

Climate and ecosystem change: What does it mean for biodiversity conservation in India?

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Abstract

Climate change as a consequence of human activity such as emission of greenhouse gases into the atmosphere is now a distinct possibility according to the assessment of the Intergovernmental Panel on Climate Change. During the 21st century climate change can be expected to make impacts on ecosystems and biodiversity on a global scale. In this paper I briefly review the implications of climate change for forest and wildlife conservation in India. Outputs from general circulation models of temperature and precipitation changes over India are examined in the context of possible impacts on forests. A regional model of climate and vegetation change in Nilgiri Biosphere Reserve of south India is presented. Implications of this model for conservation of various vegetation types and endemic species such as the tahr (*Hemirragus hyllocrins*) are discussed. Some adaptation strategies are outlined.

Key Words: Climate change, vegetation change, biodiversity, Western Ghats.

1. Introduction

During the Quaternary period (c. 1.8 million years ago to the present), the Earth has gone through phases of cool and warm periods that have occurred as part of natural processes.^{1, 2} However, during the 20th century, the observed increase of 0.5°C in mean global temperature is being directly attributed to anthropogenic activities, primarily those which have resulted in net emissions of greenhouse gases.³ A whole body of science is now being devoted to understanding the mechanisms of the greenhouse effect and climate change, and the possible impacts of this on natural and man-made ecosystems.³ Climate change can be expected to have significant impacts on forest distribution, dynamics, productivity and biodiversity.^{4–7} The projected impacts of climate change on forests also have implications for forest product flows and trade, and forest management.⁸ Even if this is speculative at present, it is useful to consider the possible impacts of climate change on forests and wildlife in India.

2. Natural climate change

While the Earth's climate has varied naturally over geological time, the changes in the past one or two million years are better understood than those of earlier periods.⁹ These changes seem to be caused by long-term rhythmic variations in the orientation of the earth's axis within its orbit around the Sun. These are the obliquity of the Earth's axis; the precession of the equinoxes and the eccentricity of the Earth's orbit.^{10, 11} These essentially alter the amount of radiation re-

ceived each season and thus alter seasonality, which is a measure of how warm the summers are in contrast to the severity of the winters. Evidence from pollen, marine plankton and oxygen-isotopes in foraminifera shells has provided data on climatic conditions at different times. Over the past million years, the most noticeable pattern of global variation has been the oscillation between glacial and interglacial climates, with glacial periods occurring roughly every 100,000 years.⁹ Corresponding to this the global mean temperatures have also varied. However, the rate of change anticipated over the next century may be much higher than any past change in climate.

2.1. IPCC assessment of climate change

The Intergovernmental Panel on Climate Change (IPCC) published in 1996 its second detailed assessment of the evidence for climate change based on the available literature, in addition to addressing the possible environmental and socioeconomic impacts of climate change and mitigation strategies.³ Briefly, their conclusions were as follows. Atmospheric concentrations of greenhouse gases (which tend to warm the atmosphere) and aerosols (which in some regions partially offset the greenhouse effect) have increased since the industrial era began around 1750. Carbon dioxide (CO₂) has risen by about 30%, methane (CH₄) by more than 100%, and nitrous oxide (N₂O) by about 15% since then.³ Atmospheric concentrations of CO₂ have increased from a pre-industrial concentration of about 280 ppmv to about 366 ppmv in 1998.¹² As a consequence of greenhouse gas increase, the global mean temperature is expected to rise at the rate of 0.3°C per decade to 1°C above the current value by 2025, and by 3°C by the year 2100. Global warming will not be uniform, the higher latitudes might warm to a greater degree than the tropics. In general, precipitation will increase throughout the year, in the tropics and near the poles, whereas in mid-latitudes it would be only in the winters. However, rainfall would decrease on regional or local scales. On the whole, climatic variability is expected to increase. A rise in global sea levels between 6 and 65 cm between 2030 and the end of the next century is anticipated.

2.2. Models of climate change impacts on landscapes

Climate change is expected to make impacts on boundaries of forest types and areas, primary productivity, species populations and migration, occurrence of pests and disease, and forest regeneration. Several models have been used to assess the impacts of climate change on vegetation on a global scale.

