Climate change and Indian forests

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An assessment of the impact of projected climate change on forest ecosystems in India based on climate projections of the Regional Climate Model of the Hadley Centre (HadRM3) and the global dynamic vegetation model IBIS for A1B scenario is conducted for short-term (2021–2050) and long-term (2071–2100) periods. Based on the dynamic global vegetation modelling, vulnerable forested regions of India have been identified to assist in planning adaptation interventions.

The assessment of climate impacts showed that at the national level, about 45% of the forested grids is projected to undergo change. Vulnerability assessment showed that such vulnerable forested grids are spread across India. However, their concentration is higher in the upper Himalayan stretches, parts of Central India, northern Western Ghats and the Eastern Ghats. In contrast, the northeastern forests, southern Western Ghats and the forested regions of eastern India are estimated to be the least vulnerable. Low tree density, low biodiversity status as well as higher levels of fragmentation, in addition to climate change, contribute to the vulnerability of these forests. The mountainous forests (sub-alpine and alpine forest, the Himalayan dry temperate forest and the Himalayan moist temperate forest) are susceptible to the adverse effects of climate change. This is because climate change is predicted to be larger for regions that have greater elevations.

Keywords: Climate change, forest ecosystems, impacts, net primary productivity.

Introduction

CLIMATE is one of the most important determinants of vegetation patterns globally and has significant influence on the distribution, structure and ecology of forests[1]. Several climate–vegetation studies have shown that certain climatic regimes are associated with particular plant communities or functional types[2]. It is therefore logical to assume that changes in climate would alter the distribution of forest ecosystems. Based on a range of vegetation modelling studies, the IPCC[3] suggests potential forest dieback towards the end of this century and beyond, especially in the tropics, boreal and mountain areas[4,5]. The most recent report from the International Union of Forest Research Organization[6] paints a rather gloomy picture about the future of the world forests in a changed climate, as it suggests that in a warmer world the current carbon regulating services of forests (as carbon sinks) may be entirely lost as land ecosystems could turn into a net source of carbon dioxide later in the century.

India is a key country with respect to tropical forests, with around 20% of the geographic area classified as forests[7]. A recent study[8] provides a detailed discussion on the current status of forests in India, including the forest area, carbon stocks in Indian forests and aforestation trends in the country. Another study[9] using BIOME4 vegetation model concluded that 77% and 68% of the forested grids in India are likely to experience shift in forest types due to climate change under A2 and B2 scenarios respectively. Impacts of climate change on forests have severe implications for the people who depend on forest resources for their livelihoods. India is a mega-biodiversity country. With nearly 173,000 villages classified as forest villages, there is a large dependence of communities on forest resources in India[10]. The country has a large afforestation programme of over 1.32 mha/annum (ref. 11), and more area is likely to be afforested under programmes such as ‘Green India Mission’ and ‘Compensatory Afforestation Fund Management and Planning Authority’ (CAMPA). Thus it is necessary to assess the likely impacts of projected climate change on existing forests and afforested areas, and develop and implement adaptation strategies to enhance the resilience of forests to climate change.

The present study investigates the projected impacts of climate change on Indian forests using a dynamic global vegetation model (DGVM) and for the short-term (2021–2050) and long-term (2071–2100) periods. It specifically assesses the boundary shifts in vegetation types, changes in NPP (net primary productivity) and soil carbon stocks, as well as the vulnerability of existing forests in different regions to future climate change.

Methods

The impacts of climate change on forests in India are assessed based on the changes in area under different forest

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types, shifts in boundary of forest types and NPP. This assessment was based on: (i) spatial distribution of current climatic variables; (ii) future climate projected by relatively high-resolution regional climate models (RCMs) for two different periods for the A1B climate change scenario, and (iii) vegetation types, NPP and carbon stocks as simulated by the dynamic model IBIS v.2 (integrated biosphere simulator)[12].

