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Distribution and abundance of white grubs (Coleoptera: Scarabaeidae) on groundnut in southern India

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Abstract

Scarab species associated with groundnuts were surveyed in Andhra Pradesh, Karnataka and Tamil Nadu, southern India, between 1995 and 2001. Scarab adults were collected from trees on which they were feeding and/or mating, and larvae (white grubs) from groundnut fields. *Holotrichia* species, especially *H. reynaudi* and *H. serrata* were the major species associated with groundnut. *H. reynaudi* predominated in the central Deccan area, while *H. serrata* was most abundant in the south and west. A new, undescribed, *Holotrichia* species near *H. consanguinea* was collected in south and southwest of Hyderabad in mixed populations with *H. reynaudi*. However, the full extent of this new species' distribution remains uncertain. *H. rufoflava* was rarely associated with groundnut, but was common as an adult at some locations. Other genera encountered during surveys were *Anomala*, *Adoretus*, *Schizonycha*, and *Autoserica*. In survey data, densities of *Holotrichia* larvae and 'all other white grubs' were both very highly correlated with the percentage of damaged groundnut plants. These correlations in combination with concurrent observations of plant damage establish a causal link between white grubs and plant damage and death in southern Indian groundnut. Ranking of preferred host trees for adults were developed from field observations for four *Holotrichia* species and *Schizonycha* spp. and will assist grower-initiated surveys of pest occurrence. In combination with insecticide-efficacy data published elsewhere, the survey provides the basis for an environmentally friendly and economically viable pest-management system for white grubs on groundnut in southern India.

Keywords: *Holotrichia serrata*; *Holotrichia reynaudi*; Peanut; *Anomala*; *Adoretus*; *Schizonycha*; *Autoserica*

1. Introduction

Wightman and Ranga Rao (1994) reviewed the Scarabaeids causing damage to groundnut (peanut) in the world, listing a total of 22 species from 9 genera associated with groundnut in India. More recent overviews by Yadava and Sharma (1995) and Musthak Ali (2001) indicate that of the many Melolonthine genera found under the crop in India, the genus *Holotrichia* includes the most important pest species in groundnut. In northern regions (Gujarat, Rajasthan, Punjab, and Bihar), *H. consanguinea* is the predominant species. At the time of the Wightman and Ranga Rao (1994) review, the predominant species known to be associated with groundnut in southern India was *H. serrata*. Yadava and Sharma (1995) and Musthak Ali (2001) record *H. serrata* as a serious pest in many parts of western and peninsular India, including Gujarat, Maharashtra, and parts of Karnataka, Tamil Nadu and Andhra Pradesh. *H. reynaudi* has been recognised as a significant pest species only since the Wightman and Ranga Rao (1994) review, and is now known to be the major species in the central peninsular areas of India (Karnataka, Andhra

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Pradesh and Tamil Nadu) (Anitha, 1997). Little was known of its biology or distribution prior to Anitha (1997).

Adults of Indian *Holotrichia* species become active with the arrival of the monsoon or heavy pre-monsoon showers; if the monsoon is late, the beetles' emergence is accordingly delayed (Yadava and Sharma, 1995). As the monsoon's arrival initiates groundnut planting, there is a close association between crop and pest phenologies. Once active, adults fly to trees at dusk for mating and feeding for a few days after the arrival of the monsoon before returning to the soil each day. What constitutes a host for adults of these species is somewhat problematic because mating and feeding can, but do not have to, occur on the same tree species. Mating can occur on trees not normally fed on, with beetles subsequently moving to preferred species to feed (Yadava and Sharma, 1995). Females subsequently lay eggs in the soil. Larvae develop rapidly, reaching full size in 67 days for *H. reynaudi* (Anitha, 1997), and 82–113 days for *H. consanguinea* (Yadava and Sharma 1995).

Preferences of adult *Holotrichia* for mating and feeding trees are known for some species in other parts of India. For *H. consanguinea* in northern India, adult host trees include ber (*Zizyphus* spp.), neem, (*Azadirachta indica*) and drumstick (*Moringa oleifera*) (Yadava and Sharma, 1995) with a 1:1 sex ratio for adults on trees (Leal et al., 1996). *H. serrata* occurs most commonly on neem, *Butea monosperma* and *Acacia* spp. (Yadava and Sharma, 1995). Host-tree preferences of *Holotrichia* species in central peninsular India are much less known, in part because the tree fauna differs, and in part because of a lack of knowledge of the biology of the *Holotrichia* species that occur there.

