Endemism due to climate change: Evidence from *Poeciloneuron* Bedd. (Clusiaceae) leaf fossil from Assam, India

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A fossil leaf resembling *Poeciloneuron indicum* Bedd. (Clusiaceae) is described from the Late Oligocene (Chattian 28.4–23 Myr) sediments of Assam. The modern analogue is endemic to the Western Ghats which is situated in the same palaeolatitude. Its presence, along with other known fossil records, indicates that the seasonality in temperature was less pronounced and CMMT (cold month mean temperature) was not less than 18°C with plenty of rainfall, in the region during the period of deposition. The study also indicates that the plant phenology is sensitive towards climate change. The present study is in congruence with the global data.

1. Introduction

Global climate during the Cenozoic displayed an overall cooling trend within which a series of warming and cooling rhythms occurred (Zachos *et al.* 2001). Of them, Late Oligocene was the time of global warming known as 'Late Oligocene Warming' (Zachos *et al.* 2001; Mosbrugger *et al.* 2005). The data needed for the reconstruction of land palaeoclimate is mainly based on terrestrial plants which are spatially fixed and therefore, have to be well adapted to local environmental conditions in order to survive and due to this their distribution is strongly controlled by their corresponding climate (Woodward *et al.* 2004). Among the land plants, endemic taxa are important because they grow in restricted environmental conditions (Jansson 2003). The fossil record of such taxa is also important to study their past distribution and sensitivity towards the climate change (Prasad *et al.* 2009).

The Makum Coalfield (27°15′–27°25′N; 95°40′–95°55′E) which has an exposure of Late Oligocene (Chattian 28.4–23 Ma) sediments (Srivastava *et al.* 2012b), is situated in the Tinsukia District, Assam (figure 1a) and is an important basin because of its diverse assemblage of plants (Awasthi and Mehrotra 1995; Mehrotra *et al.* 2003, 2009; Srivastava and Mehrotra 2010a, 2012; Srivastava *et al.* 2012a). Infact, there is no other Oligocene sedimentary basin in India which contains such a rich assemblage. The basin was situated at a low palaeolatitude, i.e., ∼10°–15°N (Molnar and Stock 2009) at the time of deposition, when suturing between the Indian and Eurasian plates was not sufficiently complete to facilitate the plant migration (Srivastava and Mehrotra 2010b) and shows a deltaic, mangrove or lagoonal depositional environment (Awasthi and Mehrotra 1995; Mehrotra *et al.* 2003; Srivastava *et al.* 2012b). In the present communication, we have described a new leaf impression/compression whose modern analogue is endemic to the Western Ghats occurring in the same palaeolatitude. An attempt has also been made to explain the reasons for its endemism.

Keywords. Climate change; Clusiaceae; leaf; Makum Coalfield; Tikak Parbat Formation.