- (a) The BIOME model¹³ is an equilibrium model, which defines a set of plant functional types characterized by minimal sets of climate thresholds. Solomon *et al.*¹⁴ using BIOME and different future climate scenarios under doubling of CO₂ project the area under tropical forests to expand in the range of 11% to 16%, depending on the climate model used. A large increase in temperate forest types is predicted, corresponding to a similar decrease in the area under boreal forests.
- (b) The MAPSS (Mapped Atmosphere–Plant–Soil System) model¹⁵ is also an equilibrium model under doubling of CO₂ which projects a significant decline in area under tropical rain forest, a corresponding increase in tropical dry forest and, interestingly, decreases in both temperate and boreal forests.

- (c) The IMAGE (Integrated model to assess the Greenhouse Effect) model¹⁶ goes further by incorporating the BIOME vegetation classification into a model of interacting human population, land-use, vegetation, and climate. Its application is most useful where land-use changes are important. Using IMAGE, Zuidema *et al.*¹⁷ projected the area under tropical forests to decline by 24% by 2020 and 48% by 2050, as compared to the 1990 area. More modest decreases in the area under temperate and boreal forests were also projected.

In summary, all the three models project significant changes in the area under the world's major forest types. Except in the temperate zone, there may be a net loss of forest area in the other zones.

2.3. *Potential impacts of climate change on ecosystems and species*

The possible impact of climate change on ecosystems, communities and species populations is still rather poorly understood. One approach is to look at past climate change events and deduce the changes that occurred from the paleo-record. Changes in species populations in recent times because of climate change are poorly documented with a few exceptions. I shall illustrate this with a few examples.

Increased CO₂ concentrations in the atmosphere can stimulate photosynthetic rates, especially in C3 plants, which may be further aided by higher temperatures. There may, however, be limits to increased productivity as higher temperatures may also stimulate photorespiration. At the same time, a combination of various influences including temperature changes, soil nutrient dynamics, water availability, and pest and pathogen attacks could make substantial impacts on productivity and forest composition. The ability of plants to migrate, through dispersal and establishment, to keep pace with changing climate may also be a critical factor in their survival. The fastest changes are likely to be seen on the boundaries between vegetation types or in areas where climate changes most abruptly. The studies so far indicate that migration rates of 40 to 500 m per year may be possible in the mid-latitudes.⁴ Nothing much is known about plant migration rates in the tropics. These recorded rates from the past have to be compared with likely rates of shifts in vegetation boundaries in the future due to climate change. One additional factor today is that human interference and fragmentation of natural habitat may slow down or block migrations. While plants could migrate in response to previous climate change episodes, they may be unable to do so now because of a human-altered landscape in many areas.

Changes to the climate add another important element to the current role of fire in alteration, and often degradation of natural ecosystems. Warmer temperatures, and increased periods of drought, are likely to add to the number and severity of fires.¹⁸ A study in Indonesia found forest fires related to drought and the arrival of El Nino linking these climatic conditions to the huge forest fires in eastern Borneo that occurred between 1992 and 1993.¹⁹

Concurrent with changes to terrestrial vegetation, we can expect the fauna to be impacted. Climate change has been implicated as a major cause of the late Pleistocene extinctions of the larger mammals, for instance McLean.²⁰ Future climate change could affect species from a variety of animal taxa. Unlike in most birds or mammals, environmental factors (temperature)

determine sex ratios in many reptile species. Production of both sexes takes place only over a narrow thermal range. In map turtles (*Graptemys pseudogeographica*), incubation at 23–28°C, 28–30°C, and above 30°C produces only males, males and females, and essentially females, respectively.^{21, 22} Increases in mean temperatures could cause distortions in the demography of reptilian species through changes in the sex ratios of populations. A recent study in the highland forests of Monteverde, Costa Rica, showed that 20 out of 50 species of anurans (frogs and toads) in a 30-km² study area, including the locally endemic golden toad (*Bufo periglenes*), disappeared following synchronous population crashes in 1987. The results show that these crashes probably belong to a constellation of demographic changes that have altered communities of birds, reptiles and amphibians in the area and are linked to recent warming. The changes are all associated with patterns of dry-season mist frequency, which is negatively correlated with sea-surface temperatures in the equatorial Pacific and has declined dramatically since the mid-1970s.²³