On a global scale, southern India is a major groundnut producing region, with the states of Andhra Pradesh, Karnataka and Tamil Nadu producing more than 5 million tonnes of nuts from almost 5 million hectares in 1998/99, i.e. almost 60% of Indian production and 16% of world production (Ali, 2003; Maneepun, 2003). Groundnut is, by far, the largest single crop grown in central Deccan area, and is almost the only cash crop that will successfully grow in the region's demineralised soils and highly variable climate. Because of this, any biotic constraints to groundnut productivity have significant economic impacts at both the village and regional levels.

Early reports of white grubs damaging groundnut in the region include Husain (1974), Rao et al. (1976) and Pal (1977). These authors variously identified the pest species in Andhra Pradesh as *H. consanguinea*, *Phyllophaga consanguinea*, or *H. serrata*. The present study aimed (a) to clarify the uncertainties of species identity and distribution from these earlier reports because susceptibility to insecticides differs between *Holotrichia* species (Anitha et al., in press), and (b) to identify any association between white grub incidence, edaphic and cropping system factors, and the incidence of plant damage. This formed part of establishing a pest-management system for groundnuts in central peninsular India based on accurate pest identification, understanding of the pests' damage potential on groundnut, and minimum-dose intervention with insecticides.

2. Materials and methods

2.1. Adult surveys

2.1.1. 1995 and 1996

Adult surveys to determine species occurrence and relative abundance were conducted in the five important groundnut-growing areas in Andhra Pradesh during the rainy seasons of 1995 and 1996. In 1995, beetles were collected at locations near Anantapur, Tirupathi, Kurnool, Patancheru (ICRISAT research farm), and Mahbubnagar, from areas known to be endemic to groundnut white grubs. In 1996, collections were repeated at the first four locations. After suitable rainfall events, representative samples of beetles were collected during May–August and October from trees, including neem, wild ber (*Zizyphus* spp.), acacia (*Acacia arabica*), and drumstick located on roadsides of the predominantly groundnut-growing region, or in the groundnut fields. In these areas, trees 3–5 m high are commonly found on roadsides and at the margins of groundnut fields, as well as scattered trees through the fields at densities of approximately 3–5 per hectare. They provide shade and fodder for animals, and firewood, and so are actively retained within the cropping system. Because beetles rest in the soil during the day, and so are not readily available for collection, they were hand-picked and/or shaken from the host trees during their night activity period (between 1900 and 2300 h) and preserved in 70% ethyl alcohol for later identification. During the evening adult-sampling program, sites were selected along roads by stopping at milepost markers and searching trees with 20–30 m of the marker. Trees in adjacent groundnut fields, if present, were also searched. For the purpose of this survey, any tree on which Scarabaeids adults could be collected feeding and/or mating was considered to be a host tree.

2.1.2. 1998

During July 1998, and at the time of the first monsoon rains, adult collections were made from six villages across the Anantapur district where damage to groundnut had been previously reported by farmers or non-government organisations (NGOs). Beetles were hand-picked and/or shaken from trees, especially wild ber, kalivi (*Carissa* spp., a spiny shrub usually entwined in neem trees), between 1900 and 2200 h and preserved in 75% ethyl alcohol for later identification. Trees in and around a village were sampled in a semi-systematic manner, ensuring that all tree species at the locality were examined.

2.1.3. 1999

During this season, surveys were extended with the assistance of local NGOs working in Kolar, Raichur,

Kadiri, Angallu, Kalyandurg, Chittoor, and Dharmapuri. The process involved supplying collection equipment and the provision of demonstrations and detailed collection instructions to the NGO village leaders. Trees in and around a village were sampled, with beetles collected by the NGO staff and villagers wherever they were found on trees.

The beetles were hand-picked and/or shaken from trees, killed with insecticide spray, shade dried for 3 days, and then stored in plastic containers lined with cotton to prevent damage to the beetles in transit. The dried beetles were later collected and taken back to the laboratory for identification.

2.1.4. 2000 and 2001

The survey results in previous years led to a focus on the Raichur and Mahbubnagar districts in the final years of fieldwork. The beetles were collected off the same host trees as previously, but with the addition of moduka (*Butea monosperma*) and *Carissa* sp.

2.2. Larval surveys

2.2.1. 1995/96

The locations selected for beetle collection during 1995 and 1996 were also surveyed for larvae during September–October of 1995 and 1996. Wilting groundnut plants and plants that had died prematurely were uprooted and the soil around these plants was searched for larvae. Larvae were transferred to the laboratory to be reared through to the adult stage to facilitate identification because knowledge of adult–larval associations was incomplete for white grub species occurring in central peninsular India at the time of commencing this study.