Vegetation model

The dynamic vegetation model IBIS is designed around a hierarchical, modular structure. The model is broken into four modules, viz. (i) the land surface module, (ii) vegetation phenology module, (iii) carbon balance module and (iv) vegetation dynamics module. These modules, though operating at different time steps, are integrated into a single physically consistent model. The state description of the model allows trees and grasses to experience different light and water regimes, and competition for sunlight and soil moisture determines the geographic distribution of plant functional types and the relative dominance of trees and grasses, evergreen and deciduous phenologies, broadleaf and conifer leaf forms, and C3 and C4 photosynthetic pathways. IBIS was selected for the exercise as it is a DGVM, and is well-validated for India[8].

Input data

IBIS requires a range of input parameters, including climatology and soil parameters. The main climatology parameters required by IBIS are: monthly mean cloudiness (%), monthly mean precipitation rate (mm/day), monthly mean relative humidity (%), monthly minimum, maximum and mean temperature (°C) and wind speed (m/s). The main soil parameter required is the texture of soil (i.e. percentage of sand, silt and clay). The model also requires topography information.

Observed climatology was obtained from Climatic Research Unit (CRU; University of East Anglia)[13], whereas soil data were obtained from IGBP[14]. For climate change projections, RCM outputs from the Hadley Centre model HadRM3 were used[15]. The climate variables for future scenarios were obtained using the method of anomalies. Briefly, this involved computing the difference between the projected values for a scenario and the control run of the HadRM3 model, and adding this difference to the value corresponding to the current climate as obtained from the CRU climatology. The climate data analysis tool (CDAT)[16] was used for data processing and generation of various maps and plots. All input data were re-gridded to a $0.5° \times 0.5°$ (lat. × long.) resolution, and used for the run.

Scenarios of climate change

In this study, we consider only SRES scenario A1B. Further, two future time-frames are considered. (i) Time-frame of 2021–2050 (atmospheric CO_2 concentration reaching 490 ppm). This is also labelled as ‘2035’, for brevity (which is the median of the period). (ii) Time-frame of 2071–2100 (atmospheric CO_2 concentration reaching 680 ppm) which is labelled as ‘2085’. We compare the results of these with the ‘baseline’ scenario, which represents the simulation of vegetation using the 1961–1991 observed climatology. ‘Baseline’ is also referred to as either ‘reference’ or ‘control’ case. The A2 and B2 scenario results for the time-frame of 2071–2100 are detailed in another recent publication[8].

Model validation

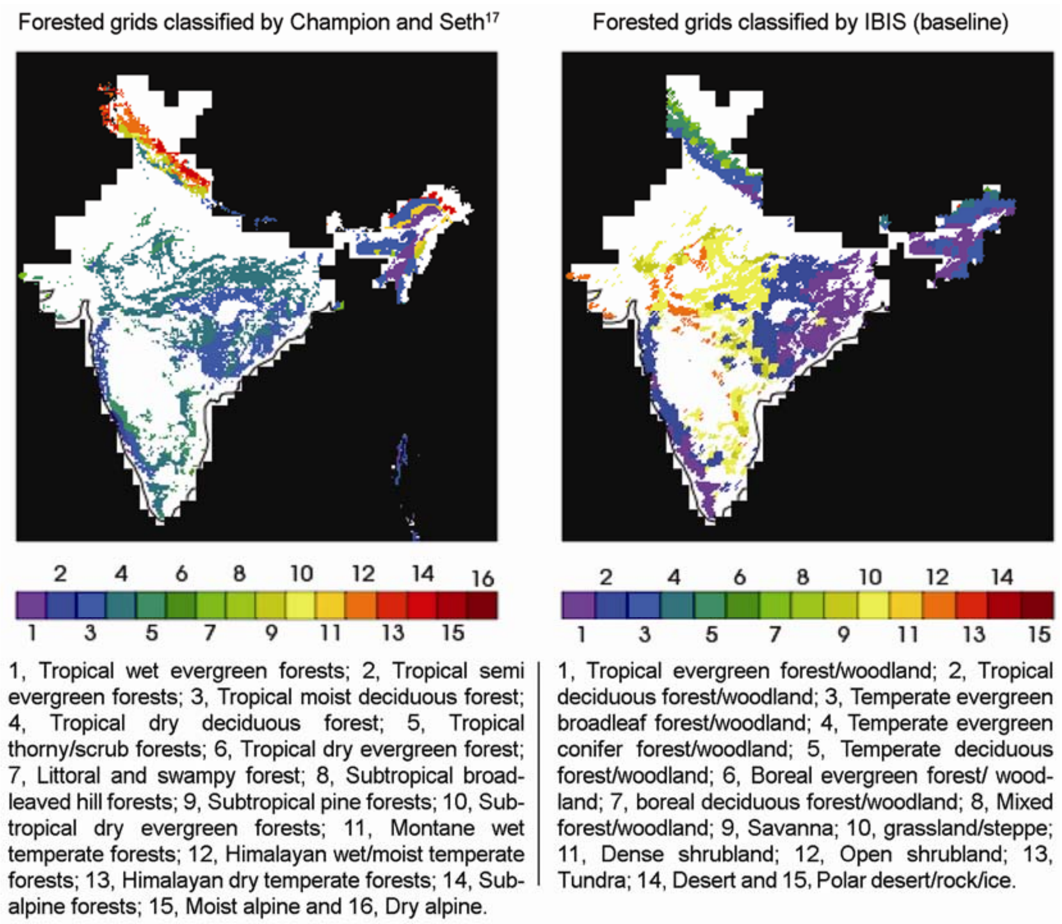
We simulated the current vegetation pattern, NPP, biomass and soil carbon over India using the IBIS model driven by observed climatology. A few salient aspects of the validation of IBIS model are as follows.

