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Cover: Illuminating the cruelty of Pangolin trade in India for the purpose of black magic, for the sanctity of protection. Using an animal's shell, ripping its armor against the world to protect oneself. When does one become the evil they are trying to ward off? — Acrylic on wood. © Maya Santhanakrishnan.

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ARTICLE

Taxonomy, distribution, and ecology of *Impatiens violacea* (Balsaminaceae) a steno-endemic species in Pettimudi, an area of endemism in southern Western Ghats, India

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Abstract: *Impatiens violacea* is a steno-endemic species in a valley in Pettimudi forest adjacent to Eravikulam National Park, Kerala, India. Taxonomic treatment, morphology, vertical distribution, ecology, phenology, ethnobotany, threats, and conservation status of the species are provided. *Impatiens violaceae* is a threatened species under the 'Vulnerable' category with substantial anthropogenic stress. The present study on endemic species in Pettimudi forest revealed 13 endemic species of the southern Western Ghats reside at area of (1.87 km^2) in a U-shaped valley within the forest of Pettimudi, of which three species, namely, *Impatiens violacea*, *I. johnii*, and *Cnemaspis anamudiensis* were exclusively endemic to this valley whereas *I. pandurangani* to the Pettimudi forest. The findings suggest that the u-shaped valley in Pettimudi forest is an area of endemism (AoE) and a 'hot speck' within the Western Ghats, recognised as one of the global hotspots. Based on the study result, the authors recommend the u-shaped valley in Pettimudi forest be attached to the Eravikulam National Park territory to conserve the endemic species.

Keywords: Anthropogenic stress, conservation, endemic species, habitat fragmentation, hot speck, tropical montane cloud forest, vertical distribution.

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Author contributions: AT—conceptualisation, fieldwork, photographs, maps, and manuscript preparation; JJ—fieldwork, supervision throughout research work and guidance during manuscript preparation.

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INTRODUCTION

The Western Ghats-Sri Lanka is one of the hottest hotspots with 4,780 plant species having 2,180 endemic species, which is 17.5% of the global endemic plant community (Myers et al. 2000). In India, the Western Ghats extends from southern Gujarat and run approximately 1,600 km and end up in Kanyakumari in the southernmost tip of India (Singh et al. 2019). The southern Western Ghats lies between south Canara of Karnataka and Kanyakumari of Tamil Nadu with a 30–40 km discontinuation called Palghat Gap at Kerala (Nair 1991; Augustine 2018). One of the unique features of the southern Western Ghats is the presence of tropical montane cloud forests, which occurs at 1,400–2,400 m, popularly known as shola forests and this high-elevation cloud forest habitat hosts a high level of endemism (Robin & Nandhini 2012; Singh et al. 2019).

Endemism is the term for a species' exclusive existence in a designated geographic area. Since the endemism idea is purely phenomenological, various taxa may be endemic to the same region as a result of disparate historical processes (Fattorini 2017). Areas where the distributions of at least two taxa overlap are called areas of endemism (AoE) (Quijano-Abril et al. 2006). Endemic areas or areas of endemism are the foundation of comparative biogeography, and identifying areas of endemism is essential for biogeographical regionalisation (Parenti & Ebach 2009). Local endemism and hot specks are observed within the Western Ghats-Sri Lanka biodiversity hotspot (Cherian 1996; Bossuyt et al. 2004). Hot specks are small niches within the biodiversity hotspots with a high concentration of diverse species including endemic ones. Identification of hot specks or small local hot spots is requisite for extensive conservation management (Trivedi & Bharchula 2023; Harris et al. 2005; Murray-Smith et al. 2009) and endemic species are most convenient to identify biodiversity hotspots (Myers et al. 2000; Mittermeier et al. 2005; Orme et al. 2005). For the identification of the area of endemism, the study based on endemic flora and fauna is very helpful in locating such hot specks for regional conservation management.