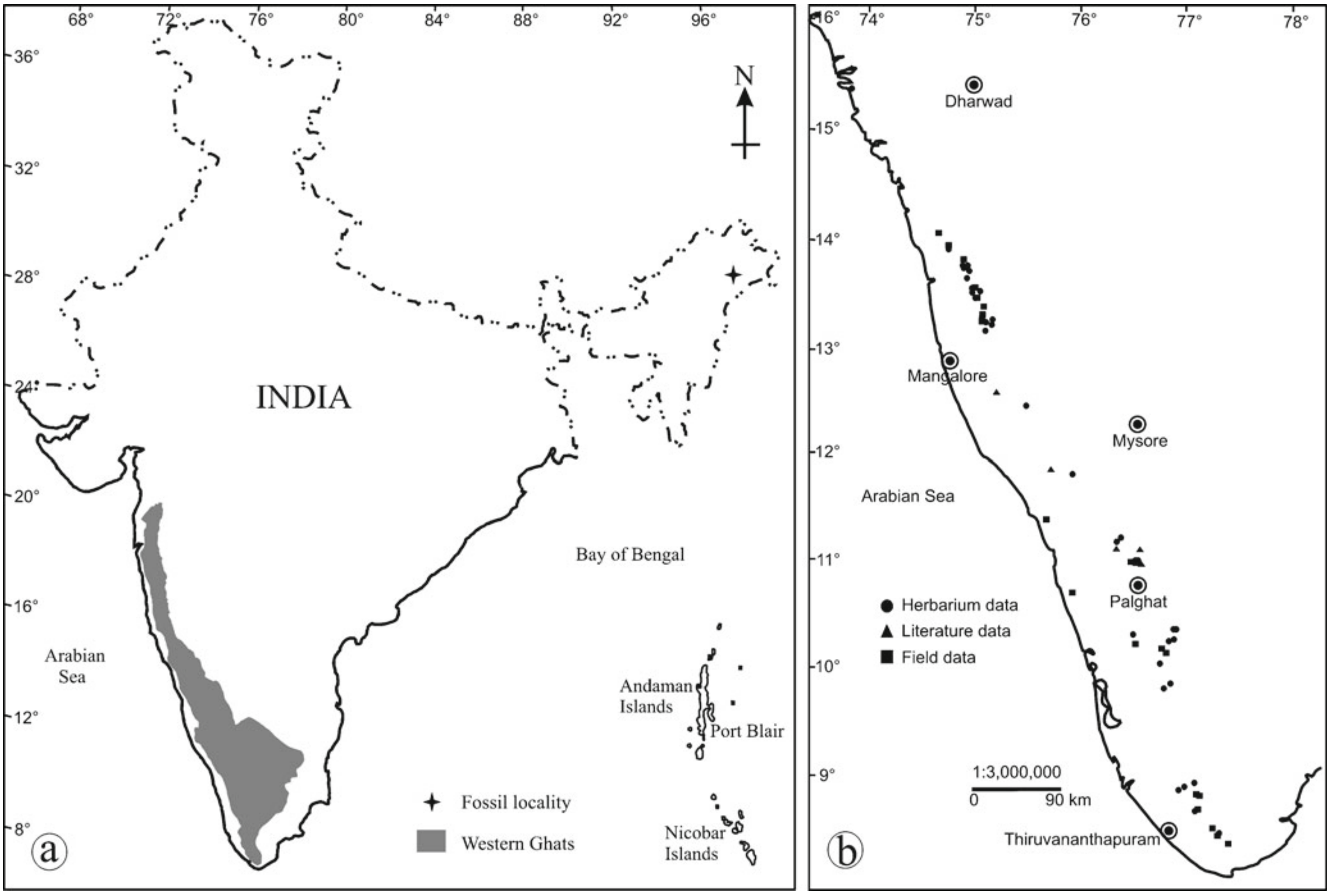

Figure 1. **(a)** Map of India showing fossil locality and Western Ghats. **(b)** Map showing modern distribution of *Poeciloneuron indicum* in the Western Ghats (Ramesh *et al.* 1997).

2. Materials and methods

The present fossil leaf was collected from the Tirap Colliery of the Makum Coalfield. After clearing the dust from the surface of the leaf, the fossil was photographed under low angle sunlight using 10 megapixel digital camera. The terminology used in describing the fossil leaf is based on Hickey (1973), Dilcher (1974) and Ellis *et al.* (2009). The identification of the fossil was made at the Central National Herbarium, Howrah and the Forest Research Institute, Dehradun after comparing it with herbarium sheets of the extant plants. The type specimen (holotype) bearing registration number BSIP 40060 is deposited in the museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

3. Systematic description

Family: Clusiaceae Lindl.
Genus: Poeciloneuron Bedd.
Poeciloneuron preindicum Srivastava and Mehrotra, sp. nov. (figure 2a, c)

Description: Leaf symmetrical, mesophyll, narrow oblong to lorate in shape; preserved lamina length 9.4 cm and maximum width 2.7 cm (near the middle); apex slightly broken, appearing attenuate; base symmetrical, normal obtuse; margin entire; texture coriaceous; petiole not preserved; venation pinnate, brochidodromous; primary vein moderate in thickness, slightly curved near the apical part; secondary veins 17 pairs visible, alternate to opposite, distance between two secondaries 0.2–0.5 cm, angle of divergence narrow to wide acute (43°–67°), occasionally right angle (81°), upper pairs more acute than lower, moderately thick, uniform, joining superadjacent secondaries near the margin; intersecondary veins present, 1–2 in number, sometimes extended up to margin; tertiary veins random reticulate; marginal ultimate venation fimbriate; areoles well developed, oriented, predominantly quadrangular in shape.