Vegetation distribution and NPP

Comparison of simulated vegetation cover with the observed vegetation map over India (from Champion and Seth[17]) shows fair agreement (Figure 1). Interestingly, several important observed vegetation distribution (forest type) patterns are reproduced in the simulation, including (i) the tropical evergreen forest type in the Western Ghats and the northeast; (ii) desert and thorny vegetation types in the western and south-central parts; (iii) tropical deciduous forests in most of its present-day locations, except parts of western Madhya Pradesh, where the model simulates savanna and shrublands, and (iv) temperate evergreen conifer forests in the Himalayas and higher elevations of the northeast.

IBIS simulates forest vegetation at about 70% of the actual forested grids of the country (the location of these grids was obtained from the FSI report[7]). However, it simulates savanna and shrublands over most grids in western Madhya Pradesh, Gujarat and Rajasthan, whereas these are historically classified as forested regions[17]. This anomaly of IBIS under-representing forests in the tropics is documented in previous studies[12,18,19], which found that IBIS had higher (than observed) grass coverage in India.

The remotely-sensed mean NPP data from satellites for the period 1982–2006 were obtained[20]. The correlation between this distribution and the NPP simulated by IBIS control case was estimated to be about 0.65, indicating fair agreement. Another recent publication has a detailed discussion of the validation of the model[8].



Forested grids classified by Champion and Seth[17]

Forested grids classified by IBIS (baseline)

1, Tropical wet evergreen forests; 2, Tropical semi evergreen forests; 3, Tropical moist deciduous forest; 4, Tropical dry deciduous forest; 5, Tropical thorny/scrub forests; 6, Tropical dry evergreen forest; 7, Littoral and swampy forest; 8, Subtropical broadleaved hill forests; 9, Subtropical pine forests; 10, Subtropical dry evergreen forests; 11, Montane wet temperate forests; 12, Himalayan wet/moist temperate forests; 13, Himalayan dry temperate forests; 14, Subalpine forests; 15, Moist alpine and 16, Dry alpine.

1, Tropical evergreen forest/woodland; 2, Tropical deciduous forest/woodland; 3, Temperate evergreen broadleaf forest/woodland; 4, Temperate evergreen conifer forest/woodland; 5, Temperate deciduous forest/woodland; 6, Boreal evergreen forest/ woodland; 7, boreal deciduous forest/woodland; 8, Mixed forest/woodland; 9, Savanna; 10, grassland/steppe; 11, Dense shrubland; 12, Open shrubland; 13, Tundra; 14, Desert and 15, Polar desert/rock/ice.

Figure 1. Model-simulated current vegetation distribution (right) compared with observed vegetation distribution[17].