The genus *Impatiens* of the family Balsaminaceae is a highly diversified genus with more than 900 species distributed in tropical Africa, Madagascar, southern India, Sri Lanka, the eastern Himalaya, and southeastern Asia (Bhaskar 2012). The most striking features of this genus are the high degree of endemism and regional endemism. The genus *Impatiens* in southern India and Sri Lanka has c. 95% of endemism (Grey-Wilson 1980). In India, more than 210 species of *Impatiens* have been reported and from southern India 106 species and 13 varieties, of which 103 species and 13 varieties were endemic to the Western Ghats (Hareesh et al. 2015). From parts of the Western Ghats in Kerala, 88 taxa of *Impatiens* were reported within which 73 taxa were endemic to this region (Bhaskar 2012; Sasidharan 2013). Many new species are still being described in this region (Narayanan 2013). Kumar & Sequeira (2001) first described *Impatiens violacea* as an endemic epiphytic parrot-billed *Impatiens* from the shola forest of Pettimudi near Eravikulam National Park, Kerala.

In the Pettimudi forest, only very few studies on flora and fauna have taken place (Ramasubbu et al. 2011; Prabhukumar et al. 2017; Cyriac et al. 2018; Prasad et al. 2018). In the present study, the aim is to extend the knowledge of morphology, ecology, and spatial distribution including the vertical distribution and threats of a vascular epiphyte *Impatiens violacea*. The paper also focused on the habitats that have received less conservation and research attention by identifying endemic species of flora and fauna in Pettimudi forest and thus gaining insight into the degree of endemism in that area and the need for conservation.

MATERIALS & METHODS

Study Area

The study was conducted in a u-shaped valley at Pettimudi forest which lies in the north 10.175^{0}N, 76.995^{0}E, south 10.163^{0}N, 76.991^{0}E, west 10.172^{0}N, 76.984^{0}E and east 10.171^{0}N, 76.998^{0}E (Image 1). The area comes under the reserve forest located adjacent to the south-west periphery of Eravikulam National Park, Idukki, Kerala. This area comes under the Munnar Territorial Forest Division of the Kerala Forest Department. This valley faces towards the west and the elevation of the valley varies 1,450–1,900 m. To examine the distribution of *I. violaceae*, the type locality and surrounding areas including the Pettimudi forest and the Eravikulam National Park were investigated. The vegetation is composed of a tropical montane cloud forest surrounded by steep mountains with a single narrow corridor (Image 1) and a few small and large perennial streams flowing west towards the Edamalayar Dam. Therefore, the tribal people refer to this large patch of shola forest as "Valiyathoducholai." (Valiya – large, thodu – creek, cholai – shola). Pettimudi forest receives heavy rainfall during the south-west (June/July) and retreating (October/November) monsoons, and has

