Journal of Threatened Taxa

Building evidence for conservation globally

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

COMMUNICATION

POLLINATION ECOLOGY OF *BROWNLOWIA TERSA* (MALVACEAE), A NEAR THREATENED NON-VIVIPAROUS TRUE MANGROVE SHRUB

Aluri Jacob Solomon Raju

26 July 2019 | Vol. 11 | No. 9 | Pages: 14119–14127
DOI: 10.11609/jott.4906.11.9.14119-14127

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 July 2019 | 11(9): 14119–14127

COMMUNICATION

Pollination ecology of *Brownlowia tersa* (Malvaceae), a Near Threatened non-viviparous true mangrove shrub

Aluri Jacob Solomon Raju

Department of Environmental Sciences, Andhra University, Visakhapatnam, Andhra Pradesh 530003, India.
solomonraju@gmail.com

ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

PLATINUM
OPEN ACCESS

Abstract: *Brownlowia tersa* is a low-ground semi-evergreen shrub species. The phenological events occur sequentially—leaf fall, leaf flushing, flowering and fruiting from April to November. It is hermaphroditic, protandrous, self-compatible, facultative xenogamous, and melittophilous involving worker honey bees, small male and female carpenter bees and male and female cuckoo bees. Of these, worker honey bees and female carpenter bees forage for both pollen and nectar while male carpenter bees and both sexes of cuckoo bees forage exclusively for nectar. Cuckoo bees are very important for cross-pollination because they are swift fliers and visit many flowers from different plants in the shortest time. Carpenter bees and honey bees are largely important for self-pollination as they are not fast fliers and tend to spend more time at each flower for forage collection. The flowers have a specialized pollination mechanism to resort to autonomous autogamy if not pollinated but this mode of pollination is subject to the availability of pollen in its own anthers. Fruit is a 1-seeded follicle produced from a single carpel of the flower. It is indehiscent and floats in tidal water when detached from the plant. When settled in muddy substratum, it breaks open to expose the seed which germinates and produces a new plant in quick succession. The study reports that the plant is highly threatened due to different human economic activities taking place in the area and hence immediate in situ conservation measures are required for its protection and propagation.

Keywords: Facultative xenogamy, hermaphroditism, melittophily.

DOI: https://doi.org/10.11609/jott.4906.11.9.14119-14127

Editor: Cleofas Cervancia, University of Philippines Los Baños College Laguna, Philippines. **Date of publication:** 26 July 2019 (online & print)

Manuscript details: #4906 | Received 18 February 2019 | Final received 31 May 2019 | Finally accepted 16 June 2019

Citation: Raju, A.J.S. (2019). Pollination ecology of *Brownlowia tersa* (Malvaceae), a Near Threatened non-viviparous true mangrove shrub. *Journal of Threatened Taxa* 11(9): 14119–14127. https://doi.org/10.11609/jott.4906.11.9.14119-14127

Funding: UGC, New Delhi, India and Society for Conservation Biology, Washington DC, USA.

Competing interests: The author declares no competing interests.

Author details: Prof. A.J. Solomon Raju is the recipient of several national and international awards. He has more than 300 research papers in international and national Journals.

Acknowledgements: The work reported in this paper was carried out with the financial support received under BSR Mid-Career Award instituted by the University Grants Commission, New Delhi, and Marine Section - Small Grants Program instituted by the Society for Conservation Biology, Washington DC, USA.

