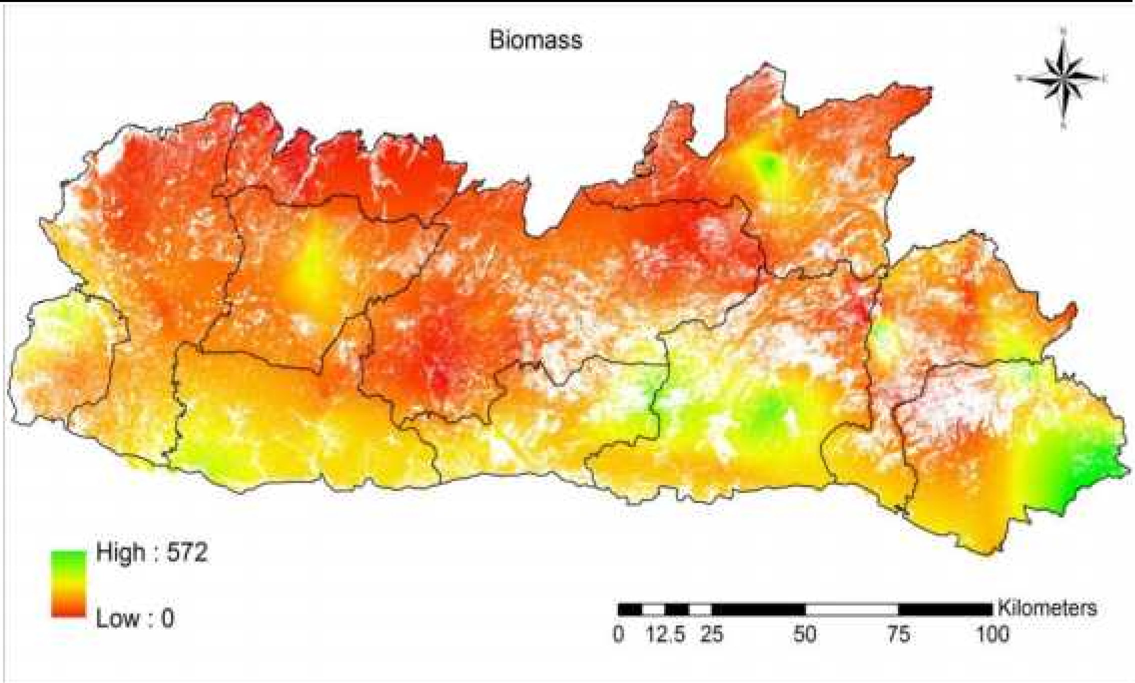


Figure 2.6: Spatial distribution of biomass density biomass in the forests of Meghalaya

Forest carbon stock in Meghalaya is estimated to be an average of about 55 tonnes carbon per hectare (in the above ground biomass pool). Figure 2.7 shows the distribution of forest carbon density in Meghalaya. The Forest carbon stock densities shows a large variability in Meghalaya.

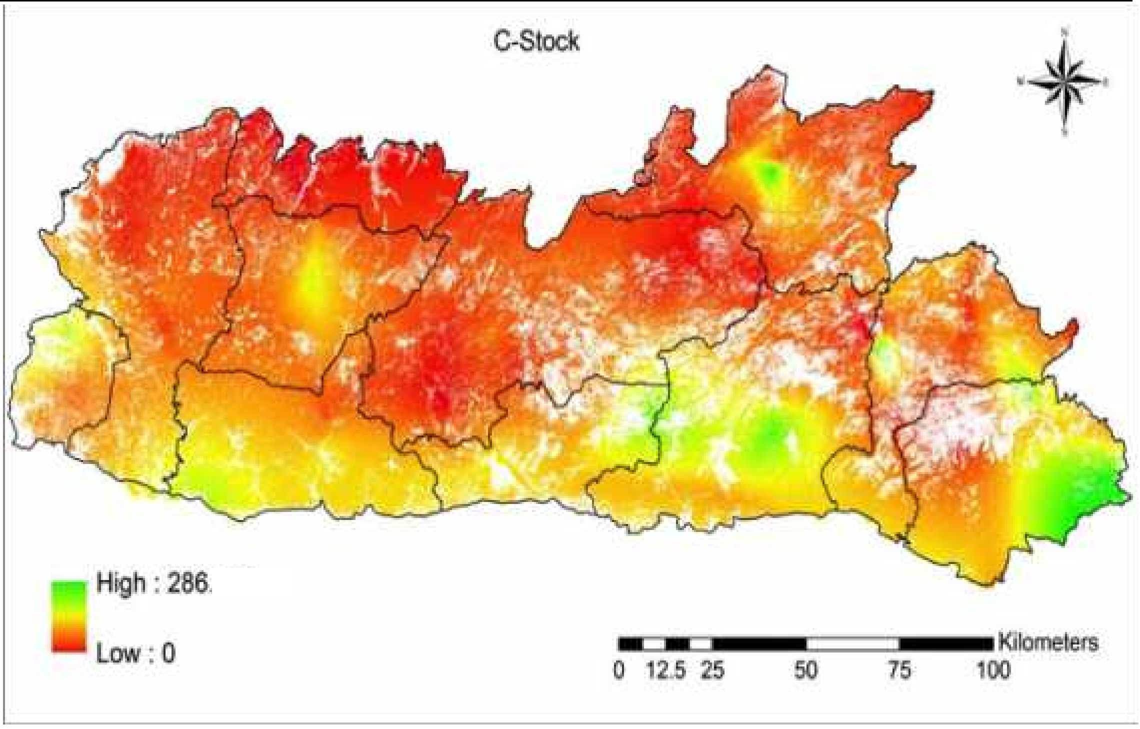


Figure 2.7: Carbon stock distribution in the forests of Meghalaya

This field study documents an average basal area for Meghalaya to be 14.8 m^2/ha. Figure 2.8 shows the spatial distribution of the basal area in the state of Meghalaya. The Basal area is shown to be highest in south-west Khasi hills and the lowest in west Garo hills (Table 2.1)

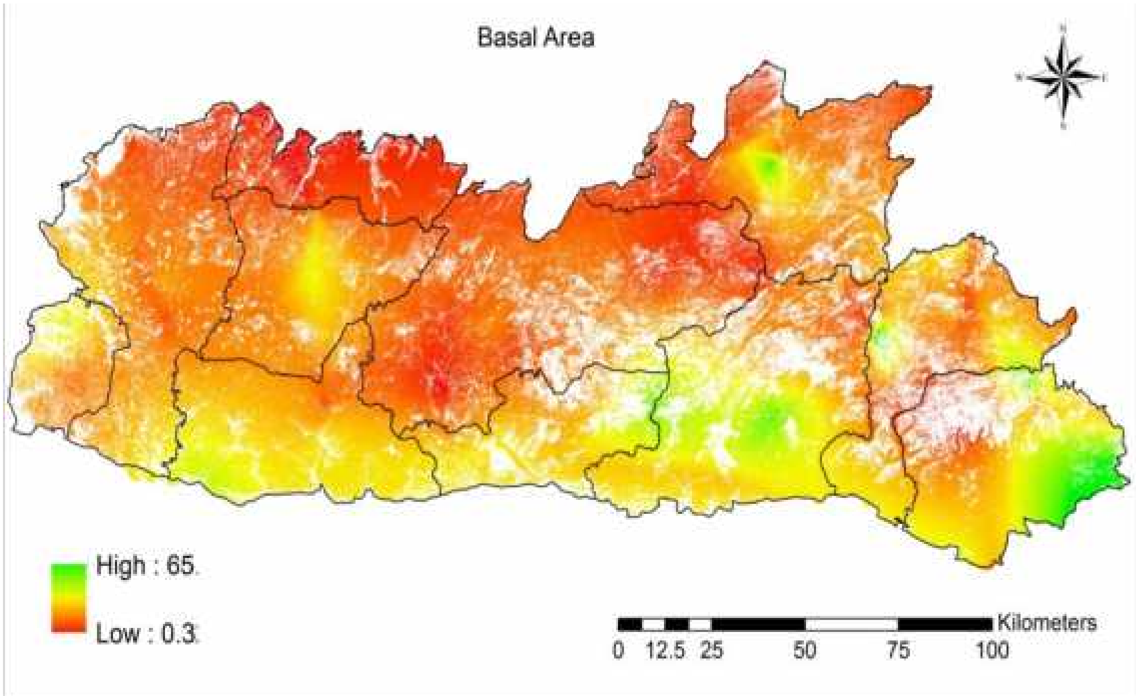


Figure 2.8: Distribution of basal area in the forests of Meghalaya

Table 2.1 summarises the key outcomes of the field study in terms of the description of the forest structure and composition in different parts of Meghalaya

Table 2.1: Forest structure and composition in different zones of Meghalaya

Sl. No.	Zones	Study area (ha)	Tree density (Count/ha)	Basal area (M^2/ ha)	Species richness	Shannon-Wiener Index
1	East Garo Hills	0.32	600	18.44	31	3.0
2	East Jaintia hills	0.72	603	24.36	93	3.3
3	East Khasi Hills	0.88	772	14.73	40	2.1
4	North Garo Hills	0.4	300	11.66	17	1.8
5	Ri-Bhoi	0.8	550	15.81	37	2.8
6	South Garo Hills	0.4	448	18.03	30	2.5
7	South West Garo Hills	0.4	248	19.08	31	2.8
8	West Garo Hills	1.04	485	11.05	61	3.1
9	West Jaintia Hills	1.12	737	13.62	46	2.4
10	West Khasi Hills	0.8	363	7.43	25	2.3
11	South West Khasi Hills	0.4	485	23.56	26	2.5
	Total	**7.28**	**543**	**14.78**	**243**	**3.70**

To assess the observed changes in the forests of Meghalaya we used satellite based Normalized Differential Vegetation Index (NDVI) and Net Primary Productivity (NPP) metrices. The NDVI is a measurement of the balance between energy received and energy emitted by objects on Earth. When applied to plant communities, this index establishes a value for the 'greenness' i.e. how green the area is, that is, the quantity of vegetation present in a given area and its state of health or vigour of growth. Since

NDVI is a dimensionless index, its values range from –1 to +1. Generally, the values that are below 0.1 correspond to bodies of water and bare ground, while higher values are indicators of high photosynthetic activity linked to forestlands and agricultural activity. NDVI is generally considered an indicator of vegetation health, as degradation of ecosystem vegetation, or a decrease in 'greenness', is reflected in a decrease in NDVI value (Tovar, 2011). The spatial trend in NDVI change across Meghalaya is shown in Figure 2.9. Our satellite data (MODIS) based analysis suggests that about 50% of the forest area in Meghalaya has experienced negative change in greenness (NDVI) over the last 16 years (Figure 2.10).

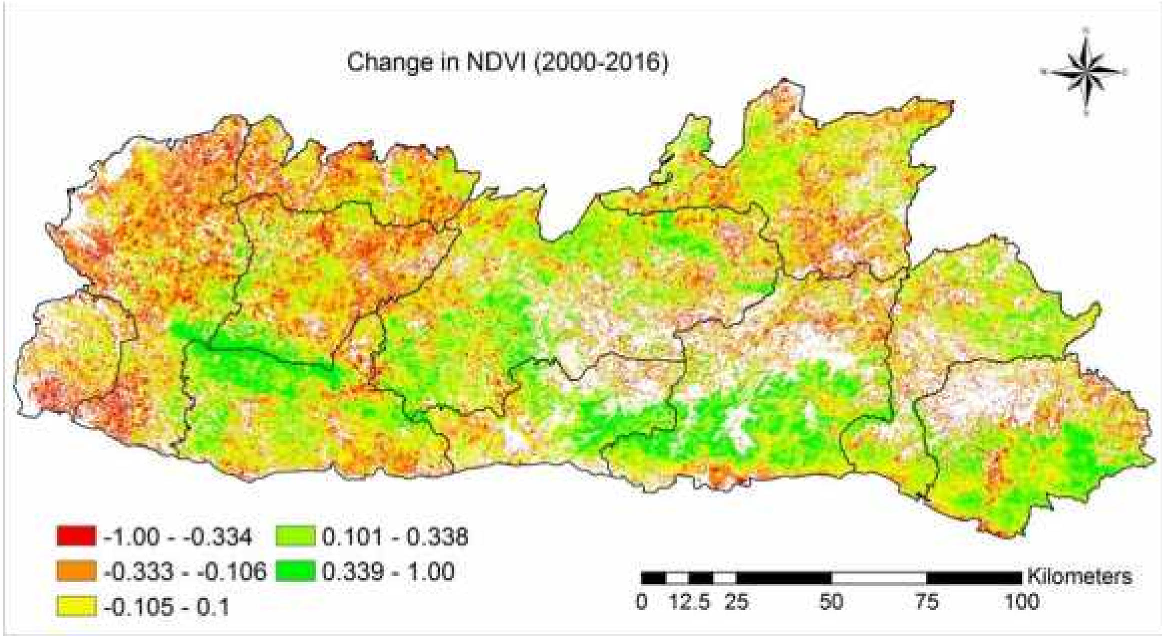


Figure 2.9: Change in NDVI over the forests of Meghalaya (2000 to 2016)

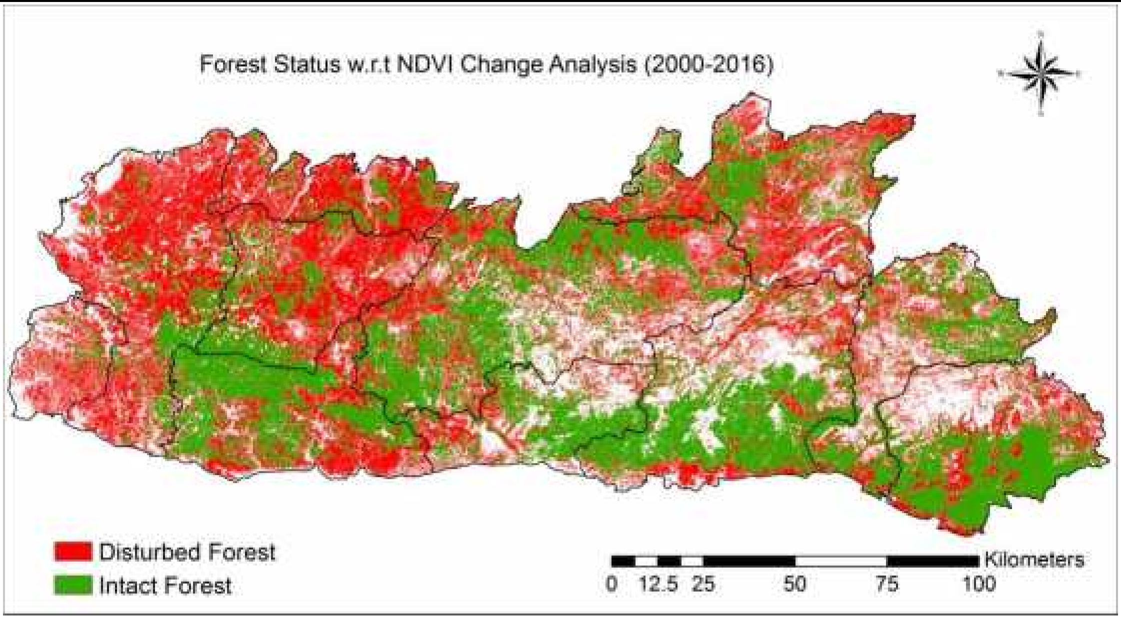


Figure 2.10: Status of forests as inferred from the NDVI analysis

Satellite based assessment of Net Primary Productivity (NPP) over the last 15 years (2000-2015) suggests that overall NPP has declined in the state over this period again indicating increased forest disturbance over this period

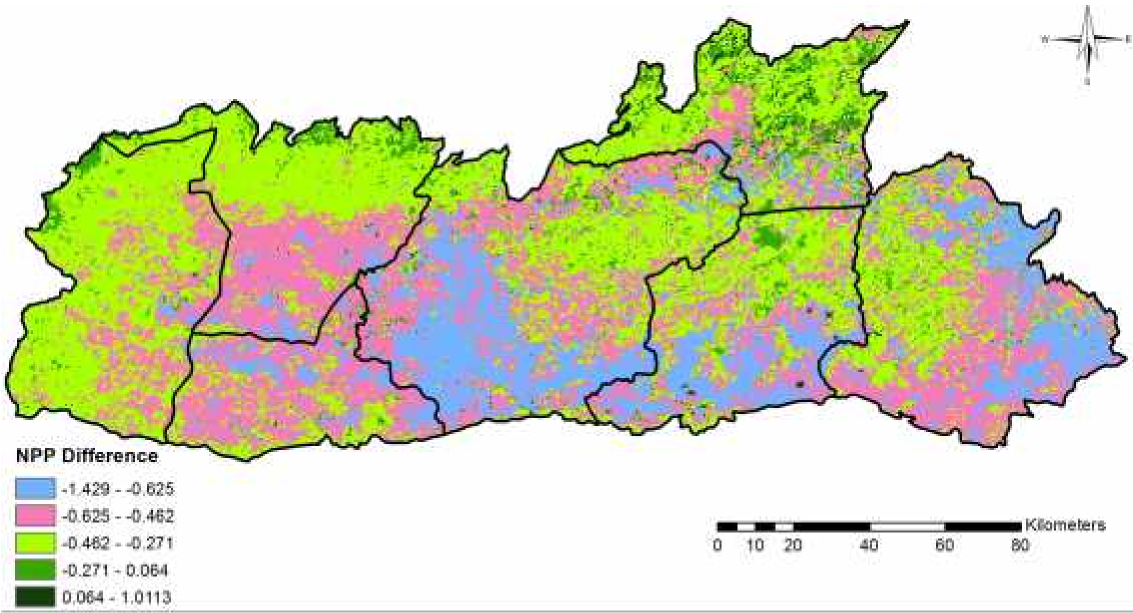


Figure 2.11: Change in Net Primary Productivity in the state over 2000-2015 (satellite based assessment)

Figure 2.10 and Figure 2.11 show the changes in NDVI and NPP over the period 2000 to 2015. Satellite based data products such as NDVI and NPP indicate the forest health and productivity. However, satellite based estimates do not provide an idea about the changes in biodiversity in the forests. Below we compare our new field study based estimates of forest floral biodiversity with a previous study carried out for a small part of the Garo hills. Figure 2.11 shows the change in floral species diversity over the period 2014 to 2017. Figure 2.12 shows the changes in Shannon-wiener index for the same region.

