# Growth and physiological responses to an elevation gradient by co-occurring tree species in a shola forest of Kerala, India

Shola forests of Kerala in peninsular India belong to the broad category of tropical montane forests represented in the continents of Asia, Africa and America. In Kerala, typical shola forests are distributed along the crest of the Western Ghats, where the altitude goes beyond 1800 m (ref. 1). In these forests, like in other tropical forest belts[2], altitudinal gradient is one of the ecological factors which influence structure, composition and diversity of plant community. Indeed, majority of the tropical tree species may maintain a regularly high level of growth-related activity through morphological, phenological and physiological changes in response to a wide range of environmental conditions prevailing along an altitudinal gradient[3]. It is also reported that fine-scale differences in ecophysiology and growth rate can influence the distribution pattern of some species with similar ecologies[4]. However, studies to assess variation in ecophysiological characteristics among co-occurring tree species in a tropical montane forest are lacking. The present study conducted in shola forests of Anamudi Shola National Park (10°05′–10°20′N lat. and 77°0′–77°10′E long.) examines how the physiological properties and relative growth rates of a set of co-occurring tree species alter along elevation gradients.

Three plots, one each in 1900 (hereafter P1), 2100 (P2) and 2300 m (P3) amsl, were selected in the shola forest tract. Seedlings of seven tree species present in all the three plots and in all three tree phases (mature tree, sapling and seedling) were selected. These were *Cinnamomum sulphuratum* Nees (family Lauraceae), *Litsea wightiana* Hook. f. (family Lauraceae), *Neolitsea scrobiculata* (Meisner) Gamble (family Lauraceae), *Persea macrantha* (Nees) Kosterm. (family Lauraceae), *Phoebe lanceolata* Nees (family Lauraceae), *Syzygium densiflorum* Wall. ex Wight & Arn. (family Myrtaceae) and *Turpinia nepalensis* Wall. ex Wight & Arn. (family Staphyleaceae). For each species (hereafter generic name of these species will be used), 15 seedlings were selected in each plot, their biomass increment at six month intervals in a given plot was calculated using the regression equation[5] and then averaged to obtain one biomass increment value at a given time interval. The relative growth rate (RGR) was then calculated as $\text{RGR} = (\ln W_2 - \ln W_1)/(t_2 - t_1)$, where $W_1$ and $W_2$ are initial and final biomass values and $t_1$ and $t_2$ are initial and final time periods respectively. Using a portable photosynthesis system, LiCor-6400 (LiCor Instruments, USA) three physiological traits, namely photosynthetic rate (*Pn*), stomatal conductance (*Gs*) and transpiration rate (*E*) of five marked seedlings of each species were measured at each plot during April 2010 and April 2011. The seedlings were approximately 70–80 cm in height and collar girth ranged from 4.5 to 9.5 cm; the measurements were taken for fully developed leaves. The light intensity was 200–300 μmol $m^{-2} s^{-1}$, as measured by LiCor-6400. There was no significant difference in light intensity between plots. Statistical analysis was performed using SPSS software (Version 10.0, SPSS Inc., Chicago, IL, USA). Intra-species differences along the elevation gradients in physiological and growth variables were determined using analysis of variance (ANOVA) and Tukey's post-hoc test.

With the increase in altitude, RGR and *Pn* increased significantly in *Turpinia* and decreased significantly in *Cinnamomum* (Table 1). As observed in the present study for *Turpinia*, an increase in photosynthetic rate and growth rate of certain species with increase in elevation was also recorded by others[3]. Genetic adaptation in these species to high elevation through maintenance of high nitrogen and chlorophyll content in the leaves, stomatal conductance and carboxylation efficiency could be the reason for high values for photosynthetic rate and growth rate in high-elevation plots[3]. However, the reduction in photosynthetic rate of *Cinnamomum* with increasing altitude reflects the pattern recorded for several tree species elsewhere in the tropics[4].