Society for Conservation Biology

INTRODUCTION

The Malvaceae family contains herbs and shrubs (Tang et al. 2007). Flowers of this family are usually hermaphroditic and entomophilous (Ruan 2010). Wind pollination in the species of this family is unlikely because the pollen grains are sticky and tend to clump together. Pollinators are mostly bees and butterflies; however, other pollinators are species-specific and include hawk moths, hummingbirds, and other birds (Rathcke 2000; Ruan 2010). In this family, the sub-family Brownlowioideae consists of eight genera with 70 species distributed in palaeo-tropical latitudes. This sub-family is characterized by sepals fused into a campanulate tube (Burret 1926), many stamens either unfused or slightly fused into fascicles at their base with or without staminodia (Ridley 1922; Hutchinson 1967), and ovaries sessile or borne on a short-stalk representing gynophore. Among these genera, *Brownlowia* consists of about 30 species widely distributed in southeastern Asia through Malaysia and the Pacific Islands (Tomlinson 1986). Different authors reported that *Brownlowia* is a genus of trees, comprising about 25 species in southern and southeastern Asia with Borneo as centre of its distribution where it is represented by 17 species of which 15 are endemics. Many species of this genus grow along rivers, in swamp forests and mangroves (Kostermans 1965; Turner 1995; Bayer & Kubitzki 2003). This genus is distinguished from other genera by its apocarpous fruits and loosely connected carpels (Bayer & Kubitzki 2003). Only two shrub hermaphroditic species *B. argentata* and *B. tersa* have been reported as occurring in swamp forests and river banks, and mangroves inundated by the highest tides (Tomlinson 1986). These two species have been classified as true mangrove species by different authors (Duke 1992; Giesen et al. 2007; Polidoro et al. 2010). *B. tersa* is distributed from India to southeastern Asia where it has been recorded in Myanmar, Cambodia, Thailand, Malaysia, Brunei, Singapore, the Philippines, Indonesia (Giesen et al. 2007). In India, its distribution is restricted to the east coast where it is common in West Bengal and Odisha but rare in the Godavari estuary of Andhra Pradesh, and the Andaman & Nicobar Islands (Venu et al. 2006; Kathiresan 2010; Bhatt et al. 2011). This species is distinguishable in the field based on certain characters such as the presence of brown-scaly twigs, lanceolate leaves with dull silvery undersurface and pear-shaped, 2-valved fruits. It often grows in stands along the banks, remains almost half-submerged during high tide, and withstands the tidal surges due to its intricate root system. Globally, it is reported as a true mangrove species (Duke 1992; Giesen et al. 2007; Polidoro et al. 2010) though it has not been included in the Indian mangrove flora in certain national and international status reports (Kathiresan & Bingham 2001; Kathiresan & Rajendran 2005; Anonymous 2008; Mandal & Naskar 2008). But, it is reported as a true mangrove species in the mangrove flora of Andaman & Nicobar Islands (Sahni 1958; Debnath 2004). In the IUCN Red List, it is included in the Near Threatened category (Kathiresan 2010; Polidoro et al. 2010) and the reasons stated for this status include habitat loss from coastal development, erosion and the construction of shrimp and fish ponds throughout its range. Further, it is also stated that this species may qualify for threatened category in the near future due to its occurrence only on the landward margin where it is the most vulnerable to coastal development and human activities (Kathiresan 2010). *B. tersa* has been in use as a traditional folk remedy for diarrhoea, dysentery, wounds and boils. Roots possess antibacterial activity while leaves possess anti-inflammatory, antioxidant, analgesic and anti-diarrhoeal activities (Hossain et al. 2013). Despite its threatened status, there have been no studies on the reproductive biology of this species in any part of its distribution. Further, the other species *B. argentata* has also not been investigated for its reproductive biology so far. Tomlinson (1986) noted that the pollination biology of *Brownlowia* is unknown. Since then, no one has ever attempted to report on the pollination biology of any species of this genus.

The study is aimed at providing certain details of floral biology and pollination in *B. tersa* which is currently in threatened status at Coringa Mangrove Forest (CMF), Andhra Pradesh, India. This information is useful to understand the sexual, breeding, and pollination systems and fruiting ecology. Further, it provides clues to understand why it attained threatened status not only at this forest and also at other mangrove forests where it is distributed.

MATERIALS AND METHODS

CMF covering an area of 188km^2 lies at 16^{0}43’47.413”N and 82^{0}12’54.864”E. It is located in the delta in East Godavari District; it is created by the river Godavari. Freshwater flows into the mangrove wetlands of the Godavari delta for a period of six months and peak flow normally occurs during July to September, coinciding with the southwest monsoon season. During this period the entire delta, including the mangrove wetland is

submerged under freshwater, since penetration of sea water is completely blocked by the large amount of incoming freshwater. Brackish water conditions prevail from October to February and sea water dominates the entire mangrove wetland from March to May due to the absence of freshwater discharge. In recent times, however, freshwater discharge from the river system is low due to insufficient and erratic rainfall during monsoon seasons.

Field studies were carried on the populations of *Brownlowia te*rsa (L.) Kosterm. in the areas of Ratikalva Reserve Forest which falls under non-sanctuary area of CMF. Observations regarding the organization of inflorescences, the spatial positioning of flowers, and their position on the plant were made since these features are regarded as important for foraging and effecting pollination by flower-visitors. The flower longevity was recorded by marking 20 just open flowers and following them until fall off. Anthesis was initially recorded by observing 10 marked mature buds in the field. Later, the observations were repeated five times on different days, each day observing 10 marked mature buds in order to provide accurate anthesis schedule. The same marked mature buds were followed for recording the time of anther dehiscence. The presentation pattern of pollen was also investigated by recording how anthers dehisced and confirmed by observing the anthers under a 10x hand lens. The details of flower morphology such as flower sex, shape, size, colour, odour, sepals, petals, stamens and ovary were described.

Twenty-five mature but un-dehisced anthers were collected from five randomly chosen plants and placed in a petri dish. Later, each time a single anther was taken out and placed on a clean microscope slide (75 x 25 mm) and dabbed with a needle in a drop of lactophenol-aniline-blue. The anther tissue was then observed under the microscope for pollen, and if pollen grains were not there, the tissue was removed from the slide. The pollen mass was drawn into a band, and the total number of pollen grains was counted under a compound microscope (40x objective, 10x eye piece). This procedure was followed for counting the number of pollen grains in each anther collected. Based on these counts, the mean number of pollen produced per anther was determined. The characteristics of pollen grains were also recorded. The stigma receptivity was observed by H_2O_2 test as given in Dafni et al. (2005).

The presence of nectar was determined by observing 50 mature buds and open flowers collected at random from 10 plants. Individual volumes of nectar were recorded for 20 flowers and then the average volume of nectar per flower was determined and expressed in µl. The flowers used for this purpose were bagged at the mature bud stage, opened after anthesis and nectar squeezed into micropipettes to measure the volume of nectar. Nectar sugar concentration was also simultaneously determined using a hand sugar refractometer (Erma, Japan).

