

Ant community variation in urban and agricultural ecosystems in Vadodara District (Gujarat State), western India

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Abstract. Studies on ant communities of India are sparse and needed. This is the first comprehensive survey of ant communities from the Vadodara district located in the central part of Gujarat, India (west coast of the Indian Peninsula). The present study was undertaken to (i) assess ant diversity and density changes along a habitat gradient and (ii) establish the species composition of ant communities in urban and agricultural ecosystems. Study sites comprised (a) agricultural ecosystems, which included fields of cotton, castor, tobacco and some vegetable crops, and (b) urban ecosystems, which included the community gardens of Vadodara. Pitfall traps and hand collection methods were used for collecting ants. Twenty-two ant species from 13 genera and five subfamilies were collected. Ants of nine genera and 15 species were found in urban ecosystems, and ten genera and 16 species in agricultural ecosystems; rarefaction curves indicated these totals to be complete for the detectable ant fauna. *Pheidole* showed greatest species richness in urban ecosystems, whereas *Camponotus* and *Pheidole* were equally speciose in the agricultural ecosystems. Results indicate that the composition of ant species is unique to each habitat, and most likely governed by the vegetation and the other biota around it.

Keywords: ant communities, agricultural ecosystems, urban ecosystems, diversity, Gujarat State

INTRODUCTION

Ants play a major role in most terrestrial ecosystems by performing key ecological functions. Ants are biological control agents in agricultural ecosystems. They are also bio-indicators and efficient invaders of new habitats (Holway et al. 2002). Due to this, ants are increasingly used for biodiversity assessments, and comparison of habitats and ecosystems (Andersen & Majer 2004). A rigorous understanding of each specific system is essential to avoid disillusionment among farmers and abandonment of environmentally friendly agricultural practices in agro ecosystems (Philpott & Armbrrecht 2006).

In India, few reports on ant ecology and diversity exist. Gunawardene *et al.* (2007) have published work on ants of the Western Ghats – Sri Lanka hotspot. Kumar *et al.* (1997) reported on the ant fauna from some areas of Bangalore City, and recently a list of 591 species of ants in India was released by Bharti & Alpert (2007) on the Internet. However, there are still no specific reports that compare ant diversity in urban versus agricultural ecosystems of India, and no ant community studies from the western Indian state of Gujarat. With this in mind, the present study was conducted on ant biodiversity from the Vadodara district of Gujarat. The main objectives of the work were to: (1) establish species composition of the ant

community in urban and agricultural ecosystems of Vadodara district; and (2) assess ant diversity in both ecosystems.

MATERIALS AND METHODS

A reconnaissance survey of the community gardens and agricultural fields was made in and around Vadodara District from January 2005 to December 2007. Vadodara District is located in the eastern part of the state of Gujarat in western India at 22°17'59"N, 73°15'18"E, 35 m above sea level. The population of the city of Vadodara was 1.5 million according to the 2001 census and is projected to rise to 2.1 million by the year 2011. The climate of Vadodara is semi-arid, characterised by a dry and increasingly hot summer from the end of February to June, a warm monsoon from July to September and a dry and cold winter from October to early February. The monsoons arrive every year in the later half of June and continue until September. July and August receive the heaviest downpours. Vadodara experiences great extremes of temperature. The heat during the summer (March- June) is intense, with the daytime temperature rising as high as 43°C in May. The temperature drops in December and January; mean monthly temperatures for the warmest and coldest months are 30 and 13°C respectively. Relative humidity is at the minimum during the winter month of December (31%) and at the maximum during the monsoon, especially in July (92%).

Sampling period

During the sampling period of three years (2005-2007) each year was divided into two phases of four months: Phase I (January - April) and Phase 2 (September - December). Each phase had four sampling periods as field visits were conducted once every month.

No sampling was done in May as it is extremely hot for fieldwork, or from June to August due to heavy rainfall. The average minimum and maximum temperature was recorded for all sampling periods along with the average rainfall (see Electronic Appendix 1).

Survey sites

Survey sites were divided into two categories: (1) community gardens in urban areas of Vadodara City and (2) agricultural fields in Vadodara District (Fig.1).