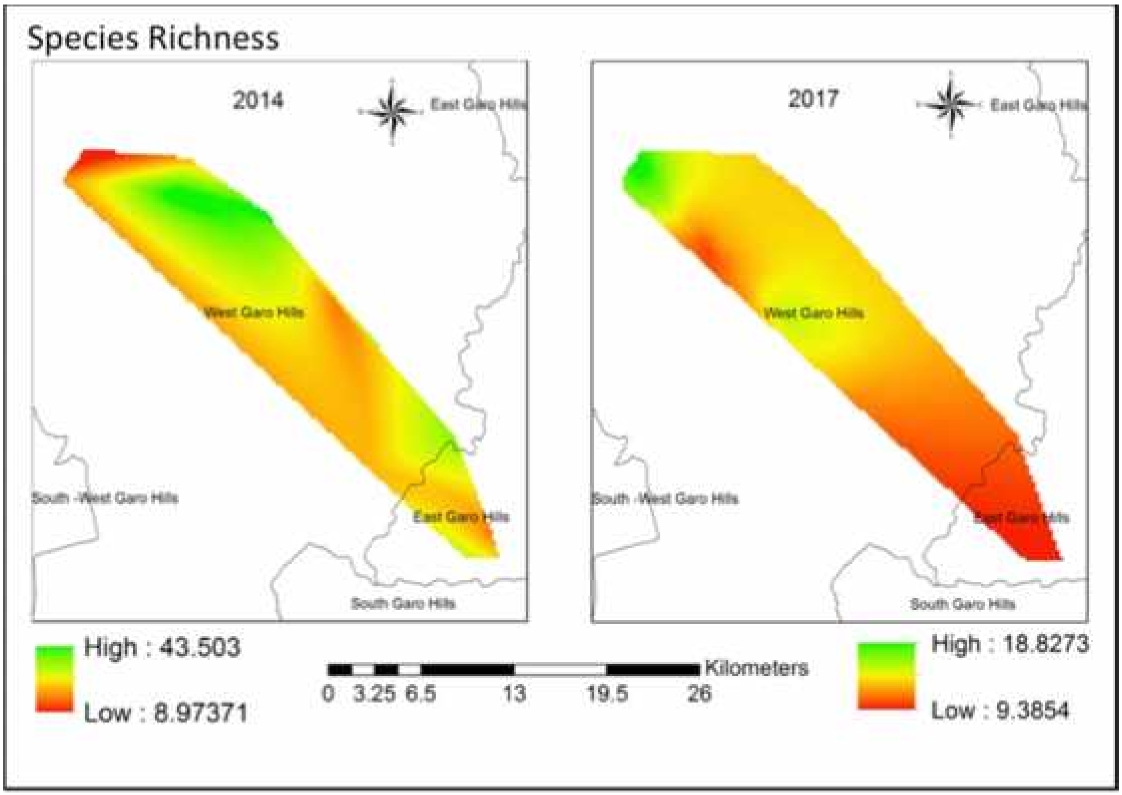


Figure 2.12 : Change in 'Species Richness' over the period 2014 to 2017 in a small part of the Garo hills

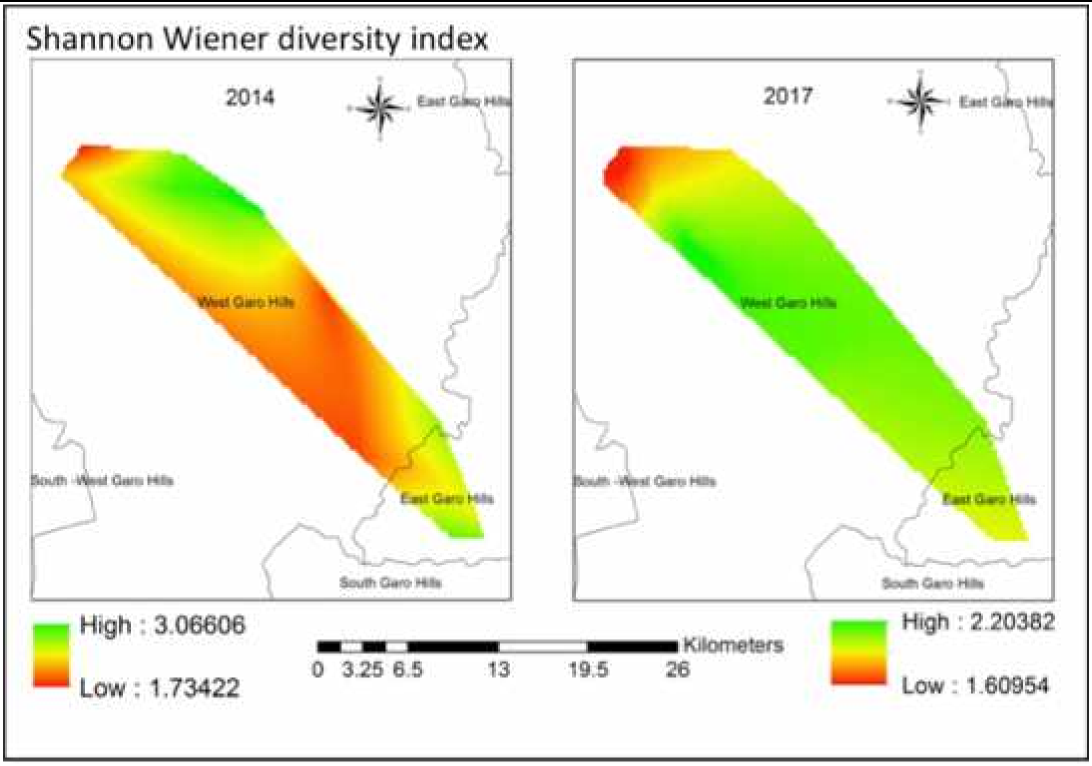


Figure 2.13 : Change in Shannon Wiener diversity index over the period 2014 to 2017 in a small part of the Garo hills

Figure 2.12 and 2.13 suggest a small reduction in species richness in this part of the state. However, we would like to caution that the sample location points in these studies are not the same and hence there could be uncertainties associated with the results shown in Figure 2.12 and 2.13. To assess long-term changes ecological change in forest structure and composition in the forests of Meghalaya, there is a need to establish long-term ecological monitoring plots in the forests of the state.

Photo Credit: Meghalaya climate Change Centre

CHAPTER 3

Inherent (current) vulnerability of the forests of Meghalaya

To assess the vulnerability of forests under current climate, we have operationalized the concept of inherent vulnerability. The concept of inherent vulnerability of forests and its usefulness in dealing with the risks to forest under climate change is discussed by Sharma et al. 2013. Sharma et al 2013 explain the concept of inherent vulnerability in the context of climate change as "a system property that determines the capacity of a system to resist a disturbance and adjust to it. It is independent of exposure". Assessment of inherent vulnerability of forest ecosystems under current climate is a reliable and practical option for the forest ecosystems as treating for current vulnerabilities identified during inherent vulnerability assessment attempts to restore the impacted forest ecosystems and enhances their inherent adaptive capacity (García-López and Allué 2012; Locatelli et al. 2008). Secondly, it reduces the chances for maladaptation, as implementation of adaptation plans that are based on the uncertain future projections are avoided (Metzger et al. 2006). Further, assessing the inherent vulnerability of forests under current climate and dealing with its drivers is a robust approach to deal with the risks to forests from current climate variability and future climate change. This is particularly useful in view of the uncertainty associated with the future climate projections, as adaptation plans based on such projections can lead to maladaptation. Figure 3.1 shows the general steps for assessment of the inherent vulnerability. Box 3.1 further elaborates these steps in specific details.

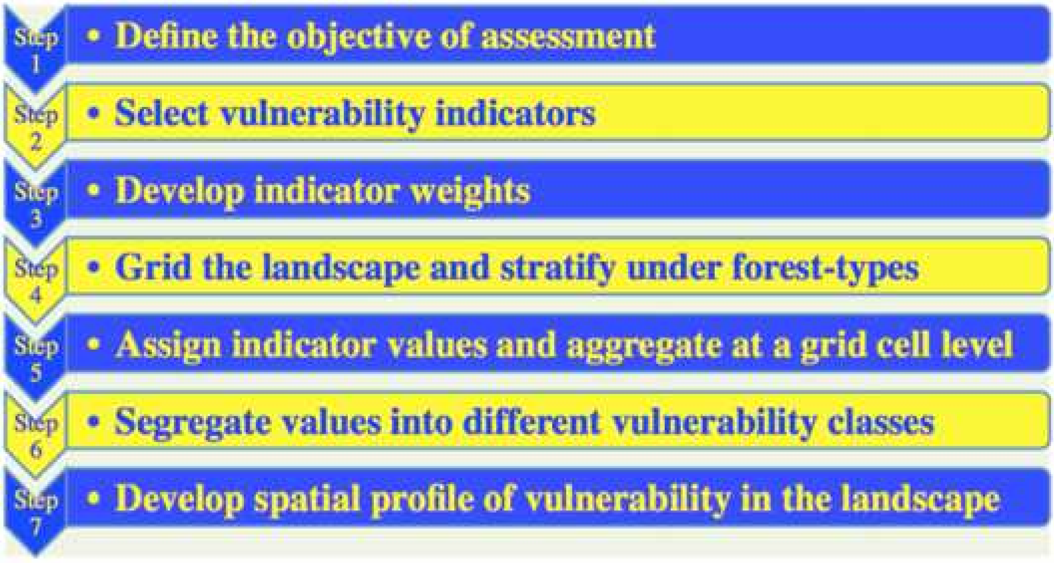


Figure 3.1: Steps for assessment of the inherent vulnerability

1. The first step involves identification of inherent vulnerability indicators specific to the region of study based on local knowledge and expertise.
2. The second step involves the compilation of the indicator data (in the form of maps, tables, graphs).
3. The third step is the preparation of indicator point maps and raster maps to work in a GIS environment.
4. The fourth step is to interpolate the point data and normalize the data for all the variables,
5. The fifth step is to reclassify the indicator maps (Biological diversity index, Disturbance index, Canopy cover index and slope gradient) based on the ranges to obtain vulnerability class map (1=least/no vulnerability, 2=low, 3=medium, 4=high)
6. The sixth step is assign normalized weights (*W*) for each indicator based on the relative importance of the indicators to obtain vulnerability due to an indicator (VC_{ij} x W_i). Where, $VC_{ij}$is vulnerability class value for ith indicator in jth grid and $W_i$is the weight for ith indicator.
7. The seventh step is the calculation of the vulnerability value (VV_j) at that grid cell level by adding the values for all the indicators in a grid cell ($VV_j = \sum_{i=1}^{13} VC_{ij}\ X\ W_i$). It is the vulnerability value for ith indicator of the jth grid.
8. The eight step involves mapping the assessment of vulnerability of forests at grid levels using the four composite indicator variables for the entire state, within forested boundary
9. The last step involved the calculation of the area under each vulnerability class with in the forested boundary and the entire state.

Box 3.1: steps involved for assessment of the inherent vulnerability in this study

As discussed in Box 3.1 first we describe the framework for indicator selection

Step 1: Identification of inherent vulnerability indicators

For the identification of the inherent vulnerability indicators we followed the framework developed by Sharma et al (2017). Figure 3.2 taken from Sharma et al (2017) describes the framework for identification of the inherent vulnerability indicators in a tropical forest ecosystem. Sharma et al (2017) developed the framework for the Western Ghats region of South India we applied the same framework for identification of the inherent vulnerability indicators in the state of Meghalaya.

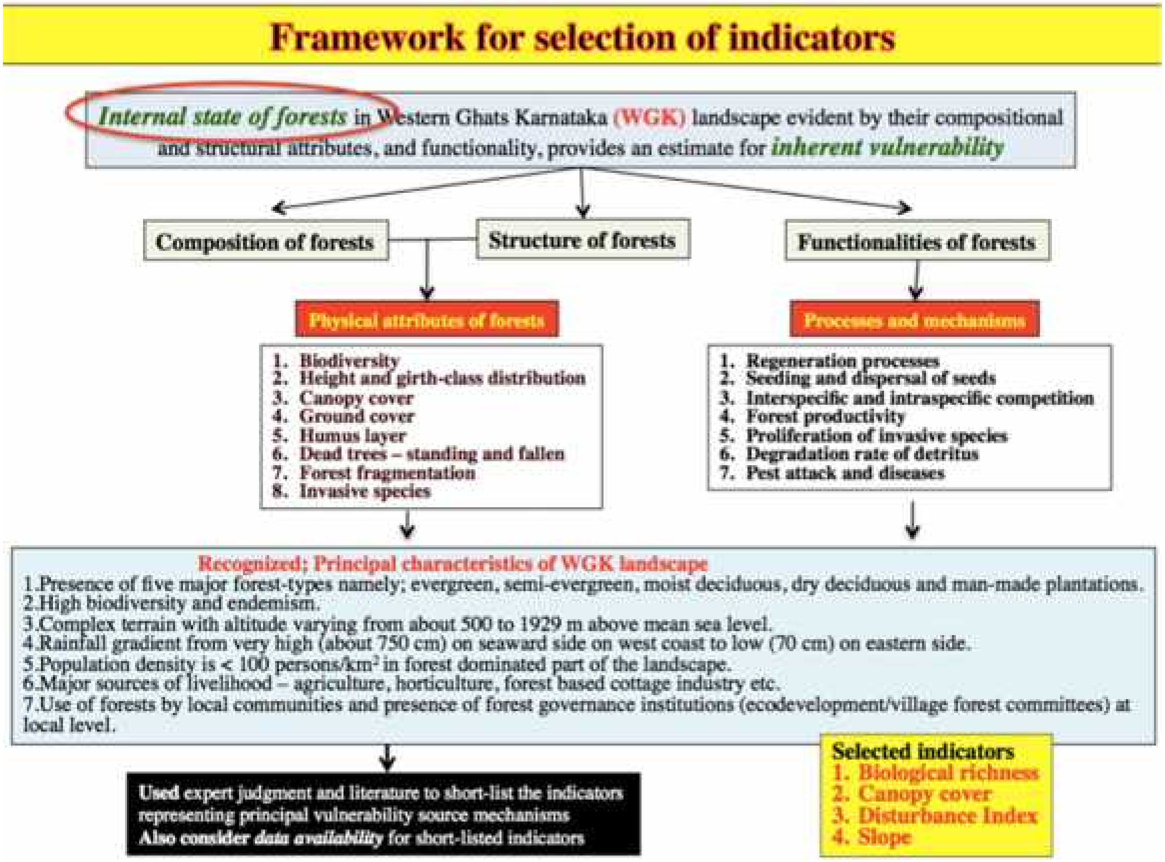


Figure 3.2: Framework for indicator selection for inherent vulnerability assessment

We selected the following four indicators of inherent vulnerability in the state of Meghalaya: 1) Floral Biodiversity Index, 2) Disturbance Index, 3) Canopy and biomass index and 4) Slope.

Second step in vulnerability assessment involves collection and compilation of the indicator data. Below we describe the generation of the indicator data with the help of satellite data, field-work and secondary data.

Step 2: Compilation of the indicator data (spatial maps)

1. Disturbance Index

We created a composite spatial disturbance index for Meghalaya using anthropogenic disturbances (such as road network, settlements and slash and burn affected areas) as well as natural disturbances in the vegetation systems in the state as illustrated by satellite based Normalized Difference Vegetation Index (NDVI) changes over the last 16 years (2000 to 2016) for which high resolution satellite data is available. Methodology for calculation of the disturbance index is shown in figure 3.3.

