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Advanced sub social behaviour in the scorpion *Heterometrus fulvipes* Brunner (Arachnida)

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Abstract· Scorpions arc generally non-social, solitary animals that interact with conspecifics at birth, courtship or predation only· The present study reports the presence of advanced sub social behaviour in *Heterometrus fulvipes* Brunner and evaluates the importance of its burrowing as a cause for such social behaviour· *Heterometrus fulvipes* constructed deep angular burrows at the base of plants· Burrows provided (i) protection against predation, (ii) increased availability of food and (iii) ideal microclimate for year round activity of the scorpions· No cannibalism was observed in laboratory maintained colonies· The risk of predation and the difficult by immatures to dig tunnels during dry soil conditions may have forced the mother and offspring to live together in the burrow for longer durations. The cohabitation of relative offsprings transforms the burrow into a nest· The members of a colony exhibits division of labour for nest expansion and in foraging· The mother communicates with the immatures through "Buzz" sound and may provide premasticated food· There is food sharing also among colony members· All these behaviours indicate the presence of advanced sub social behaviour in *Heterometrus fulvipes*·

Keywords· Scorpion; predation; burrow; thermoregulation; ensconsement; division of labour; communication·

1. Introduction

Scorpions are one of the oldest terrestrial arthropods, known as "living fossils" (Cloudsley-Thompson 1958; Vachon 1953; Polis and Lourenco 1986)· Scorpions are generally non-social, solitary animals that only interact with conspecifics at birth, courtship or during cannibalism· Majority of the species of scorpions exhibit cannibalism (Vachon 1953; Polis and Lourenco 1986)· Recent studies have demonstrated brood care and group living in a few species (Polis and Lourenco 1986; Krapf 1986).

The present study evaluates the burrowing behaviour as a major cause for advanced sub social behaviour in *Heterometrus fulvipes* Brunner· *H. fulvipes* is especially interesting because its sociality is primitive enough that the selective factors that initially favoured social behaviour may still be in evidence·

2. Materials and methods

2.1 *Study site*

The study was conducted from 1985-1989 at Gandhi Krishi Vignana Kendra, University of Agricultural sciences, Bangalore (el.= 915m), Karnataka, India· The study site was in an open scrub forest interspersed with eucalyptus and small patches of thick vegetation locally covering 60 to 100% of the substrate surface. Leaf litter was sparse.

Burrow density and distribution was measured in 39 grids, each of 10 × 10 sq m area· The burrow position in relation to the vegetation was recorded.

2.2 *Foraging*

The presence of the scorpion at the burrow opening (foraging) was recorded at hourly interval for 24 h· The per cent active scorpions at the entrance was calculated for the total number of burrows (n = 178) observed· Foraging and prey capture was observed from a distance of 2 meters, to minimize disturbance·

2.3 *Burrowing behaviour*

Three functions were hypothesized for the burrowing behaviour: the burrow (i) increases access to prey, (ii) provides thermoregulation and (iii) provides protection from predators·

(i)Prey abundance was measured below the plant adjacent to the burrow and at one meter away in the open· At both sites artificial burrows (n = 58) similar to the original burrow were constructed· Adhesive traps coated on clear plastic sheets 4·5 × 3·5 cm (corresponding to the foraging area of the scorpion pit) were placed in front of the opening of the artificial burrows, during the foraging hours of the scorpion· The prey captured were examined for size and taxon·

(ii) Temperature in the burrow (at a depth of 2·5 cm) and on the substrate surface was measured (sample size given in table 1) at hourly intervals (for 24 h) using a Dhiel thermotron·

(iii) Survival of the marked burrows was checked at monthly intervals· Any damage to the burrow, by way of digging was recorded as possible predation·

Observations were made between 2030-2130 h in May (3 days) and July (2 days) to record the number of live and dead scorpions found on the substrate surface in transect of 3 x 50 m (n= 10)· The presence of scorpion remnants in an area of 1 sq m was considered predation·

2.4 *Burrow survival and architecture*

Sixty eight large burrows (single opening of size 3·5–4·5cm width) were marked and observed for survival by visiting the burrows at monthly intervals and recording the active and inactive burrows· Active burrows were neat and tidy compared to inactive burrows which were covered with fallen leaves and twigs and were considered as dead burrows· Burrow transformation (into nest) was recorded from December 1985 to August 1988· From these, 18, 12 and 7 burrows were excavated in 1986, 1987 and 1988, respectively (table 1)· The scorpion/s of each burrow was recorded· The burrows were grouped into burrows with (i) one opening or (ii) multiple openings (here after called nest)· Nest architecture was studied by pouring liquid plaster of pans (2 : 1 dilution with water) into the nest through the large opening until it was filled· After 24 h these nests were carefully excavated (figure 1).