In coastal ecosystems, a principal threat comes from sea-level rise and associated changes in sediment dynamics and salinity, which will inundate many mangroves or erode their substrate. Research on past sea-level rise suggests that low island mangroves are the most vulnerable, only keeping pace with a rise of about 10 cm per century, whilst predicted changes in the next few decades are almost an order of magnitude greater. Autochthonous mangroves will be unable to accumulate sediment fast enough to keep pace with rising water. They may also suffer problems from salinity changes, erosion, inundation stress and increased storms. In coral reefs, an increase in sea-water temperatures (but sometimes cooling), changes in water salinity or silt deposition results in the expulsion of zooxanthellae from the cells of coral polyps, leading to bleaching and even mortality. Either short-term increases of 3–4°C, or longer periods of 1–2°C above normal can cause bleaching. The 1982–83 and the 1997–98 El Niño events coincided with coral bleaching in many of the world's oceans.²⁴

An IPCC report on regional climate change²⁵ concluded that there are few studies on the potential impacts of climate change on forests and forestry for the tropical Asian region.

2.4. Projected change in climate over India and impacts on forests

Any assessment of the potential impact of climate change on forests requires a climate change model and a vegetation change model. While the former can be obtained from the several general circulation models (GCM) in use currently, the latter, which links climate with vegetation (BIOME and IMAGE are two examples), have limitations when applied to India. Due to the complex topography and inadequate climatic data sets for the Western Ghats in southern India, BIOME fails to adequately discriminate between the diverse natural vegetation types here,²⁶ (also see Prentice *et al.*¹³). This model, however, may be usefully applied to certain other regions. IMAGE makes projections of unrealistically large declines of forest cover in South Asia.

There are two possible scenarios of climate change in India—one based on greenhouse gas increase and the other also incorporating sulphate aerosols. Their possible impacts on forests are also considered here. Two scenarios have to be considered because the simulated climate projections are substantially different over the northern part of the country.

2.4.1. *Scenario 1: Climate change and impacts under greenhouse gas forcing*

The climate parameters used in this scenario²⁷ are largely based on projections made by Hulme and Viner²⁸ for the 2060s. In southern India increased temperatures of 2–3.5°C during winter and summer would potentially stress vegetation through increased evapotranspiration. The increased rainfall, however, coupled with elevated CO₂ and increasing water use efficiency could compensate for this loss. In the balance, the marginal increase in soil moisture projected for this region could result in increased productivity in all forest types. Further, a shift in vegetation-type boundaries could be expected along a west-east gradient (with moist forest types expanding farther east) and along an altitudinal gradient (with species adapted to the warmer, lower elevations migrating to higher altitudes). An increase in dry-season length could also place forest types such as dry and moist deciduous forests at increased risk of dry-season fires. The montane regions of the Western Ghats featuring a mixture of stunted evergreen forest and grasslands with sharp ecotones are a sensitive indicator of past climate change.^{29, 30} With an increase in temperature and reduction in incidence of frost, the montane forests dominated by Lauraceae and Rubiaceae could potentially expand into the grasslands.

In central India, increase in rainfall and soil moisture during the southwest monsoon could potentially transform the forests to moister vegetation types. In northwest India there seems little scope for significant changes. In northeast India, however, the climate change scenario is not very clear with high variability over small areas in this region. This region already experiences very high rainfall and any increase may not have much consequence for the vegetation.

2.4.2. *Scenario 2: Climate change and impacts under greenhouse gas and sulphate aerosol forcing*

The Intergovernmental Panel on Climate Change had recognized that sulphate aerosols would exert a strong negative forcing on climate.³ A recent experiment run at the Max Planck Institute using the European Community Hamburg (ECHAM version 3) coupled ocean atmosphere model,³¹ incorporating data on sulphate aerosols, provides the only detailed projections for the Indian subcontinent, and this forms the basis for this scenario.

The major consequence of this simulated temperature change scenario is on the patterns of precipitation. With a reduction of the land–ocean thermal contrast, the strength of the Indian summer monsoon is expected to actually decline, with significantly reduced precipitation in parts of the country. While peninsular India may still show increased rainfall of up to 2 mm/day at the extreme south, a gradual decrease in this figure is simulated as one proceeds northward, with a deficit in rainfall (as compared to the 1980s) above 20°N latitude. Northern India may experience up to a 1 mm/day decrease, while in central India this may be as high as 2 mm/day.

