Differential reproductive success in *Cassia fistula* in different habitats—A case of pollinator limitation?

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Differences in flower success patterns in two habitat types that differed drastically with respect to rainfall, tree density and species composition were studied at Mudumalai wildlife sanctuary, India. Observations on phenological patterns of two species, *Cassia fistula* and *Gmelina arborea*, were made from April 1988 through June 1990. Quantitative data on flower–fruit ratio, insect visitation rates, pollen grain per stigma and the number of fruits per tree were recorded. Data were also collected on the number of pollen deposited on the stigma after different types of bees visited the flower. The data suggested that only carpenter bees (*Xylocopa* spp) effect pollination in *C. fistula*. The differences in fruit–flower ratios were attributed to the differences in insect visitation rates to inflorescences between sites. The low pollen number per stigma and the resultant reduction in reproductive success in *C. fistula* are attributed to the competing species *G. arborea* receiving more visitations from pollinators in the wetter site. These results suggest that pollinator limitation is another constraint in reproductive success of plants.

Low success of flowers in setting fruits has been demonstrated in many hermaphroditic species[1]. Low flower–fruit ratios have been argued to be a mechanism of resource allocation to male and female functions in hermaphroditic plants[2–4]. Several workers have implicated lack of successful pollination as a major cause of flower abortions[5,6]. However, differences in per cent fruit set within a species have been reported as a function of plant age[7], plant height and altitude[8] to maximize the reproductive success by altering resource allocation patterns. However, low flower success could also be due to competition for pollinators among species that share the same pollinator[9,10]. Competition for pollinators could lead to interspecific pollen transfer[11] or reduced visitation rates. Both processes lead to decreased fruit and seed set resulting in reduced reproductive success.

In this article I demonstrate the limitation of pollinators causing differences in reproductive success of *Cassia fistula* between two habitats of Mudumalai sanctuary which show marked differences in number of fruits per tree.

Study organism

Cassia fistula (Caesalpinaceae) is an understorey tree growing to a height of 5–8 m. The bright yellow inflorescences attract many pollinators. However, it has a special kind of pollination mechanism called 'Buzz pollination' which is effected by carpenter bees. Flowering occurs during March through June. The long cylindrical dark brown pods contain the seeds surrounded by gummy substance. These are particularly relished by sloth bear (*Melursus ursinus*) and porcupines (*Hystrix indica*). Bear droppings containing *C. fistula* seeds are seen during dry season.

Site

The study was conducted at Mudumalai sanctuary (321 km^2), Tamil Nadu, India (11°32′–11°43′ N and 76°22′–76°43′ E). The terrain is very undulating varying from 600 to 1200 m above MSL with varying rainfall. The other details pertaining to the sanctuary are given elsewhere[12,13]. Two sites were selected in the sanctuary which differed with respect to rainfall and species composition. One site was selected in dry deciduous forest with an annual rainfall of about 1200 mm (herein after called wet site) and the other was dry thorny forest or scrub forest with an annual rainfall of about 600 mm (herein after called dry site). In the wet site dominant tree species are *Anogeissus latifolia*, *Terminalia crenulata*, *Lagerstroemia microcarpa* and *Kydia calycina*. But in the dry site the dominant trees are *Ziziphus xylopyros*, *Ziziphus mauritiana*, *Anogeissus latifolia* and *Premna tomentosa*. The density of *C. fistula* was less in dry site (0.48 per Ha.) compared to wet site (1.77 per Ha) and that of *G. arborea* at wet site was 0.38 per Ha.

Methods

Studies of flowering phenology were conducted during April 1988 through August 1990 at both the sites. Ten trees each of *C. fistula* and *G. arborea* (Verbenaceae)

were tagged in wet site and five trees of *C. fistula* were tagged in dry site (*G. arborea* was not found in dry site), and observations on the presence and absence of flowers were recorded every month.

Twenty naturally pollinated fresh flowers from a tree, where only the corolla had withered but the flower is intact with the rachis were plucked and the pollen number deposited on the stigma was counted using a microscope. Five inflorescences each in five marked trees were tagged and the number of flowers in the inflorescences were counted. One inflorescence was selected randomly and observed for insect visitation for five min. The number and type of bees visiting the inflorescence were recorded. Five such observation schedules were conducted for each tagged tree over different times of the day. Similar observations were made for *G. arborea* also for insect visitation patterns. The rate of visitation was computed and expressed as number of visits per minute. The tagged inflorescences were followed to know the fate of flowers and the number of fruits produced on each of these tagged inflorescences were recorded. To assess the important pollinating agent, ten flowers were plucked after the visit of a carpenter bee; ten more were plucked after the visit of other bees. The number of pollen grain deposited on the stigma of plucked flowers was counted.

The differences in means for number of fruits per plant and number of pollen per stigma were compared using Student's *t*-test and the differences in proportions were compared using binomial test for fruit–flower ratio and insect visitation rates[14]. Overlap index was computed to know the overlap of flowering periods of *C. fistula* and *G. arborea*[15]. Differences in the density of pollinators between the sites were calculated by summing the visiting rates of *C. fistula* and *G. arborea* at wet site and compared with the dry site using binomial test. Difference in the insect visitation rates between *C. fistula* and *G. arborea* at wet site was compared using binomial test.

Results and discussion

The frequency of individuals of *C. fistula* and *G. arborea* in flower shows that there is complete overlap in their flowering season (Figure 1). The overlap index was very high (overlap index = 0.907, $\chi^2 = 16.0$, $df = 28$, $P > 0.2$).