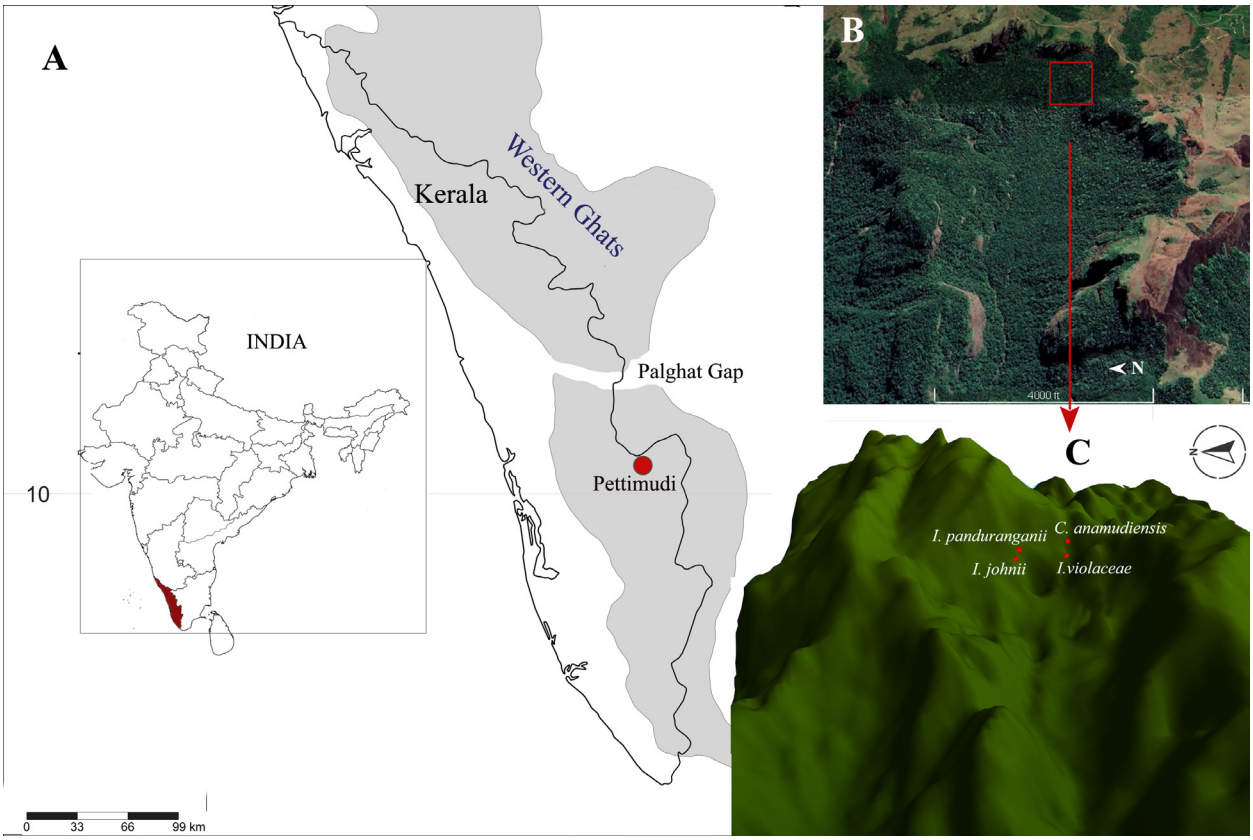

Image 1. A—location map of Pettimudi Forest in the Western Ghats, Kerala | B—u-shaped valley in Pettimudi Forest with type locality area of steno endemic species (red square) (Source: Google Earth) | C—enlarged type locality area of *Impatien s violacae*, *I. johnii*, *I. pandurangani*, and *Cnemaspis anamudiensis* (red circles) in u-shaped valley in Pettimudi Forest (GIS image).

an annual rainfall average of 5,500 mm making it one of the wettest places in Kerala with the ever-recorded highest rainfall of 61.6 cm/day on 6 August 2020 (Achu et al. 2021). The temperature varies 10–24 °C with the lowest temperature from December to January and the highest in April and May. The average humidity during the winter season is above 80%.

Sampling

Field studies were conducted from August 2020 to November 2022. The study site location was noted using the geographic positioning system (GPS) including exact altitude with latitude and each tree (phorophyte) having *I. violacea* species were selected. Each selected tree was divided up into five vertical tree zones according to Johanson (1974) and Krömer & Gradstein (2016) (Figure 1). These zones were categorized as the base (Z 1; from the ground to 2 m), trunk (Z 2; 2 m above the ground to the first bifurcation), Zone 2 is subdivided into a humid lower part of the trunk (Z 2a) and a dryer upper part (Z 2b). Inner canopy (Z 3; the inner third of the branches in the crown), mid-canopy (Z 4; the middle third branches of the crown) and (Z 5; the outer third of the branches of the crown (Figure 1). The epiphytes were classified into one of three ecological groups (Acebey et al. 2003; Krömer & Kessler 2006; Krömer et al. 2007): habitat generalists (occurring in three or more zones) and habitat specialists (occurring only in one or two zones or three continuous ones); the latter were further subdivided into canopy epiphytes (occurring (> 90% in Zones Z3–5) and trunk epiphytes (> 90% in understory and Zones Z1–2). Within each tree zone, the occurrence of *I. violacea* was observed along with abiotic factors such as relative humidity, temperature, light, and wind using Lutron LM 800A. Binoculars were used for the observation of *I. violacea* anchoring in the canopy branches and if necessary climbing the host trees were also done using single and double rope techniques (Lowman & Moffett 1993). Detailed morphological studies were done using a Leica EZ4W stereomicroscope. Herbarium specimens were prepared as per the standard method (Jain & Rao 1976). Voucher specimens were deposited at St. Albert's College Herbarium (SAC). For the distribution of endemic species of plants and

animals in the study area we conducted a field survey along with the details available from literature and other zoological records.

