Climate change and its impact on tropical montane ecosystems in southern India

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Abstract. The montane regions (> 2000 m MSL) of the Western Ghats in southern India feature stunted evergreen forests (C3 plant type) interspersed with extensive grasslands (C3 or C4 plant types). We have studied the vegetational history of this ecosystem in relation to climate change during the late Quaternary through stable-carbon isotope analysis of peat deposits as indicators of C3 or C4 plant types. Grasslands (of C4 type) were predominant during the last glacial maximum (20–18 kyr BP) and again during 6-3.5 kyr BP, while forest and possibly C3 grassland expanded during the deglaciation, attaining their peak distribution at 10 kyr BP. The shift in C3 and C4 plant types seems related to changes in moisture and atmospheric CO_2, with lower moisture and CO_2 levels favouring the latter plant types.

The oscillating climate and vegetation has influenced the structure and composition of the montane ecosystem. Plant diversity of the near-pristine montane forests is relatively lower than other comparable sites in the neotropics. The implications of global change on the tropical montane ecosystem, in particular the composition of the angiosperm and vertebrate communities, are discussed. In particular, an expansion of montane forest and replacement of C4 with C3 grassland can be expected. Human impact on the natural vegetation, such as conversion of grasslands to monoculture plantations of wattle and eucalypts may, however, interfere with natural succession caused by global climate change. Endemic mammals such as the Nilgiri tahr would face increased risk of extinction.

Key words. Climate change, vegetation change, tropical forest, montane ecosystem, stable isotopes, southern India.

INTRODUCTION

Due to their complex topography and a biogeographic history featuring regular altitudinal migrations of vegetation zones in response to climate change, the montane ecosystems around the globe usually have distinct biological communities and high levels of endemism (Gentry 1993). Montane ecosystems also play an important role in the hydrology of lowland ecosystems and thus their integrity has broader conservation implications. This ecosystem has received little scientific attention until recently, at least in the neotropics (Gentry, 1993).

The montane regions (> 2000 m MSL) of the Western Ghats in southern India feature stunted evergreen forests interspersed with grasslands. The forests are largely confined to the sheltered folds of the mountains and stream courses, while the grasslands cover the hill slopes. The ecotone between forest and grassland is very sharp and is maintained by a combination of frost and fire (Meher-Homji, 1984).

Many of the valleys feature peat deposits which provide a vegetational and climatic record of the late Quaternary

(Sukumar *et al.*, 1993), and can be used as palaeo-analogues for predicting impact of global change on the montane ecosystem. Using a combination of pollen and stable isotope analyses of peat samples, we have been reconstructing the late Quaternary vegetation and climate of this region.

In this paper we review briefly the palaeoecological record of the montane region and use this to make qualitative predictions of the possible impact of future climatic change on the montane ecosystem.

THE PALAEOCLIMATE RECORD

Our palaeoclimatic reconstruction using stable-carbon isotope analysis is based on the well-known difference in the ratio of ^{13}C and ^{12}C in plants possessing the C3 and C4 pathways of photosynthesis. The C3 plants (most dicotyledonous plants and temperate grasses) typically have $\delta^{13}C$ values in the range of − 26 to − 30 mil, while the C4 plants (tropical grasses) have values of − 11 to − 13 per mil (Smith & Epstein, 1971). The C3 and C4 plants are known to have different ecological preferences, with the former dominating areas of higher soil moisture and the latter areas with low soil moisture (Tieszen *et al.*, 1979),

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TABLE 1. Summary of stable-carbon isotopic values in peats and the climatic and vegetational inferences

Time period in years BP	Peat $\delta^{13}C$ (per mil)	Atmospheric CO_2 (p.p.m.)	Vegetation and monsoon pattern
1. 20,000–16,000	$-12.8--14.4$	< 200	Arid phase with C4 grass predominance
2. 11,000–9000	-24.2	230–285	C3 vegetation increases, possible expansion of montane forests
3. 6000–3500	$-14.3--18.6$	210–250	Relatively arid climate with C4 vegetation

Radiocarbon dates and peat $\delta^{13}C$ values are based on work by Sukumar *et al.* (1993) and atmospheric CO_2 as reported by Robinson (1994).

and thus used as palaeoclimatic indicators (Cerling *et al.*, 1989; Ambrose & Sikes, 1991). C4 plants also have higher photosynthetic efficiencies as compared to C3 plants at low atmospheric CO_2 levels.