With increasing altitude, there is a decrease in temperature as well as the partial pressure of air, water vapour and $CO_2$, whereas there is an increase in solar radiation flux and incidence of cloud cover[6]. Thus, the mean values of stomatal conductance and transpiration rate are expected to be lower in plants growing in higher altitudes than those in lower altitudes. Among the seven species studied, only one (*Turpinia*) showed significant reduction in its transpiration rate with increase in altitude (Table 2). It is also reported that in some species, transpiration rate may decrease with increase in elevation, but photosynthetic rate may increase due to increase in water use efficiency of plants with elevation[3]. This could be the reason for significant decline in stomatal conductance and transpiration rate and increase in photosynthetic rate of *Turpinia* in high-elevation plots. However, in the remaining six tree species no significant relation between *E* (or *Gs*) and elevation was noticed (Table 2). In conclusion, among the seven species, *Cinnamomum* and *Turpinia* were

**Table 1.** Relative growth rate (RGR) of tree seedlings in three plots (P1: altitude 1900 m amsl; P2: altitude 2100 m amsl, and P3: altitude 2400 m amsl) situated along an altitudinal gradient in the Anamudi Shola National Park, Kerala. Values are mean ± SE; *N* = 15 seedlings

| | RGR ($g\ g^{-1}\ yr^{-1}$)* | | |
|---|---|---|---|
| Species | P1 | P2 | P3 |
| *Cinnamomum* | $1.615 \pm 0.007^A$ | $1.386 \pm 0.002^B$ | $1.370 \pm 0.006^C$ |
| *Litsea* | $1.384 \pm 0.005^A$ | $1.426 \pm 0.007^B$ | $1.285 \pm 0.004^C$ |
| *Neolitsea* | $1.221 \pm 0.006^A$ | $1.280 \pm 0.018^A$ | $1.286 \pm 0.010^A$ |
| *Persea* | $1.418 \pm 0.005^A$ | $1.421 \pm 0.003^A$ | $1.315 \pm 0.019^B$ |
| *Phoebe* | $1.430 \pm 0.004^A$ | $1.481 \pm 0.004^B$ | $1.327 \pm 0.012^C$ |
| *Syzygium* | $1.298 \pm 0.004^A$ | $1.304 \pm 0.006^A$ | $1.290 \pm 0.004^A$ |
| *Turpinia* | $1.282 \pm 0.002^A$ | $1.325 \pm 0.012^B$ | $1.423 \pm 0.006^C$ |

*Within rows, plots not sharing the same uppercase letters denote significant differences ($P < 0.05$) among them for that species.

**Table 2.** Photosynthetic rate (*Pn*), stomatal conductance (*Gs*) and transpiration rate (*E*) of tree seedlings in the three plots (P1–P3). Values are mean ± SE, $N = 15$ seedlings

| | *Pn* ($\mu$mol m$^{-2}$ s$^{-1}$)* | | | *Gs* (mmol m$^{-2}$ s$^{-1}$)* | | | *E* (mmol m$^{-2}$ s$^{-1}$)* | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | P1 | P2 | P3 | P1 | P2 | P3 | P1 | P2 | P3 |
| *Cinnamomum* | $6.38^{A}$ (0.09) | $6.16^{AB}$ (0.07) | $6.10^{B}$ (0.07) | $36.30^{A}$ (0.38) | $36.80^{A}$ (0.28) | $37.20^{A}$ (0.42) | $112.88^{A}$ (1.17) | $117.86^{AB}$ (0.94) | $120.76^{B}$ (1.39) |
| *Litsea* | $5.54^{A}$ (0.04) | $5.90^{B}$ (0.07) | $5.88^{B}$ (0.06) | $45.76^{A}$ (0.61) | $47.20^{B}$ (0.23) | $48.30^{B}$ (0.28) | $147.22^{A}$ (1.97) | $153.84^{B}$ (0.91) | $162.6^{C}$ (0.97) |
| *Neolitsea* | $4.44^{A}$ (0.05) | $4.82^{B}$ (0.04) | $4.78^{B}$ (0.04) | $48.12^{A}$ (0.29) | $49.20^{B}$ (0.39) | $49.04^{B}$ (0.33) | $173.72^{A}$ (1.02) | $184.46^{B}$ (1.44) | $180.74^{B}$ (2.76) |
| *Persea* | $5.90^{A}$ (0.07) | $5.80^{A}$ (0.07) | $5.10^{B}$ (0.07) | $43.60^{A}$ (0.36) | $42.68^{A}$ (0.34) | $40.30^{B}$ (0.29) | $136.80^{A}$ (1.13) | $125.06^{B}$ (0.99) | $121.62^{C}$ (0.88) |
| *Phoebe* | $5.98^{A}$ (0.07) | $6.40^{B}$ (0.03) | $4.88^{C}$ (0.10) | $38.20^{A}$ (0.36) | $41.60^{B}$ (0.16) | $39.14^{C}$ (0.22) | $120.30^{A}$ (1.14) | $137.78^{B}$ (0.61) | $127.9^{C}$ (0.71) |
| *Syzygium* | $5.18^{A}$ (0.07) | $5.06^{A}$ (0.09) | $5.18^{A}$ (0.06) | $46.24^{A}$ (0.28) | $47.80^{B}$ (0.42) | $47.36^{B}$ (0.32) | $157.76^{A}$ (0.97) | $164.62^{B}$ (1.47) | $166.38^{B}$ (1.58) |
| *Turpinia* | $4.92^{A}$ (0.05) | $5.41^{B}$ (0.07) | $6.34^{C}$ (0.07) | $52.16^{A}$ (1.73) | $42.60^{B}$ (1.83) | $31.30^{C}$ (0.41) | $267.02^{A}$ (8.87) | $218.22^{B}$ (9.37) | $183.28^{C}$ (1.23) |