Community gardens (U): Vadodara's public gardens contribute to the maintenance of urban biodiversity and are also a hub of social activities. They harbour native as well as exotic (introduced) species of plants and represent man-made ecosystems. Studies were carried out in the following gardens: (1) U Site 1 (Sayaji Baug), an extensive park of 40 ha; (2) U Site 2 (Sardar Baug), 2.5 ha; (3) U Site 3 (Lal Baug), 3.6 ha; (4) U Site 4 (Akota Garden), 2.0 ha. Soil type is a mixture of deep black and yellow sandy loam in all four gardens. In the gardens, annual average daytime soil temperature ranges from 30°C to 33°C which is slightly higher than air temperature.

The dominant flora of the gardens of Vadodara City includes *Ficus benghalensis* (Banyan), *Azadirachta indica* (Neem), *Terminalia catappa* (Indian Almond), *Dalbergia latifolia* (Indian Rosewood), *Mangifera indica* (Mango), *Murdannia nudiflora*, *Tephrosia purpurea*, *Ixora coccinea*, *Catheranthus roseus* (Madagascar Periwinkle) and *Rosa chinensis*. Vegetation comprises trees, shrubs and herbs.

Agricultural fields (A): Located within 25 km of the city centre, all fields sampled were 5 ha or more in size: (1) A Site 1 -Timbi (West); (2) A Site 2 Savli (North); (3) A Site 3 Waghodia (East); (4) A Site 4- Padra (South west). Soil type was sandy loam. The annual average daytime soil temperature ranged from 28° to 32°C, slightly lower than the air temperature.

Main crops of the agricultural fields in Vadodara District were *Gossypium* sp. (Cotton), *Nicotiana tobacum* (Tobacco), *Saccharum officinarum* (Sugarcane), *Ricinus communis* (Castor), *Cajanus cajan* (Pigeon Pea), *Sorghum bicolor* (Sorghum), *Pennisetum glaucum* (Pearl Millet), *Zea mays* (Maize) and vegetables like *Brassica oleracea* (Cabbage and Cauliflower),