Affinities: The important characters of the fossil, such as narrow oblong to lorate shape, attenuate apex, entire margin, coriaceous texture, brochidodromous venation, relatively numerous, closely spaced secondaries, angle of divergence of secondaries narrow to wide acute (43°–67°), upper pairs

Figure 2. **(a)** Fossil leaf of *Poeciloneuron preindicum* Srivastava and Mehrotra, sp. nov. showing shape, size and venation pattern; **(b)** modern leaf of *Poeciloneuron indicum* showing similar shape, size and venation pattern as in the fossil; **(c)** middle portion of the fossil leaf showing intersecondary (yellow arrow) and secondary veins (white arrow); and **(d)** middle portion of the modern leaf showing similar intersecondary vein (yellow arrow) and secondary veins (white arrow) (scale bar = 1 cm).

more acute than lower, presence of very common occurrence of intersecondary veins (often one or more between each pair of secondary veins), running perfectly parallel to secondaries and sometimes extended upto the margin, random reticulate tertiary veins, fimbriate marginal ultimate venation, collectively suggest its close resemblance with the modern leaves of *Poeciloneuron* in general and *P. indicum* Bedd. (Herbarium Sheet No. FRI 52079) (figure 2b, d) in particular of the family Clusiaceae. A large number of herbarium sheets were examined at the Central National Herbarium, Howrah and the Forest Research Institute, Dehradun. However, during the herbarium consultation, some of the taxa within the family, viz., *Mesua ferrea* L., *M. thwaitesii* Planch. and Triana, *Mammea americana* L., *Kayea assamica* Prain, *K. elegans* King, *K. floribunda* Wall., *K. paniculata* Merr., *K. racemosa* Planch. and Triana and *Garcinia atroviridis* Giff. ex T. Anders. show apparent similarity to the fossil leaf but after close examination they were found different. In *Mesua ferrea* the secondary veins are more acute at the base in contrast to those found in the present fossil. In *M. thwaitesii* and *Mammea americana* shape is elliptic and secondary veins are more acute than those of the fossil. In *Kayea assamica* the leaf is elliptic and the secondary veins in the middle of the lamina are wide acute to right and at the base acute; all these characters are different from those of the fossil. In *K. elegans, K. floribunda* and *K. racemosa*, the venation is eucamptodromous, while in *K. paniculata*, the secondary veins are not narrow acute as found in the fossil. Moreover, tertiary veins in *K. paniculata* are percurrent in contrast to random reticulate in the present fossil. In *Garcinia atroviridis* secondary veins are more acute throughout the lamina, which is a feature different from the fossil.

There is no fossil leaf record of *Poeciloneuron* so far, therefore, a new species, *Poeciloneuron preindicum* Srivastava and Mehrotra, sp. nov. has been created, the specific epithet is after the modern species – *Poeciloneuron indicum.* The only other palaeobotanical record of this genus, of which we are aware, is the fossil wood of *Poeciloneuron* named *P. palaeoindicum* Srivastava and Awasthi (1996) from the Middle Miocene of Warkali beds, Kerala. Therefore, the present fossil seems to be the oldest fossil record of the genus. The fossil record of the family indicates that the Clusiaceae was well established by the Turonian (89.3–93.5 Ma) (Crepet and Nixon 1998) and in India its oldest fossil record is known from the Deccan Intertrappean sediments (Bande and Khatri 1980). *Poeciloneuron* is a monotypic genus (Rajkumar and Janarthanam 2007) and *P. indicum* is a large tree (15–26 m in height) of evergreen forests endemic to the

Western Ghats (figure 1a, b), where it is found between 700 and 800 m above sea level, i.e., in a very narrow belt, a little below the crest of the Ghats and is situated wholly on western slope which is exposed to monsoon winds (Pascal 1988).