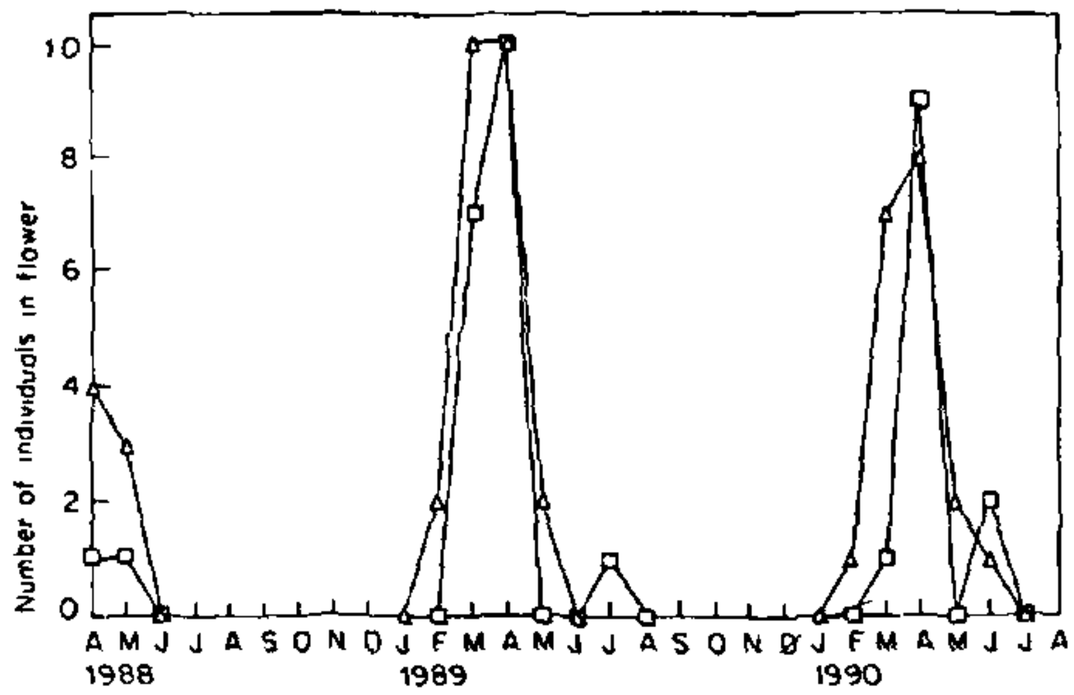

Figure 1. Frequency of flowering individuals of *Cassia fistula* (open squares) and *Gmelina arborea* (open triangles) over the study period.

The number of fruits per plant, the number of fruits per inflorescence, insect visitation rates and number of pollen grains per stigma were significantly lower in wet habitat than in dry habitat (Table 1).

Although density of carpenter bee between sites was not estimated, it was observed that the visitation rates to the flowers of *G. arborea* (0.6) were higher than to the flowers of *C. fistula* (0.08). Pooling such observed frequencies and comparing the visitation frequencies indicated that there was no significant difference between the two sites (Table 2). This may be taken as an indication that the density of pollinators was constant between the sites. Despite the lesser density of *C. fistula* trees (0.4) at drier site, visitation rates were higher and flower success was also higher than at wet site. These results suggest that there is a direct relationship between the pollinator visitation rates and the success of flowers to set fruits[12]. From this study it can be concluded that due to a competitor species *G. arborea*, *C. fistula* is at a disadvantage with respect to the pollen transfer (male function). In fact, it was noted that *G. arborea* receives nearly 34 times more visitations than *C. fistula* by comparing the visitation rates of each species considering their densities. This competition brings reduction in visitation rates of bees, and the amount of pollen deposited on the stigma. But in the dry site where no other species pollinated by carpenter bee is in flower during that time, *C. fistula* receives more visits leading to higher pollen load on the stigma

Table 1. Mean values of different traits observed between two sites on *C. fistula*

Traits	Wet site (Mean ± SE)	Sample size	Dry site (Mean ± SE)	Sample size	Statistic*
Number of fruits per plant	3 0 ± 1.33	66	28.0 ± 7.79	47	8.29*
Pollen grain per stigma	1.4 ± 0 49	100	51 5 ± 11 16	100	14.69*
Fruit–flower ratio	0 014	1159	0 07	723	5 89**
Insect visitation rates	0 08	25	0.40	25	2.31**

* Student's *t* value; ** *Z* value.

Table 2. Differences in pollinator visitation rates between sites

Location	Mean	Sample size
Wet site	0.34	50
Dry site	0.40	25

$Z = 0.41$, $P > 0.05$.

Table 3. Efficiency of pollinators to deposit pollen on *Cassia fistula*

Pollinator	Mean ± SD	Sample size
Carpenter bee	169.4 ± 43.17	10
Other bees	27.4 ± 52.29	10

t-value = 3.24, $P < 0.01$.

resulting in higher flower success. This may be because the drier site was more open and hence the advertisement with profuse flowering by *C. fistula* was effective unlike in wet site which had higher tree density but had relatively more closed canopy. *G. arborea* being a canopy tree in the forest did benefit by shading the understorey *C. fistula*.

The carpenter bee *Xylocopa* sp. deposits more pollen on the *C. fistula* flower than any other bee (Table 3). The average number of pollen deposited by carpenter bee was 169.4 and that by other bees was 27.4. The pollen deposition was very high when flowers were visited by carpenter bees as against other small social bees like *Apis dorsata*, *Apis florea* and *Apis cerena*, indicating pollinator specificity in *C. fistula*. It has been demonstrated that an optimum number of pollen has to be deposited, for the pollen to germinate on stigma[16]. Hence the flowers which receive less pollen are more likely to abscise, whereas those which have more pollen develop into fruits. It appears that only the *Xylocopa* bees are effective pollinators than other bees. These results thus suggest that visitation of pollinators could be another constraint for fruit–flower ratios which in turn affect the reproductive success of plants[5,11,17].

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