Fifty flowers each from 10 randomly selected plants were used for each mode of the breeding system. The stigmas were pollinated with the pollen of the same flower manually by using a brush; they were bagged for fruit set through manipulated autogamy. The flowers were fine-mesh bagged without hand pollination for fruit set through spontaneous autogamy. The emasculated flowers were hand-pollinated with the pollen of a different flower on the same plant; they were bagged and followed for fruit set through geitonogamy. The emasculated flowers were pollinated with the pollen of a different individual plant and bagged for fruit set through xenogamy. All these modes of pollination were followed for one month for calculating the percentage of fruit set in each mode. Twenty inflorescences consisting of 125 flowers were tagged on 20 plants prior to anthesis and followed for fruit set rate in open-pollinations. Fruit maturation period, fruit dehiscence, seed dispersal and establishment were observed in detail.

The insects visiting the flowers were bees only and they had their nesting sites close to *B. tersa* populations. They were observed carefully for 10 hours a day for 15 days in different weeks during the flowering season. The hourly foraging visits of each bee species were recorded on 10 different days for which 30 inflorescences were selected. The data obtained was used to calculate the percentage of foraging visits made by each bee species per day in order to understand the relative importance of each bee species. Simultaneously, the bees were observed for their foraging behavior such as mode of approach, landing, probing behaviour, the type of forage they collected, contact with essential organs to result in pollination, and inter-plant foraging activity. The bees were captured from the flowers during 10.00–12.00 h on five different days for pollen analysis in the laboratory. For each bee species, 10 specimens were captured and each specimen was washed first in ethyl alcohol and the contents stained with aniline-blue on a glass slide and observed under a microscope to count the number of pollen grains present. In the case of pollen collecting bees, pollen loads on their corbiculae/scopae were separated prior to washing them. From pollen counts, the average number of pollen grains carried by each bee species was calculated to know the pollen carryover efficiency of different bees.

RESULTS

Habit and phenology

Brownlowia tersa is a semi-evergreen bushy and spreading shrub distributed in sunny locations along tidal creeks and brackish water creeks where mud is accreting (Image 1a). A green snake (unidentified) uses the habitat of this plant in all locations where the plant occurs (Image 1b,c). It grows up to two meters in height without any above ground roots. It is fast growing, much-branched and forms pure stands. The branches are grey, smooth and marked with lines and grooves along their length. Leaves are petiolate, lanceolate to elliptic-lanceolate and leathery with a rounded base and a pointed tip; the upper surface is glossy and smooth while the lower surface is grey-green and covered with a dense layer of tiny, hairy scales. Leaf fall occurs during late April to late May, leaf flushing during June–July and flowering during late July to second week of September at population level. Individual plants flower for about four weeks only. Inflorescence is terminal and axillary; it is a paniculate cyme with several flowers which open over a period of about a week. (Image 1e,f). Cauliflorous flowers are also borne on main stems and woody trunks.

Flower morphology

Flowers are pedicellate, 5–7 mm long, 5-6 mm wide, creamy-brown coloured, mildly odoriferous, bisexual and actinomorphic. Calyx is bell-shaped, 5-sepalled, connate below and light yellow with brown dots all over. Corolla is cream-coloured with light yellow base, 2–3 mm longer than calyx, 5-petalled, free and apex rounded. Stamens are many, free, present in five bundles and free from calyx and corolla. Anthers are petaloid and attached to the filament by the base. Ovary sits on a well-developed stalk. It has four carpels which are partially joined and each carpel has two reniform ovules (Image 2k–n). All four carpels are joined by a common style tipped with a simple stigma.

Floral biology

Mature buds are globose and open during 09.00–11.00 h with peak opening at 10.00h (Image 2a–g). The stamens show anther dehiscence by longitudinal slits during anthesis. In mature buds, the stigma is below the height of stamens but stands straight and erect beyond the height of the anthers during anthesis. The stigma remains so for 6 hours and gradually curves towards the anthers of the same flower and eventually contacts its own pollen. It attains receptivity three hours after anthesis and remains so for five hours. The pollen grains are oblate-spheroidal, yellow, 3-colporate, sexine thinner than nexine and 27–29 µm in size (Image 2h–j). They are initially sticky but later turn powdery with a gradual increase in temperature and fall as single grains. Individual anthers produce 890.6 ± 52.83 pollen grains and the total pollen output by a flower depends on the number of stamens produced. The stigma terminates