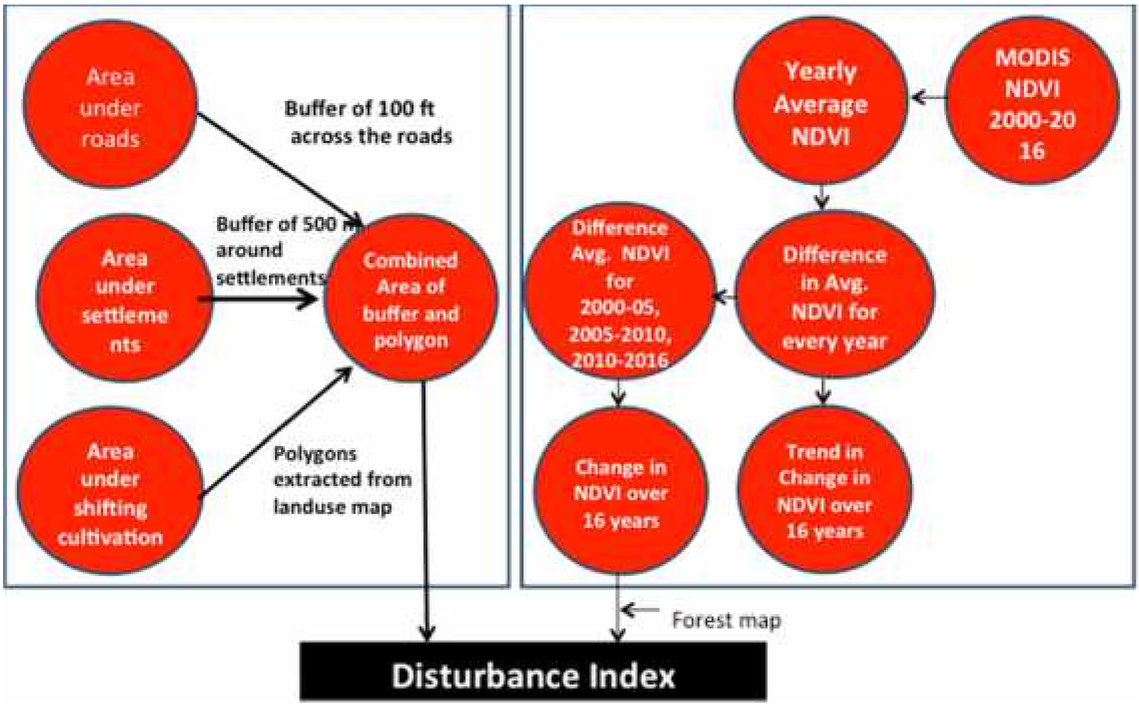


Figure 3.3: Methodology for computation of the disturbed forest area

Figure 3.4 shows the road network in the state and how a disturbance buffer is created around these road networks

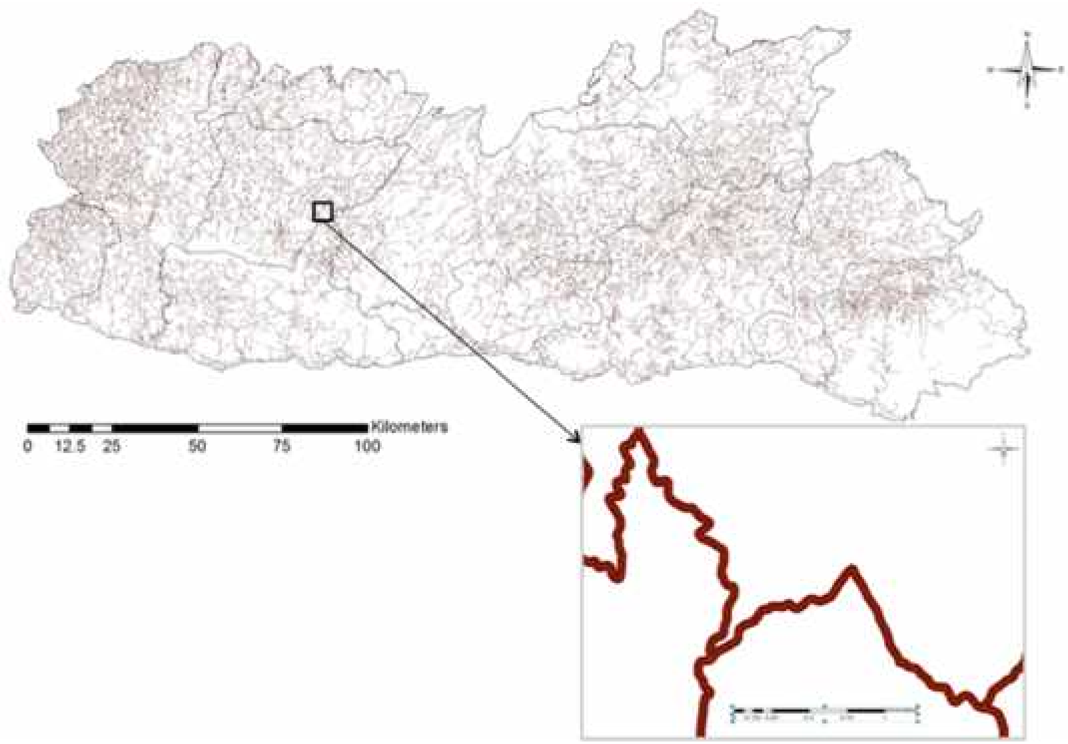


Figure 3.4: Road Network in forested areas in Meghalaya and the 100 feet buffer around the roads (inset)

Figure 3.5 shows the spatial distribution of settlements in Meghalaya and how a disturbance buffer is created around these settlements

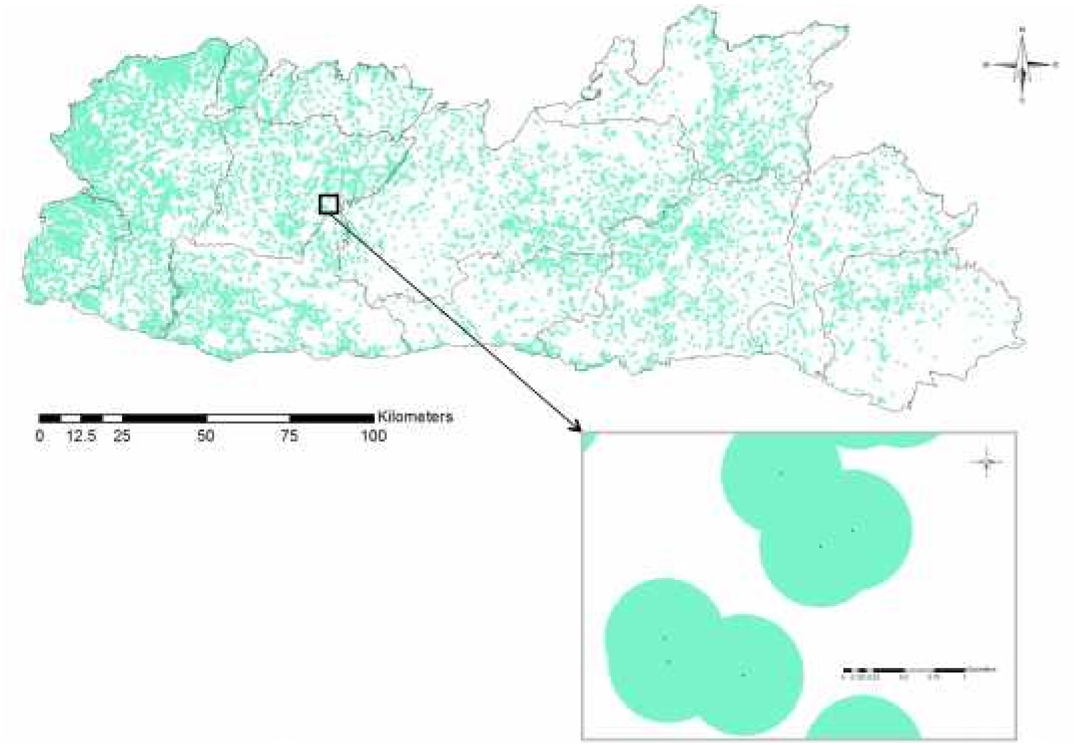


Figure 3.5: Distribution of settlements in Meghalaya and the 500 meter buffer around the roads (inset)

Figure 3.6 shows the spatial distribution of shifting cultivation areas in Meghalaya and how a disturbance buffer is created around these settlements

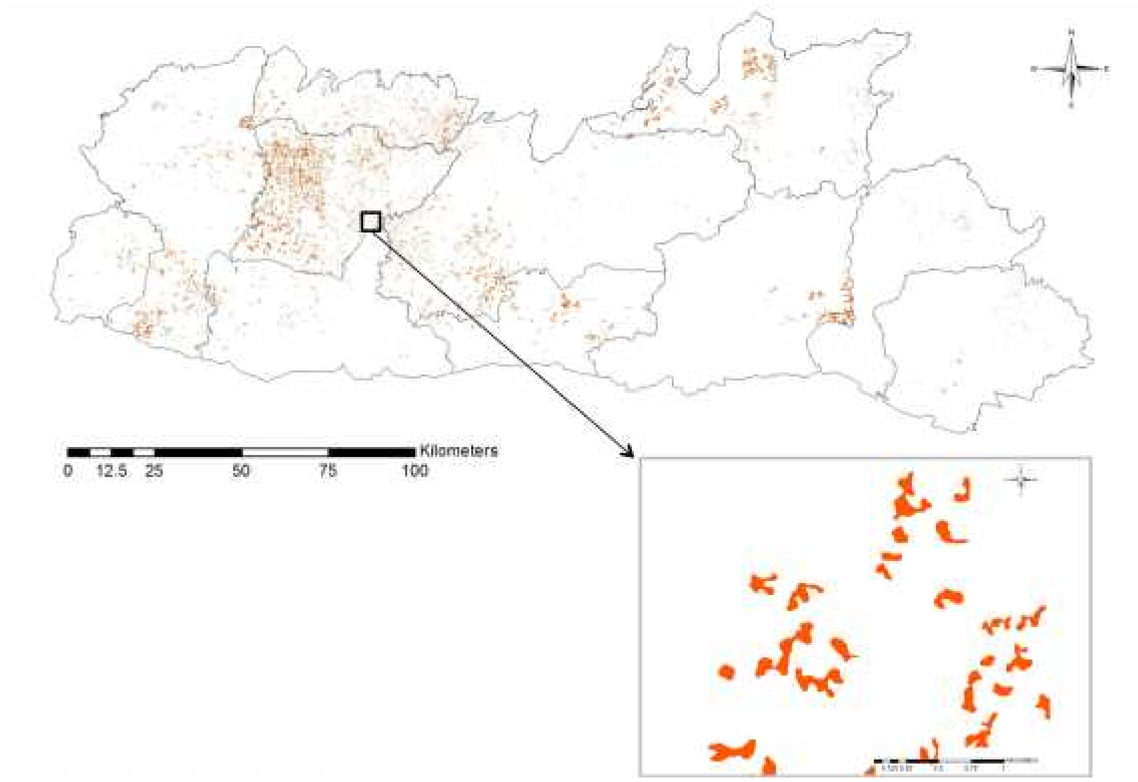


Figure 3.6: Distribution of shifting cultivation areas in Meghalaya and the buffer around these (inset)

Figure 3.7 shows the combined spatial distribution of the disturbed (within the forests of the state) area comprising roads, settlements and shifting cultivation in the state of Meghalaya. It also shows how a disturbance buffer is created around these areas

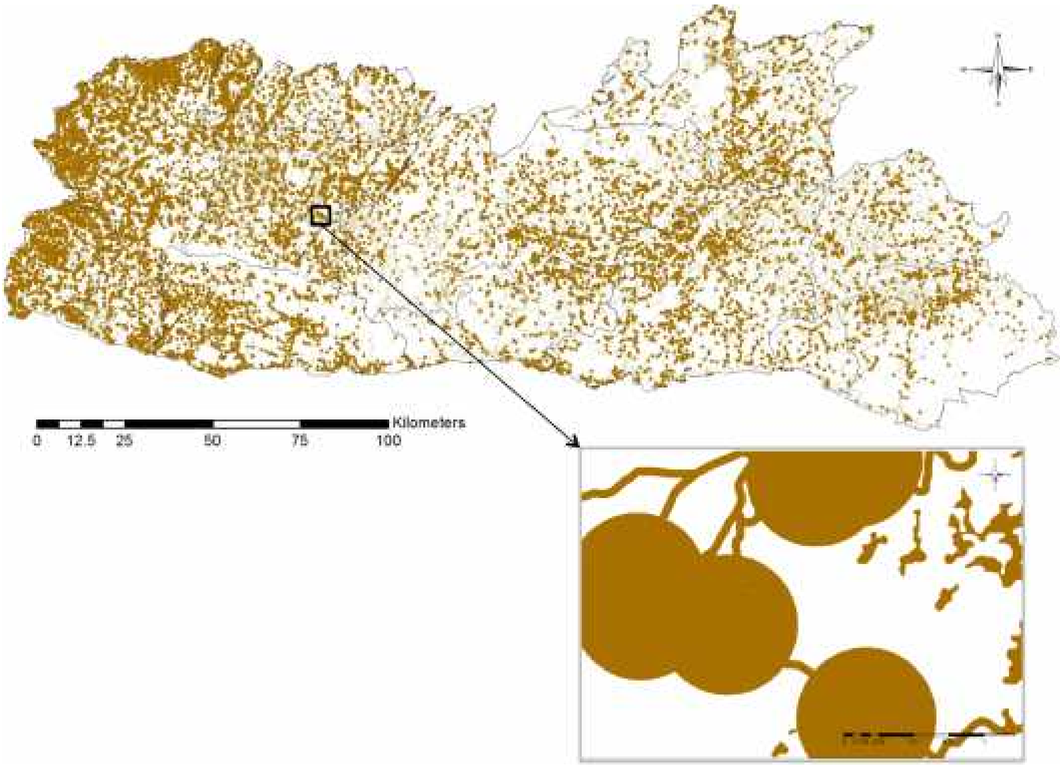
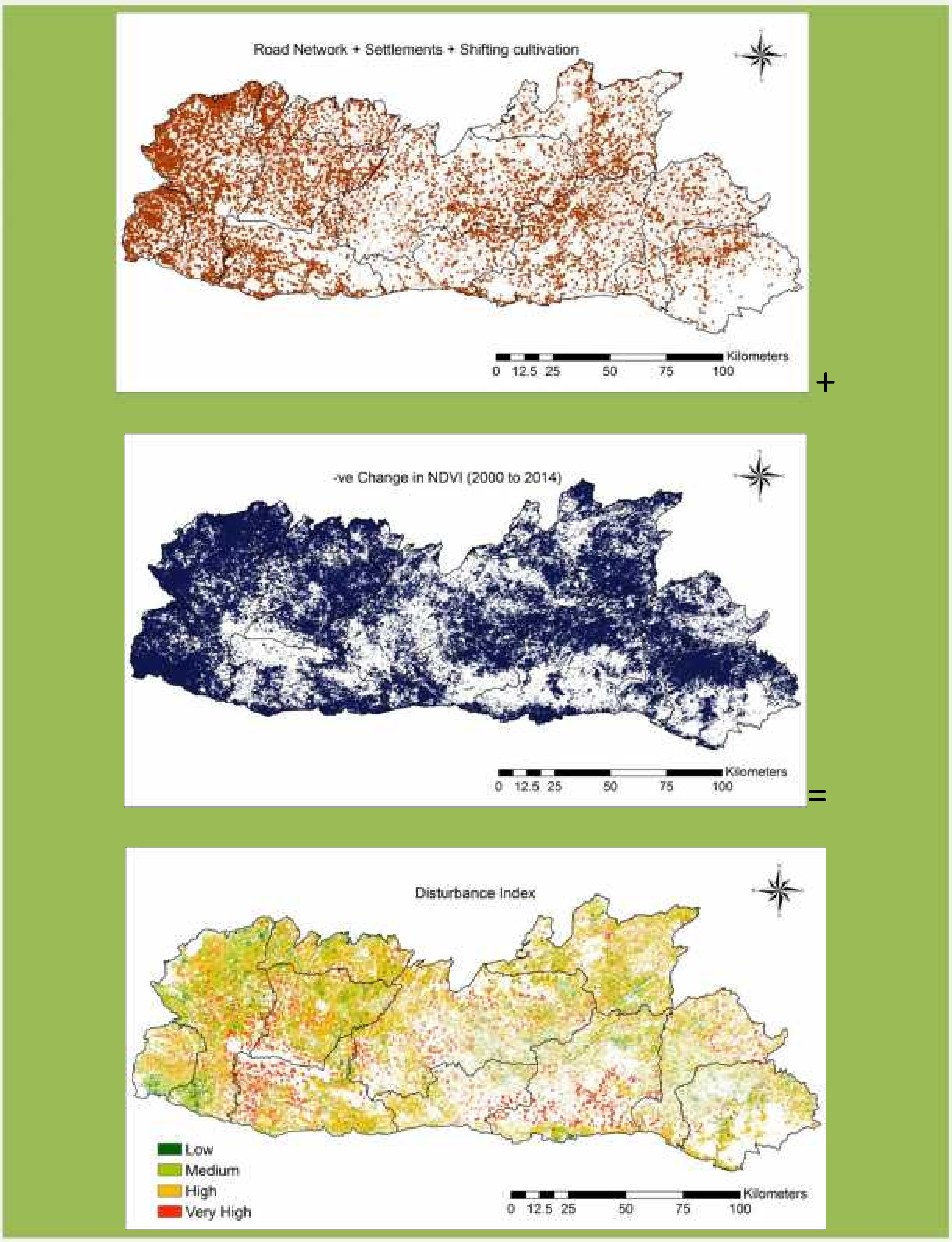


Figure 3.7: Distribution of the combined disturbed area in the forests of Meghalaya comprising of roads, settlements and shifting cultivation, and the buffer around these (inset)

The disturbance index combines the anthropogenic disturbances such as roads, settlements and shifting cultivation with the natural disturbances of the forest systems in Meghalaya as evident from the changes in NDVI in the forested areas in the state.

Figure 3.8 shows the development of disturbance index from a combination of the anthropogenic and natural disturbances and the methodology for creation of the disturbance index is shown in Figure 3.3.