RESULTS & DISCUSSIONS

Taxonomic Treatment

Impatiens violacea M.Kumar & Sequeira, Sida 19: 798. 2001; N.C. Rathakr. et al. in P.Daniel, Fl. Kerala 1: 563. 2005. (Figure 1, Image 2).

Types: INDIA. Kerala: Idukki Dt., Munnar, Pettimudi, Way to Edamalakudy, Sequeira 20731 (holotype KFRI**!** isotypes MH).

Perennial succulent, epiphytic herbs, up to 15 cm or higher. Suffrutescent stems woody at the bottom, herbaceous above, 1–2.5 cm dia., leaf-scare prominent, succulent, glabrous. Leaves crowded at the top of the stem, whorled, glabrous, asymmetric 2–6 by 1.4–4 cm, base obtuse to round, apex acute or obtuse, margins scalloped, sinus of the crenation with cilia, venation eucamptodromous, usually 4. Inflorescence 1–4 cm flowered raceme, terminal; peduncle 1.5–2 cm, cylindrical green, glabrous with sparingly flowered; pedicel 2–4 cm cylindrical, violet. Flowers violet, bisexual, zygomorphic. lateral sepals small, flat linear-lanceolate, glabrous, green 1.2 x 0.4 mm; lower sepal large, bag-shaped, spurred, 1.75–2 × 0.6–1.1 cm, violet, glabrous, wrinkled, with a short prominent hook at the mouth; dorsal petal erect, 0.9 × 0.95 mm, yellowish-green, gland-dotted, deeply hooded, hood dark green; lateral petals fleshy, 0.8 × 1.2 mm, 3-lobed. Androecium 1.9 mm long, stamens 5 in number, filaments short; anthers 0.16–0.19 × 0.18–0.2 mm dithecous, dehiscent transversely. Ovary elliptic-ovate, glabrous, 0.6 × 1.40 mm; style short; stigma obtuse. Capsule fusiform with five valves, glabrous, loculicidal dehiscence. Seed oblong to ovate, brownish 0.45 × 0.85 mm diam, wrinkled with dense tuft hairs on both ends.

Vernacular name: Neelakondrapoo (Muthuvan tribal language) (Neela – Blue, Kondra – prawn shaped, poo – flower)

Phenology: Flowering period is limited to three months (August–October), coinciding with the two main monsoon periods. The fleshy stems effectively close down, lose their leaves, and shrink in diameter throughout the dry summer months. When the rainy season finally arrives, the stems swell to their previous size. The stems end up looking like a string of beads as a result of this. All of the Indian epiphytic species belonging to *Impatiens* including *I. parasitica*, *I. jerdonia*, and *I. viridiflora* have this type of moniliform growth pattern. This trait may aid the epiphytic species in surviving dry, droughty conditions and can be considered an ecological adaptation for epiphytism.

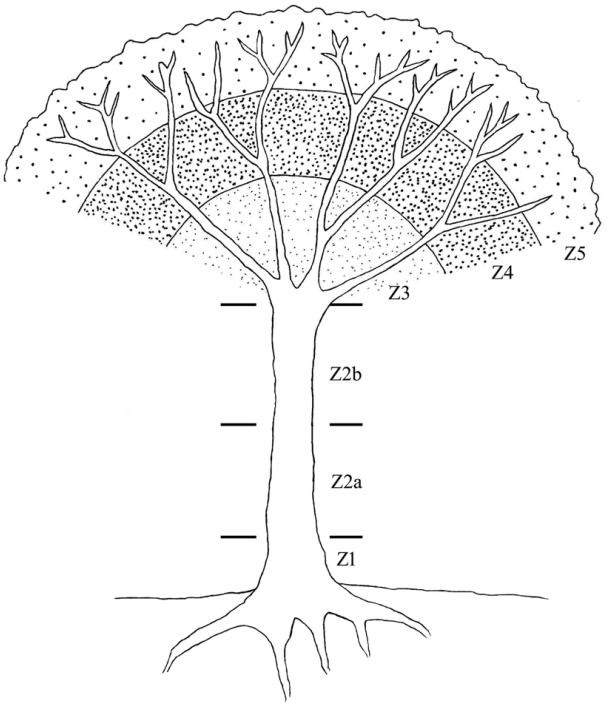

Figure 1. Illustration of vertical zones: Z1—trunk base | Z 2a/b—lower/upper part of the trunk | Z3—lower canopy | Z4—middle canopy | Z5—outer canopy. This figure shows the adapted version of the system, where the trunk is divided into two separate zones (Steege & Cornelissen 1989).