Impacts on the forests of southern India may be negligible. However, with an increase in temperature and a decrease of 20% or more in summer rainfall, the forests of central India would face considerable soil moisture stress. Similar trends, though of lower magnitude, are indicated for the entire northern India, including the forests of the Himalayan slopes and foothills, and those of the northeastern states.

2.5. *Past vegetation and climatic change in the Western Ghats*

Much of the evidence for vegetational and climatic change during the past 40,000 years comes from carbon stable isotopic studies of peat deposits in the Nilgiris^{29, 30, 32} and pollen studies in the Nilgiris³³ and coastal Uttara Kannada.³⁴ The Nilgiri studies show that the balance of C3 plants (most tropical trees, shrubs and herbs, and temperate grasses) and C4 plants (tropical grasses and sedges) has fluctuated considerably as a result of climatic change.^{29, 30} During the last glacial maximum (16,000–18,000 yrs BP), when mean global temperatures were considerably lower than at present, there is evidence for an arid climate with a dominance of C4 vegetation. During the deglaciation (14,000–10,000 yrs BP) there is a gradual increase in C3 vegetation, suggesting an expansion of C3 herbs and possibly montane forest as well under a warming and moister climate. The early Holocene (10,000–9,000 years BP) is marked by a predominance of C3 vegetation under conditions of peak soil moisture. An arid period with C4 vegetation is again clearly established during 5,000–2,000 years BP. With an almost equal mixture of C3 and C4 vegetation, the present-day climate is moderate as compared to the extremely arid or moist phases indicated during the late Quaternary period. Correlations between global atmospheric CO₂ levels and the proportions of C3 and C4 plants in the Nilgiris³⁵ also suggest that the vegetational changes may be also influenced by CO₂ in addition to soil moisture.

2.6. *Modelling future climate and vegetation change in the Western Ghats*

The Western Ghats are topographically complex with corresponding variation in climate. In order to assess the potential impacts of climate change on forests in two regions of the Western Ghats, the Nilgiri Biosphere Reserve and Uttara Kannada district, a simple equilibrium model was set up. This inter-linked the present-day vegetation with climate, and then used the outputs of GCM-based climate projections as reported by Kelly³⁶ to derive potential shifts in areas under different vegetation types. From the GCM projections, for any given scenario of temperature and precipitation change for a given year, it was seen that the lower latitude is projected to experience the least change from the baseline climatology (1961–1991) while the higher latitudes show the greatest change. This south–north gradient, with the south being better buffered against change, possibly as a result of the greater moderating influence of the ocean, is one of the most consistent and striking features of climate modelling for South Asia as a whole. For studying the potential vegetation change in the Nilgiris, the six major natural vegetation types defined are a) wet evergreen forest, b) montane stunted evergreen forest and grassland, c) degraded moist forest, d) moist deciduous forest, e) dry deciduous forest, and f) dry thorn forest. Only four vegetation types were defined for Uttara Kannada. To illustrate the possible changes in vegetation, I shall give only the Nilgiri case study.

Three possible scenarios of climate change were considered. These were: a) Most likely scenario 2020 (temp. +0.3°C, rainfall +2%); b) Most likely scenario 2050 (Temp. +0.6°C, rainfall +4%); and c) Worst case scenario 2050 (Temp. +0.9°C, rainfall –8%). With both the Most likely scenarios, there is an increase in evergreen, moist deciduous and dry thorn forest types, and a decline in the montane forest/grassland and dry deciduous forest. As expected, the moister forest types show an increase with increasing rainfall. A typical sequence could be a shift from dry deciduous forest through moist deciduous forest, semi-deciduous forest to wet

evergreen forest as a result of increased moisture. The dry deciduous forest, thus, declines by as much as 36% by 2050, probably as a result of some shift to moist deciduous forest in response to increasing precipitation, while other parts shift to dry thorn forest as a consequence of increasing temperature. The montane ecosystem, characterized by low temperatures, declines by 7% (year 2050) in the area in response to increased temperatures. Under the Worst case scenario, where temperature increases and precipitation decreases, there is a substantial increase in the driest vegetation type (the dry thorn forest increasing by 33%), at the expense of dry deciduous forest (-48%), with modest change in other vegetation types by 2050.