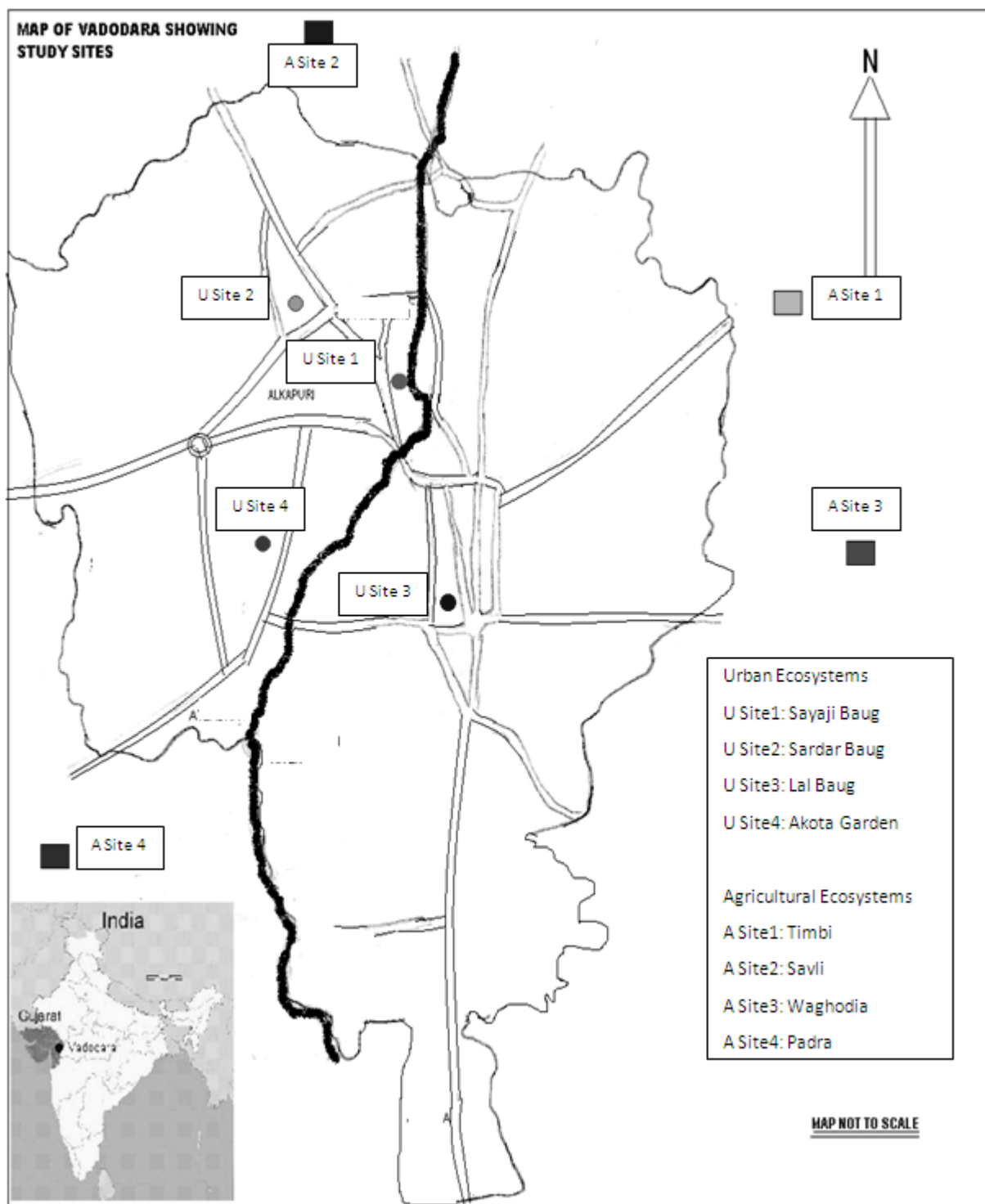


Fig. 1. Map of Vadodara City showing study sites

Spinacea oleracea (Spinach), *Rhaphanus sativus* (Radish) and *Solanum melongena* (Brinjal or Aubergine). The Timbi site also had paddy fields.

Each plot was a mixture of annual crops. Farming was mainly done by conventional methods. Organophosphate fertilizers were used in most of the fields. Major trees surrounding the agricultural fields were *Mangifera indica*, *Azadirachta indica* and *Tamarindus indica* (Tamarind), *Euphorbia nerifolia*, *Ziziphus mauritiana* (Jujube), *Moringa oleifera* (Horseradish tree) and *Caesalpinia crista* are also popularly grown

Sampling methods

Pitfall trapping, one of the most reliable methods for collecting insects (Majer 1983), was employed at all study sites. For ant species that were seen but not caught by pitfall traps, we used hand collection. Both sampling methods, pitfall trapping and hand collection, were carried out during each sampling period. While arboreal ants were mainly collected manually, ground dwelling ants were sampled through pitfall traps.

We installed pitfall traps at 18:00 h and collected them 24 hours later. Eight pitfall traps were installed in each sampling site. Pitfall traps were set at least 2 m apart in various microhabitats. We collected ants manually (hand collection) from 08:00 h to 10:00 h and subsequently from 18:00 h to 20:00 h on the same day. This was done by nudging ants with a brush into a vial. The ants were later transferred and preserved in 70 % ethanol. This method involved searching and collecting ants from different microhabitats. Therefore for each site there were 24 (3 years x 2 phases x 4 months) sampling periods and 9 “samples” (8 pitfall + 1 hand collection) per sampling period. This yielded a total of 216 samples from each site, so altogether 1728 samples. The number of pitfalls that had no ants was 23 in urban ecosystem samples and 6 in agricultural ecosystem samples, bringing the actual number of successful samples to 841 and 858 in urban and agricultural ecosystems respectively.

Photography in both habitats was done using a Sony digital camera (Cyber Shot, DSC H2, 12x optical zoom).

