Snail-pollination in *Volvulusis nummularium*

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Pollination is a crucial ecological process that aids sexual reproduction in flowering plants. Although a variety of animals are known to bring about pollen transfer, pollination by snails (malacophily) has remained a rare and obscure phenomenon. Here we conclusively demonstrate the incidence of malacophily in *Volvulusis nummularium* (family Convolvulaceae, commonly known as the morning glory family), a prostrate rainy-season weed, which is also visited by honey bees. Flowers open in the morning and last only for half a day. *Apis cerana indica* and Graceful Awlsnail (*Lamellaxis gracile*) are the pollinators. Snails are exclusive pollinators on rainy days, when bees are not active. Contrary to the belief that snails are destructive, we found that they do not affect the natural fecundity of *V. nummularium*. Manual-pollinations indicated that the plants were facultative autogamous. Pollination in *V. nummularium* by snails and honey bees represents an interesting guild, which is of adaptive significance in achieving high reproductive success without resorting to obligatory selfing.

**Keywords:** Honey bees, malacophily, reproduction, snails, *Volvulusis nummularium*.

Pollination is a significant process and one of the prerequisites for ensuring fruit- and seed-set in all sexually reproducing seed plants¹⁰¹³. A great majority of plants are pollinated by animals¹⁰ and only a few involve abiotic agencies¹⁰⁻¹². Among the zoophilous species, nearly 80% are pollinated by insects. The remaining involve a variety of birds, reptiles and mammals¹⁰⁻¹ⁱ. Pollination by snails and slugs (malacophily) is a rare and infrequent phenomenon; so far it has been reported in seven species: *Rohdea japonica*, *Philodendron pinatifidum*, *Colocasia odora*, *Calla palustris*, *Lemma minor*, *Chrysanthemum alternifolium* and *Phragmites caudatum*¹²⁻¹⁴. Prostrate habit of the plant and floral arrangement in which the stigma and anthers do not extend much beyond the corolla, are believed to be conducive to malacophily¹². However, some investigators doubt the possibility of snails or slugs being successful pollinators, and consider malacophily to be ‘notorious and obscure’¹⁵ or even ‘ridiculous’¹⁴.

Snails are usually active at night and also during the day in the rainy season. In an unexpected field observation, we found mass floral foraging by the terrestrial gar-
through ascending ethanol series (20, 40, 60 and 70%) and finally stored in 70% ethanol\(^{10}\) for identification. The samples were sent to the Zoological Survey of India, Kolkata for identification.

The role of floral visitors in pollination and their efficiency was ascertained on the bases of foraging behaviour, flower-handling time, pollen load and the number of pollen grains deposited on the stigma after their visit. For computing the stigmatic pollen load on the freshly opened flowers and after the visits of the foragers, flowers \((n = 20,\) each site\) were collected in dry screw-cap vials \((2\text{ ml})\), and their stigmas were mounted in a drop of auramine O\(^+\) and observed under an epifluorescence microscope \((\text{Nikon, AXII Optiphot})\). Foraging period and flower-handling time were recorded separately for each forager from all the study sites \((\text{a total of 90 h of observation})\). The average amount of pollen load on each floral forager \((\text{snails, } n = 300; \text{ honey bees, } n = 200)\) was counted by removing the pollen grains with a brush on separate clean microslides under the stereomicroscope \((\text{Nikon, SMZ 800})\), staining with auramine O\(^+\) and examining them under the epifluorescence microscope.

To ascertain whether or not the visit of snails and bees could lead to subsequent fruit- and seed-set, the flowers

**Figure 1.**  
\(a\). Close-up of *Volvulopsis nummularium* plant showing prostrate habit with open flowers.  
\(b\). Whole mount of a stamen showing latroverse (arrow) longitudinal line of dehiscence of the anther.  
\(c\). Fruits with variable number of seeds \((1–4)\). Fruit size is proportional to seed number.  
\(d–g\). Pollination mechanism in *V. nummularium*.  
\(d\). A snail approaches the flowers at anthesis.  
\(e\). It gradually crawls towards the anthers to forage.  
\(f\). The shell comes in contact with the dehisced anthers and pollen grains get adhered to the last whorl.  
\(g\). Pollen transfer occurs when the snail visits the next flower.  
\(h\). A snail entering a partially opened flower during a rainy day. Note vertical orientation of the shell.  
\(i\). A honey bee foraging the flower.
were bagged after their first visit (n = ~500 each) and kept under observation for fruit-set. Interfloral movement of the foragers in a flowering patch was independently analysed for snails and bees on separate occasions (at five study sites) over a period of two months. Honey bee activity was traced by following the individual bee (n = 200) till it left a patch of plants, whereas the snails were marked with a dot of red on their shells for following their interfloral movement. The extent of phytophagy by snails was ascertained by recording the type of floral parts consumed, and also by dissecting the snails and examining the contents of their gut under the microscope.