Figure 3.8: Disturbance index for the forests of Meghalaya as a summation of the anthropogenic disturbances such as roads, settlements and shifting cultivation and natural disturbance as represented by changes in NDVI


Road Network + Settlements + Shifting cultivation
Kilometers
0 12.5 25 50 75 100
+
-ve Change in NDVI (2000 to 2014)
Kilometers
0 12.5 25 50 75 100
=
Disturbance Index
Low
Medium
High
Very High
Kilometers
0 12.5 25 50 75 100

2. Biological diversity Index

A created a composite index called Biological diversity index by combining the indicators of species richness, Shanon-Wiener diversity index and species importance index for each forest grid cell in Meghalaya as shown in the below flow chart (figure 3.9)

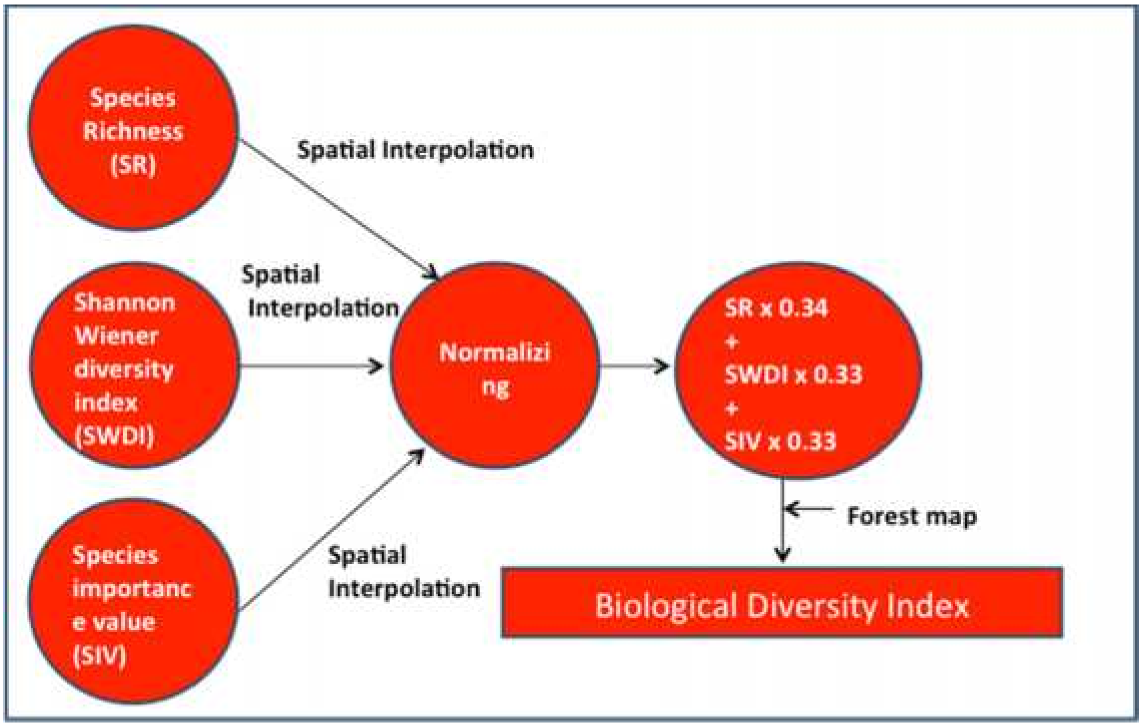


Figure 3.9: Methodology for computation of the biological diversity index

Species richness, diversity index and species importance values are estimated based on a field sampling of 180 plots from 84 different locations in the state. The study locations are shown in the figure below (Figure 3.10).

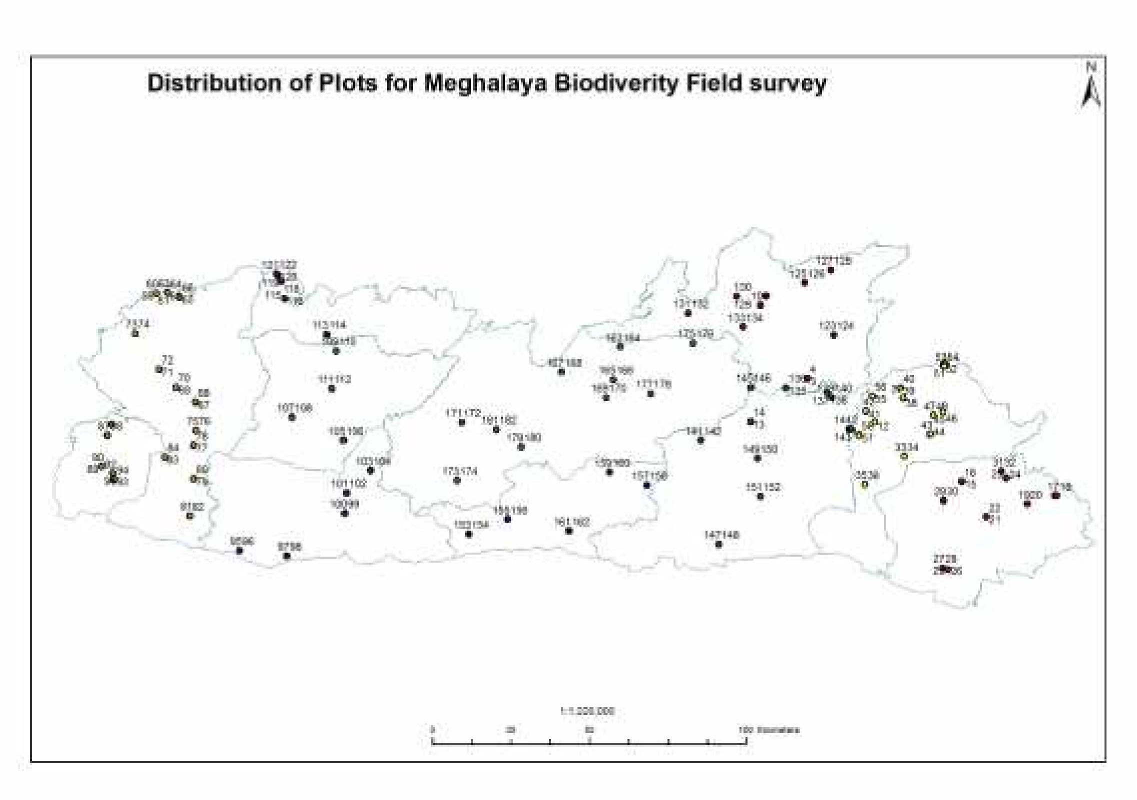


Figure 3.10: Distribution of sample locations across Meghalaya

At each location multiple plots of 20 meter* 20 meter tree plots are laid and within these plots shrubs and herbs are sample in a sub-plot as shown in the figure 3.11.

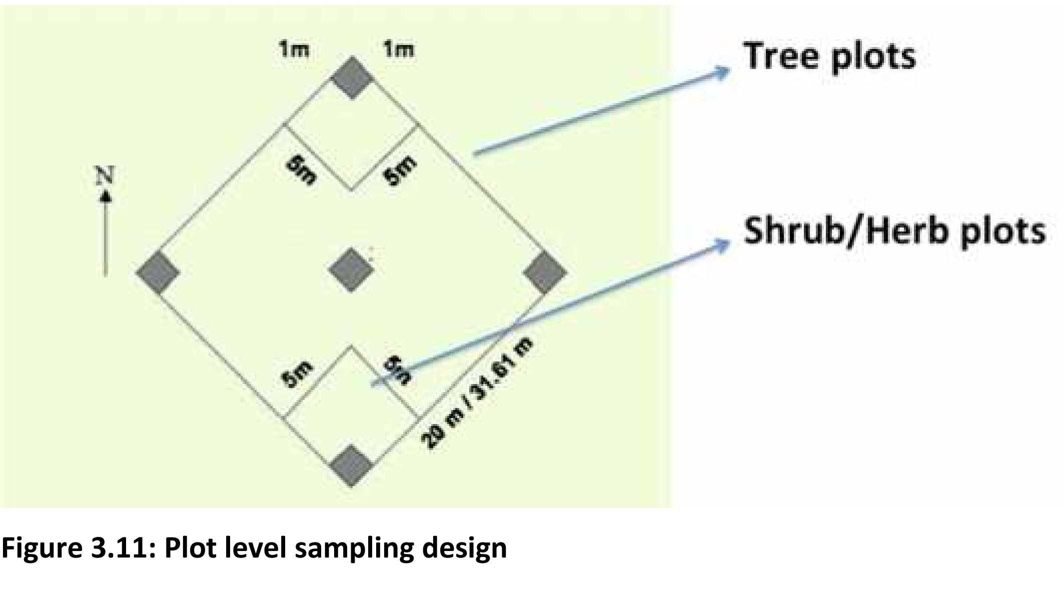


Figure 3.11: Plot level sampling design

Distribution of species diversity, Shanon-Wiener diversity index and species importance value across the state are shown in chapter 2 (state of the forests of Meghalaya). We are not repeating these figures here, rather below in Figure 3.12 we show the spatial distribution of composite floral biodiversity index for Meghalaya. Much of the areas in the state exhibit medium and high floral biodiversity, however fringe areas around the state show low biodiversity. It should be noted that canopy cover values are mentioned in the reverse order since the index will be used for construction for vulnerability indicator and not the resilience indicator.

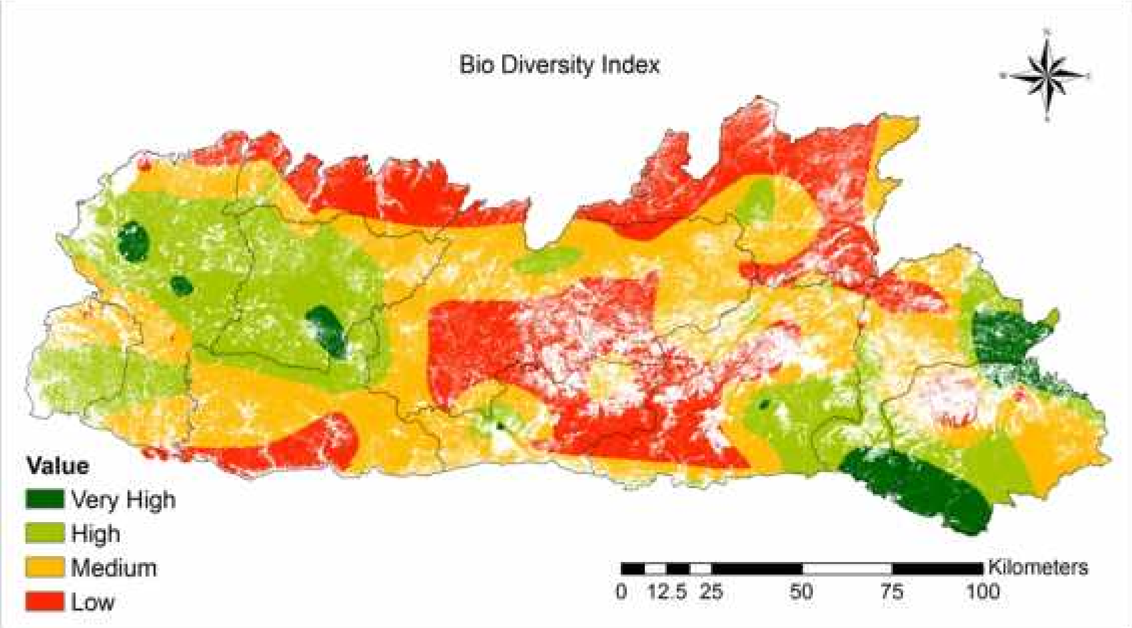


Figure 3.12: Biological diversity Index map for Meghalaya

3. *Canopy and biomass Indicator*

Canopy and biomass related indicators such as biomass stock, tree density, basal area indicates the health of the forest ecosystem. This indicator as shown in figure 3.13 combines tree density, basal area, forest biomass, carbon stock and canopy cover.

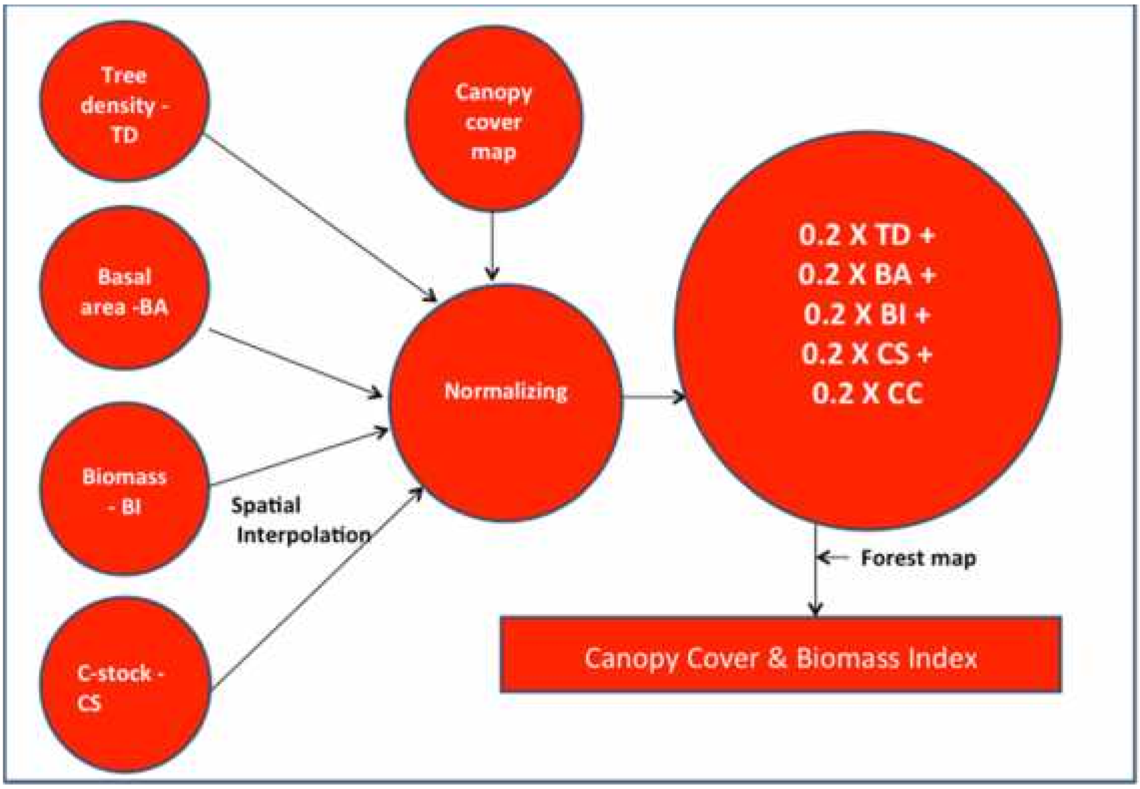


Figure 3.13: Methodology for computation of the Canopy Cover Index

The distribution of Canopy cover index is shown in figure 3.14. It should be noted that canopy cover values are mentioned in the reverse order since the index will be used for construction for vulnerability indicator and not the resilience indicator.

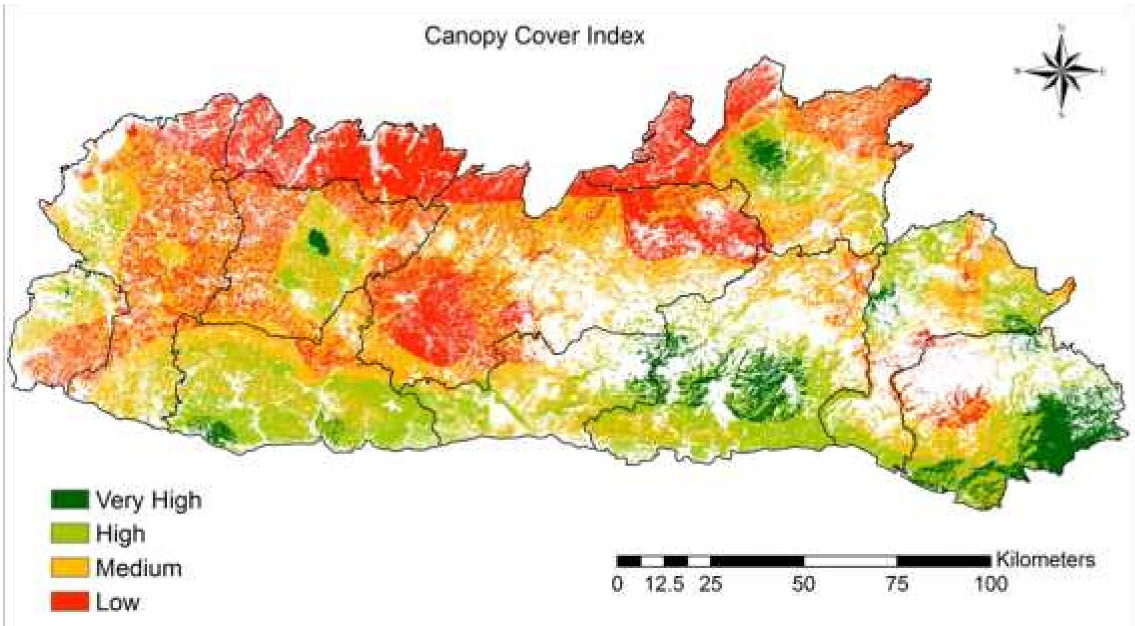


Figure 3.14: Spatial distribution of Canopy Cover Index for the state of Meghalaya

4. Slope gradient

Slope is one of the important indicators of habitat suitability for vegetation growth. Vegetation assemblages, generally located on steep slopes are more vulnerable to natural disasters such as landslides and other developmental stresses. Slope class distribution as used in this study is shown in Figure 3.15.