In the montane Nilgiris we have to consider another possible change in habitat characteristics. Much of the area under natural grassland has been planted in recent decades with exotic plants such as wattle (*Acacia* spp.) and bluegum (*Eucalyptus* spp.). Wattle has the potential to spread into nonplanted areas as a weed. Their spread is today constrained by the occurrence of frost during the winter months. Increasing temperatures could lower the incidence of frost and facilitate the spread of wattle into the remaining grasslands. Plants such as wattle with a C3 pathway of photosynthesis could also be expected to show increased productivity under increasing atmospheric CO₂ concentration (the so-called CO₂ fertilization effect).³⁷

It is important to note that the projections made for the Nilgiris are based on the 'equilibrium model'. The transient responses of vegetation have not been considered here. Forest die-back or mortality may occur in the transient period.³

2.7. Possible impacts of climate change on wildlife

Climate change as through increase in temperature could directly affect several species of animals.³⁸ Shifts in vegetation boundaries and areas under different vegetation types could also have major impacts on wildlife species, especially when dispersal to more suitable habitat is constrained by fragmentation and development. We can only speculate at this stage on which species are more likely to be at risk. For instance, as a consequence of a reduction in the area under natural grassland in the Nilgiris (or similar habitat in the montane Western Ghats), the Nilgiri tahr (*Hemiragus hylacrius*), which is endemic to these montane grasslands, would be at risk of extinction.³⁰ Similarly, an upward shift in vegetation boundaries in the Himalayas could result in the disappearance of certain habitat types, as these are under human settlement or ecologically untenable because of the prevailing climate. Wildlife species associated with such habitats would be at risk. If the mangroves of the Sunderbans in India and Bangladesh are reduced because of sea-level rise, one of the largest populations of the tiger (*Panthera tigris*) would be threatened. In both these cases, there is no possibility of natural dispersal to new habitats because these are isolated amidst human-transformed landscapes. Increasing climate variability could pose a threat of a different kind. A severe drought would threaten populations of several wildlife species in isolated reserves. Severe flooding would pose a similar threat in certain wildlife parks. The 435 km² Kaziranga National Park, home to the largest population of one-horned rhinoceros (*Rhinoceros unicornis*) in addition to the Asian elephant (*Elephas maximus*), the tiger (*Panthera tigris*), and the Asiatic buffalo (*Bubalus bubalis*), is subject to annual floods from river Brahmaputra. Increased precipitation in the extensive catchment of the Brahmaputra in northeast India could flood the park to the extent that animal populations would suffer high mortality, especially because their movement into higher ground in the

Mikhir hills of Karbi Anglong district has been severely hampered by development. Indeed, a severe flood did occur during the monsoon season of 1998 when most places in the national park were covered under 13–14 feet of water, resulting in the drowning of several species of animals including the endangered rhino.

2.8. *Adaptation measures to climate change impacts*

There is obviously much uncertainty as to the magnitude and direction of climate change. Policy responses can be based on differing perceptions of the risks posed by climate change. These are a) Maintain the status quo; b) Follow no-regret strategies; c) Take precautionary measures; and d) Follow pro-active strategies.

Several suggestions have been made with respect to forestry practices. A shift from planting monocultures and exotics to diverse and broader deployment of species, seed sources and families would assist in adaptation in the wake of uncertainty. Planting programmes may also have to deploy nonlocal seed sources, imported from further south or from lower elevations as a precaution against increasing temperatures.³⁹ Leaving one-quarter to one-third of the plantation area in its natural state for promoting forest succession through natural regeneration reduces the occurrence of pest and disease.⁴⁰ Short-rotation plantation forestry provides opportunities for any adaptation option in terms of changes in species mix or silvicultural practices. For conserving wildlife species perhaps one of the most important considerations is to assist natural migration through maintaining habitat contiguity. Protected areas must function in landscapes where ecological integrity is sufficient to permit the movement of populations. There must be a comprehensive approach to conserving both community and reserved lands.⁴¹

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