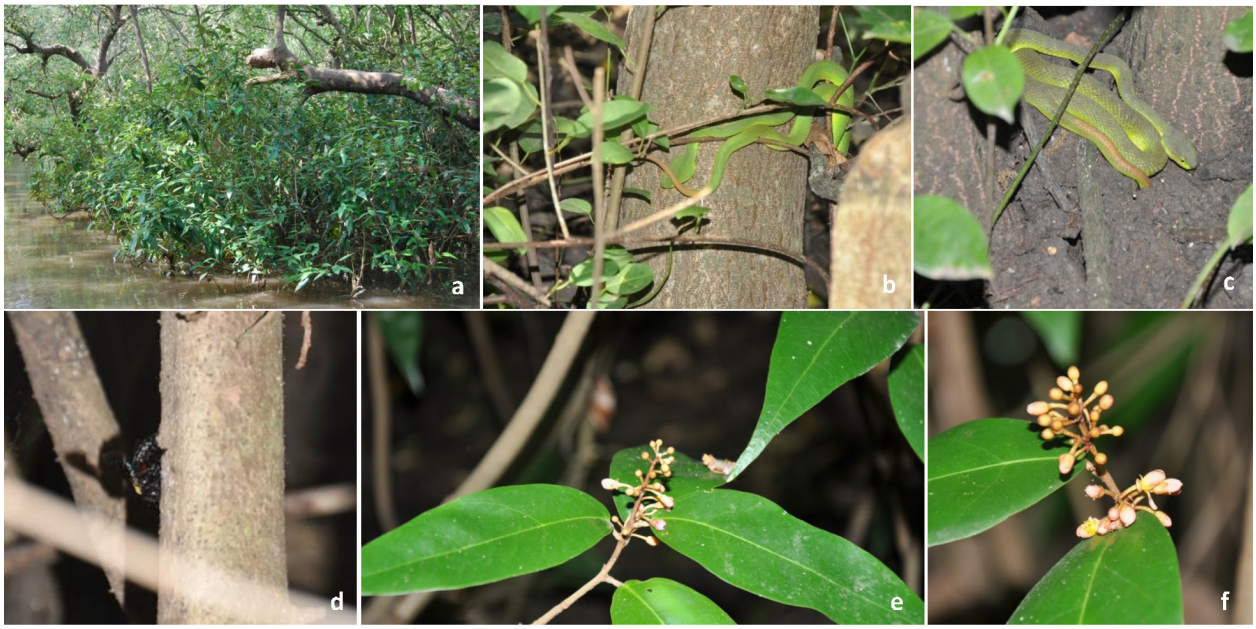

Image 1. *Brownlowia tersa*: a - Habitat | b&c - Habitat for Green Snake | d - *Thyreus histrio* resting on the stem | e - Twig with early stage of inflorescence | f - Inflorescence with maturing buds. © A.J. Solomon Raju.

its receptivity by the end of the day. Nectar is produced in minute volumes around the base of the carpels and is protected by the basally connate calyx; it amounted 1.2 ± 0.23 µl per flower and the sugar concentration stood at 28 ± 1.5%. The flowers fall off by noon of the second day.

Breeding systems

Hand-pollination tests showed that the plant produces fruit through self and cross-pollination. Fruit set rate varied from 14–34 % in unmanipulated and manipulated autogamy, 50% in geitonogamy, 72% in xenogamy and 34% in open-pollination. These results indicate that fruit set is the highest in xenogamy and lowest in unmanipulated autogamy among hand-pollination tests. Fruit set evidenced in open-pollination is taken as the product of auto-, geitono- and xeno-gamy (Table 1).

Table 1. Results of breeding systems in *Brownlowia tersa*.

Pollination mode	No. of flowers pollinated	No. of fruits formed	Fruit set (%)
Autogamy (unmanipulated)	50	7	14
Autogamy (manipulated)	50	17	34
Geitonogamy	50	25	50
Xenogamy	50	36	72
Open-pollination	125	43	34

Flower visitors and pollination

The flowers were foraged exclusively by bees during 09.00–17.00 h with peak activity during 10.00–13.00 h coinciding well with the availability of more fresh flowers (Fig. 1). The bees belong to Apidae family and included honey bees (*Apis cerana* F. and *A. florea* F.), a small carpenter bee (*Ceratina binghami* Cockerell) and a cuckoo bee (*Thyreus histrio* F.; Image 1d). In honey bees, only worker bees visited the flowers and foraged for both pollen and nectar. Worker bees collected pollen, groomed and brushed it down towards the hind legs and packed the pollen into the corbiculae or pollen baskets which are located on the tibia of the same legs. They used nectar collected by them for their own consumption and also for feeding the queen and male bees of the hive nearby in the same forest. In other bee species, both male and female bees visited the flowers. The male carpenter bee foraged for only nectar while female bee foraged for both pollen and nectar. The male carpenter bee collected nectar for its own consumption while female carpenter bee used the nectar collected by it for its own consumption and also mixed it with pollen to make bee bread to feed the larvae. The female carpenter bee collected pollen and packed it as honey bees did but they packed it into the weak scopa surrounded by sparse body hairs located on the tibia of hind legs. The male and female cuckoo bees foraged for only nectar for their own consumption. The floral architecture facilitated the bees to probe for the forage with great ease and during probing they contacted the stigma and stamens effecting pollination. Worker honey bees and the female carpenter bees tended to spend more time at each flower, plant and patch as they were involved in collecting both pollen and nectar while male carpenter bees and both sexes of cuckoo bee tended to spend less time at each flower, plant and patch as they were involved in collecting only nectar. All four bee species made inter-plant and inter-patch flower visits in