Ethno-medical uses: *Impatiens violacea* have been used as medicine for the treatment of paralysis. The entire plant is ground into the paste and applied to the affected part. This tribal medical practice is recorded in the oral tradition of Muthuvan tribes.

Specimens examined: India, Kerala, Idukki District, Pettimudi, 2,000 m, 25 August 1998, Sequeira 20731 (Holotype KFRI!); Pettimudi, 10.167^{0}N, 76.997^{0}E, 1,836 m, 25 October 2020, Arjun & Jameson 572,573 (SAC!).

Distribution and ecology of *I. violacea*

During the present study, *I. violacea* was recorded and collected only from the Pettimudi forest valley (1,836 m; 10.167^{0}N, 76.997^{0}E) in the Idukki district of Kerala, India (Image 1B). The habitat of *I. violacea* was fragmented into two by a long gravel forest road from Pettimudi towards Edamalakkudy, a tribal Gram panchayat consisting of 25 settlements inhabited by Muthuvan tribes, one of the isolated indigenous tribes

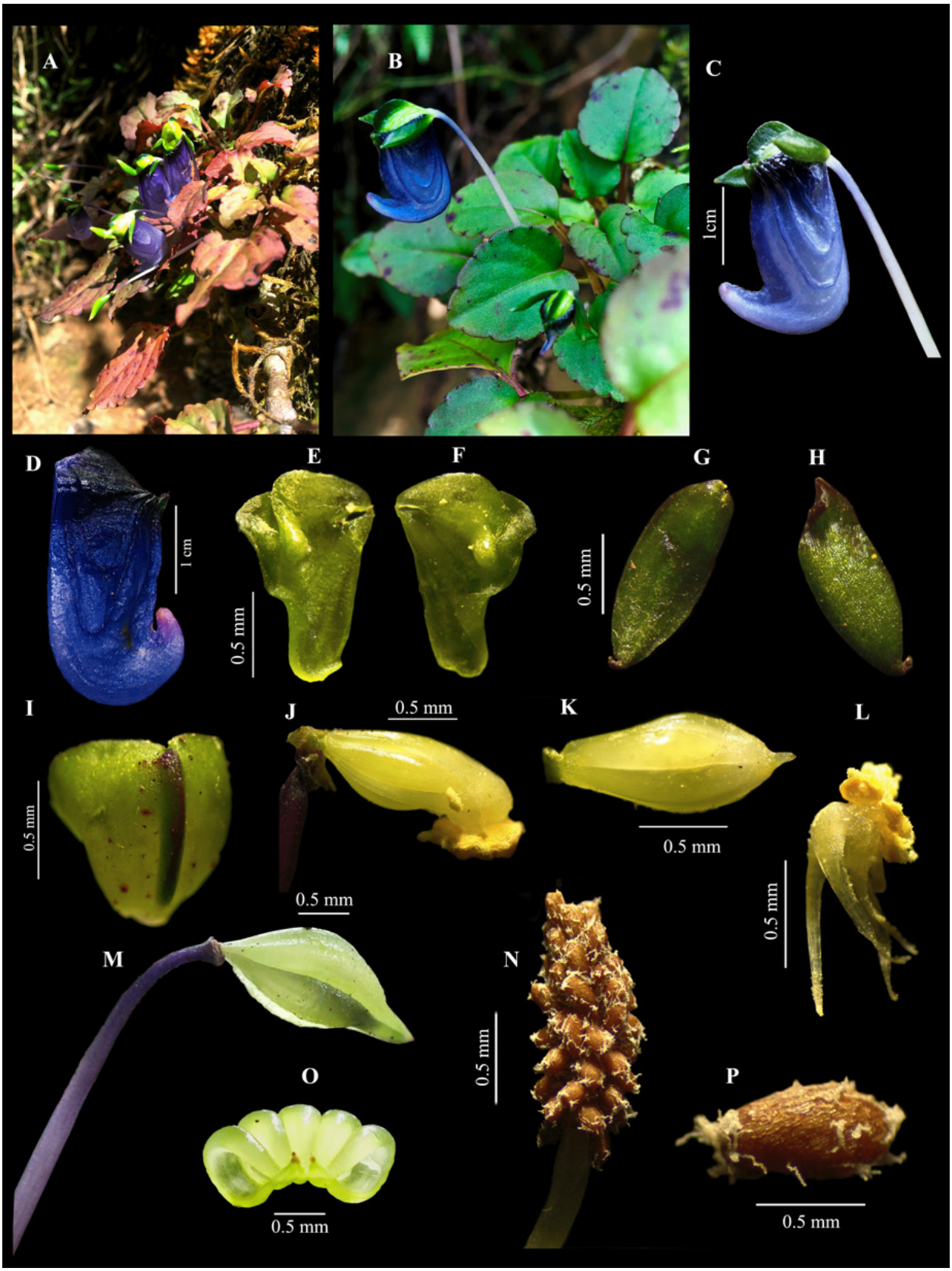

Image 2. ***Impatiens violacea*****: A&B—plant habit | C—a flower | D—lower sepal | E&F—lateral petals | G&H—lateral sepals | I—dorsal petal | J—column | K—gynoecium | L—androecium | M—capsule | N—Infructescence | O—dehisced capsule | P—seed. © A. Thomas.**

of the Western Ghats. This epiphyte can be regarded as a true epiphyte because it remains detached from the forest floor and the phorophyte's vasculature during its whole existence. This species was found distributed on the trees with closed canopy located on both sides of this forest road at an altitude of 1,800–1,900 m. Even though the valley is very closely connected to Eravikulam National Park (ENP), the species was observed only at a u-shaped valley in Pettimudi forest indicating the ineffectiveness of seed dispersal along with heavy and few numbers of seeds compared (Image 2) to the minute and numerous seeds of successful epiphytes such as orchids and ferns (Grey 1980). *I. violacea* possesses explosive ballistic dispersal with a high likelihood of reaching an unfavorable place for the seed to germinate, which is a crucial stage in the life cycle of plants. Another element influencing the limited dispersion may be the valley surrounded by steep mountains highly humid conditions and very low or null wind inflow inside a closed canopy.

The plant species were vertically distributed on phorophytes in three tree zones from Z3 to Z5 and were more prevalent in mid-canopy (Zones 3 and 4). This epiphytic species can be considered an ecological group, habitat generalists (Occurring in three or more zones).