Fruit- and seed-set through open pollination was computed by tagging the floral buds (n = 540) 12 h before anthesis. Any incidence of apomixis was ascertained by bagging (with transparent paper bags, 4 × 2 cm) the emasculated flowers (n = 220) 12 h before anther dehiscence. For assessing spontaneous autogamy, flowers were bagged without emasculation. Hand-self (forced autogamy) and cross-pollinations (xenogamy) were performed to ascertain the extent of self-incompatibility, if any, in the species. Self-compatibility index (SCI) was computed based on these results. For all statistical purposes, SPSS12 was used. One-way ANOVA was employed for determining any significant difference in fruit- and seed-set between pollination treatments. The percentage values were arc-sine transformed before subjecting to ANOVA.

Flowering in V. nummularium occurred in a synchronous and seasonal manner at all the study sites. On bright and sunny days, flowers anthesized between 0700 and 0800 h, and remained open until noon. On rainy days, anthesis was delayed by ~60 min. and the flowers remained only partly open (Figure 1h). The corolla was slightly twisted in the bud and after complete opening, it assumed a sub-rotate shape (Figure 1a, e–g). The corolla measured 6.66 ± 0.28 mm across in a fully opened flower. Flowers were odourless and lacked nectar.

During anthesis, five epipetalous stamens diverged from the throat of the corolla tube. The pistil is made up of a superior, unilocular ovary with four ovules borne on the basal placenta, and an inconspicuous style with a four-lobed stigma (6.2 ± 1.3 mm in length). Anther dehiscence occurs simultaneously with anthesis by a longitudinal line of dehiscence. The pollen grains were presented latroely (Figure 1b). On an average, each flower bore 968 ± 12 pollen grains and ~96.3% of them were fertile. The fresh pollen grains were primarily lipidic, sticky and exhibited 93% viability. Viability dropped to <3% within 5 h (Figure 2f).
Table 1. Comparison of results of fruit- and seed-set following different modes of pollination

<table>
<thead>
<tr>
<th>Pollination treatment</th>
<th>% Fruit-set (n)</th>
<th>F</th>
<th>Average number of seeds in a capsule (n)</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-pollination</td>
<td>74.5 (540)</td>
<td>–</td>
<td>2.60 ± 0.04 (402)</td>
<td>–</td>
</tr>
<tr>
<td>Spontaneous autogamy</td>
<td>51.8* (158)</td>
<td>4.67</td>
<td>1.73 ± 0.11* (82)</td>
<td>2.03</td>
</tr>
<tr>
<td>Manual self-pollination (forced autogamy)</td>
<td>70.6* (551)</td>
<td>3.28</td>
<td>2.32 ± 0.04* (389)</td>
<td>1.98</td>
</tr>
<tr>
<td>Manual cross-pollination (xenogamy)</td>
<td>82.7* (503)</td>
<td>1.18</td>
<td>3.3 ± 0.06* (416)</td>
<td>0.06</td>
</tr>
<tr>
<td>Snail-pollination (malacophily)</td>
<td>74.4 (504)</td>
<td>a.s.</td>
<td>3.4 ± 0.08* (375)</td>
<td>1.26</td>
</tr>
<tr>
<td>Bee-pollination (meliphotilph)</td>
<td>89.4* (503)</td>
<td>0.88</td>
<td>3.6 ± 0.08* (450)</td>
<td>1.01</td>
</tr>
</tbody>
</table>

*Values significantly different at $P = 0.05$, when independently compared with open pollination using one-way ANOVA; df = 9; n.s. Difference with open-pollination not significant.

The stigma lobes were dry and non-papillate. Stigma receptivity was attained before the opening of flowers at 0630 h and lasted till 1130 h. The pollen to ovule ratio was 241:1.

Flowers were visited by the terrestrial garden snail (L. gractile; Figure 1 d–h), and honey bees (Apis cerana indica; Figure 1 i). The population size of snails in the soil in which the plants were growing was approx. 30–50 per sq. m. Foraging activity of both animals resulted in pollen transfer to the stigma, pollen germination and eventual fertilization and fruit-set (Figures 2 c–e and 3).

On sunny days foraging occurred in a successive manner; snails came first followed by honey bees. Snails foraged flowers between 0700 and 0900 h, and each snail spent 10 ± 3.3 min in a flower (n = 43). While consuming the pollen grains and anthers, the head, foot and broader portion of the shell (last whorl) of the snail came in contact with the dehisced anthers and stigma lobes, and effected pollen transfer (Figure 1 e, f). Foraging behaviour, gut analysis after fresh foraging of flowers (Figure 2 b) and faecal analysis showed that the snails primarily consumed the whole stamen or only the pollen grains. A snail carried approx. 180 ± 14.2 (n = 87) pollen grains on its shell (Figure 2 a). The average pollen count on the stigma of the snail-visited flowers (n = 30) was 95 ± 8.7, 75% (n = 504), Nearly 74% of snail-visited flowers developed into fruits (Table 1).