Identification

Ants collected by various sampling methods were separated from other organisms, and sorted to subfamily and genus using the key provided by Bolton (1994). We assigned morphospecies that were in some cases identified using Bingham (1903) and reliable Internet sites, such as www.antbase.net. A stereomicroscope Leica MPS 60 ϕ 28/8x/MPS was used for identification.

Data analysis

Statistical analysis was done using presence-absence data, i.e. species were recorded in a matrix on the basis of their presence (or absence) in a sample (Longino 2000). Pseudo-abundances (species occurrences within the single samples) were then calculated as abundance measurements – the summed presence of species in samples of habitats.

Species richness and diversity

To obtain a measure of sampling success, species richness and diversity in the two habitats was estimated using the software package EstimateS (version 7.0, R.K. Colwell, http://viceroy.eeb.uconn.edu/EstimateS_). Rarefaction curves were calculated using the sample-based rarefaction approach (Gotelli & Colwell 2001). We used the Mao Tao rarefaction to plot the rarefaction curves.

To optimise the estimation of species richness by the choice of optimal species estimators we used the method published by Brose & Martinez (2004) and used by Pfeiffer *et al.* (2008) in their study of ant communities in Borneo and Peninsular Malaysia. According to their method we first estimated S_{true} based on all samples by a range of estimators (ACE, ICE, Chao1, Chao2, MM Mean). Then the estimated mean of sample coverage was calculated. The choice of the most accurate estimator for sample coverage was then done according to the tables provided by Brose & Martinez (2004). Finally species richness was estimated with this estimator and with the maximum number of samples per site. Alpha diversity was

assessed by computing Shannon Wiener and Simpson's D diversity indices with Estimate S. Comparisons were made between the two habitats and within the four plots of each habitat using Sorensen's classic similarity index for beta diversity.

RESULTS

Overall taxonomic composition

We recorded a total of 6319 ant species occurrences from urban ecosystems and 6669 from agricultural ecosystems (Table 1). Twenty-two ant species from 13 genera and five subfamilies were collected. Nine genera and 15 species were found in urban ecosystems, and ten genera and 16 species in agricultural ecosystems. Of the five subfamilies, the most speciose were Formicinae in agricultural ecosystems and Myrmicinae in urban ecosystems. Subfamilies Dorylinae, Pseudomyrmecinae and Ponerinae were less well represented. Only one species of Dorylinae was found in the urban ecosystems. One species of subfamily

Pseudomyrmecinae was collected from urban ecosystems and ants of subfamily Ponerinae were found only in agricultural ecosystems (Table 1).

Species richness

The mean species richness estimation was 15.01 for urban ecosystems and 16.01 for agricultural ecosystems indicating that the most accurate species estimator was the number of observed species (Sobs), which was 15 for urban and 16 for agricultural ecosystems (Table 2). Species rarefaction curves indicated that sampling was almost complete (Fig. 2). In urban ecosystems 15 and in agricultural ecosystems 16 species accounted for 100% of all species occurrences.

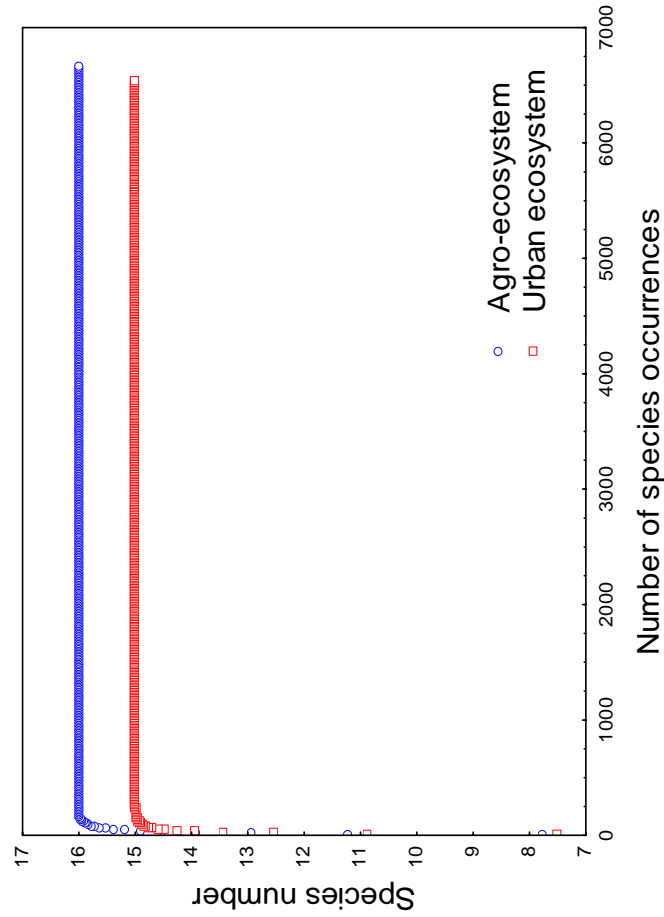
Highest ant species richness was found at the edges of agricultural fields (by observation). Six species, i.e. 40% of all species found in urban ecosystems, were unique to them (*Pheidole* sp. 4, *Solenopsis* sp. 3, *Monomorium* sp. 1, *Monomorium* sp. 2, *Tetraponera rufonigra* (Fig. 3) and *Dorylus labiatus*) whereas seven species (44%) were exclusively found in agricultural ecosystems