Impacts of climate change on forest type and extent

Changes in the distribution of forests

The vegetation distribution simulated by IBIS for baseline and A1B scenario in the simulation grids is shown in Figure 2. One can notice that there is an expansion of tropical evergreen forests (IBIS vegetation type 1) in the eastern India plateau in the A1B scenario. The same trend can be seen in the Western Ghats. It is interesting to note that there is almost no vegetation type change in the northeast. Further, there is a slight expansion of forests into the western part of Central India. One caveat to the expansion trend of forests (like tropical evergreen forests) is the assumption that they are not fragmented, and there is no dearth of seed-dispersing agents. In the real world, forests are fragmented (vastly due to anthropogenic pressure), and seed dispersal may not be efficient in the view of the loss or reduction in the number of dispersal agents due to human habitation pressures and climate change[21]. As the population of seed-dispersing agents may decline, predicted forest expansion is not guaranteed. Another interesting observation is the shrinkage in the polar desert/rock ice in the Himalayas to the (mostly) tundra type. This is consistent with higher projections of warming in high-altitude areas[3].

Impact on NPP and soil organic carbon

The NPP tends to increase over India (Figure 3) for the A1B scenario. It increases by an average of 30.3% by 2035 and by 56.2% by 2085. Notably, increase is higher in the northeastern part of India due to warmer and wetter climate predicted there. A trend similar to NPP distribution is simulated for soil organic carbon (SOC), which is to be expected as increased NPP is the primary driver of higher litter input to the soil. However, the quantum of increase compared to baseline in this case is lower. This increase is less due to the inertia of the SOC pool and increased soil respiration.

The estimates for both NPP and SOC increase should be viewed with caution as IBIS, compared with other dynamic vegetation models, tends to simulate a fairly strong CO_2 fertilization effect[18,22]. This can be partly explained by the fact that the nitrogen cycle and acclimation of soil

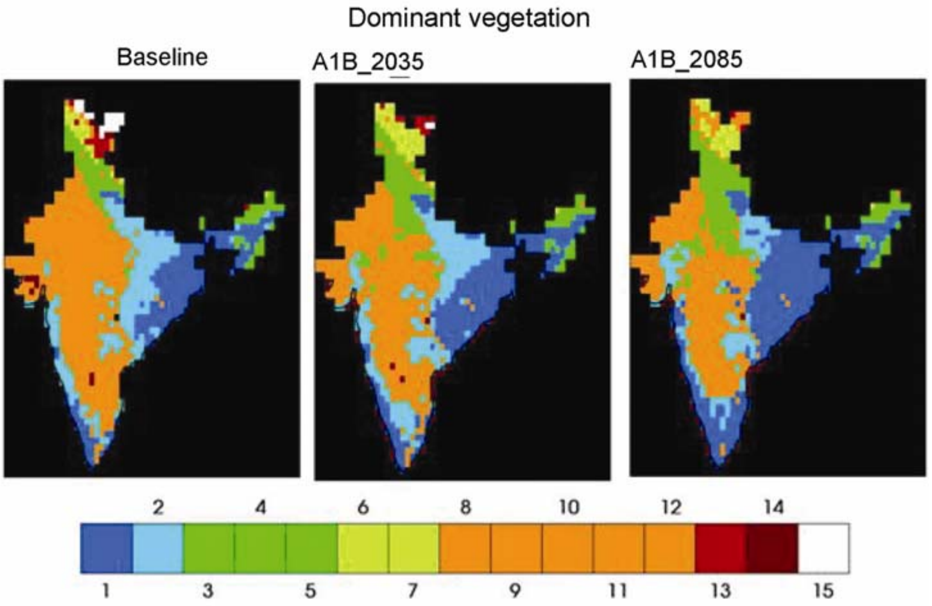


Figure 2. Forest type distribution and extent simulated by IBIS for the baseline case and A1B (2035 and 2085) scenarios. The numbers refer to the following vegetation types: 1, Tropical evergreen forest/woodland; 2, Tropical deciduous forest/woodland; 3, Temperate evergreen broadleaf forest/woodland; 4, Temperate evergreen conifer forest/woodland; 5, Temperate deciduous forest/woodland; 6, Boreal evergreen forest/woodland; 7, Boreal deciduous forest/woodland; 8, Mixed forest/woodland; 9, Savanna; 10, Grassland/steppe; 11, Dense shrubland; 12, Open shrubland; 13, Tundra; 14, Desert and 15, Polar desert/rock/ice.