2.2.2. 1999

During August 1999, larval and plant damage surveys were conducted in locations that had recorded significant beetle collections, plus some additional areas where there were no local NGO co-operators. Also, white grub densities and damage and the incidence of crown rot disease (*Aspergillus niger* Tiegh.) were assessed, because until then farmers in the region did not distinguish between the two causes of plant death and so were therefore regularly misdiagnosing plant death problems. Samples were taken from 21 villages in 18 districts of Andhra Pradesh, six villages in two districts of Tamil Nadu, and four villages in three districts of Karnataka. The fields of three farmers were sampled in each village. Each sample consisted of 15 randomly selected 30×30 cm patches in each farmer's field. For each sample, numbers of white grubs and crown-rot-infected plants were recorded. Larvae were either preserved in KAA (1 part kerosene, 2 parts glacial acetic acid, 10 parts 95% ethyl alcohol) or returned to the laboratory for rearing through to adults. At the same time as larval samples were collected, data were gathered from farmers on their soils, cropping patterns, area under groundnut cultivation, and FYM and insecticide use.

Associations between the presence of white grubs and the incidence of plant damage and crown rot disease were evaluated using correlation analysis. Because there were insufficient records of *H. serrata* to include each *Holotrichia* species individually, this genus was included as a single group in a partial correlation analysis. Similarly, the incidence of each of the approximately one dozen other white grub species (Tables 1, 2 and 4) was also insufficient to include them as separate species; these were grouped under 'others' category for this analysis.

2.2.3. 2000

To establish the consistency of larval populations under groundnuts in the absence of insecticide use over years, three farms at each of two Andhra Pradesh sites (Mahbubnagar and Mulkalacheruva) that were sampled in 1999 were re-sampled in August 2000 season using the same methods.

2.3. Identification of species

The Scarab adults collected during the surveys and the adults emerging from larval collections were identified to species level based on the keys and characters lists given by Veeresh (1977), Mittal and Pajni (1977) and Khan and Ghai (1982). The identity of adult beetles was confirmed by Dr. Musthak Ali, Department of Entomology, GKVK,

Table 1
Melolonthine white grub species collected as adults on trees in the groundnut ecosystem of Andhra Pradesh, 1995 and 1996

Species	Location	Tree hosts
Apogonia ferruginia (F.)	Chittoor, Patancheru	Acacia, Drumstick
Apogonia sp.	Anantapur, Kurnool, Patancheru	Acacia, Ber, Drumstick, Neem
Autoserica spp. (2 species)	Chittoor, Patancheru	Neem
Brahmina mysorensis Frey	Chittoor	Acacia, Ber, Neem
Holotrichia reynaudi Blanchard	Anantapur, Chittoor, Kurnool, Mahbubnagar, Patancheru	Acacia, Ber
H. rufoflava F.	Chittoor, Patancheru	Ber, Neem
H. serrata Hope	Anantapur, Chittoor, Kurnool, Patancheru	Acacia, Ber, Neem
Schizonycha decipiens Arrow	Chittoor, Kurnool	Acacia, Ber, Neem
S. fuscescens Blanchard	Anantapur, Chittoor	Acacia, Ber, Neem
S. ruficollis (F.)	Anantapur, Chittoor, Patancheru	Acacia, Ber, Neem
Maladera spp. (2 species)	Anantapur, Patancheru	Ber, Neem

Table 2
Ruteline white grub species collected as adults on trees in the groundnut ecosystem of Andhra Pradesh, 1995 and 1996

Species	Location	Tree hosts
Adoretus bicolor Brenske	Anantapur, Chittoor, Kurnool, Patancheru	Acacia, Ber, Neem
Ad. decanus Oh.	Patancheru	Ber
Ad. versutus Harold	Kurnool	Ber
Adoretus sp.	Chittoor	Acacia
Anomala dorsalis F.	Anantapur	Ber
An. ruficapilla Burmeister	Patancheru	Acacia

University of Agricultural Sciences, Bangalore, India. Samples of *H. reynaudi* and several series of straw-coloured atypical individuals from Raichur and Mahbubnagar were compared by Dr. John Maxen, Insect/Mite Identification Services, CABI Bioscience, UK. Representative specimens from the surveys reported here are lodged with Dr. Musthak Ali, Department of Entomology, GKVK, University of Agricultural Sciences, Bangalore, India.

3. Results

3.1. Adult surveys

3.1.1. 1995 and 1996

The surveys of major groundnut-growing areas of Andhra Pradesh during the rainy seasons of 1995 and 1996 revealed 13 species of Melolonthinae in 6 genera (Table 1), and six Ruteline species in 2 genera (Table 2).