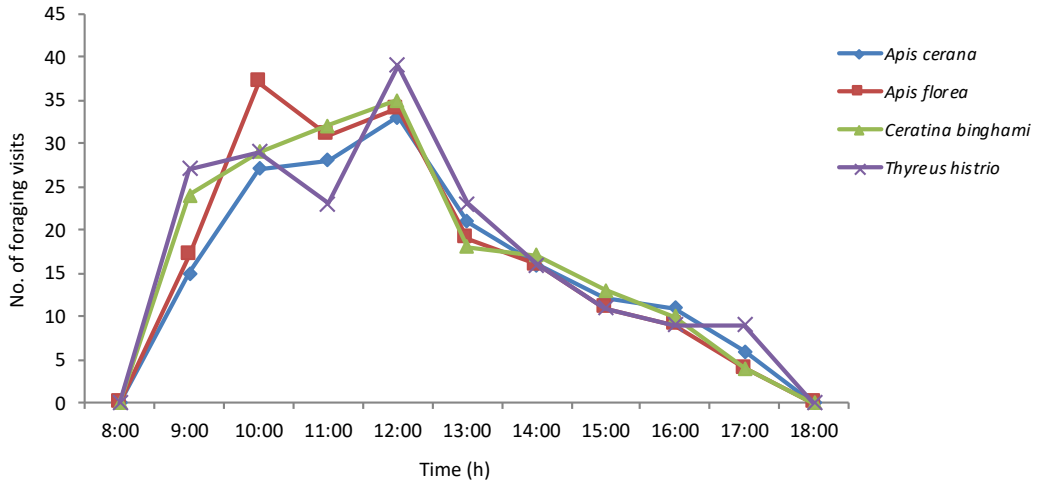

Figure 1. Hourly foraging activity of bees on *Brownlowia tersa*.

Image 2. ***Brownlowia tersa:*** **a–g - Different stages of anthesis | h - Dehisced anthers with yellow powdery pollen | i&j - Pollen grains | k&l - Ovary, style and stigma | m - Simple stigma | n - Ovules | o - Fruiting | p - Cauliflorous fruits | q - Seed germination | r - Seedling | s - New plant. © A.J. Solomon Raju.**

Table 2. Pollen recorded in the body washings of insect foragers on *Brownlowia tersa.*

Insect species	Sample size (N)	Range	Mean	S.D.
Apis cerana	10	54–208	115.4	50.08
Apis florea	10	93–156	99.1	19.44
Ceratina smaragdina	10	95–129	98.1	12.23
Thyreus histrio	10	67–304	162.3	75.49

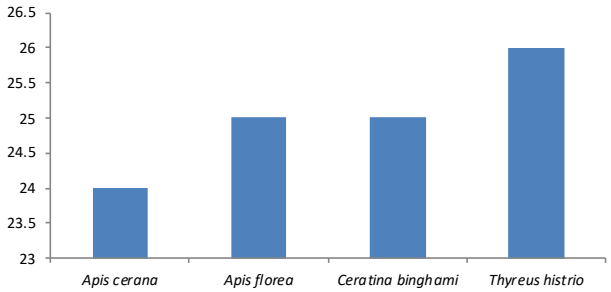

Figure 2. Relative percentage of foraging visits of bees on *Brownlowia tersa.*

quest of more forage and in the process they effected both self- and cross-pollinations. Among all four bee species, *T. histrio* made 26%, *A. florea* and *C. binghami*, each 25% and *A. cerana* 24% of total visits recorded at the flowering patch (Fig. 2). The pollen recorded in body washings of sampled specimens of bees indicated that all of them carry and transfer pollen to other flowers either in the same or different patches. The average number of pollen grains recorded was 115.4 for *A. cerana*, 99.1 for *A. florea*, 98.1 for *C. binghami* and 162.3 for *T. histrio* (Table 2).

Fruiting ecology and seed dispersal

In fertilized flowers, calyx remains for about a week without any further development and falls off subsequently. A single carpel produces fruit in fertilized flowers. Fruits mature in about four weeks; remain greyish-green from fruit initiation and until dispersed (Image 2o,p). Individual fruit is a woody, fibrous heart-shaped follicle, 12–15 mm long and bi-lobed with a single seed. It is indehiscent while on the plant, falls off when due, floats due to its fibrous husk of fruit carpel, imbibition of water by it; this floating state of fruits

facilitated their dispersal by tidal water. When it settles on the muddy substratum and upon imbibition, it breaks open exposing the seed but fruit carpel remains intact until seed germination. With initiation of root growth and development, the cotyledons shed the fruit carpel and show continued growth to form seedlings and subsequently new plants (Image 2q–s).

DISCUSSION

Brownlowia tersa is a shrubby, spreading plant and forms patchy distribution along the tidal creeks connecting the landward zone at the study area. An unidentified green snake has been found to use this gregarious shrub at all locations of its occurrence for its shelter but why it uses the habitat of this particular plant is unknown. In *B. tersa*, flowering and fruiting seasons are variously reported by different authors. Kathiresan (2010) noted that it flowers and fruits during July–October but he has not mentioned the location where it was recorded. Ragavan et al. (2016) noted that it flowers during February–March and fruits during April–July in India and Andaman & Nicobar Islands. The present study made at CMF India showed that all phenological events occur sequentially—leaf fall, leaf flushing, flowering, and fruiting—from April to November. Flowering starts in late July and continues for about seven weeks while fruiting during October–November at population level, however, individual plants flower for less than a month. The flowers are borne in terminal and axillary paniculate cymes as well as on main stems and woody trunks indicating that the plant with shrubby habit perhaps evolved to compensate the brief period of flowering by producing cauliflorous flowers in order to attract pollinators and maximize fruit set at plant level.