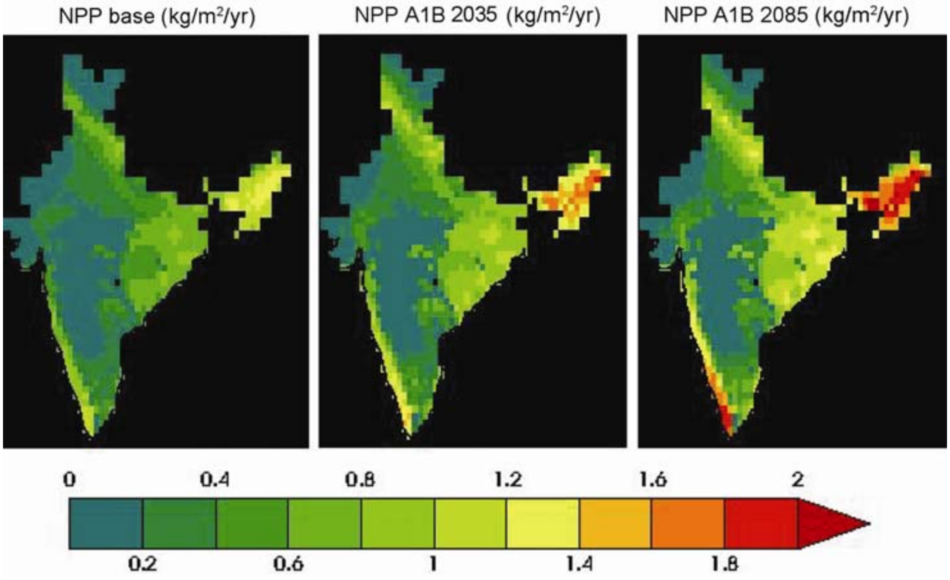


Figure 3. Net primary productivity (NPP) distribution (kgC/m^2/yr) simulated by IBIS for baseline and A1B scenarios.

microbiology to the higher temperatures are not explicitly taken into account in IBIS[23,24]. It also does not simulate forest fires dynamically, which are common, especially in the dry deciduous forests of India[25]. IBIS does not simulate changed pest-attack dynamics. Majority of forest species in India are susceptible to pest attack, and we have not included the impact of increased or decreased pest attack in a changed climate.

Vulnerability of Indian forests

Forests in India are already subject to multiple stresses, including over extraction, insect outbreaks, fuelwood collection, livestock grazing, forest fires and other anthropogenic pressures. Climate change will be an additional stress, which may have an over-arching influence on forests, through other stresses (insect and pest incidence,

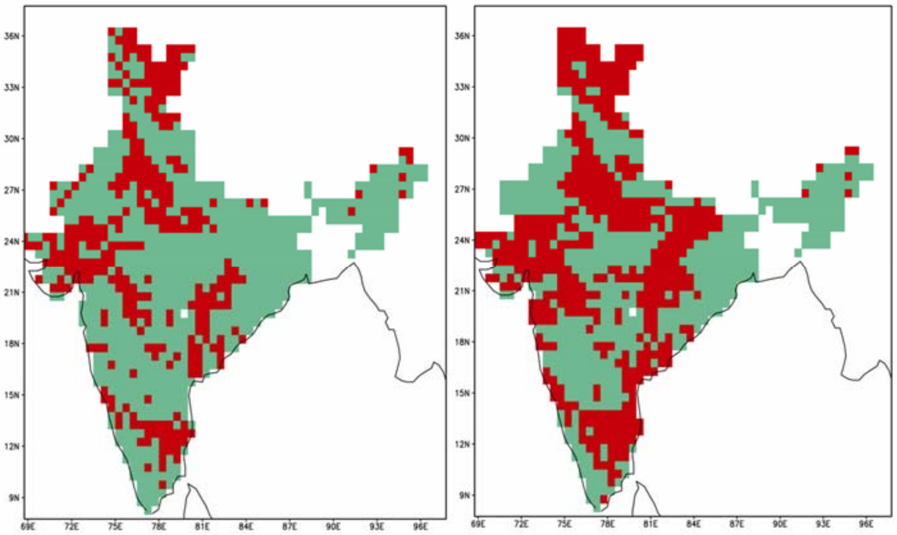


Figure 4. Vulnerable grids (marked red) in the A1B scenario. (Left panel). For the time-frame of 2021–2050. Here 326 (30.6%) out of a total number of 1064 grids are projected to be vulnerable. (Right panel) For the time-frame of 2071–2100. In this case, 489 (45.9%) grids are projected to be vulnerable. In turn, all forest areas in such vulnerable grids are projected to be vulnerable to climate change.