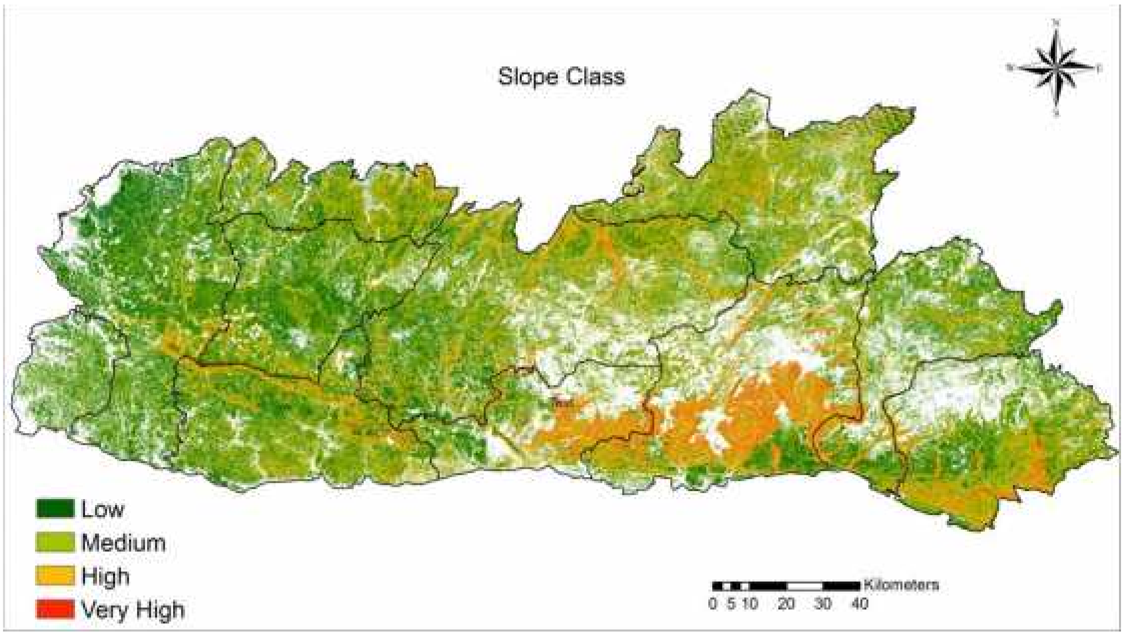


Figure 3.15: Distribution of Slope gradient class across the state of Meghalaya

The indicators as discussed above are used for creation of an inherent vulnerability, as shown in figure 3.16.

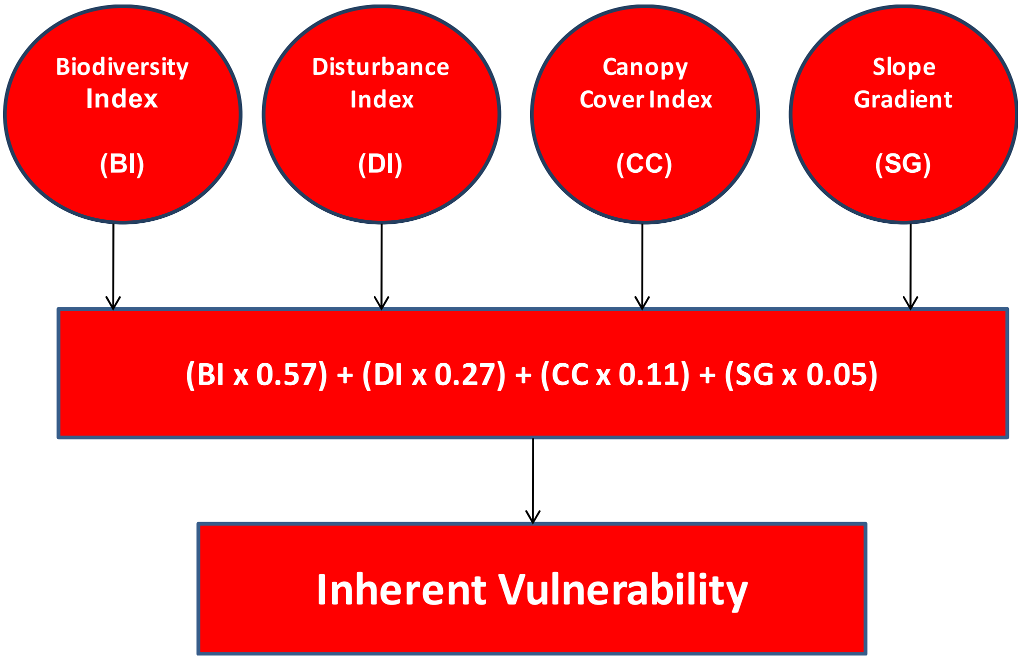


Figure 3.16: Methodology for assessment of Inherent Vulnerability

The inherent vulnerability of the Meghalaya state is created for two scenarios, one focusing only on the disturbance (negative changes in NDVI) and two, focusing on disturbance and resilience of forests in Meghalaya (negative as well as positive change in NDVI). The vulnerability index with disturbance focus is shown in Figure 3.17 for the state of Meghalaya.

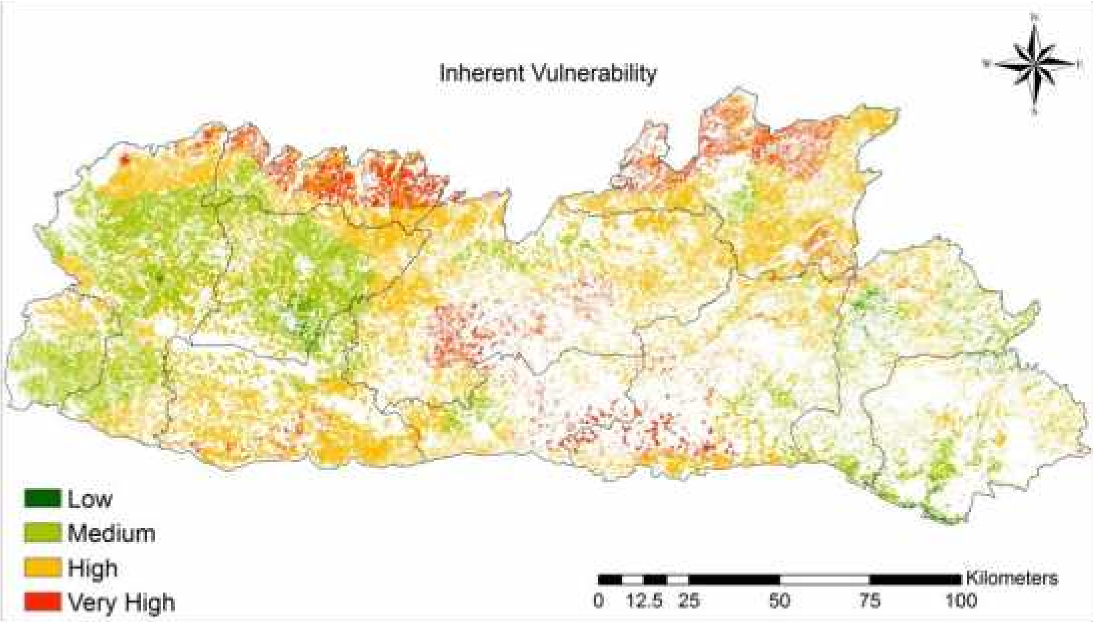


Figure 3.17: Spatial distribution of Inherent vulnerability index across Meghalaya

Figure 3.17 shows 10% of the total forested area in Meghalaya to be having very high inherent vulnerability, and 54% of the forested area to have high inherent vulnerability. Further it suggests 35% of the forested area to be moderately vulnerable and only about 1% of the forested area has low inherent vulnerability. It can also be seen that forests in the districts of West Khasi Hills, North Garo Hills and Ri-Bhoi are currently the most vulnerable forests in the state, while the forests from East Garo Hills district being the most resilient.

Figure 3.17 provides an inherent vulnerability map for Meghalaya that considers only the disturbances i.e. negative changes in NDVI. We improve the vulnerability analysis to include for forest resilience as well. The improved inherent vulnerability index for the state is presented in figure 3.18.

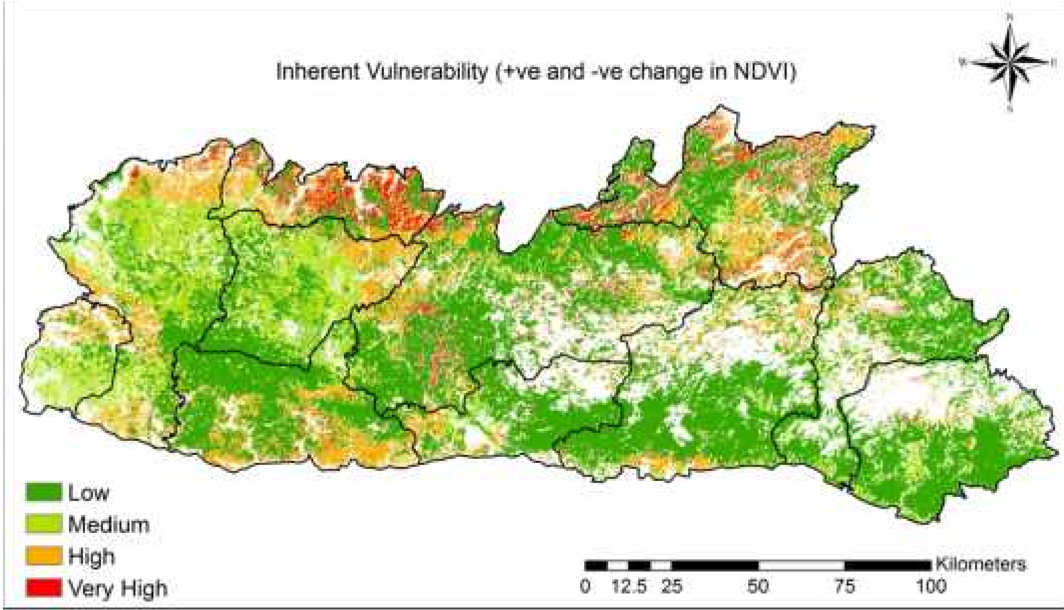


Figure 3.18: Inherent vulnerability of the forests in Meghalaya under the scenario that negative as well as positive both NDVI values are taken in to account

Figure 3.18 shows that 4.37% of the total forested area has very high inherent vulnerability and 19.13% of the forested area has high inherent vulnerability. 12.91% of the forested area is moderately vulnerable and only about 63.58% of the forested area has low inherent vulnerability. It can also be seen that forests in the districts of North Garo Hills and Ri-Bhoi are the districts with most vulnerable forests in the state, while the forests from East Jaintia Hills and East Khasi Hills districts being the most resilient.

Inherent vulnerability map for the forests of Meghalaya at the block level is shown in Figure 3.19.

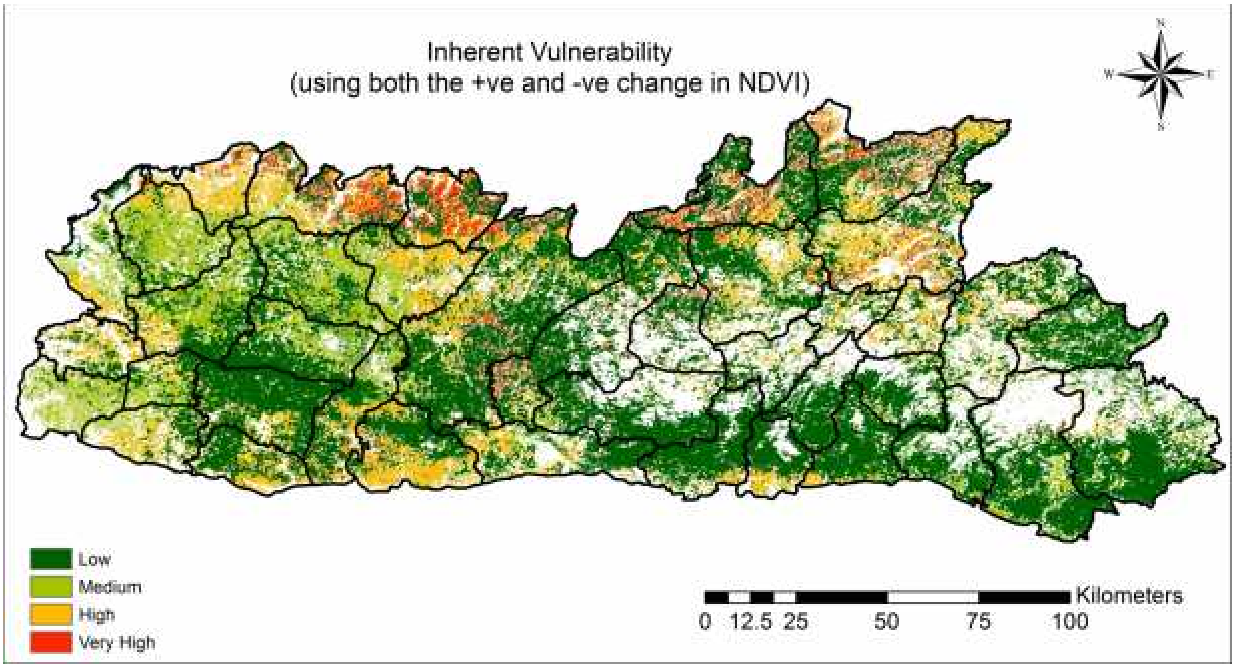


Figure 3.19: Inherent vulnerability of the forests in Meghalaya at the Block level under the scenario that negative as well as positive both NDVI values are taken in to account

CHAPTER 4

Impact of climate change on the forests and floral biodiversity of Meghalaya

Introduction

IPCC (2014) suggests that 'phenology', 'growth rates/ productivity' and 'shifting distributions of species and biomes' are the most prominent indicators of change in forest ecosystems in response to climate change. In terms of forest productivity Bala et al (2013) estimated that Net Primary Productivity (NPP) over the Indian region has increased by 3.9% per decade, over the period 1982 to 2006, driven mainly by elevated atmospheric CO_2 concentration in different ecosystems. It is understood from this study that the forests in Meghalaya are also experiencing an increase in net primary productivity over the last three decades. Estimation of 'forest range shifts' require long-term monitoring of forest inventory/ observation plots. For example, in case of US, Zhu et al (2012) based on the observations of 92 species collected from more than 43000 forest plots in 31 US states demonstrated that in this part of the World climate change is occurring more rapidly than the trees can adapt, with 59% of tree species showing signs that their geographic ranges are contracting from both North and South. However, such long-term monitoring plots are not maintained in India and reliable data in this regard is not available in public domain. It is universally accepted that Dynamic Global Vegetation Models (DGVMs) are one of the most important tools to project the impact of climate change on forest ecosystems (IPCC, WG2, 2007). At all India level Chaturvedi et al 2011, based on a DGVM analysis conclude that under the climate change scenarios net productivity of the Indian forests increases by 51-68% and about 34-39% of the forest grids may experience vegetation type shifts by the end of the 21st century. In this study we assess the impact of climate change on the forests of Meghalaya using a dynamic vegetation modeling framework i.e. Lund Postdam and Jena (LPJ) model (sitch et al 2003).

Climate change impacts on forest ecosystems arise from the following factors:

1. Impacts due to rising CO_2 concentration in the atmosphere
2. Impacts due to changes in climatic factors such as temperature, rainfall, etc.
3. Impacts due to rising sea levels

Global CO_2 concentration in the atmosphere has increased from 256 ppm in pre-industrial times, to 400 ppm today. Multiple studies have confirmed that due to rising CO_2 concentrations in the atmosphere net primary productivity and biomass productivity is increasing including in South Asia (Bala et al. 2013). In this chapter we assess the impact of rising CO_2, projected changes in climatic factors on the forests of Meghalaya.

Methodology

A number of approaches are available to assess the impact of climate change on forests and terrestrial ecosystems. The models used to predict large-scale vegetation responses to future climate change can be categorized as deterministic and statistical models as shown in Figure 4.1. Deterministic models can be classified as 'Static' and 'Dynamic'. The static and dynamic models can be based on bio-geography/bio-geochemistry based modules or both.

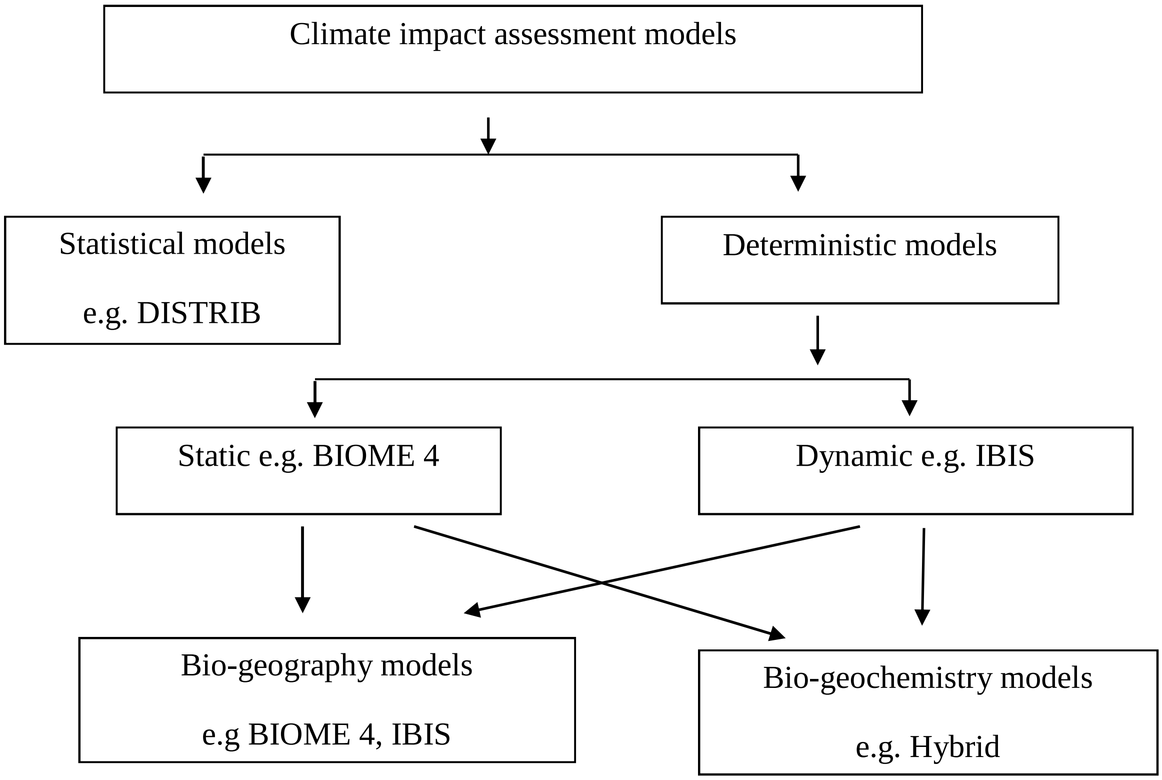


Figure 4.1: Different types of models available for assessment of climate change impacts on forests and biodiversity

Model

Fischlin et al. (2007) conclude that the most advanced tools to estimate the impact of climate change on vegetation dynamics at a global scale include Dynamic Global Vegetation Models (DGVMs). DGVMs simulate time-dependent changes in vegetation distribution and properties, and allow mapping of changes in ecosystem function and services (Metzger et al. 2006; Schroter et al. 2005). Fischlin et al. (2007) further conclude that with the adoption of DGVMs reliability of results has improved in relation to previous generations of models. Hence in this assessment we decided to use a DGVM for assessing the impact of projected climate change on forest ecosystems in Meghalaya. A number of DGVMs are available; we chose to use one of the most active and advanced DGVMs i.e. Lund Postdam and Jena model (LPJ; Sitch et al 2003). The structural outline and processes of the LPJ model is shown in Figure 4.2.