Abiotic factors such as temperature, relative humidity, light intensity, and wind at each vertical zone of phorophytes having *I. violacea* were observed. Microhabitats in the phorophyte reveal a model of vertical change where abiotic factors such as temperature, and light availability increase with the height of the phorophyte, while humidity simultaneously decreases with height and wind velocity are null to calm. Another contrasting observation in the habitat of *I. violacea* was the close association with non-vascular epiphytes. All *I. violacea* individuals were observed in moss-covered bark of phorophytes and none of them were observed on bare bark.

The vertical distribution pattern observed in this study can be associated with the ecological adaptation of *I. violacea*. This true epiphyte is vertically distributed from phorophyte (Z3–Z5), these zones receive maximum light with low humidity. The distribution pattern of abiotic factors such as temperature and humidity in our study was in accordance with studies of (Walsh 1996; Freiberg 1997) where temperature increases from the ground level to the canopy, while air humidity decreases. The most important parameters determining epiphyte placement are humidity and temperature (Benzing 2008). This drought-avoider epiphyte has desiccation-prone foliage with a woody tuberous stem to withstand canopy zones with maximum light along with low humidity and dry seasons. This species found only on the moss and humus-covered bark of phorophytes may be a result of the lack of specialized root systems that may anchor to the phorophyte's bare bark. According to numerous findings, epiphytic bryophytes help vascular epiphytes establish themselves, survive and coexist (Van Leerdam et al. 1990; Tremblay et al. 1998; Zotz & Vollrath 2003; Thomas & Jameson 2020). Especially in tree species with smooth bark, bryophytes may improve seed anchoring and result in a more dependable water supply during germination, but they may also lessen the severity of drought in later ontogenetic phases. This impact is anticipated to be a diminishing function of plant size (Zotz et al. 2001), which may be attributed to the *I. violaceae* having a variety of small- to large-sized plants. In montane forests, the constant presence of humidity can be favourable for the specialization of microhabitats of epiphytic plants (Gentry & Dodson 1987).