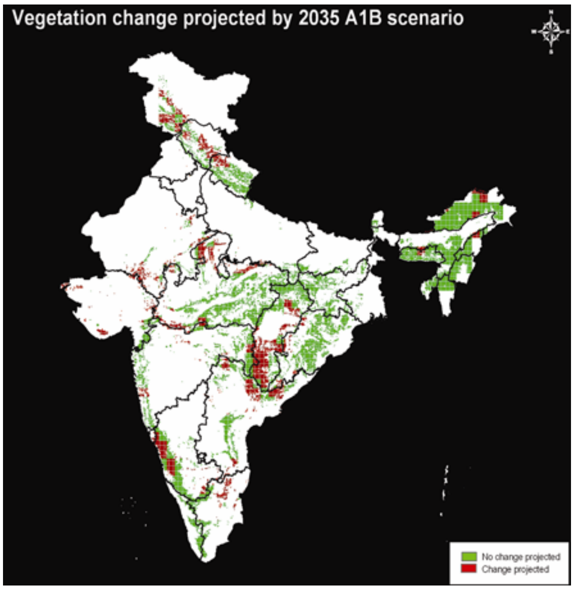


Figure 5. All forested grids in India are shown in colour (red or green). Red indicates that a change in vegetation is projected at that grid in the time-period 2021–2050, and green indicates that no change in vegetation is projected by that period. The black lines indicate state boundaries.

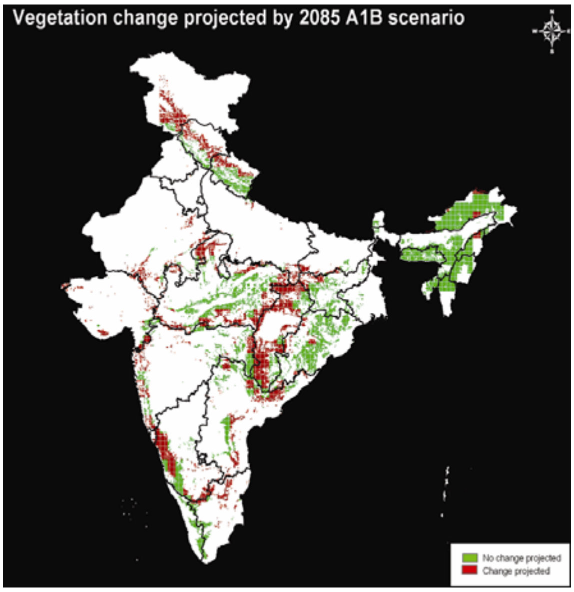


Figure 6. All forested grids in India are depicted in colour (red or green). Red indicates that a change in vegetation is projected at that grid in the time-period 2071–2100, and green indicates that no change in vegetation is projected by that period. The black lines indicate state boundaries.

diseases, etc). Here, we develop a vulnerability map and assess the vulnerability of different forest types and regions due to projected climate change. A grid is marked vulnerable if there is a change in vegetation, as simulated between the baseline and the future (both 2035 and 2085, and A1B SRES scenario in this case) vegetation. This means that the future climate may not be optimal to the present vegetation in such grids. The distribution of this vulnerability in the country is shown in Figure 4.

A digital forest map of India[7,8] was used to determine the spatial location of all forested areas. This map was based on a high-resolution mapping (2.5′ × 2.5′), wherein the entire area of India was divided into over 165,000 grids. Out of these, 35,899 grids were marked as forested grids (along with the forest density and the forest type). The projected change in vegetation information was combined with the spatial location of the FSI grids (Figures 5 and 6).