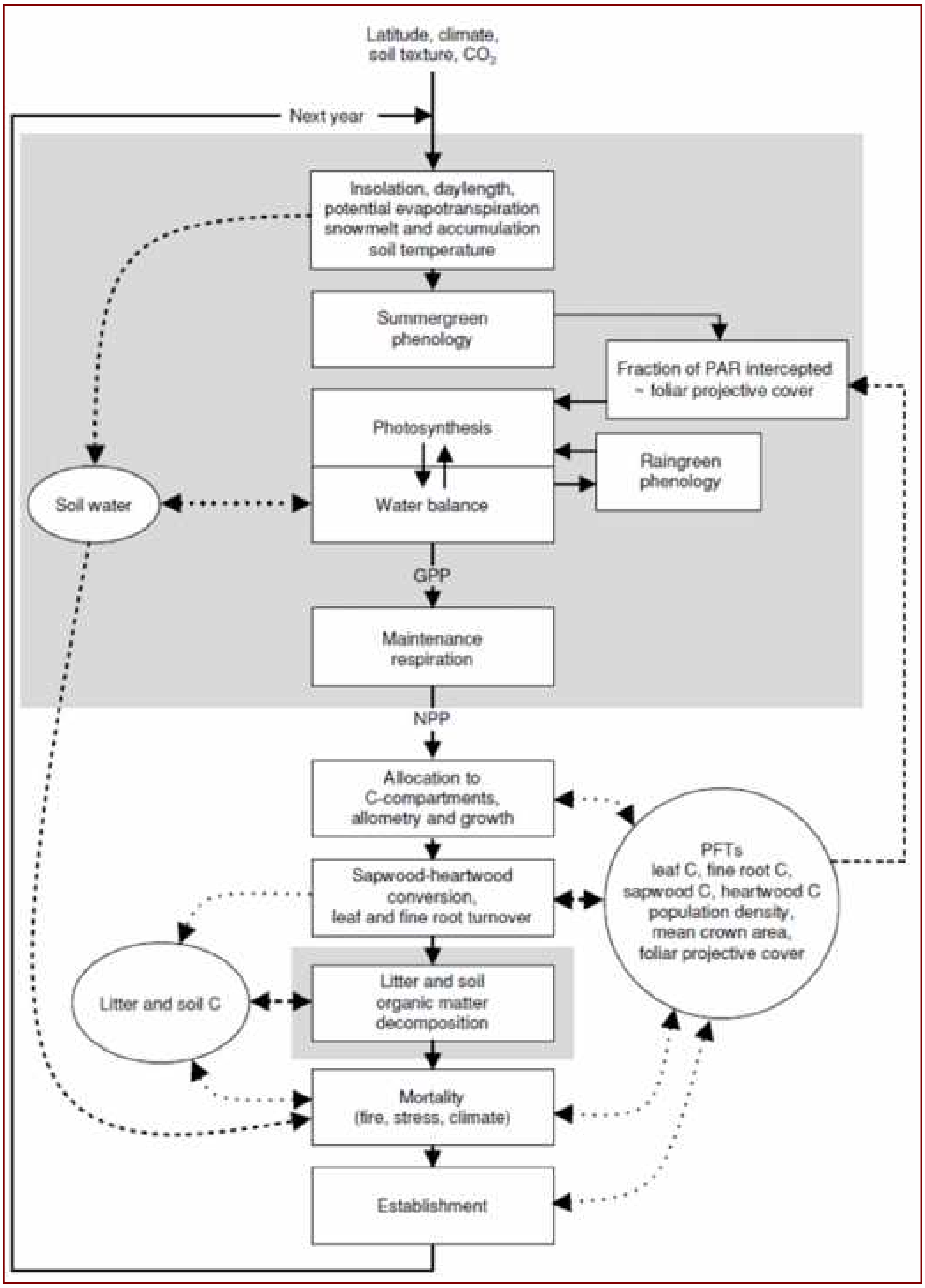


Figure 4.2: Flow-chart showing the model processes in LPJ (Source: Sitch et al. 2003)

Table 4.1 shows the key input data requirements from LPJ; it also shows the key outputs from LPJ

Table 4.1: Key input variables and outputs for LPJ model

Input variables	Outputs
1. Monthly mean cloudiness 2. Monthly mean precipitation rate 3. Percentage of sand 4. Percentage of clay 5. Monthly mean temperature 6. Topography 7. Initial vegetation types 8. Atmospheric CO_2 concentration	1. Total soil carbon (SOC) 2. Average evapotranspiration 3. Fractional cover of canopies 4. Leaf area index 5. Average soil temperature 6. Net Primary Productivity (NPP) 7. Total soil nitrogen 8. Average sensible heat flux 9. Height of vegetation canopies 10. Vegetation types 11. Total carbon from exchange of CO_2 12. Biomass carbon

The LPJ-DGVM uses inputs on monthly climatology, atmospheric CO_2 concentration, and soil type.

Climate and non-climate data needs for LPJ

The model requires the following climate data for the current climate (baseline) as well as the future climate, sources of these datasets are listed in Table 4.2.

Table 4.2: Sources of Baseline and GHG impacted climatology data*

	Baseline observed	**Downscaled climate projection at 0.25 Km resolution (Projected)**
Climate Parameters	**Source**	**Source**
Monthly mean cloudiness (%)	CRU	Multi-model ensemble (Obtained from the CMIP5 GCMs)
Monthly mean precipitation rate (mm/day)	CRU	Multi-model ensemble
Monthly mean temperature (°C)	CRU	Multi-model ensemble
Non Climate Parameters		
Soil	FAO	FAO
Elevation	International database	International database

**CRU data is used as it provided data on all the input climatology parameters, cloud cover parameter is not available from the downscaled climatology products*

Its key outputs are vegetation structure, plant functional types (PFT), and biomass carbon. The PFTs represented in the LPJ-DGVM are listed in Table 4.3.

Table 4.3: Representation of different Plant Functional Types in the LPJ model

	Representation of PFTs in LPJ-DGVM
Trees based PFTs	
1	Boreal conifer evergreen trees
2	Boreal conifer deciduous trees
3	Temperate conifer evergreen trees
4	Temperate broadleaf evergreen trees
5	Temperate broadleaf cold-deciduous trees
6	Tropical broadleaf evergreen trees
7	Tropical broadleaf deciduous trees
Shrubs and grasses based PFTs	
8	Evergreen shrub
9	Cold grass (C_3)
10	Warm grass (C_4)

The climate models, scenarios and input climate data

By using 18 CMIP5 GCMs it has been demonstrated by Chaturvedi et al. 2012 that use of multiple climate models better helps in quantification of the range of uncertainty in climate change projections. Chaturvedi et al. 2012 also demonstrated that multi-model ensemble based climate projections help in reducing the uncertainties of both the temperature and precipitation variables. Hence for this study we decided to use multi-model ensemble based climate change projections. In this study we use a total of 3 regionally downscaled climate models. The availability of cloud cover is one of the limiting factor in model selection as not many teams provide this variable and almost none of the statistically/dynamically downscaled climate products available for the South-Asian region provide this variable. The list of downscaled NASA/NEX models used in this study is shown in Table 4.4.

Table 4.4: List of climate models and ensemble outputs used in this study, their resolutions, and research groups responsible for their development

S. No.	Model	Modeling Center (or Group)	Resolution Lat – degree	Resolution Lon – degree	Ensemble used / remark
1	CCSM4	National Center for Atmospheric Research, USA	0.25	0.25	r1i1p1
2	IPSL-CM5A-LR	Institut Pierre-Simon Laplace, France	0.25	0.25	r1i1p1 for RCP 4.5, 6.0, r3i1p1 for RCP 2.6, 8.5
3	MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, The University of Tokyo), and National Institute for Environmental Studies	0.25	0.25	R1i1p1
4	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, The University of Tokyo), and National Institute for Environmental Studies	0.25	0.25	R1i1p1

Climate change projections were bias corrected by using historical climate observations for Meghalaya.

Model validation

LPJ Model is validated for the Indian forests by a team from the Indian Institute of Science, Bangalore.

Impact of climate change on the forests of Meghalaya

This section presents the impact of climate change on vegetation distribution, NPP and carbon stocks in soils of Meghalaya.

Impact of climate change on vegetation distribution in Meghalaya

Figure 4.3 shows the forested grids in Meghalaya that are projected to undergo vegetation change under high emission scenario of RCP 8.5 in long-term (2080s) compared to the baseline of 1975-2005.

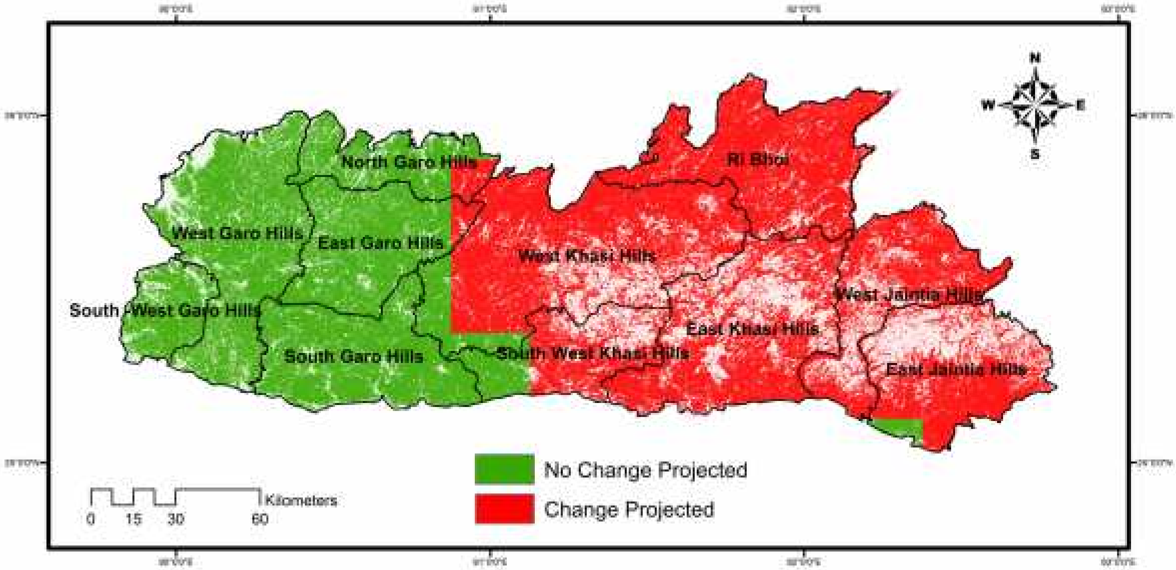


Figure 4.3: Model simulated vegetation grid shifts in Meghalaya (2080s, RCP8.5)

Note: green colour refers to forest areas where no vegetation change is projected and the red colour refers to areas where the current vegetation is not likely to remain optimally suitable for the projected climate

Figure 4.3 shows the projected vegetation change in the districts of Jaintia hills and east and west Khasi hills. These projected forest grid changes could lead to vulnerability, especially in the case of fragmented and disturbed forests. In fragmented forest patches, seed dispersal may not be efficient in the view of loss or reduction in number of dispersal agents due to human habitation pressures and climate change. It should also be noted that vegetation change projections are associated with uncertainty, largely coming from the uncertainty inherent in the climate change projections and especially the uncertainty related to rainfall projections.

Impact of climate change Net Primary Productivity (NPP) in Meghalaya

Figures 4.4 shows the impact of climate change on the Net Primary Productivity (NPP) distribution over the forested grids in Meghalaya. It shows that in the short-term NPP increases from less than 20% to more than 80% across Meghalaya with parts of the

Khasi and Jaintia hills experiencing the highest increase in productivity and the parts of Garo hills experiencing the least increase in productivity. Spatial differences in NPP projections over the state mainly arise due to differences in rainfall projections and soil characteristics in different forest areas. Also it has been established that much of the NPP increase is driven due to the CO_2 fertilization effect. However, in the long-term the CO_2 fertilization benefits are likely to saturate due to the effects of the increased warming. Thus, climate change certainly provides an opportunity for increased productivity in some parts of the state at least in the near future.

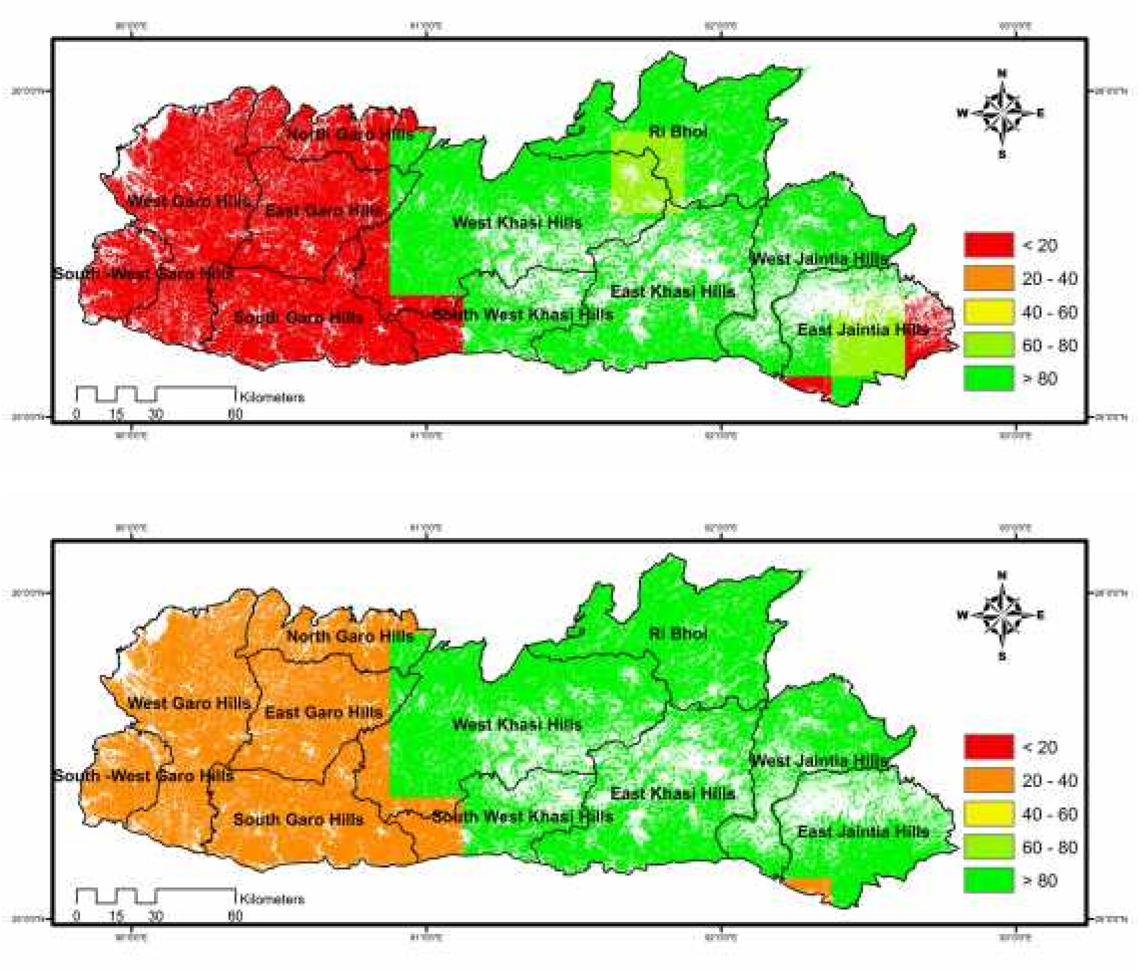


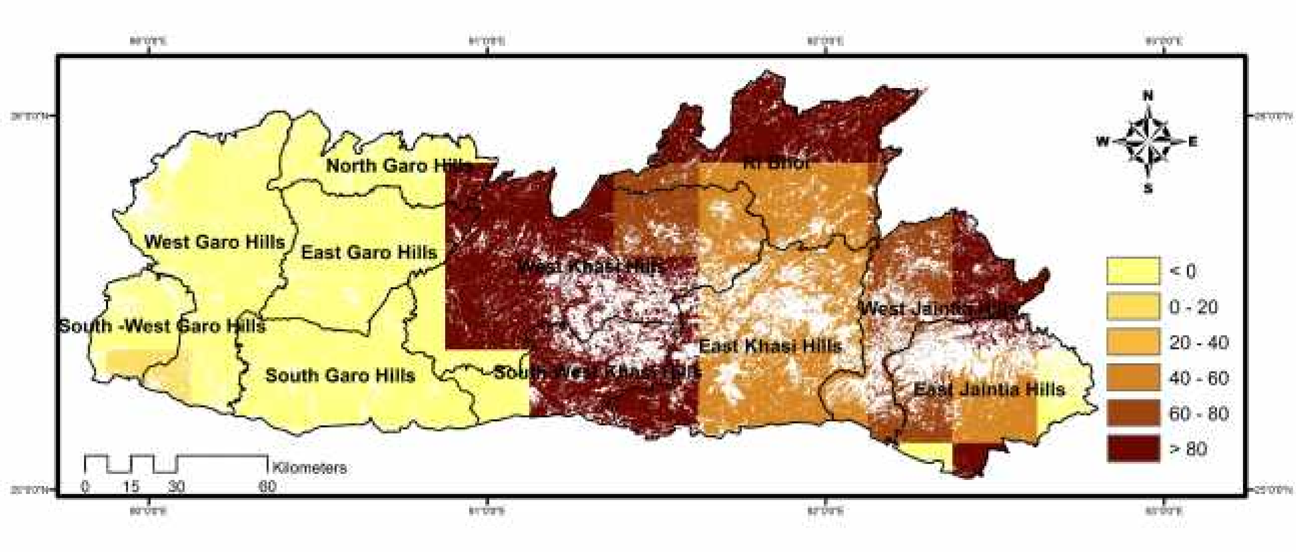
Figure 4.4: Projected change in NPP distribution (%) over the forests of Meghalaya under the RCP8.5 scenario by 2030s (upper) and 2080s (lower)

Note: NPP refers to Net Primary Productivity, projected changes in NPP distribution are shown in terms of percentage changes in 2030s and 2080s under different scenarios compared to the baseline (1975-2005). Overall NPP is projected to increase in future, smaller increases in NPP are shown in red color and larger increases are shown in green color.