Different authors provided taxonomic characters of *B. tersa* but certain characters have been incorrectly reported. Judd & Manchester (1997) reported that *Brownlowia* flowers have five elongate antipetalous staminodia while Chung & Soepadmo (2017) noted that *B. tersa* flowers have lanceolate staminodes and persistent androgynophore. The present study showed that *B. tersa* lacks staminodia and androgynophore but it has gynophore on which the ovary is well seated. Further, the stamens are bundled, anthers petaloid which dehisce by longitudinal slits, and the carpels with reniform ovules are partially joined by a common style terminated with a simple stigma. The floral details of *B. tersa* clearly indicate that the plant is morphologically and functionally hermaphroditic. Protandry and the erect position of the stigma above the anthers facilitate the occurrence of only geitonogamy and xenogamy for a brief period; in addition, vector-mediated autogamy also occurs upon the commencement of stigma receptivity. Finally, the flowers resort to autonomous autogamy by gradually curving the style and stigma towards the anthers; this pollination mode is a "fail-safe" strategy evolved by the plant to ensure pollination in flowers that have not been pollinated by pollinator bees. Its occurrence, however, is subject to the availability of pollen in the anthers of the same flower. Ruan et al. (2010) reported on style curvature and its role in effecting self-pollination in 52 species of Malvaceae. These authors classified the studied species into two types: species with style curvature before pollen shedding, and species with style curvature after pollen shedding. In the former type, the styles remain erect if stigmas are pollinated or cease to curve if pollination occurs in the process of style curvature or continue to curve downwards towards the anthers if not pollinated. In the latter type, the styles curve eventually bringing stigmas down to establish contact with the anthers. The style curvature and eventual occurrence of self-pollination in *B. tersa* represents the second type, sensu Ruan et al. (2010). Therefore, *B. tersa* is a perfect hermaphroditic species with facultative xenogamous mating system.

Ruan (2010) stated that anemophily is unlikely in Malvaceae because the pollen grains are sticky. Spira (1989) reported that *H. moscheutos* with sticky pollen grains is not anemophilous and a vector other than wind is needed for successful pollination. The present study shows that *B. tersa* pollen is also sticky and in effect, the bees foraging on the flowers collect pollen slowly indicating that the plant is not anemophilous. Further, the sticky nature of the pollen enables the plant to avoid anemophily during non-receptive phase of the stigma to maximize cross-pollination and minimize self-pollination. Feng (1984) and Rachcke (2000) reported that many species of Malvaceae are entomophilous and pollinated by bees, butterflies, hawk moths and birds. Faegri & van der Pijl (1979) and Proctor et al. (1996) reported that bee-pollinated flowers vary in their size, shape and colouration; they may be open and bowl-shaped (radially symmetrical) or more complex and non-radially symmetric (zygomorphic), and offer nectar and pollen as rewards. The present study reports that *B. tersa* displays a radially symmetrial flower shape, dull-coloured corolla, mildly odoriferous and also offers nectar and pollen as rewards to pollinators; in line with this, the plant is pollinated exclusively by bees and hence it is melittophilous. Among bees, *Apis* spp. carry

pollen in pollen baskets located on their hind legs for use subsequently by their colony while female bees of *C. binghami* carry pollen in the scopae located on their hind legs for brood provisioning. The pollen collection activity by these bees significantly decreases pollen availability for pollination purpose although pollination is effected by them, and also it mostly undermines the occurrence of autonomous autogamy towards the end of the day. The production of many flowers in paniculate cymes, on main stem and woody trunk daily, individual flowers with several stamens and each stamen producing copious pollen appear to enable the plant to compensate the pollen loss caused by *Apis* and *C. binghami* bees, however. Male bees of *C. binghami* and both sexes of *T. histrio* act exclusively as nectar feeders and play principal role in the pollination of *B. tersa*. Further, *T. histrio* is a swift flier, collects nectar from as many flowers as it could in a single visit and hence is very important in effecting cross-pollination. *Apis* bees build their colonies on the peripheral branches of *Excoecaria agallocha* while *C. binghami* has its nests in the stems of *Acanthus ilicifolius*; these plant species occur 5–10 m away from *B. tersa*. *T. histrio* does not have its own nest but it uses the underground nests of *Amegilla* sp. which occur nearby on the landward side of the mangrove forests. Since the nests of all these bee species occur near *B. tersa*, they display a situation of floral constancy and effect pollination due to massive flower production by the plant during the flowering season.