H. reynaudi was collected from all the major groundnut-growing areas of Andhra Pradesh, and contributed 90–95% of white grub adults collected during the 1995 and 1996 seasons. It is thus considered to be the dominant species in the southern groundnut zone. The other two species that were abundant in adult collections were *H. serrata* and *Schizonycha ruficollis*. *H. serrata* was dominant at the ICRISAT site in Patancheru, but this is not located in a core groundnut production area. *S. ruficollis* was also collected from Patancheru and the Anantapur and Chittoor districts. All other species were uncommon in the collections of adult from feeding trees.

The number of beetles observed on—and collected from—various tree species indicated that distinct host preferences occur among the species encountered. *H. reynaudi* was collected predominantly from ber (*Zizyphus jujuba* and *Zizyphus sp.*) and acacia; few were found on neem and drumstick. *H. serrata* was collected almost exclusively from neem, with occasional specimens taken from acacia and ber. *S. ruficollis* was mostly found on acacia and ber, with few collections from neem.

3.1.2. 1998 and 1999

In the six locations surveyed in the Anantapur district in July 1998, the predominant species was again *H. reynaudi*. A total of 1331 adults were collected (mostly from ber), of which all but two (*H. serrata*) were *H. reynaudi*.

The adult survey in 1999 resulted in 116 samples, totalling 4500 beetles from 51 villages in four districts, and collected between 4 May and 8 June (Table 3). Seventy samples were from neem, 25 were from tamarind, three each from acacia and drumstick, and 15 others from 11 'other' plant species. The range of plants species was representative of the flora of the region (Tables 1 and 2). The range of Scarab genera is similar to that reported by Nath and Singh (1987) (Melolonthinae: *Apogonia*, *Autoserica*, *Schizonycha*. Rutelinae: *Adoretus*, *Anomala*) in a survey of crops in eastern Uttar Pradesh, except for the absence of *Holotrichia* in the northern state.

Regional trends are apparent from the adult survey. In the Dharmapuri district of Tamil Nadu, Scarabs other than *Holotrichia* species predominated, with *Anomala* being the most abundant genus (70.7% of 276 beetles collected), followed by *Schizonycha* (12.3%) and *Holotrichia* spp. (10.5%). In Chittoor, both *H. serrata* and *H. reynaudi* were collected regularly, with the former being most common on neem (53.6% of 179 beetles collected on neem) and tamarind (92.9% of 56 beetles collected on tamarind) and the latter on drumstick (76.2% of 21 beetles). In Chittoor and Kolar, the trend was for one or the other of these species to predominate at an individual site (typically $>50\%$ of all beetles collected); only rarely were they approximately equally common.

In the Raichur district, no *H. serrata* were collected in the 1999 adult survey. All *Holotrichia* individuals keyed to *H. reynaudi*, but up to three-quarters were a straw-coloured variant of the normally mid- to dark brown *H. reynaudi* that was first collected at Midagaldinne during the 1999 survey. This variant was included as *H. reynaudi* in Table 4 because they appeared to be partially sclerotised *H. reynaudi*. However, subsequent rearing showed they maintain their pale colour. Subsequent examination of variant and normal specimens indicated that the straw-coloured specimens represent an undescribed species of *Holotrichia* nr *H. consanguinea* (John Maxen, personal communication). At Raichur, these species were collected on both acacia and neem, indicating that where a Scarab species is present in large numbers at a location, it will be detected, even on relatively non-preferred hosts.

Table 3
Scarab species collected as adults (as % of total collection) on trees in southern India 1999

State, district and host tree	Number of Sites	Beetles collected	*H. serrata*	*H. reynaudi*	*H. rufoflava*	*Schizonycha* spp.	*Anomala* spp.	Other spp.
State: Andhra Pradesh								
District: Chittoor	18	290	51.0	6.2	5.9	1.0	12.4	23.5
Tree: drumstick	2	21	0.0	76.2	4.8	4.8	0.0	14.2
Tree: neem	12	179	53.6	1.1	8.9	0.6	2.8	33.0
Tree: tamarind	3	56	92.9	0.0	0.0	1.8	5.4	0.0
State: Karnataka								
District: Kolar	63	3666	20.0	2.6	22.4	6.3	17.2	31.5
Tree: neem	39	3152	21.5	1.0	22.3	4.3	19.1	31.8
District: Raichur	8	268	0.0	77.2	0.0	7.1	0.0	15.7
Tree: acacia	3	93	0.0	88.2	0.0	11.8	0.0	0.0
Tree: neem	3	116	0.0	58.6	0.0	5.2	0.0	36.2
State: Tamil Nadu								
District: Dharmapuri	27	276	4.7	0.4	5.4	12.3	70.7	6.5
Tree: neem	6	38	0.0	0.0	7.9	15.8	65.8	10.5
Tree: tamarind	21	238	5.5	0.4	5.0	11.8	71.4	5.9