Table 1. The overall taxonomic composition of ants of the study area, with total number of species occurrences in each habitat type.

SUBFAMILY	SPECIES	URBAN	AGRO
Dorylinae	<i>Dorylus labiatus</i> Shuckard,1840	127	0
Formicinae	<i>Camponotus compressus</i> Fabricius,1787	666	619
	<i>Camponotus sericeus</i> Mayr,1879	0	695
	<i>Camponotus</i> sp.2	0	159
	<i>Formica</i> sp. 1	487	166
	<i>Formica</i> sp. 2	0	333
	<i>Oecophylla smaragdina</i> Fabricius,1775	422	188
	<i>Paratrechina longicornis</i> Latreille,1802	0	526
	<i>Polyrhachis lacteipennis</i> Smith,1858	0	373
	<i>Prenolepis</i> sp. 1	384	237
	Myrmicinae	<i>Crematogaster soror</i> Forel,1902	0
<i>Monomorium</i> sp. 1		555	0
<i>Monomorium</i> sp. 2		282	0
<i>Pheidole</i> sp. 1		491	562
<i>Pheidole</i> sp. 2		449	483
<i>Pheidole</i> sp. 3		408	456
<i>Pheidole</i> sp. 4		320	0
<i>Solenopsis</i> sp. 1		582	565
<i>Solenopsis</i> sp. 2		315	506
<i>Solenopsis</i> sp. 3		282	0
Ponerinae	<i>Leptogenys chinensis</i> Mayr,1870	0	353
Pseudomyrmecinae	<i>Tetraponera rufonigra</i> Jerdon,1851	549	0

Table 2. Recorded (S_{obs} = Species observed) and expected number of species as calculated with different species richness estimators.

Habitats	SAMPLES	Individuals computed	S_{obs} (Mao Tao)	ACE Mean	ICE Mean	Chao1 Mean	Chao2 Mean	Jack1 Mean	Jack2 Mean	Bootstrap Mean	MMRuns Mean	MMMeans 1 Run	Mean Species estimation
URBAN	841	6319	15	15	15	15	15	15	15	15	15.06	15.05	15.01
AGRICULTURAL	858	6669	16	16	16	16	16	16	16	16	16.05	16.06	16.01

**Fig. 2.** Rarefaction plot based on S_{obs} (Mao Tao). Confidence intervals were similar to species numbers after 250 species occurrences for both plots and were left out for clarity. Species saturation was reached for both sites.

(*Crematogaster soror*, *Camponotus* sp. 2, *Camponotus sericeus*, *Formica* sp. 2, *Paratrechina longicornis*, *Polyrhachis lacteipennis* and *Leptogenys chinensis*).

Species diversity

Alpha diversity indices as calculated by Shannon Wiener and Simpson D, showed similar diversity in urban and agricultural ecosystems. The values of H were 2.65 and 2.69, and D 13.60 and 13.95, for urban and agricultural ecosystems respectively (Table 3).