Table 1. Foraging by *H. fulvipes* in relation with the surface and burrow temperature (January).

Time (h)	Number of samples	Surface temperature (°C)	Burrow temperature (°C)	Scorpions foraging (%)
01·00*	49	17·46(0·58)	22·17(0·85)	85·71
02·00*	48	16·21(0·04)	21·12(0·62)	87·76
03·00*	44	15·86(0·54)	19·89(0·80)	85·50
04·00*	47	15·19(0·90)	19·69(0·94)	48·90
05·00*	45	14·21(0·72)	19·05(0·81)	47·82
06·00*	38	14·80(0·91)	19·08(0·85)	34·21
07·00*	39	15·72(0·85)	20·73(1·40)	10·23
08·00	31	17·64(0·73)	19·03(0·89)	3·23
09·00**	31	23·18(2·51)	22·18(1·94)	0
10·00**	30	26·91(2·38)	24·74(1·04)	0
11·00**	32	32·39(2·30)	27·03(1·41)	0
12·00**	36	35·80(3·21)	27·90(1·74)	0
13·00**	34	38·94(3·54)	28·75(1·24)	0
14·00**	36	36·86(1·28)	30·24(1·30)	0
16·00**	30	35·50(1·24)	31·04(2·89)	0
17·00	34	28·98(2·03)	29·10(0·90)	5·56
18·00	41	24·48(0·75)	26·34(1·08)	82·93
19·00*	170	23·03(1·21)	25·61(1·15)	89·51
20·00*	118	22·64(0·98)	25·19(1·61)	93·22
22·00*	35	20·78(0·82)	22·66(0·67)	97·13
23·00*	23	19·80(0·82)	22·49(1·10)	82·61
24·00*	39	18·58(0·39)	22·12(0·74)	84·62

Burrow temperature significantly ($P < 0{\cdot}01$) *higher; **lower than surface temperature.

Figure 1. Nest structure of the scorpion.

2.5 *Laboratory studies*

Scorpions collected from the field were transferred into glass troughs (30 cm diameter) containing 20 cm of native soil· The soil was kept moist (moderately) by adding water daily· The feeding behaviour by the scorpions on grasshoppers and beetles was recorded in two colonies kept in glass troughs without any soil; this allowed us to watch the feeding behaviour of all the members of a colony at the same time. Two colonies, each consisting of one adult and 8 immatures were kept without food, one in dry soil and other in moist soil. Number of days that scorpions remained alive in both soils were recorded.

2.6 *Tunnel excavation*

Scorpions of size 0·5, 1·5, 1·5, 2·5, 3·0 and 3·5 cm [cephalothorax length (CL)] were kept separately in small containers having moist and dry soil· The depth and width of the tunnel excavated was measured after two days·

2.7 *Cannibalism*

One female and 17 immatures of 2·7 cm (CL, from three different colonies) were put in a single container. These scorpions were starved for 15 days. The number of scorpions that remained alive at the end was recorded as an index of cannibalism.

2.8 *Communication*

A colony with one adult and 13 offsprings was kept in a empty jar. After one hour, the adult was touched with a long stick (30 cm length) to avoid effects of air current and vibrations· Bare was taken to avoid all other sounds while conducting this experiment. The effect of sound produced by the adult on the offspring (movement or freezing response) was recorded·

2.9 *Differentia foraging*

An artificial nest was constructed using plaster of paris and cardboard box with five openings (similar to field). The size of one opening was 3·5 cm wide and the others were 2·0 to 2.5 cm wide· A colony having one adult (3·6 cm CL), first brood [seven individuals (Fl to F7) all of size 2·3 to 3·1 cm CL] and second brood [six individuals (S1 to S6) of size 0·85 to 1·3 cm CL] were placed in this nest. All the scorpions were marked individually for identification. The colony was starved for one week prior to release in this nest· From the next day on-wards, nest openings were observed at 1930, 2030 and 2130 h for the presence of animals. Any individual at any opening, showing the foraging posture (pedipalps wide open) for a period of at least 15 s was considered foraging and its tag was recorded· A total of 21 such recordings were made for each opening in a week.

3. Results

3.1 *Field studies*

3.1a *Burrow and its distribution*: On an average 2·16 (SD = 2·33) burrows (burrows with multiple openings were considered as a single burrow) were observed in each grid· Seventy two per cent of the burrows had a single opening· These burrows could be grouped into adult (41%) (3·5–4·5 cm wide) and immature (31%) (2·5-3·2 cm wide) burrows· The remaining 28% were nests with multiple openings (figure 2)· Nests had on average 5·11 (SD = 1·25) openings, consisting of one large central and small lateral openings·