Table 4
Species composition of 1999 larval survey sites with at least 5 *Holotrichia* larvae

State and location	Total larvae collected	% *Holotrichia*	*Holotrichia* species composition (%)		
			H. serrata	*H. reynaudi*	*H. rufoflava*
Andhra Pradesh					
Dhone	28	67.9	0.0	100.0	0.0
Hindupur	31	100.0	0.0	100.0	0.0
Kollapur	51	76.5	2.6	97.4[a]	0.0
Madanapalli	25	44.0	0.0	100.0	0.0
Mahbubnagar	25	92.0	0.0	100.0[a]	0.0
Mulakalacheruvu	26	100.0	0.0	100.0	0.0
Rayadurg	38	73.7	32.1	67.9	0.0
Wanparthi	28	42.9	0.0	100.0[a]	0.0
Karnataka					
Bangarupet	9	77.8	71.4	28.6	0.0
Gauribindanur	58	86.2	4.0	96.0	0.0
Raichur	34	100.0	0.0	100.0[a]	0.0
Tamil Nadu					
Denkanikottai	67	91.0	90.2	8.2	1.6
Kelamangalam	12	75.0	44.4	55.6	0.0

[a]At these locations in the 2000 season, both *H.* reynaudi and *Holotrichia* sp., near *consanguinea* were shown to occur.

At several locations, more than one tree species was sampled. These samples reinforced the host-tree preferences documented in 1995 and 1996. Where neem and either tamarind or drumstick were sampled at the same site, *H. serrata* was collected only from neem while *H. reynaudi* was found on one or the other of the other two species. *H. rufoflava* adults occurred everywhere except in the Raichur district. However, associated larval surveys showed that this species was weakly associated with groundnut.

3.1.3. 2000 and 2001

Adult collections at Raichur in June 2000 established the presence of mixed populations of *H. reynaudi* (10–20% of the population) and *H.* sp. nr *consanguinea* (80–90%). The host-tree preferences of the two species were markedly different. *H. reynaudi* was most common on ber, while *H.* sp. nr *consanguinea* was found on a number of hosts, including *Carissa* entwined on neem (43.6% of collection), *Carissa* alone (36.7%), on the ground (10.2%), on ber (6.8%) or on *Cassia* (2.7%). This reinforced the argument

for considering these straw-coloured variants as a new species.

The sex ratio of the *H*. sp. nr *consanguinea* collection varied from the expected 1:1, with 70% of individuals being female. A collection at the same location in June 2001 found 75% of *H*. sp. nr *consanguinea* collections were female, in contrast to a 1:1 ratio for *H. reynaudi* collected at the same time at the same site. In 2000, *H*. sp. nr *consanguinea* predominated; in 2001, it formed 87% of the collection, with *H. reynaudi* the remainder. More than 100 mating pairs were observed. None involved a mixed *H. reynaudi* and *H*. sp. nr *consanguinea*, pair.

3.2. Larval surveys

3.2.1. 1995 and 1996

All of the 381 insects collected from farmers' fields and reared through to adults (75% success rate) were *H. reynaudi*, confirming that this species is the predominant white grub associated with the Andhra Pradesh groundnut crop. However, as the new species was subsequently collected from the Mahbubnagar district some of the larvae could have been misidentified.

3.2.2. 1999

A total of 673 larvae were collected from groundnut fields during the larval survey. The total white grub densities in the absence of insecticide were higher in Andhra Pradesh (1.86 larvae m^{-2}, range 0–5.2) than in either Karnataka (0.82 larvae m^{-2}, range 0–1.5) or Tamil Nadu (0.53 larvae m^{-2}, range 0–1.7). Of the larvae collected under groundnut, *Holotrichia* spp. were by far the most common (365 or 54.2%). *H. reynaudi* was the most common of the *Holotrichia* species, comprising 77.5% of all *Holotrichia* specimens, while *H. serrata* was 22.2%. Only two larvae of *H. rufoflava* were collected from under groundnut (0.3% of all larvae), even though this species featured significantly in beetle collections made in the vicinity (Table 3). Most of the remaining larvae were Rutelines.