The NPP increase is likely mainly driven by the CO_2 fertilization effect. Increased productivity may translate into increased supply of forest products, including woods, fuel wood and NTFPs. However, in the long-term, NPP increase is likely to be countered by increased losses from heterotrophic respiration leading to tapering or declining net ecosystem productivity.

Impact of climate change on soil organic carbon distribution in Meghalaya

Figure 4.5 shows the impact of climate change on the soil organic carbon distribution over the forested grids in Meghalaya. It shows increasing soil carbon especially in the parts of Khasi and Jaintia hills of Meghalaya. Soil carbon increase is caused largely by the availability of excess litter biomass in the soils. The excess litter in turn comes from the increased NPP in the system due to CO_2 fertilization effects



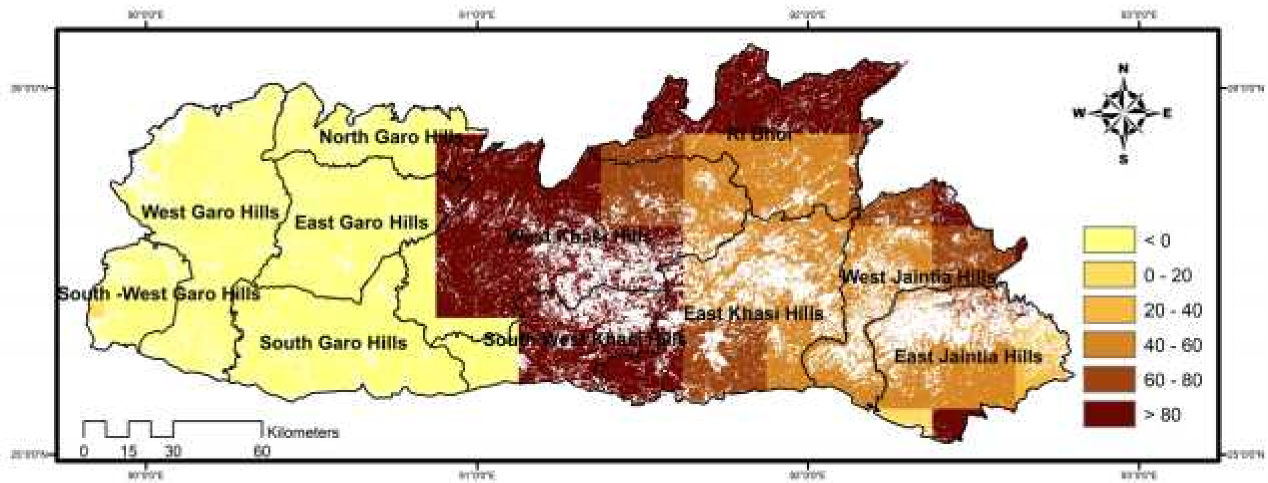


Figure 4.5: Projected change in soil carbon distribution (%) over the forests of Meghalaya under the RCP8.5 scenario by 2030s (upper) and 2080s (lower)

Note: Projected changes in soil carbon distribution are shown in terms of percentage changes in 2030s and 2080s under different climate change scenarios compared to the baseline.

Viewed together, projections on vegetation shift, NPP, biomass and soil carbon show an increase in many parts of Meghalaya and, thus, suggest that climate change presents both an opportunity and a threat to the forests in Meghalaya. The opportunity arises from the projections of increased net primary productivity, increased biomass, and increased soil organic carbon in some parts of the country. However the threat comes from the projections of shifting vegetation boundaries. Shifting vegetation boundaries in itself may not be a big problem, however, in combination with the lack of biodiversity, disturbed and fragmented habitats, it poses serious threats to forest ecosystems. The fragmented and isolated forests in low biodiversity areas are especially vulnerable to the impacts of climate change which, in turn, could hamper the dispersal and migration of species. This analysis further suggests that in the presence of forest fragmentation, low biodiversity and forest disturbance the likely increase in productivity may not be realised. However if we are able to address the issues of forest fragmentation through strategic afforestation and corridors, climate change could well be a positive in limited aspect of increased NPP in the short-term, as in the long-term, NPP benefits are likely to be countered by respiration losses. Further, we would like to highlight the uncertainties associated with long-term climate change projections and climate impact assessment. While we have used the best available downscaled climate projections and most advanced dynamic vegetation model, still we note that climate change projections especially rainfall projections are generally associated with high levels of uncertainty at local levels, especially in a hilly state like Meghalaya.

Photo Credit: Meghalaya Climate Change Centre

CHAPTER 5

Current and Climate change vulnerability of the forests of Meghalaya

As shown in Chapter 2 and Chapter 3 the forests in Meghalaya are already vulnerable to current climatic as well as socio-economic stresses. Climate change is likely to add to the existing vulnerabilities in future. In this chapter we add climate change impacts on to the inherent vulnerability assessment as carried out in Chapter 3. The methodology for the assessment of climate change vulnerability is shown in Figure 5.1.

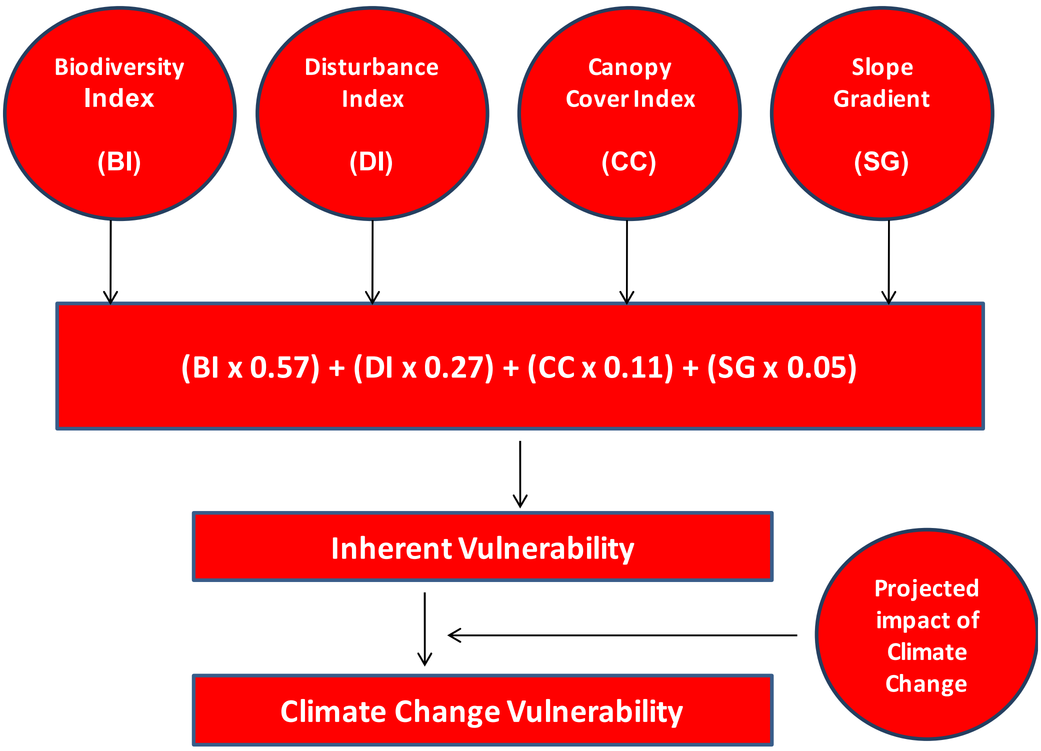


Figure 5.1: Methodology for assessment of Climate Change Vulnerability in the forests of Meghalaya

In Chapter 4 we assessed the impact of climate change on vegetation productivity, distribution of vegetation across the state and soil carbon. Shifting forest type in a warming world is likely to constitute a key vulnerability to forests in future. Purpose of the assessment of climate change driven vulnerability of forests is to identify the forest grid points that are likely to experience increased stress due to changing climate. The distribution of forest grids experiencing vegetation shift in climate scenarios is presented in chapter 4. Climate change vulnerability of the forests of Meghalaya is shown in Figure 5.1 (High emission scenario in long-term).

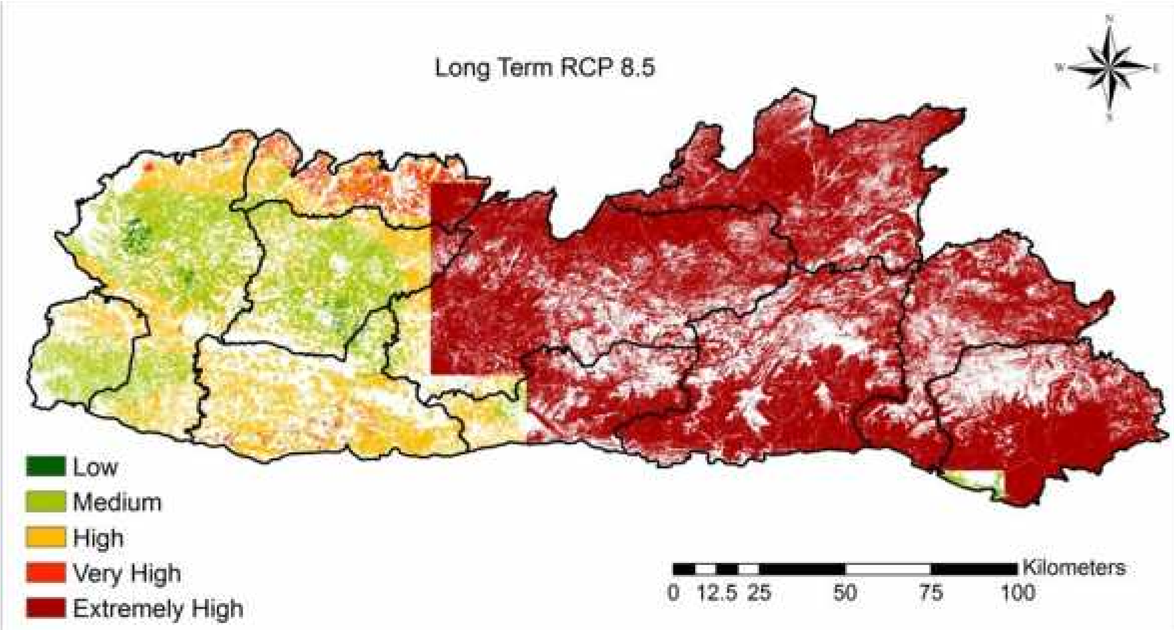


Figure 5.1: Climate Change vulnerability in Meghalaya under RCP8.5 (2080s)

Table 5.1 describes the results of climate change vulnerability assessment. It is clear from Table 5.1 that climate change significantly increases the vulnerability. Table 5.1 shows that almost 70% of the state forests become vulnerable in high emissions scenario.

Table 5.1: Percent Area of vulnerability class under high emission scenarios in 2080s

Vulnerability class	% Area - Long term
	RCP 8.5
Low	0.35
Medium	13.16
High	14.81
Very High	2.06
Extremely High	69.62

The spatial analysis of the climate change vulnerability suggests that under the high emissions scenario forests in the districts of West Khasi Hills, Sout-West Khasi Hills, East Khasi Hills, East Jaintia Hills, West Jaintia Hills and Ri-Bhoi are the most vulnerable forests in the state. The forests in district of South West Garo Hills and West Garo Hills are projected to being the most resilient. The climate change vulnerability (for the scenario RCP8.5 in long-term) at the block level is shown in Figure xxx.

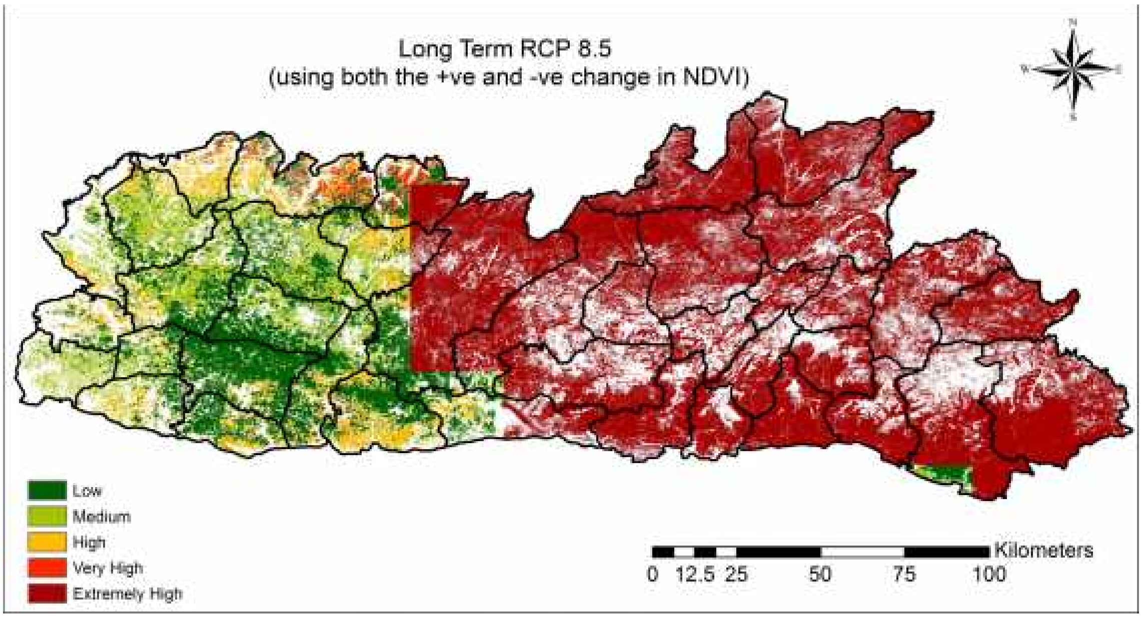


Figure 5.2: Climate Change vulnerability in Meghalaya under RCP8.5 (2080s) at the block level

Although, the climate change driven vulnerability projections are not sufficient to guide forest management at field level, these provide valuable information about the likely impacts of climate change that should be considered while developing adaptation responses (Millar et al. 2007). Reducing vulnerability of forests and plantations in anticipation of climate change is a ‘win-win’ option despite the uncertainties associated with climate projections and climate change impact projections.

CHAPTER 6

Conclusions and Recommendations

Meghalaya has about 80% of its geographic area under forest and tree cover and it is a part of the Indo-Myanmar global biodiversity hotspot and home to diverse plants and animal groups. This analysis suggests that about 50% of the forests in Meghalaya have experienced increased disturbance in the last 16 years. Further, Indo-Myanmar is one of the most threatened biodiversity hotspots, due to rapid resource exploitation and habitat loss. Based on the structure, composition and biodiversity characteristics of he Meghalaya forests, currently we estimate about 25% of the state's forests to be highly vulnerable.

Climate change is likely to further add to the current stresses and vulnerabilities in the forest ecosystems of Meghalaya. IPCC (2014) suggests that addressing current vulnerabilities, lead to the reduction in future (i.e. climate change) vulnerabilities as well. The current vulnerabilities of the forest systems in Meghalaya arise from forest disturbances, forest fragmentation, patchiness, low biodiversity, and precarious mountain slopes. Thus, it is important to address the drivers of current vulnerabilities such as forest disturbance, fragmentation and biodiversity loss.

In future, climate stress is likely to manifest itself in the form of reduced productivity (in long-term) and in form of the projections of shifting vegetation boundaries. Shifting vegetation boundaries in itself may not be a big problem, however, in combination with the lack of biodiversity, disturbed and fragmented habitats, it poses serious threats to forest ecosystems. The fragmented and isolated forests in low biodiversity areas are especially vulnerable to the impacts of climate change which, in turn, could hamper the dispersal and migration of species. Thus it is clear from the above discussion that the management interventions required to address the current vulnerabilities and climate change vulnerabilities are identical and synergistic. By strengthening the structure and compostion of forests and augumenting the biodiversity in the state, we will not only manage current vulnerabilities and weaknesses of the forest systems in the state but at the same time we will make our forests more resilient to future climatic stresses.