In the present study, hand-pollination tests on *B. tersa* indicated that the plant is self-compatible and fruits through all modes of pollination with varying levels of reproductive success, however, fruit set rate in open-pollinations is not commensurate compared with the ability of the plant to fruit through autogamy with or without involvement of pollinators and through geitonogamy and xenogamy with the involvement of pollinators. Further, the flowers characteristically produce 1-seeded fruits only from a single carpel indicating that only one out of four carpels forms fruit and only one of 2-ovules of the carpel forms seeds. The fruits are indehiscent and float in tidal water upon detachment from the plant. Different authors noted that *Brownlowia* species are often dispersed by water indicating that they float in tidal water (Kostermans 1965; Turner 1995; Bayer & Kubitzki 2003). Similarly, Rachmadiyanto et al. (2017) reported that *B. peltata* also produces 1-seeded fruits from a single carpel but the fruits dehisce into carpels to expose the seeds; the fruits float and disperse by water. The fruits of *B. tersa* float because fruit pericarp is fibrous and imbibe water. Since the locations of the plant are situated towards landward zone, the fallen fruits do not disperse longer distances and soon they settle in muddy substratum. Gradually, the seed inside the fruit imbibes water and breaks the fruit open exposing the seed which soon germinates and produces a seedling and then a new plant. The fruit pericarp, however, remains enclosing the cotyledons until the initiation of root formation by the seedling. Similar process of fruit floating and seed germination is reported in *B. peltata* by Rachmadiyanto et al. (2017).

Gopal & Chauhan (2006) noted that *B. tersa* populations are experiencing severe loss at the range margins due to human activities and coastal development and hence has become an endangered species in India while Kathiresan (2010) mentioned that *B. tersa* is Near Threatened. Field studies conducted in this mangrove forest area for the last 12 years for the reproductive ecology information on different mangrove plant species showed a gradual decrease in the population size of *B. tersa* due to deforestation and modification for fuel wood collection, cattle shelter and eco-tourism activities. This situation is to be corrected otherwise this species would face the risk of genetic erosion and become extirpated in the course of time. Therefore, immediate and effective in situ conservation measures are necessary for its protection and propagation.

CONCLUSIONS

Brownlowia tersa is a low-ground semi-evergreen shrubby species. It displays phenological events sequentially—leaf fall, leaf flushing, flowering, and fruiting—from April–November. It is hermaphroditic, protandrous, self-compatible, facultative xenogamous and melittophilous. It has the ability to fruit with or without pollinator activity but fruit set rate is the highest with pollinator activity. Pollinators are exclusively bees consisting of honey bees, small carpenter bees, and cuckoo bees of which the last one is very important for cross-pollination due to their swift flying behavior and ability to collect nectar from many flowers of different plants. Fruit is a 1-seeded follicle and produced from a single carpel of the flower. It is indehiscent and floats in tidal water when detached from the plant. When settled in muddy substratum, it breaks open to expose the seed which germinates and produces a new plant. The study reports that the plant is highly threatened due to land use changes and regular human and cattle activity, and hence immediate in situ conservation measures are required for its protection and propagation.

REFERENCES

Anonymous (2008). Mangroves for the future: national strategy and action plan, India. Ministry of Environment and Forest, Government of India, 63pp.

Bayer, C. & K. Kubitzki (2003). Malvaceae, pp225–311, In: Kubitzki, K. & C. Bayer (eds.). The *Families and Genera of Vascular Plants Volume V, Flowering Plants Dicotyledons Capparales, Malvales and Non-betalain Caryophyllales.* Springer, Berlin, I–IX+418pp. https://doi.org/10.1007/978-3-662-07255-4_28

Bhatt, J.R., J.D. Macintosh, T.S. Nayar, C.N. Pandey & B.P. Nilratna (Eds.) (2011). *Towards conservation and Management of Mangrove ecosystems in India*. Ministry of Environment and Forest, New Delhi, 278pp.

Burret, M. (1926). Beietrage zur Kenntnis der Tiliaceen. *Notizblatt des Botanischen Gartens und Museums zu Berlin-Dahlem* 9: 592–880.

Chung, R.C.K. & E. Soepadmo (2017). *Brownlowia latifiana* (Malvaceae-Brownlowioideae), a new species from Terengganu, Pensinsular Malaysia. *Phytotaxa* 298: 134–146. https://doi.org/10.11646/phytotaxa.298.2.3

Dafni, A., P.G. Kevan & B.C. Husband (2005). *Practical Pollination Biology*. Enviroquest Ltd., Ontario, 583pp.

Debnath, H.S. (2004). *Mangroves of Andaman and Nicobar Islands: Taxonomy and Ecology. A Community Profile.* Bishen Singh Mahendra Pal Singh. Dehradun, 133pp.

Duke, N.C. (1992). Mangrove floristics and biogeography, pp63–100. In: Robertson, A.I. & D.M. Alongi (eds.). *Tropical Mangrove Ecosystems - Vol. 41*. American Geophysical Union, Washington DC, 329pp. https://doi.org/10.1029/CE041

Faegri, K & L. van der Pijl (1979). *The Principles of Pollination Ecology.* Pergamon Press, New York, 244pp.

Feng, K.M. (1984). *Flora*. Science Press, Beijing. 49: 1–238.