Analysis of larval samples from 13 locations where there were more than 5 *Holotrichia* per sample showed that the species balance was variable (Table 4). *H. reynaudi* predominated in the centre of the tract (from Mahbubnagar to Mandanpalli) while *H. serrata* was most common in the southern and western areas (Denkanikottai and Bangarupet, Kalyandurg and Rayadurg). The 1999 survey featured the collection of *H*. sp. nr *consanguinea* (John Maxen, personal communication) in Raichur and Mahbubnagar.

The 1999 larval survey provided a 'snapshot' of the relationship between larval numbers and the number of dead and dying plants on the day of sampling (Fig. 1). Regression analysis indicated the relationship was strong and positive ($r = 0.94$, df = 28, $P < 0.01$). Plant inspections confirmed that the grubs were responsible for plant death. The densities of *Holotrichia* species and 'all other white grub species' (largely Rutelines) did not correlate with each other ($P > 0.05$), but the density of the *Holotrichia* and 'others' groups were both very significantly associated with plant damage (for *Holotrichia* species, r (partial) = 0.9520, df = 27, $P < 0.01$; for all other species, r (partial) = 0.8470, df = 27, $P < 0.01$). There were no significant correlations ($P > 0.05$) between the percentage of plants damaged by crown rot and white grub damage or white grub density, suggesting that white grub feeding does not provide an entry point for the crown rot fungus, and so exacerbate the disease problem.

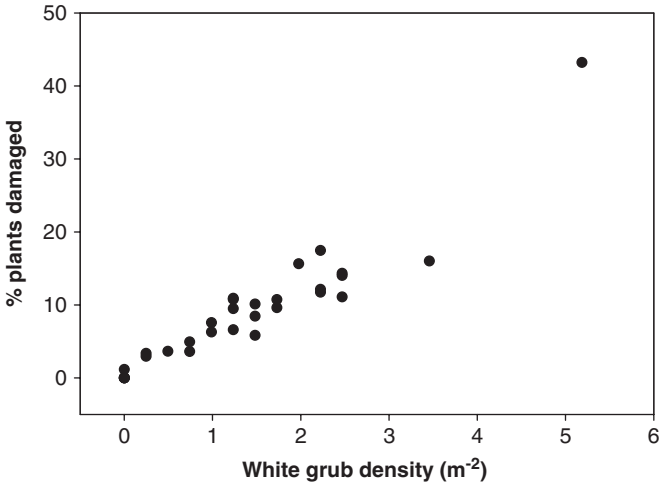

Fig. 1. Relationship between white grub density and plant damage in the 1999 larval survey of groundnuts in southern India ($r = 0.9372$, df = 28, $P < 0.01$; for *Holotrichia* species, r(partial) = 0.9520, df = 27, $P < 0.01$; for all other species, r(partial) = 0.8470, df = 27, $P < 0.01$).

Neither the information collected from farmers on crop rotations and farming practices, nor reference to soil maps of the region (using the Soil Survey Staff (1999) classification), gave any insight into the factors that influence the density and distribution of the white grub species (Fig. 2).

3.2.3. 2000

The re-sampling of the farms at Mulkalacheruvu and Mahbubnagar in 2000 (Table 5) showed that farms at both locations were similarly infested, and damaged, by *Holotrichia* species in both years. In Mulkalacheruvu, *H. reynaudi* was recorded, while in Mahbubnagar, there was a mix of *H. reynaudi* and *H*. sp. nr *consanguinea*. These data support farmers' comments across the groundnut regions of the Deccan that where they occur, white grubs are a consistent problem from year to year.

3.3. Compilation of species distribution, and adult host-tree data over years

Table 6 presents the data on adult preferences for trees for feeding/mating for four *Holotrichia* species individually, plus *Schizonycha* spp. combined over years. From these data, it is clear that *H*. sp. nr *consanguinea* has very