Nine species were shared between both sites; the mean Sorensen's index of similarity was 0.580 showing moderately similar species composition. Beta diversity among the four plots differed significantly between the two ecosystems, with more differences among the agro-ecosystem sites, while all plots of the urban sites showed the same species composition (Sorensen's index of

similarity: 0.87 (SD = 0.05) vs. 1.00 (SD = 0.00), $n = 6$, Mann-Whitney U-Test $U = 0$, $Z = 3.08$, $P < 0.01$, see Electronic Appendix 2-5).

Ecological remarks on the species

Camponotus compressus and the dimorphic *Pheidole* spp. nested around the roots of large trees, e.g. *Tamarindus indicus*. *Camponotus compressus* was also found on *Acacia nilotica* and *Moringa oleifera* growing on field margins. They were tending homopterans, e.g. leafhoppers *Oxyrachis tarandus* and aphids for honeydew. *Tetraponera rufonigra* foraged and nested on trunks of trees like *Caesalpinia crista*, while *Monomorium* spp. and *Solenopsis* spp. foraged inside the fields and nested at field margins. Some ant species (e.g. *Tetraponera rufonigra*, *Polyrhachis lacteipennis*, *Leptogenys* sp, and *Crematogaster soror*) were observed foraging solitarily on large trees like *Caesalpinia crista*



Fig. 3. Arboreal bicoloured ant *Tetraponera rufonigra* Jerdon

Table 3. Alpha diversity indices

HABITATS	Samples	Individuals (Computed)	Sobs (Mao Tao)	Alpha Mean	Shannon Mean	Simpson Mean
URBAN	841	6319	15	1.84	2.65	13.60
AGRICULTURAL	841	6536.86	16	1.97	2.69	13.95

while others moved in trails on the tree trunks e.g. *Monomorium*). *Camponotus sericeus* (Fig. 4) was conspicuous in showing tandem running movement described for this species (Hölldobler *et al.* 1974). *Oecophylla smaragdina* and *Solenopsis* spp. were seen preying in groups upon large insects like *Conocephalus indicus* and lepidopteran caterpillars. *Formica* sp. and *Camponotus* spp. were observed tending aphid colonies on many plants.

Interactions between different ant species, e.g. *Camponotus compressus* and *Pheidole* sp., were also observed. Both the species were found in urban habitats nesting in close proximity, *C. compressus* at the base of large trees (e.g. *Ficus bengalensis*) and *Pheidole* sp. nesting in the nearby flower beds. Both species were found foraging on the same tree trunks. *Tetraponera rufonigra* and *Camponotus sericeus* were seen foraging solitarily, while smaller species like *Solenopsis* sp., *Monomorium* sp. and *Paratrechina longicornis* moved in trails.

DISCUSSION

The results of this study point toward the potential of the two habitats to support considerable ant species diversity and richness. However, keeping in view the large number of ant species found in India, as reported by Bharti & Alpert (2007), the

number of species found in our study was very low. There was hardly any difference in ant species diversity between urban and agricultural ecosystems, although agricultural ecosystems housed one species more than urban ecosystems. Beta-diversity was higher in agro-ecosystems, presumably due to higher habitat heterogeneity and the greater spatial separation between sites. The rarefaction curves proved our sampling was complete, pointing to the disappointing conclusion that ant species richness in this area is limited. Since there is no previous record of ant species richness specifically from this part of India, it is difficult to prove a decline, but this must be inferred.

In interviews with farmers, the indiscriminate use of insecticides was revealed. The same was found to be the case in community gardens where more insecticides were sprayed in order to avoid 'menace' caused to the public as these gardens are used more as places of recreation than sites for biodiversity conservation. This may be one factor contributing to low ant diversity.

Up to now most species are not identified, so it is not possible to assess the prevalence or impact of invasive species, but we expect our list will include many tramp species originating from other places of the tropics (Holway *et al.* 2002). In this case the originally species-rich Indian ant fauna would appear to have been even further depleted.



Fig. 4. Solitary foraging is seen in *Camponotus sericeus* Mayr

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