Table 1. Percentage of FSI grids projected to undergo change, aggregated by the major forested states

State	Number of FSI grids	Projected to change by 2035 (%)	Projected to change by 2085 (%)
Rajasthan	802	61.22	78.18
Jammu and Kashmir	910	57.03	88.35
Chhattisgarh	3292	48.00	75.85
Himachal Pradesh	838	47.49	65.39
Andhra Pradesh	2288	39.20	51.57
Karnataka	1947	38.37	62.20
Tamil Nadu	776	27.45	47.04
Madhya Pradesh	4432	22.59	48.17
Maharashtra	2197	21.21	45.33
Uttaranchal	1203	19.04	31.92
Arunachal Pradesh	2666	12.27	6.90
Orissa	2564	9.71	13.53
Meghalaya	829	7.96	0.00
Assam	1261	5.23	1.11
Jharkhand	1148	0.00	24.30

Table 2. Percentage of FSI grids projected to undergo change, aggregated by Champion and Seth[17] forest types

Forest type (by Champion and Seth[17])	Number of FSI grids	Projected to change by 2035 (%)	Projected to change by 2085 (%)
Tropical dry evergreen forest	37	70.27	72.97
Sub-tropical dry evergreen forest	133	54.14	67.67
Himalayan dry temperate forest	106	52.83	76.42
Himalayan moist temperate forest	1144	52.62	88.02
Sub-alpine and alpine forest	400	49.75	77.50
Tropical thorn forest	1278	41.39	75.12
Tropical semi evergreen forest	1239	30.67	50.36
Littoral and swamp forest	7	28.57	28.57
Tropical dry deciduous forest	9663	25.62	46.73
Tropical moist deciduous forest	11266	22.63	37.88
Sub-tropical pine forest	1662	20.64	17.39
Sub-tropical broadleaved hill forest	192	15.10	15.10
Tropical wet evergreen forest	2862	14.61	14.68
Montane wet temperate forest	940	5.64	0.32

Figures 5 and 6 show the forested grids where a vegetation shift is projected by IBIS. For example, in 2035, one can see that most of the grids are projected to undergo change in the state of Chhattisgarh. Other forested areas that may be vulnerable to climate change are the northern parts of the Western Ghats (in the north part of Karnataka) and the northern parts of the forests of the Himalayas.

The above information is aggregated by the major forested states, and presented in Table 1. From Table 1, one can infer that Chhattisgarh has a sizable amount of forest area (almost 3300 FSI grids) and a large fraction of it (~ 48%) is projected to undergo vegetation change by the 2030s, and is thus vulnerable. Forests of Rajasthan and Jammu and Kashmir, even though less in area, are projected to be significantly vulnerable. Moreover, the vegetation cover of India can be divided into a number of vegetation zones, according to the classification of Champion and Seth[17]. We also aggregated the FSI forest grids as per these zones, and the results are presented in Table 2. Here, we can infer that the Himalayan moist temperate forests (comprising almost 1200 FSI grids) are significantly vulnerable to climate change.

- The forests in the central part of India, especially the northwestern part, are highly vulnerable. There are regions of vulnerability surrounded by non-vulnerable regions in the area.
- There are relatively few areas in the northeastern part of India that have high vulnerability. Low vulnerability in this region is because climate is predicted to get hotter and wetter there, which is conducive to the existing vegetation types (such as tropical evergreen forests).
- A significant part of the Himalayan biodiversity hotspot that stretches along the north-western part of India along the states of Punjab, Jammu and Kashmir and Himachal Pradesh is projected to be highly

vulnerable. This may be mostly attributed to the higher elevation of these regions. Our studies have shown that these regions will experience higher levels of warming.

- The northern and central parts of the Western Ghats seem to be vulnerable to climate change. The northern parts of the Western Ghats contain significant extent of open forests, which may drive up the vulnerability. Vulnerability in the central part of the Ghats is likely to be caused by the negligible precipitation increase (with more than 3°C rise in temperature). The southern Western Ghats region appears to be quite resilient as IBIS simulates mostly tropical wet evergreen forests which, according to the simulations, are likely to remain stable.