Threats and Conservation status of *I. violacea*

The population is estimated to be 87 individuals (mature – 60 and juvenile – 27) where all are observed only from the type locality. Moreover, the type locality of this species is in a landslide-prone area. A catastrophic landslide event occurred at the windward slope of this valley mountain in August 2020 due to heavy downpours (Achu et al. 2021). A major anthropogenic threat observed was habitat fragmentation; a gravelled forest road fragmenting the habitat into two and the government's new proposed project to make this gravel road motorable from Pettimudi to Eddalipparakkudy will severely affect the survival of this beautiful species in the wild. Habitat fragmentation in plants can potentially impact a huge number of progenies in the quantity of progeny produced, but also the genetic and biological quality (Aguilar et al. 2019). It has been observed that this threatened species is illegally harvested and traded in the national and international markets. In general, the illegal plant trade threatens and destroys numerous species, and important natural resources, and can cause phytosanitary risks (Lavorgna & Sajeva 2021). The whole plant part used by Muthuvan tribals for ethnomedical purposes also makes this plant reduce in number of individuals. All these threats altogether make the remaining populations in this valley face in an uncertain future. Being a steno-endemic species to Pettimudi Valley, very restricted distribution in the upper montane cloud forest (shola forest) with small population size in the wild and high risk of natural and anthropogenic stress makes the species threatened and can be classified as

Table 1. List of endemic taxa from U-shaped valley in Pettimudi Forest. TMCF—tropical montane cloud forest | WG-SRI Western Ghats–Sri Lanka | WG—Western Ghats | SWG—southern Western Ghats | VU—Vulnerable | EN—Endangered | CR—Critically Endangered | NE—Not Evaluated.

Scientific name	Family	Habitat	Categories	Endemic
Impatiens violaceae M.Kumar & Stephen Sequiera	Balsaminaceae	Herb (Epiphytic in TMCF)	VU	Pettimudi
I. pandurangani K.M.P.Kumar, R.Jagad. & G.Prasad	Balsaminaceae	Herb (Lithophyte in TMCF)	CR	Pettimudi
I. johnii Barnes	Balsaminaceae	Shrub (Lithophyte in TMCF)	EN	Pettimudi
I. platyadena C.E.C.Fisch.	Balsaminaceae	Shrub in TMCF	CR	SWG
I. phoenicea Bedd	Balsaminaceae	Herb (Suffruticose in TMCF)	EN	SWG
I. modesta Wight	Balsaminaceae	Herb (Lithophytes / epiphyte in TMCF & EGF)	NE	SWG
I. leschenaultii (DC.) Wall. ex Wight & Arn	Balsaminaceae	Shrub (Lithophyte in TMCF)	NE	WG
I. latifolia L.	Balsaminaceae	Shrub - TMCF	NE	WG-SRI
I. disotis Hook.f	Balsaminaceae	Herb (Terrestrial/ epiphytic in TMCF & EGF)	NE	SWG
I.coelotropis C.E.C.Fisch.	Balsaminaceae	Terrestrial/ epiphyte	VU	SWG
I. parasitica Bedd.	Balsaminaceae	Herb (Epiphyte/ on wet rocks)	NE	SWG
Henckelia macrostachya (E.Barnes) A.Weber & B. L.Burtt.	Gesneriaceae	Herb (Lithophyte in TMCF)	EN	SWG
Cnemaspis anamudiensis Cyriac, Johny, Umesh & Palot	Gekkonidae	Reptile. Crevices of rock boulders	NE	Pettimudi

Vulnerable under criterion D2 (VU D2) under the IUCN Red List Categories and Criteria.