*For given parameter, within rows, plots not sharing the same uppercase letters denote significant differences ($P < 0.05$) among them for that species.

most responsive in terms of growth and physiological traits to altitudinal gradients. On the other hand, RGR, *Pn* and *Gs* of *Litsea*, *Neolitsea*, *Persea*, *Phoebe* and *Sygygium* were least responsive to changing altitude. Thus they may have the ability to acclimate to a wider range of environmental conditions prevailing in these tropical montane forests. This kind of species-level understanding of variation in physiological and growth rates, and their interaction with altitude-driven variables will have implications for predicting plant responses to possible alteration in the microclimate triggered by climate change and anthropogenic disturbances.


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# Observations on morphometry, egg size and juveniles of the endemic caenophidian snake *Xylophis perroteti* (Dumeril, Bibron and Dumeril, 1854) in the Nilgiris, Western Ghats, India

The caenophidian snake genus *Xylophis* Beddome, 1878, is endemic to the southern Western Ghats region of peninsular India[1–3]. Within the genus *Xylophis*, three species are currently recognized – *Xylophis perroteti* (Dumeril, Bibron and Dumeril, 1854), *Xylophis stenorhynchus* (Gunther, 1875) and a new species *Xylophis captaini* (Gower and Winkler, 2007). Among these snakes, *X. perroteti* has restricted distribution in the Nilgiris and Wayanaad in North Kerala[3–6]. This snake found in high ranges of the Western Ghats over 1500 m altitude in Kerala and Tamil Nadu[3]. Very few studies have been carried out on this species; mostly only short notes[3–6]. Almost nothing is known about the ecology and biology of *X. perroteti*. Any information on this genus is thus of both immediate and potentially broader interest[7]. The present study describes morphometry, egg size and juveniles of *X. perroteti.*

The study was conducted in the upper Nilgiris, southern Western Ghats, Tamil Nadu, lying between 11–12°N lat. and 76–77°15′E long. Total area of the Nilgiris district is 2543 km$^2$. These hills are in fact a mountainous plateau formed at the junction of the Eastern Ghats and Western Ghats. The elevation ranges between 300 and 2700 m amsl. Temperature shows a wide range of variation, during summer it may exceed a maximum of 21–25°C, while minimum temperature is during winter 10–12°C. Major vegetation types in the upper Nilgiris are Montane shola grasslands and plantations of exotic species such as wattle (*Acacia* spp.), blue gum (*Eucalyptus* spp.) and pine (*Pinus* spp.).

Visual encounter survey method[8] was used to collect data in the field for two years between January 2013 and December 2014. Samplings were carried out during morning and evening hours during every month. Searches were made on several micro habitats like under leaf litter, on boulders, fallen logs and in the bushes. Gravid females were identified by palpation. Adult and sub males were