Giesen, W., S. Wulffraat, M. Zieren & L. Scholten (2007). *Mangrove Guide Book for Southeast Asia*. FAO and Wetlands International, Dharmasarn Co., Ltd., Bangkok, 781pp.

Gopal, B. & M. Chauhan (2006). Biodiversity and its conservation in the Sundarban mangrove ecosystem. *Aquatic Science* 68(3): 338–354. https://doi.org/10.1007/s00027-006-0868-8

Hossain, H., I.A. Jahan, S.I. Howlader, J.H. Shilpi, S.K. Dey & A. Hira (2013). Anti-inflammatory and antioxidant activities of ethanolic leaf extract of *Brownlowia tersa* (L.) Kosterm. *Oriental Pharmacy and Experimental Medicine* 13: 181–189.

Hutchinson, J. (1967). *The Genera of Flowering Plants (Angiospermae).* Clarendon Press, Oxford, 660pp.

Judd, W.S. & S.R. Manchester (1997). Circumscription of Malvaceae (Malvales) as determined by a preliminary cladistics analysis of morphological, anatomical, palynological, and chemical characters. *Brittonia* 49: 384–405. https://doi.org/10.2307/2807839

Kathiresan, K. (2010). Globally threatened mangrove species in India. *Current Science* 98: 1551.

Kathiresan, K. & B.L. Bingham (2001). Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology* 40: 81–251. https://doi.org/10.1016/S0065-2881(01)40003-4

Kathiresan, K. & N. Rajendran (2005). Mangrove ecosystems of the Indian Ocean region. *Indian Journal of Marine Sciences* 34: 104–113.

Kostermans, A.J.G.H. (1965). Miscellaneous botanical notes 5. *Bulletin of Botanical Survey of India* 7: 128–131.

Mandal, R.N. & K.R. Naskar (2008). Diversity and classification of Indian mangroves: a review. *Tropical Ecology* 49: 131–146.

Polidoro, B.A., K.E. Carpenter, L. Collins, N.C. Duke & A.M. Ellison (2010). The loss of species: mangrove extinction risk and geographic areas of global concern. *PLoS ONE* 5: e10095. https://doi.org/10.1371/journal.pone.0010095

Proctor, M., P. Yeo & A. Lack (1996). *The Natural History of Pollination*. Timber Press, Portland, 487pp.

Rachcke, B.J. (2000). Birds, pollination reliability and green flowers in an endemic island shrub, *Pavonia bahamensis* (Malvaceae). *Rhodora* 102: 292–414.

Rachmadiyanto, A.N., Peniwidiyanti & P.W.K. Hutabarat (2017). Fruit description and evaluation of five treatment to break seed dormancy of *Brownlowia peltata* Benth, pp46–53. In: ICBS Conference Proceedings, International Conference on Biological Science, 2015, KnE Life Sciences, Dubai. https://doi.org/10.18502/kls.v3i4.686

Ragavan, P., A. Saxena, P.M. Mohan, R.S.C. Jayaraj & K. Ravichandran (2016). The rediscovery of *Brownlowia tersa* (L.) Kosterm. (Malvaceae), from the Andaman Islands, India - a Near Threatened mangrove species. *Check List* 12: 1–5.

Ridley, H.N. (1922). *The Flora of the Malay Peninsula, Volume I, Polypetaleae*. L. Reeve & Co., Ashford, Kent, 918pp. https//doi.org/10.5962/bhl.title.10921

Ruan, C-J. (2010). Review and advances in style curvature for the Malvaceae. *International Journal of Plant Developmental Biology* 4: 98–111.

Sahni, K.C. (1958). Mangrove forests in the Andaman and Nicobar Islands. *Indian Forester* 84: 554–562.

Spira, T.P. (1989). Reproductive biology of *Hibiscus moscheutos* (Malvaceae), pp247–255. In: Bock, J.H. & Y.B. Linhart (eds.) *The Evolutionary Ecology of Plants*. Westview Press, Boulder, Colorado, 614pp.

Tang, Y., M.G. Gilbert & L.J. Dorr (2007). *Flora of China*. *Vol. 2.* Science Press & Missouri Botanical Gardens Press, Beijing, 264–298pp.

Tomlinson, P.B. (1986). *The Botany of Mangroves*. Cambridge University Press, New York, 413pp.

Turner, M. (1995). A catalogue of the vascular plants of Malaya. *Gardens' Bulletin Singapore* 47: 1–757.

Venu, P.W., Arisdasan, C.R. Magesh & T. Sathyamurthy (2006). *Brownlowia tersa* (L.) Kosterm. (Tiliaceae) in India. *Rheedea* 16: 111–114.

Journal of Threatened Taxa

www.threatenedtaxa.org

PLATINUM OPEN ACCESS

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

July 2019 | Vol. 11 | No. 9 | Pages: 14087–14246
Date of Publication: 26 July 2019 (Online & Print)
DOI: 10.11609/jott.2019.11.9.14087-14246

Publisher & Host

WILD ZOOREACH Threatened Taxa

Partner

صندوق محمد بن زايد للمحافظة على الكائنات الحية
The Mohamed bin Zayed SPECIES CONSERVATION FUND

Member

FJN