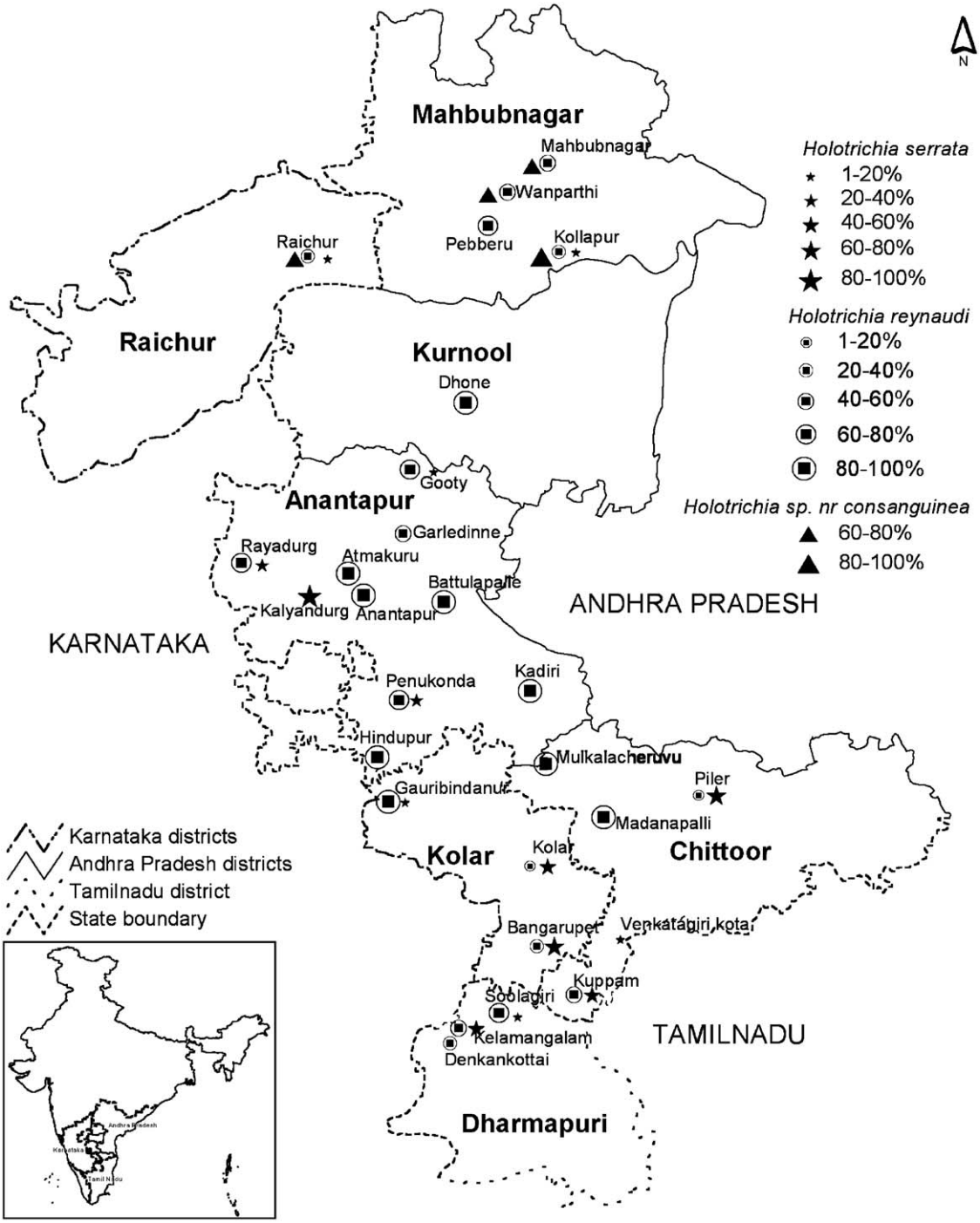

Fig. 2. Distribution of *Holotrichia* species that damage groundnut in southern India, compiled from all study data. For each species, symbol size indicates species predominance at each site (smallest symbol = 1–20% of *Holotrichia* at site, largest symbol = 80–100% of *Holotrichia* at site).

different adult host preferences from the other southern *Holotrichia* species.

The compiled species data for the four *Holotrichia* species are presented in Fig. 2, based on all larval and adult survey data. This map points to the markedly different distributions of the *Holotrichia* species attacking groundnut in southern India. *H. reynaudi* is primarily found in the central Deccan, while *H. serrata* occurs in more southern and western regions. *H.* sp. nr *consanguinea* has, so far, been detected in the most northern sections of the surveyed region, and overlapping with *H. reynaudi*. The full extent of its distribution remains unresolved. *H. rufoflava* was found in the extreme south, in very low numbers under groundnut. It cannot be regarded as a significant pest of groundnut in southern India on the available data. However, its presence in adult surveys (Table 4) indicates that it is common in the region and may cause damage to crops other than groundnut.