In view of the recent COP21 (UNFCCC's Conference of Parties' 21st meeting in Paris) agreement, forests and terrestrial ecosystems are increasingly assuming a more prominent role, both as a very important carbon sink as well as an adaptation option, due to its positive role in diversifying livelihood opportunities of the rural communities along with its moderating impact on climate, climate extremes, land degradation, water resources and biodiversity conservation.

As part of its NDC (Nationally Determined Contributions), India has promised to carry out a massive afforestation drive to sequester an additional 2.5-3.0GtCO2 till 2030. Globally, the COP21 agreement relies heavily on forests to achieve zero carbon emissions in the next half of this century – Which is a pre-requisite for limiting warming to a rise of 2°C.

Hence, it is important to carry out afforestation and forest restoration activities, keeping in mind the need to build corridors to link fragmented and isolated forests. While building these corridors, a mix of native and relevant species should be selected. Such corridors will not only be useful for building resilience of the forest ecosystems, but they will also provide crucial points for the movement of fauna as well. It needs to be understood that the needs of plants are in synergy with the needs to the animals including the large mammals.

a) Keeping these synergies as well as India's forest sector commitments in mind, the feasibility of an ambitious project like 'interlinking of forests' of the state should be investigated.

b) Forest conservation, afforestation/reforestation activities in the state should be designed such that these activities reduce the fragmentation and degradation of the existing forests. Anticipatory planting and assisted natural migration through transplanting plant species could also be considered.

c) It is important to carry out the forest conservation activities in a way that these activities increase the overall biodiversity richness of these forests, by planting of mix species, and the native species.

d) Since water and nutrients are a critical bottleneck for realising the benefits of increases in NPP, it is important that water conservation activities are initiated in forests of the state.

e) In the state, a large number of people depend on forest resources for their livelihood. However, in a climate change scenario, increasing climate extremes have the potential to disrupt the supply of NTFPs in the short or long term (as this study largely assesses the impact of mean climate changes and does not account for the impacts of extremes of climate on forest ecosystems and NTFPs in the state). Hence, it is important that the livelihoods of the forest- dependent communities is diversified and modernized via market linkages.

f) Govt. of India has proposed large scale afforestation and reforestation activities in its NDC. Afforestation and reforestation activities, proposed as mitigation activities, provide opportunities for adaptation as well. Some examples of adaptation practices that can be (and need to be) incorporated in any afforestation and reforestation mitigation project are as follows: i) Promotion of regeneration of native species through protection and natural regeneration in degraded natural forest lands, to reduce vulnerability to changing climate; ii) Promotion of multi-species plantation forestry incorporating native species, in place of mono-culture plantation of exotic species to reduce vulnerability; iii) Adoption of short-rotation species in commercial or industrial forestry to enable adaptation to any adverse impact of climate change; iv) Incorporation of several silviculture practices such as sanitation harvest, increased thinning to reduce occurrence of pests and diseases; v) Incorporation of fire protection measures to reduce vulnerability of forests to fire hazards due to warming accompanied by droughts; vi) Incorporation of soil and water conservation measures to reduce the adverse impacts of drought on forest growth; vii) Soil and water conservation: a key adaptation practice aimed at reducing vulnerability, which also reduces carbon loss from soils as well as enhances soil carbon density by increasing the biomass growth rate of forests or plantation or grassland; viii) Drought-resistant varieties or clones, which not only reduce vulnerability of tree and grass species to droughts and water stress but also increase carbon sequestration rates; ix) Enhancing soil organic matter content through organic manure to increase the moisture retention and soil fertility, which not only reduces the vulnerability to drought and moisture stress but also increases the carbon sequestration rates of trees as well as grass species; x) Forest and biodiversity conservation, through halting deforestation, expanding protected areas and adopting sustainable harvest practices, is a vital adaptation strategy to reduce vulnerability of forest ecosystems. All such programmes or practices could also be considered as mitigation options to conserve forest carbon sinks; and xi) Urban park and tree planting, which promotes adaptation to heat stress in urban areas by reducing air-conditioning needs and facilitates carbon sequestration in trees and soil as well.

Photo Credit: Meghalaya Climate Change Centre

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Annex

This annex provides the details of the field study and its findings

Table A1: Key details of the study area and the results

Parameters	
Total locations	84
Total zone/districts	11
Total number of plots studied	182
Each plot size (ha)	20m x 20m (= 0.04)
Total area studied (ha)	7.28
Total number of individuals	**3956**
Total tree Basal area (**sq. meters)**	**107.6579**
Species richness (total number of species)	243
Shannon Wiener diversity index	3.7033

Table A2: Key results for different zones

Sl. No.	**Zones**	**Study area (ha)**	**Tree density** **(Count/ha)**	**Basal area (M^2/ ha)**	**Species richness**	**Shannon-Wiener Diversity index**
1	East Garo Hills	0.32	600	18.44	31	3.0101
2	East Jaintia hills	0.72	603	24.36	93	3.3853
3	East Khasi Hills	0.88	772	14.73	40	2.1668
4	North Garo Hills	0.4	300	11.66	17	1.8326
5	Ri-Bhoi	0.8	550	15.81	37	2.8599
6	South Garo Hills	0.4	448	18.03	30	2.5537
7	South West Garo Hills	0.4	248	19.08	31	2.8492
8	West Garo Hills	1.04	485	11.05	61	3.1726
9	West Jaintia Hills	1.12	737	13.62	46	2.4582
10	West Khasi Hills	0.8	363	7.43	25	2.3272
11	South West Khasi Hills	0.4	485	23.56	26	2.5316
	Total	**7.28**	**543**	**14.78**	**243**	**3.7033**

Table A3: Plot level Tree and biodiversity results

Sl.No	**Plot ID**	**Tree density/ha**	**Basal area(M^2/ha)**	**Species richness**	**Shannon Wiener's diversity index**
1	B6	400	4.84	8	1.7949
2	B7	413	4.97	5	0.9173
3	C6-13	163	3.56	4	1.2711
4	C7	325	23.37	5	1.1585
5	D10-43	750	14.76	10	1.9287
6	D13	863	13.34	5	1.2513
7	D7	300	7.89	5	1.5974
8	D9	375	4.27	8	1.5327
9	E5	338	10.81	11	2.1752
10	E6	250	9.64	9	1.9158
11	F12	613	12.42	5	1.2493
12	F13	938	26.40	17	2.3922
13	F14	488	5.10	6	1.6901
14	F7	413	11.50	3	0.7731
15	F8	375	4.72	6	1.4383
16	G1_1	313	18.08	9	1.9916
17	G1_2	0	0.00	0	0
18	G1_3	500	5.26	8	1.2808
19	G1_4	950	9.79	13	1.8289
20	G10	825	11.73	5	1.1588
21	G10-1	688	4.96	9	1.8491
22	G10-10	1263	49.39	8	1.3832
23	G10-12	450	12.17	11	1.9945
24	G10-14	400	18.96	4	1.1206
25	G10-15	350	42.54	11	2.0935
26	G10-16	863	17.81	6	1.3
27	G10-2	313	5.86	6	1.1225
28	G10-25	1238	10.60	8	1.0833
29	G10-5	975	13.27	5	1.1079
30	G10-9	2013	20.06	7	0.9158
31	G11	600	17.23	5	1.2323
32	G11-17	400	4.55	7	1.4783
33	G11-20	688	10.29	10	1.6332
34	G11-6	350	9.80	7	1.7095
35	G11-8	975	10.81	8	1.2758
36	G11-C3	1238	26.48	8	1.6476
37	G12_6	213	18.77	11	2.1968
38	G12-1	238	12.34	7	1.778
39	G12-3	338	15.67	10	2.0338
40	G12-5	350	24.20	5	0.967
41	G12-7	275	10.17	13	2.2873
42	G13	1688	13.10	3	0.404
43	G13-1	300	21.68	6	0.9525
44	G13-2	225	7.85	9	2.0911
45	G13-7	713	21.93	5	1.1113

46	G13-8	488	8.81	14	1.8872
47	G13-9	513	29.86	5	1.1124
48	G16-1	175	7.83	8	1.9702
49	G16-5	625	13.36	4	0.9545
50	G16-6	438	5.00	9	1.9602
51	G17	563	21.67	9	1.8462
52	G17-14	488	12.57	14	2.2908
53	G17-20	1038	30.26	26	2.6139
54	G17-23	688	40.06	30	3.0775
55	G17-3	38	0.12	3	1.0397
56	G17-5	163	15.37	4	1.072
57	G17-7	1175	8.70	17	1.7429
58	G17-8	850	82.78	3	0.1531
59	G17-9	425	7.68	5	0.9261
60	G2-1	425	8.66	1	0
61	G2-4	213	5.05	10	1.9505
62	G2-C2	425	3.86	3	0.2645
63	G2-C5	238	1.19	1	0
64	G3	400	4.93	4	1.3209
65	G4	525	13.24	3	0.9755
66	G5	375	4.75	3	0.4677
67	G6-1	375	6.63	10	2.0904
68	G6-10	163	7.24	10	2.2048
69	G6-3	213	9.47	11	2.1192
70	G6-4	413	30.11	6	1.227
71	G6-5	1750	13.91	19	1.6033
72	G6-7	100	24.00	5	1.3862
73	G6-8	750	15.82	15	2.1351
74	G6-9	75	10.70	5	1.5607
75	G7-1	200	2.06	6	1.3306
76	G7-3	863	18.48	15	2.4216
77	G7-4	513	11.05	11	2.1369
78	G7-6	800	18.17	14	1.8946
79	G7-7	225	26.05	10	2.0621
80	H11	1075	13.69	2	0.1513
81	H3	275	2.55	4	1.3371
82	H7	450	15.27	7	1.5854
83	I12	575	41.10	13	2.2259
84	I8	500	37.81	5	1.0533
85	J11	300	2.97	5	1.3753
86	J2	600	22.65	6	1.5939
87	J3	488	23.19	14	2.3024
88	J5	388	18.89	6	0.9288
89	J9	850	18.35	4	0.4845
90	Unknown	525	6.86	6	0.633
	Total	**543/ha**	**14.78 m^2/ha**	**243**	**3.7033**

Table A4: Diameter class distribution of tree individuals in study area of Meghalaya

DBH class (cm)	Counts	Count/ha	Basal area(M^2)	BA M^2/ha	BA(%)
0 – 10	1593	219	5.808	0.7979	5.40
10 – 20	1454	200	24.033	3.3013	22.32
20 – 30	556	76	26.200	3.5989	24.34
30 – 40	225	31	20.651	2.8367	19.18
40 – 50	72	10	11.072	1.5208	10.28
>50	56	8	19.893	2.7326	18.48

Table A5: List of species observed during the field study in different parts of Meghalaya

Acer laevigatum	*Castanopsis tribuloides*	*Eugenia jambolana*	*Jatropha spp.*
Adina oligocephala	*Celtis cinomonia*	*Eugenia oblate*	*Lagera pterodanta*
Aegle marmelos	*Cenocephalus souveolens*	*Eugenia parviflora*	*Lagerstroemia parviflora*
Aeschyranthus spp.	*Cepados fruticosa*	*Eugenia spp.*	*Lagerstroemia spp.*
Agapetes lobii	*Chukrasia spp.*	*Eunonymus hamiltoneanus*	*Lannea coromoadelica*
Agrimonia pilosa	*Chukrasia tabularis*	*Euphorbia thymifolia*	*Lannea grandis*
Ailanthus malabarica	*Chukrasia velutina*	*Eurya accuminata*	*Lindira neesiana*
Albizia procera	*Cinnamomum pauciflorum*	*Eurya japonica*	*Litsea chinensis*
Albizzia lebbeck	*Cinnamomum spp.*	*Exbucklandia populnea*	*Litsea glauca*
Albizzia spp.	*Cinnamomum tamala*	*Ficus aspirima*	*Litsea glutinosa*
Albizzia stipulata	*Citrus grandulosa*	*Ficus cunia*	*Litsea polyantha*
AlsicarpusSchima wallichii	*Citrus limon*	*Ficus exaspirrata*	*Litsea salicifolia*
Alstonia scholaris	*Citrus spp.*	*Ficus hirta*	*Macaranga denticulata*
Anarcardium occidentales	*Combretum acuminatum*	*Ficus lamponga*	*Macaranga peltata*
Anarchme cordifolia	*Combretum desytachynum*	*Ficus spp.*	*Macaranga spp.*
Antidesma diandrum	*Combretum flagracarpum*	*Gamphandra exilaris*	*Mangifera indica*
Aparosa roxburghii	*Cordia spp.*	*Garcinia accuminata*	*Mastixia arborea*
Aporus dioica	*Cupiana khasiana*	*Garcinia lanceafolia*	*Meliosma arnottiana*
Artocarpus chaplasha	*Cylcostenom assamicus*	*Garcinia pendunculta*	*Meliosma monmii*
Artocarpus heterophyllus	*Cynanthus spathulifolius*	*Gaultheria griffithiina*	*Michelia champaca*
Aspidaptorys elliptica	*Dalbergia assamica*	*Gelavium multiflorum*	*Michelia spp.*
Aspidaptorys roxburghiana	*Dalbergia rimosa*	*Globba multiflora*	*Micranthus oppositifolia*
Averrhoa carambola	*Dalbergia stipulaceae*	*Glochidion coccineum*	*Milosma pinnata*

Azadirachta indica	*Daphaniphyllum himalayensis*	*Glochidion velutinum*	*Misc spp.*
Bamboo	*Darris marginata*	*Glycosmis Mauritian*	*Moniltoa polyandra*
Bambusa balkwa	*Darris monticola*	*Gmelina arborea*	*Morinda angustifolia*
Barringtonia acutangula	*Decaspermum paniculatus*	*Grewia abutifolia*	*Mulicona besicara*
Bauhinia spp.	*Desmodium racemosum*	*Grewia disperma*	*Munvonia wallichii*
Bauhinia variegata	*Dillenia indica*	*Grewia microcos*	*Myrica spp.*
Betula alnoides	*Dillenia pentagyna*	*Grewia spp.*	*Myrsine semiserrata*
Biilschmieda longifolia	*Diospyros toposia*	*Guruga gamblii*	*Ochna integerrima*
Bombax ceiba	*Doryxylon albicam*	*Gymnosporia acuminata*	*Olax acuminata*
Bombax malabarica	*Duabanga grandiflora*	*Hameltonia spp.*	*Ophiarhiza achroleuca*
Bridelia spp.	*Duabanga indica*	*Havea brasilensis*	*Ophiarhiza mungos*
Buchananiana lanzum	*Duabanga sonneratioides*	*Henslovia heterantha*	*Ormosia robusta*
Callicarpa arborea	*Echinocarpus dasycarpus*	*Heptage bengalensis*	*Oroxylum indicum*
Callicarpa vestita	*Echinocarpus sterculeacus*	*Hibiscus microphylla*	*Orxylum indica*
Callitriche stagnalis	*Elaeocarpus lanceifolius*	*Holarrhena antidysenterica*	*Osbeckia crinita*
Camelia candata	*Elaeocarpus spp.*	*Holmskiolda sanguinea*	*Peltophorum ferrugeneum*
Careya arborea	*Emblica officinales*	*Ilex excellsa*	*Phoebe attenuata*
Carydalis seberica	*Engelhardtia spicata*	*Illigera villosa*	*Phoebe augustifolia*
Caseria gravedens	*Entada purseatha*	*Ixora finlaysoniana*	*Photonia notoniana*
Cassia fistula	*Eriobatrya hookeriana*	*Jacaranda mimosifolia*	*Phyllanthus accuminata*
Castanopsis purpurella	*Erythrina indica*	*Jasminium coarctatum*	*Phyllanthus glaucus*
Castanopsis spp.	*Eugenia anisopetala*	*Eugenia jambolana*	*Phyllanthus simplex*
Pithocolobium angulatium	*Reinwardtia indica*	*Shorea robusta*	*Terminalia bellerica*
Pluerarea thumbirgiana	*Rhus semialata*	*Shynton*	*Terminalia chebula*
Polygala orientales	*Rhus Succedenea*	*Sida parviflora*	*Terminalia spp.*
Premna pingens	*Rhynchoglossum obligurum*	*Spirea chinensis*	*Tetromeles nudiflora*
Procris lavigata	*Rubus berkilli*	*Spondiac mangifera*	*Toona ciliata*
Prunus serrulata	*RUIN*	*Sterculia villosa*	*Trema orientales*
Psychotria fulva	*Sabia purpurea*	*Stereospermum chelenoides*	*Vaccinum relusum*
Psychotria simplicifolia	*Sacrosperma griffithi*	*Stereospermum chelonoides*	*Ventiligo andarospetema*
Pyrenaria barringtonifolia	*Salmalia malabarica*	*Stereospermum spp.*	*Ventiligo calyculata*
Quercus derbata	*Santalum album*	*Strobillanthus flaccidifolium*	*Vitex penduncularis*
Quercus fenstrata	*Sapindus mukorosii*	*Symplicos oxphylla*	*Vitex pinnata*
Quercus incana	*Sapium baccatum*	*Syzigium tetrogynum*	*Wendlandia grandis*
Quercus semicarpifolia	*Saurauwia armata*	*Syzygium cumini*	*Wendlania tinctoria*
Quercus serrata	*Schima wallichii*	*Tamarindus indica*	*Wrightia tomentosa*
Quercus spicata	*Semecarpus anacardium*	*Tectona grandis*	*Zanthoxylum rhetsa*