Our peat samples were collected from five basins in the Nilgiri hills (11°–11°30'N, 76°20'–77° E) and dated by the conventional radiocarbon method (Rajagopalan *et al.*, 1978; Sukumar *et al.*, 1993). Stable-carbon isotope analyses were carried out at the Physical Research Laboratory using standard techniques, and results are reported in greater detail elsewhere (Sukumar *et al.*, 1993). We have interpreted a $\delta^{13}C$ signature characteristic of predominantly C4 vegetation to indicate arid conditions and that of C3 vegetation to reflect moist conditions on a relative scale.

The isotopic record dating back to the last glacial maximum (LGM) indicates the following trends (Table 1).

1. Grasslands (of C4 type) were predominant during the LGM, about 20,000–18,000 yr BP, a period characterized by low atmospheric CO_2 levels (Robinson, 1994), lower mean temperature and low rainfall over the Indian subcontinent.

2. During the deglaciation (18,000–10,000 yr BP) there was an expansion of C3 plants, which attain their peak representation in the peats at 10,000 yr BP, a period with higher global CO_2 levels (Robinson, 1994), higher temperatures and higher precipitation from the Indian summer monsoon. It is unclear at this stage whether the increase in C3 vegetation was due to increase in C3 forest or C3 grassland, or both.

3. Another shift towards C4 vegetation (grassland) occurred during 6000–3500 yr BP as a result of lower rainfall and possibly CO_2 levels.

Our palaeoecological reconstruction of southern India is largely consistent with other lines of evidence for the subcontinent from oceanic sediments and foraminifera (Van Campo, Duplessy & Rossignol-Strick, 1982; Van Campo 1988; Duplessy 1982; Sarkar *et al.*, 1990), lacustrine pollen deposits in north western India (Singh, Wasson & Agarawal, 1990; Swain, Kutzbach & Hastenrath, 1983), fluvial deposits in central India (Williams & Clark, 1984) and climatic simulation models (Gates, 1976; Manabe & Hahn, 1977; Kutzbach 1981; Prell & Kutzbach, 1987).

DIVERSITY OF MONTANE FORESTS

The montane forests and grasslands have thus expanded and contracted, and in the process undergone turnover in species composition, in response to the changing climate. We estimated the diversity of woody species > 2.5 cm d.b.h. by enumerating all individuals within belt transects of 250 m × 4 m (0.1 hectare) each in eight montane forest patches.

Floristically, the montane forests in the Nilgiris are dominated by members of the families Lauraceae (19.3% of species), Rubiaceae (12%), Symplocaceae (9.6%), Myrtaceae (7.2%) and Euphorbiaceae (7.2%). In this respect these are similar to the floristics of neotropical montane forests (Gentry, 1993). However, when our results are compared with other similar montane sites in the neotropics, we see that the species diversity in the Nilgiri forests is the lowest among all the sites (Table 2). The Nilgiri montane forests have an average of only thirty species in 0.1 ha as compared to thirty-three in Mexico, fifty-two in Costa Rica, seventy-three in Peru and eighty-four in Colombia.

There could be several causes, including historical factors, for the lower diversity in the Nilgiri forests. However, plausible causes could be related to turnover of species (Phillips & Gentry, 1994) as the forests expanded and contracted in response to climatic oscillation. Species extinctions could also be higher in 'insular' montane forest patches in conformity with the predictions of island biogeography theory (MacArthur & Wilson, 1967; Wilcox, 1980).

POSSIBLE IMPACT OF FUTURE CLIMATE CHANGE

Over the next few decades, mean temperatures in the tropics are expected to increase by at least 1–2°C as a result of increase in atmospheric CO_2, methane and other greenhouse gases (IPCC, 1992). General Circulation Models (GCMs) predict an intensification of the Indian summer monsoon as one consequence of the increased temperature (Hulme & Viner, 1995), which is consistent with the palaeoclimate record. These climatic changes can be expected to favour the expansion of C3 vegetation over C4 vegetation for several reasons. Higher CO_2 levels would enhance

TABLE 2. A comparison of woody plant diversity in different tropical montane forest sites