Table 5
Holotrichia species larval density (larvae m^{-2}) and % of plants damaged (and range) at Mulkalacheruvu and Mahbubnagar, Andhra Pradesh (1999 and 2000)

	Mahbubnagar		Mulkalacheruvu	
	1999	2000	1999	2000
Holotrichia Larval density	5.19 (4.44–5.93)	3.70 (2.22–5.19)	3.95 (2.96–5.19)	2.47 (2.22–2.96)
Plants % Damaged	43.22 (36.42–51.35)	50.93 (50.0–50.93)	17.46 (13.07–20.39)	30.45 (14.71–53.13)

Table 6
Preference of adults from four Scarab species for host trees in groundnut-growing areas of southern India, compiled from all study data

Plant species	*H. reynaudi*	*H.* sp. nr *consanguinea*	*H. serrata*	*H. rufoflava*	*Schizonycha* spp.
Acacia	+ +	+	+		+ + +
Azadirachta indica (neem)	+	+ +	+ + +	+ + +	+ + +
Butea monosperma (moduka)		+ + +			
Carissa sp. (kalivi)		+ + +			
Carissa sp. + *Azadirachta indica* intertwined		+ + +			
Cassia sp.		+			
Moringa oleifera (drumstick)	+ +				+ + +
Tamarindus indica (tamarind)	+ +		+ +	+ +	+ +
Zizyphus spp. (ber)	+ + +				+ +

Preference rating is the frequency of occurrence on host trees: + + + = high, + + = moderate, + = low.

4. Discussion

The data provide clear evidence of the link between plant loss in groundnut on farms in southern India and the presence of *Holotrichia* larvae. The data also indicate that species other than *Holotrichia* reduce the yields of groundnut in southern India. However, because of the predominance of *Holotrichia* in the larval and adult collections and the diversity of species in the 'others' group, these other species were not studied further.

Despite attempts to relate *Holotrichia* spp. distribution and occurrence to environmental, edaphic or other variables in southern India, this study did not identify any factor that was clearly associated with the occurrence of damaging larval populations under groundnuts. However, farmers' use of insecticide seed dressings significantly reduced larval populations (Anitha et al. in press) in the areas of Andhra Pradesh where chemicals were used.

Because much of the study area is essentially a groundnut monoculture, other crops were not sampled. Consequently, the abundance of the species reported here under crops such as millet and sorghum is unknown. In other Indian cropping systems, *H. consanguinea* and *H. serrata* occur in high populations under fibrous-rooted crops, but cause less visible damage to these crops because of the nature of their root systems (Yadava and Sharma, 1995). Given the polyphagous feeding strategies of larvae of other *Holotrichia* species (Yadava and Sharma, 1995), it is likely that the species reported here also occur under other crops in the Deccan region, rather than specifically associated with groundnut. The greater impact on groundnut is related to its susceptibility to damage because of its tap root system (Rogers et al. in press; Yadava and Sharma, 1995).

The compilation of adult preferences for trees for feeding and/or mating (Table 6) provides valuable data for the southern Indian environment that will assist farmers and their advisors in identifying the existence of pest problems prior to planting, by identifying which trees to search for adults. This will enable insecticide-based management processes to be implemented at planting, if required. Pal (1977) reported that adults of *H. serrata* were attracted to neem, acacia, ber, guava (*Psidium guajava*) while Yadava and Sharma (1995) added moduka (*Butea monosperma*). However, of these five tree species, only the first two were observed as hosts in the present study. Also, an additional host tree, tamarind, not recorded by either Pal (1977) or Yadava and Sharma (1995), was recorded for *H. serrata*. These differences perhaps reflect the availability of tree species in the different environments, and suggest that adult host preferences for *Holotrichia* species need to be confirmed wherever the spectrum of tree species in the local environment is different. Further, the markedly different host preferences of *H.* sp. nr *consanguinea* adults (Table 6) indicate that when dealing with unfamiliar species or new environments, an open mind is required when determining which trees to sample. To simply focus on host trees of known species elsewhere runs the risk of missing adults of species that are locally important.

The distribution data for *Holotrichia* species in groundnut (Fig. 2) provide detailed location data for southern

India that gives additional precision to previous species distribution data (Musthak Ali, 2001). These distribution data provide, at a local level, clarity as to which *Holotrichia* species is most abundant where. The re-sampling of sites in 1999 and 2000 indicates that white grub infestation of groundnut in southern India occurs consistently from year to year. This points to the need for the prophylactic protection of groundnut crops where the presence of the pest has been established at a locality by the occurrence of crop damage in previous seasons, and especially if adults are detected on trees at the beginning of the monsoon.

As susceptibility of white grub species to insecticide varies (Anitha et al., in press), this detailed knowledge of species distribution will allow farmers and local NGOs to select the lowest possible rates of chlorpyrifos for effective seed treatment at any given site, where previously decisions had to be based on informal grower observations and guesses as to pest species and treatment rates.

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