Specific diagnosis: Leaf symmetrical, narrow oblong to lorate; apex appearing attenuate; base symmetrical, normal obtuse; margin entire; texture coriaceous; venation pinnate, brochidodromous; primary vein moderate in thickness, slightly curved near the apical part; secondary veins alternate to opposite, angle of divergence narrow to wide acute, occasionally right angle, moderately thick, uniform, joining superadjacent secondaries near the margin; intersecondary veins present; tertiary veins random reticulate; areoles well developed, oriented, predominantly quadrangular in shape.

Holotypus: Specimen no. BSIP 40060.
Horizon: Tikak Parbat Formation.
Locality: Tirap Colliery, Tinsukia District, Assam (27°17′20″N, 95°46′15″E).
Age: Late Oligocene (Chattian 28.4–23 Ma).
Number of specimens studied: One.

4. Discussion

Phenology is an important aspect in plants because it plays a significant role in capturing the variable resources in different seasons for vegetative and reproductive growth (Schwartz 2003) which is essential for the fitness and survival (Rathcke and Lacey 1985; Reekie and Bazzaz 1987; Kozlowski 1992). Due to this, the phenology is considered to be the most important feature affected by climate change (Parmesan and Yohe 2003; Root *et al.* 2003; Walther *et al.* 2005; Menzel *et al.* 2006). The modern analogue of the fossil leaf, *P. indicum,* is endemic to the Western Ghats which is situated in the palaeolatitude of the fossil locality (figure 1a, b). The occurrence of the present fossil in the Makum Coalfield suggests that during the Late Oligocene, it was growing in the area having equable climatic conditions similar to those prevailing in the Western Ghats at present. The change in the climate and extinction of the fossil from northeast India may be attributed to the following reasons:

- Change in the latitude, i.e., from approx. 10°–15° to 27°17′20″N.
- Significant uplifting of the Himalayas during the Neogene (Chatterjee and Scotese 1999; Mehrotra *et al.* 2005).
- Recession of the Bay of Bengal to its present day boundary (Lakhanpal 1970).

Seasonality in temperature became more pronounced during the Neogene and most likely after the Miocene (Mehrotra *et al.* 2011) due to the aforesaid reasons and as a result *P. indicum* became extinct not only from the fossil locality but also from northeast India and is presently confined to the Western Ghats in between latitude ∼8°–15°N (figure 1b) which is similar to the palaeolatitude of the fossil locality. The climatic variables of fossil as well as modern localities of *Poeciloneuron* (table 1) indicate that disturbance in the phenology of the fossil due to the increased seasonality in temperature and change in latitude might be the two most likely reasons for its extinction from northeast India.

Among various families reported from the Makum Coalfield (Awasthi and Mehrotra 1995; Mehrotra *et al.* 2003, 2009; Srivastava and Mehrotra 2010a, 2012; Srivastava *et al.* 2012a, b), Annonaceae, Burseraceae, Clusiaceae, Combretaceae, Lecythidaceae, Myristicaceae and Rhizophoraceae are typical pantropical megathermal in nature (van Steenis 1962) which indicates that the CMMT (cold month mean temperature)

Table 1. *Marked climatic variables in fossil and modern localities of Poeciloneuron indicum.*

Localities	Latitude; Longitude	Mean annual temperature (°C)	Mean temperature of the warmest month (°C)	Mean temperature of the coldest month (°C)	Mean annual precipitation (mm)	Relative humidity (%)
Mangalore	12°52′N; 74°51′E	27.2	29	26.7	3291	80.2
Palghat	10°46′N; 76°39′E	27.8	30.3	28.2	2058.6	78.8
Thiruvananthapuram	08°29′N; 76°57′E	27.1	28.5	26.9	1839.3	84
Climate range		27.1–27.8	28.5–30.3	26.7–28.2	1839.3–3291	78.8–84
Tinsukia (fossil locality)	27°17′20″N; 95°46′15″E	22.7	27.6	15.8	2224.4	78.4