Implications of climate impact assessment

The assessment of climate impacts showed that at the national level, about 45% of the forested grids are likely to undergo change. Vulnerability assessment showed that the vulnerable forested grids are spread across India. However, their concentration is higher in the upper Himalayan stretches, parts of Central India, northern Western Ghats and the Eastern Ghats. In contrast, the northeastern forests, southern Western Ghats and the forested regions of eastern India are estimated to be least vulnerable. Currently, within the forested area of 69 mha only 8.35 mha is categorized as very dense forest. More than 20 mha of forest is monoculture and more than 28.8 mha is fragmented (open forest) and has low tree density[7]. Low tree density, low biodiversity status and higher levels of fragmentation contribute to the vulnerability of these forests.

Western Ghats, though a biodiversity hotspot, has fragmented forests in its northern parts. This makes these forests additionally vulnerable to climate change as well as to increased risk of fire and pest attack. Similarly, forests in parts of western as well as Central India are fragmented and have low biodiversity. At the same time, these are the regions which are likely to witness a high increase in temperature, and either decline or marginal increase in rainfall.

We notice that most of the high-altitude mountainous forests (sub-alpine and alpine forest, the Himalayan dry temperate forest and the Himalayan moist temperate forests) are susceptible to the adverse effects of climate change (Figures 5 and 6). This is because climate change is predicted to be larger for regions that have greater elevation. There is a need to explore win-win adaptation practices in such regions, such as anticipatory plantations, sanitary harvest, and pest and fire management.

Forests are likely to benefit to a large extent (in terms of NPP) in the northern parts of Western Ghats and the eastern parts of the India, while they are relatively adversely affected in western and Central India (Figures 5 and 6). This means that afforestation, reforestation and forest management in northern Western Ghats and eastern India may experience carbon sequestration benefits. Hence, in these regions a species mix that maximizes carbon sequestration should be planted. On the other hand, in the forests of western and Central India, hardy species which are resilient to increased temperature and drought risk should be planted and care should be taken to further increase forest resilience.

Some of the potential recommendations with respect to climate change and forest sector include the following:

- There is a need for climate impact and vulnerability assessment using multiple global climate models as well as multiple dynamic global vegetation models. This may require generation of climate, vegetation, soil and water-related data for different forest types of India.
- There is a need to develop tropical forest or India-specific dynamic global vegetation models which will require generation of a number of plant physiological parameters.
- India should initiate long-term monitoring of vegetation response to changing climate in the long term.
- Since nearly half the forested grids are projected to experience changes in vegetation type, there is a need for serious consideration of incorporation of climate change in all forest conservation and development programmes, such as ‘Greening India Mission’.
- There is a need for developing and implementing adaptation measures to enable forest ecosystems to cope with climate risks. Many ‘win-win’ or ‘no-regret’ adaptation practices could be considered for implementation. A few examples of adaptation practices include:

    - Modifying the forest working plan preparation process, incorporating the projected climate change and likely impacts.
    - Initiating research on adaptation practices, covering both conservation and forest regeneration practices.
    - Linking protected areas and forest fragments.
    - Anticipatory planting of species along the altitudinal and latitudinal gradient.
    - Adopting mixed species forestry in all afforestation programmes.
    - Incorporating fire protection and management practices, and implementing advance fire warning systems.
    - Adopting sanitary harvest practices and thinning.

Uncertainties, model and data limitations

There are a few notable limitations in this study. IBIS tends to simulate a fairly strong CO_2 fertilization effect[18,22] because IBIS does not have representation for nitrogen and other nutrient cycles[18]. It is known to over-predict grasslands[19].

The IBIS model, in its current form, does not include a dynamic fire module[26]. It does not account for changes in pest attack in a changed climate. We believe that many of these limitations of the model have led to the overestimation of future NPP and SOC gains. Climate projections are currently not available in probabilistic terms, which currently limits us from presenting a probability-based forest dynamics scenario for India.

There is uncertainty in climate projections, particularly in precipitation at down-scaled regional levels. Land-use change and other anthropogenic influences are not represented in the model projections. Effects of afforestation and regeneration (e.g. on abandoned croplands or wastelands) on climate are also not taken into account. However, these limitations and uncertainties should not stop policies and interventions to reduce vulnerability of forests to climate risks and enhance the resilience to projected climate change.

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