Honey bees visited the flowers between 0800 and 1100 h. On an average a honeybee spent only a brief period (4.2 ± 1.26 s) in a flower. Interestingly, the bees completely avoided flowers being foraged by snails or those that had been previously visited by the snails. However, the reverse was not true; snails readily foraged bee-visited flowers. Honey bees collected the pollen grains sternotrichally on their thorax and hind legs in the form of pollen baskets. On an average each bee carried 2516.8 ± 47.64 pollen grains on its body parts. The stigmas of honey bee-visited flowers (n = 45) showed 123 ± 17 pollen grains and ~90% fruit-set occurred in the honey bee-visited flowers (n = 503 flowers; Table 1).

On rainy days, anthesis was delayed by 30 min and flower buds opened only partially. On such days, honey bee activity was totally absent. However, snails were active and forcibly entered the partly opened flowers (Figure 1 h) and foraged for a longer duration (18 ± 5.6 min, n = 28 flowers) than usual.

Flowers that were bagged after emasculation showed no fruit-set, thus ruling out pseudogamous form of apomixis. However, fruit-set resulted from other modes of controlled pollination (Table 1). The average number of pollen grains on the stigma of flowers that were bagged to assess spontaneous autogamy was as low as 11.2 ± 1.7 (n = 37) and spontaneous autogamy resulted in nearly 51% fruits (n = 158 flowers), with a seed-set of 1.73 ± 0.11 per capsule (Table 1). The percentage fruit-set through spontaneous autogamy was significantly lower than that resulting from other modes of pollination. Similarly, manual autogamy resulted in considerably lower seed-set in a
capsule than that resulting from open-pollination and xenogamy. The SCI value was 0.7.

The number of seeds ranged from one to four in each capsule (Figure 1 c). Based on the proportion of seeds in a fruit, the response among different pollination categories that yielded fruits was variable (Figure 3). The proportion of three- and four-seeded fruits was highest in manually cross-pollinated flowers (Figure 3). The difference in seed-set pattern between malacophily and mellitophily was statistically insignificant.

We have clearly established the incidence of snail pollination in V. nummularium based on: (i) presence of a large number of snails in soil inhabited by the plants, (ii) foraging pattern of the snails, (iii) presence of pollen load on their body parts, (iv) occurrence of a larger number of pollen grains on the stigma of snail-visited flowers compared to natural autogamy, and (v) development of a high proportion of fruits and seeds in snail-visited flowers. These studies adequately fulfill the requirements of the postulates:


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Do bio-shields affect tsunami inundation?

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Conversion of coastal sand dunes to plantations has intensified dramatically after the tsunami of December 2004, driven largely by the belief that bio-shields mitigated tsunami inundation. This assumption was tested using field-based mapping and remote sensing. A regression between the Normalized Difference Vegetation Index and inundation distance was non-significant, questioning the premise for large-scale bio-shield plan-

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Vegetative shelter belts or bio-shields received a great degree of attention in India after the tsunami of 26 December 2004, where they were credited with mitigating tsunami inundation. Particular attention was given to mangroves and more recently, Casuarina. The total area proposed to be covered by the Tamil Nadu Forest Department alone was 4000 ha of Casuarina and 1400 ha of mangroves during the period 2005–07. Casuarina was the preferred species due to its easy availability, low cost and high survival rate. Initial publications supported these plantations, with Dhadhough–Guebas et al.13 and Kathiresan and Rajendran11 suggesting that vegetative shelter belts, particularly mangroves were effective defences against the tsunami.

However, Kerr et al.12 re-analysed their data and showed that vegetative area explained less than 1% of the variation in human mortality. Chatenoux and Peduzzi13 showed that among geomorphological configurations, a long and shallow proximal slope caused greater wave run-up. This has been demonstrated by others as well. Thus shallow coasts such as Nagapattinam are more vulnerable than deep shelves such as those around Puducherry. Among biological configurations measured by Chatenoux and Peduzzi, areas behind sea grass seemed less heavily affected by the tsunami. They also found that mangroves appeared to have no effect on inundation.

Much of the confusion about role of vegetation as tsunami defence lies in the relationship between bathymetry, near-shore elevation, distance from coast and presence of biological ‘protection’ such as mangroves. Evidence from the Nicobar Islands questions the premise that vegetation can absorb the enormous energy dissipated by a tsunami, albeit the fact that some obstacle would be better than none.

The inundation caused by tsunami run-up was measured using a baseline corresponding to a coastline digitized from high resolution QuickBird satellite image comprising red and blue bands at 2.44 m, hybridized with a panchromatic band at 0.6 m. Images of 31 December 2004 were downloaded from the Pacific Disaster Centre site (http://www.pdc.org). River mouths and backwaters were digitized such that the coastline looped into them to ensure that the analysis took into account inundation observed along backwaters.

Inundation points were identified with local residents and their coordinates recorded using a Garmin-76 GPS