was not less than 18°C. Similarly, Fabaceae whose abundance and richness covary with temperature (Punyasena *et al.* 2008), is the most dominant family in the Makum Coalfield (Srivastava and Mehrotra 2010a) and indicates a warm climate. The presence of Avicenniaceae and Rhizophoraceae indicates the deltaic, mangrove or lacustrine environment of deposition of coal seams and associated sediments in the Makum Coalfield (Awasthi and Mehrotra 1995). The presence of abundant palms like *Nypa* (Mehrotra *et al.* 2003) renders further evidence of a coastal plain environment where both temperature and humidity remained high throughout the year (Tomlinson 1990) i.e., less seasonality in temperature. The recent CLAMP (climate leaf analysis multivariate program) analysis (MAT = 26.09 ± 2.7°C, WMMT = 27.85 ± 3.3°C, CMMT = 20.66 ± 4.3°C, MAP = 2460 ± 614 mm and RH = 76.6 ± 12.6%) from the same horizon also indicates less seasonality in temperature (Srivastava *et al.* 2012b). The warm and humid climate in the Makum Coalfield during the deposition of the sediments is not surprising, as the fossil locality was at 10°–15°N palaeolatitude, i.e., in tropics during the Late Oligocene (Molnar and Stock 2009) and it has been observed that not only the regional, but also the global climate during the Late Oligocene was warm (Zachos *et al.* 2001; Mosbrugger *et al.* 2005). The result of the present study is in congruence with the above records.

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References

Awasthi N and Mehrotra R C 1995 Oligocene flora from Makum Coalfield, Assam, India; *Palaeobotanist* **44** 157–188.

Bande M B and Khatri S K 1980 Some more fossil woods from the Deccan Intertrappean beds of Mandla District, Madhya Pradesh, India; *Palaeontographica B* **173(4–6)** 147–165.

Chatterjee S and Scotese C R 1999 The breakup of Gondwana and the evolution and biogeography of the Indian plate; *Proc. Indian Nat. Sci. Acad.* **65A** 397–425.

Crepet W L and Nixon K C 1998 Fossil Clusiaceae from the Late Cretaceous (Turonian) of New Jersey and implications regarding the history of bee pollination; *Am. J. Bot.* **85(9)** 1122–1133.

Dilcher D L 1974 Approaches to the identification of angiosperm leaf remains; *Bot. Rev.* **40** 1–157.

Ellis B, Daly D, Hickey L J, Johnson K R, Mitchell J, Wilf P and Wing S L 2009 *Manual of Leaf Architecture* (Ithaca, New York: Cornell University Press).

Hickey L J 1973 Classification of the architecture of dicotyledonous leaves; *Am. J. Bot.* **60** 17–33.

Jansson R 2003 Global patterns in endemism explained by past climatic change; *Proc. Biol. Sci.* **270** 583–590.

Kozlowski J 1992 Optimal allocation of resources to growth and reproduction: Implications for age and size at maturity; *Trends in Ecol. Evol.* **7** 15–18.

Lakhanpal R N 1970 Tertiary flora of India and their bearing on the historical geology of the region; *Taxon* **19** 675–694.

Mehrotra R C, Bera S K, Basumatary S K and Srivastava G 2011 Study of fossil wood from the Middle–Late Miocene sediments of Dhemaji and Lakhimpur districts of Assam, India and its palaeoecological and palaeophytogeographical implications; *J. Earth Syst. Sci.* **120(4)** 681–701.

Mehrotra R C, Dilcher D L and Lott T A 2009 Notes on elements of the Oligocene flora from the Makum Coalfield, Assam, India; *Palaeobotanist* **58** 1–9.

Mehrotra R C, Liu Xiu-Qun, Li Cheng-Sen, Wang Yu-Fei and Chauhan M S 2005 Comparison of the Tertiary flora of southwest China and northeast India and its significance in the antiquity of the modern Himalayan flora; *Rev. Palaeobot. Palynol.* **135** 145–163.

Mehrotra R C, Tiwari R P and Mazumder B I 2003 *Nypa* megafossils from the Tertiary sediments of northeast India; *Geobios* **36** 83–92.

Menzel A *et al.* 2006 European phenological response to climate change matches the warming pattern; *Glob. Change Biol.* **12** 1969–1976.