Country	Altitudinal range (m above MSL)	Mean number of species (± SD)	Range in number of species
India (Nilgiris)	1900–2360	30.3 (± 4.89) n = 8	23–40
Mexico	1800–2250	32.5 (± 5.72) n = 4	29–39
Costa Rica	1990–2250	52.3 (± 1.24) n = 3	51–54
Peru	1850–2450	72.8 (± 35.2) n = 4	42–129
Colombia	1800–2370	83.6 (± 16.5) n = 7	54–106

Data for neotropical sites are based on Gentry (1993).
n = number of sites sampled. All figures are based on 0.1 hectare samples and refer to woody plants > 2.5 cm d.b.h.

photosynthetic rates in C3 plants to a greater extent than in C4 plants. Higher temperatures would lower the incidence of frost and promote the survival of C3 forest plants. Higher precipitation and soil moisture would favour the growth of C3 plants. Thus, the montane evergreen forest can be expected to expand into the grasslands, while C3 grasses and herbs could potentially replace C4 grasses in the grasslands.

Species which are pioneer colonizers of the grasslands and ecotones include *Rhododendron nilagiricum* Zenk., *Rhodomyrtus tomentosus* (Ait.) Wt., *Strobilanthes* spp., *Dodonea viscosa* Jacq., *Wendlandia notoniana* W. & A., *Hedyotis stylosa* Br., *Mahonia leschenaultii* Tak., *Berberis tinctoria* Lesch. and *Gaultheria fragrentissima* Wall. Many of these shrubs are of temperate affinity. These could be the first to respond to a warmer climate, followed by other species with more tropical affinities which are otherwise limited by cool temperatures and frost. Species with better dispersal abilities (animal-dispersed, such as *Syzigium* spp. and *Cinnamomum* spp.) could also be favoured over those with poor dispersal abilities.

While the above scenario would be true if natural succession is allowed to operate, human impact on the vegetation in the montane ecosystem may interfere with this process. A considerable portion of the plateau has been under human settlement and agriculture for the past three or four centuries. Cultivation of vegetables, in particular potato, on steep hillslopes and excessive grazing have caused enormous soil erosion in recent decades. Since the early nineteenth century the British introduced several temperate crop plants and tropical commercial crops such as tea, coffee and cinchona. These commercial crops established successfully and spread rapidly over the plateau, replacing natural grassland and to a certain extent the evergreen forests (Prabhakar, 1994).

During this period, Australian wattles (*Acacia* spp.) and eucalypts (*Eucalyptus* spp.) were also introduced to provide fuelwood to immigrant labourers. A major expansion in plantations of wattle (for the tanning industry) and euca-

lypts (as pulp wood for paper industry), however, came during the period 1950–86. These species were planted on grasslands (the so-called 'grassy blanks') throughout the plateau, but these failed on the western ranges due to harsh climatic conditions. Wattle and eucalypts cover 13,000 hectares or about 40% of the Reserve Forest area in the plateau. Since 1850 the grasslands have declined by 83% and the forests by about 50% on the plateau (S. Kumar, R. Prabhakar and R. Sukumar, unpublished results).

Wattle and eucalypts (both C3 plants) have high growth rates and coppice profusely from subterranean lignotubers after harvest of the stem. Wattle also, weedlike, invades both grassland and disturbed forest. A reduction in the incidence of frost combined with enhanced photosynthetic rates (from elevated CO_2) in wattles could enable them to spread to the few grassland areas where they are now absent more rapidly than the slow growing forest tree and shrub species. Soil erosion and lower moisture retaining capacity in grasslands could also preclude the establishment of C3 forest plants.

Several animal species could also be affected by climatic and vegetational changes. While we have no precise information of invertebrate species, one vertebrate species that would be almost certainly affected in the absence of active management is the Nilgiri tahr (*Hemitragus hylocrius*), a mammal endemic to the montane grasslands of the Western Ghats. A further reduction in the area under natural grassland would increase its risk of extinction. In the Nilgiri hills, the population of Nilgiri tahr has reduced from about 400 in 1975 (Davidar, 1976) to not more than 100 in 1991 (Varman, in press).

Adverse impacts of future climate change may thus have to be combated through active management to restore degraded grasslands and those changed to other forms of land use.

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