Endemic species in Pettimudi forest

The single-patch shola of Pettimudi forest is surrounded by steep mountains harboured by endemic flora and fauna. In the study, the u-shaped valley of Pettimudi forest (1.87 km^2) consists of 12 endemic plant species and one reptile species. The type locality and distribution of three steno-endemic taxa were located within an area of 0.023 km^2 within this valley. This includes a species of geckos (*Cnemaspis anamudiensis)* and two species of *Impatiens (I. violacea* & *I. johnii*) along with *I. pandurangani* which is endemic to Pettimudi forest (Image 1) (Prabhukumar et al. 2017; Cyriac et al. 2018). Barnes described *Impatiens johnii* from Kallar Valley adjacent to Pettimudi forest in 1931. The plant was believed to be extinct until it was rediscovered by Biju & Kumar (1999) after 67 years from Pettimudi forest. A recent study on the distribution pattern of *I. johnii* revealed that the plant is restricted only to less than 5 km^2 in Pettimudi Valley (Prasad et al. 2018). A similar result was observed in our study, with the population of *I. johnii* near *I. violaecae*.

A detailed list of endemic species from Pettimudi forest is mentioned in Table 1. Areas of endemism (AoE) are places where the ranges of at least two taxa overlap (Quijano-Abril et al. 2006). Therefore, the U-shaped valley in Pettimudi forest with three steno endemic species can be considered as an area of endemism. Our results on the distribution of endemic taxa in this valley indicate that there are 13 endemic species here, making it a hotspot within the Western Ghats. A study by Shajitha et al. (2016) confirmed that southern Western Ghats species of *Impatiens* including *I. violacea* have belonged to recent lineages, so *I. violacae* can be considered as steno-endemic taxa, evolved recently, constrained by steep mountains of Pettimudi with no sufficient time to expand its range. The tropical forests of the Western Ghats are considered 'refugia' harbouring highly diverse endemic taxa and montane habitats, particularly acting as 'species pumps' (Johnson et al. 2022). According to Kumar & Sequeira (1996), the Western Ghats is a region of speciation of the genus *Impatiens.* This assessment was consistent with our observations which favour the presumption that this small valley in Pettimudi forest is a cradle of speciation. The molecular phylogeny study of the genus *Impatiens* indicates that southern Western Ghats species of *Impatiens* were colonized from southeastern Asia by two independent dispersal events, i.e., once by a southeastern Asian ancestor and another time by an ancestor with African affinities. The phylogeny and biogeography study of *I. parasitica* and *I. latifolia* showed African affinities (Yuan et al. 2004) and *I. violacea* and *I. johnii* have a southeastern Asian relationship (Sajitha et al. 2016).

In the case of endemic reptile *Cnemaspis anamudiensis* of the genus *Cnemaspis* Strauch, 1887 is one of the most species-rich genera of the family Gekkonidae which is distributed from Africa to southeastern Asia (Sayyed et al. 2018). According to Kier et al. (2009), the endemic richness of plants and

vertebrates is correlated. The topography of the valley surrounded by steep mountains was complex. A large mountain with topographic complexity, isolation, and different microclimatic conditions promotes endemism and biodiversity (Badgley et al. 2017; Noroozi et al. 2019).

CONCLUSION

In the current investigation, it was found that *I. violacea* is a threatened species that is currently Vulnerable. Due to its steno-endemic status to Pettimudi forest, rare distribution at the upper montane cloud forest (shola forest) along with its low wild population size puts it in significant danger of near extinction in the wild in the future due to multiple anthropogenic stresses**.** Our results indicated that the u-shaped valley in Pettimudi forest is an area of endemism and can be strongly considered a 'hot speck' where it is a hot spot within the southern Western Ghats hotspot and a cradle of speciation. This study highlights our understanding of the endemic diversity of the Pettimudi forest, which is essential for understanding the biogeographic relationships among the recognised areas of endemism (AoEs). Considering the relevance of the Pettimudi forest's unique endemic diversity, public policies for the conservation of this region need to be generated. Also, a proposal that recommends this u-shaped mountain valley in Pettimudi forest to be attached to the Eravikulam National Park territory. This research emphasizes the importance of comprehending the endemic biodiversity of the Pettimudi forest to better grasp the biogeographic connections between recognised AoE. Given the significance of the unique endemic biodiversity in the Pettimudi forest, it is imperative to formulate public policies for the conservation of this region. In addition, a proposal suggesting the incorporation of the U-shaped Mountain valley in the Pettimudi forest into the territory of the Eravikulam National Park is recommended.

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