Molnar P and Stock J M 2009 Slowing of India's convergence with Eurasia since 20 Ma and its implications for Tibetan mantle dynamics; *Tectonics* **28** TC3001.

Mosbrugger V, Utescher T and Dilcher D L 2005 Cenozoic continental climatic evolution of Central Europe; *Proc. Nat. Acad. Sci. USA* **102** 14,964–14,969.

Parmesan C and Yohe G 2003 A globally coherent fingerprint of climate change impacts across natural systems; *Nature* **421** 37–42.

Pascal J P 1988 *Wet Evergreen forests of the Western Ghats of India* (Pondichery: Inst. Fr. Pondichery).

Prasad V, Farooqui A, Tripathi S K M, Garg R and Thakur B 2009 Evidence of Late Palaeocene–Early Eocene equatorial rain forest refugia in southern Western Ghats, India; *J. Biosci.* **34(5)** 777–797.

Punyasena S W, Eshel G and McElwain J C 2008 The influence of climate on the spatial patterning of neotropical plant families; *J. Biogeogr.* **35** 117–130.

Rajkumar S and Janarthanam M K 2007 *Agasthiyamalaia* (Clusiaceae), a new genus for *Poeciloneuron pauciflorum*, an endemic and endangered tree of Western Ghats, India; *J. Bot. Res. Inst. Texas* **1(1)** 129–133.

Ramesh B R, Pascal J P, Nougier C and Datta R 1997 *Endemic Tree Species of the Western Ghats India* (French Institute of Pondicherry, CD-ROM).

Rathcke B and Lacey E P 1985 Phenological patterns of terrestrial plants; *Ann. Rev. Ecol. Evol. Syst.* **16** 179–214.

Reekie E G and Bazzaz F A 1987 Reproductive efforts in plants; *Am. Naturalist* **129** 876–919.

Root T L, Price J T, Hall K R, Schneider S H, Rosenzweig C and Pounds J A 2003 Fingerprints of global warming on wild animals and plants; *Nature* **421** 57–60.

Schwartz M D 2003 *Phenology: an integrative environmental science* (Dordrecht, The Netherlands: Kluwer Academic).
Srivastava G and Mehrotra R C 2010a New legume fruits from the Oligocene sediments of Assam; *J. Geol. Soc. India* **75** 820–828.
Srivastava G and Mehrotra R C 2010b Tertiary flora of northeast India vis-à-vis movement of the Indian plate; *Geol. Soc. India Memoir* **75** 123–130.
Srivastava G and Mehrotra R C 2012 Oldest fossil of *Semecarpus* L.f. from the Makum Coalfield, Assam, India and comments on its origin; *Curr. Sci.* **102(3)** 398–400.
Srivastava G, Mehrotra R C and Bauer H 2012a Palm leaves from the Late Oligocene sediments of Makum Coalfield, Assam; *J. Earth Syst. Sci.* **121(3)** 747–754.
Srivastava G, Spicer R A, Spicer T E V, Yang J, Kumar M, Mehrotra R and Mehrotra N 2012b Megaflora and palaeoclimate of a Late Oligocene tropical delta, Makum Coalfield, Assam: Evidence for the early development of the South Asia Monsoon; *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **342–343** 130–142.
Srivastava R and Awasthi N 1996 Fossil woods from Neogene of Warkalli beds of Kerala coast and their palaeoecological significance; *Geophytology* **26(1)** 89–98.
Tomlinson P B 1990 *The Structural Biology of Palms* (Oxford: Clarendon Press).
van Steenis C G G J 1962 The land-bridge theory in botany; *Blumea* **11(1)** 235–372.
Walther G R, Berger S and Sykes M T 2005 An ecological ‘footprint’ of climate change; *Proc. Biol. Sci.* **272** 1427–1432.
Woodward F I, Lomas M R and Kelly C K 2004 Global climate and the distribution of plant biomes; *Phil. Trans. R. Soc. Lond. B* **359** 1465–1476.
Zachos J, Pagani M, Sloan L, Thomas E and Billups K 2001 Trends, rhythms, and aberrations in global climate 65 Ma to present; *Science* **292** 686–693.

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