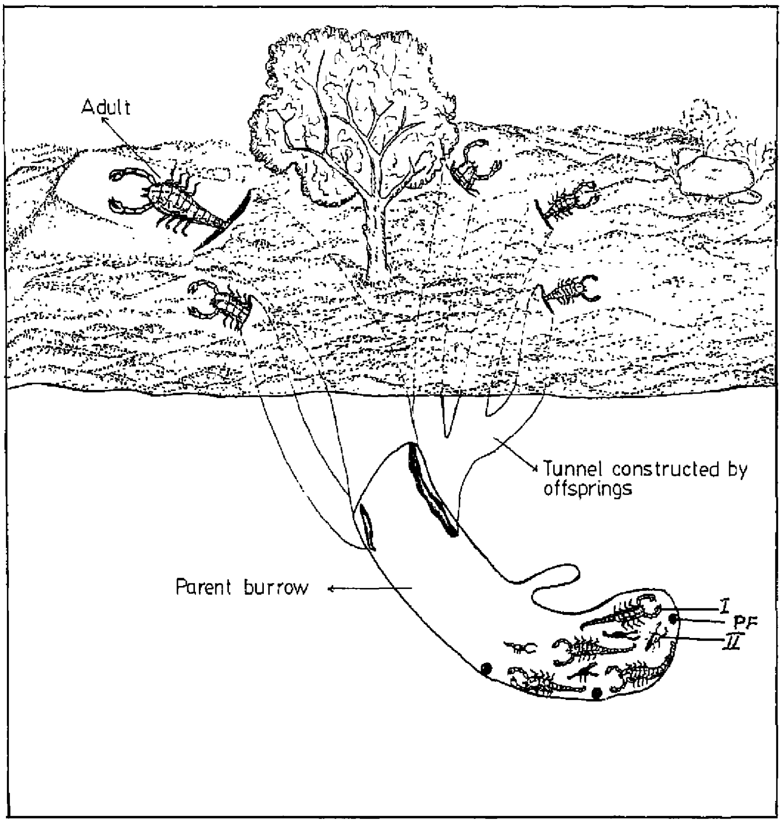

Figure 2· The nest find the foraging positions of *H. fulvipes*. At the end of the tunnel shows the presence of first and second brood and the premasticated food balls.

The majority (78%, n = 39) of the burrows were found under 21–50% vegetation cover (9, 7 and 14 in 25–30, 31–45 and 41–55% vegetaion respectively)· Areas with high (more than 65% vegetation cover) and no vegetation were devoid of scorpion burrows· Burrows (n= 148) 73, 34 and 12 were found within 5, 10 and 15 cm, respectively and the remaining burrows were found at 15–35 cm away from a plant· With increasing distance, the number of burrows decreased (χ^2 = 94·33, $P < 0·01$, df = 4)·

H. fulvipes constructed burrows during the early part of the monsoon (from May to· August)· The scorpions excavated burrows with the help of pedipalps· Scorpions dug the tunnel at an angle to the ground level· Adult *H. fulvipes* constructed deep burrows (mean = 39·6 cm, SD= 8·65). Immatures (belonging to isolated burrows and not nests) of size 2·75, 3·0 and 3·5 cm constructed burrows to a average depths of 14 (n = 8) , 19.5 (n = 6) and 23 (n = 11) cm, respectively

3.1b *Foraging: H· fulvipes* foraged from 1700-0730 h, the peak foraging was between 1800-0300 h (table 1)· The scorpions foraged by following a sit-and-wait strategy at (as shown in the figure 2) the entrance of the burrow· *H· fulvipes* oriented towards approaching prey, apparently sensing the vibrations made by the moving prey· When the prey stopped moving, the scorpion moved its pedipalps (repeated to and fro movements)· The prey either moved towards the scorpion or away· If the prey approached, it was caught with the pedipalps and was immobilized at once by stinging, then taken into the burrow·

3.1c *Prey availability:* The number (x = 3·64 ± 3·2/trap) of prey in a trap, at the base of a plant was significantly (t = 4·59, P< 0·01, n = 58) higher than in traps 1 m away from plants (x = 1·72 ± 2·0/trap). Mean prey size (x = 1·37 ± 2·35 cm) and taxon were not significantly (t = 0·38, P > 0·05, n = 58 and KS χ^2 = 2·3, P > 0·05, n = 7, respectively) different in the two sites·

3.1d *Thermoregulation :* The variation in different hours of the day in the surface temperature (24 8°C) was greater than the variation in the burrow temperature (14°C) (table 1).

3·le *Predation :* Two (< 3%) burrows (n= 178) were found partially damaged by predators· In both the cases the predator was identified as Mongoose (*Harpestes auropunctatus*), based on foot prints and nail marks· The burrows had been dug to a depth of only 6 and 9 cm, and excavation of these burrows showed the presence of active scorpions at the end of the tunnel· Foraging scorpions were very sensitive to an approaching person (or predator) and immediately retreated into the bottom of the burrow·

On an average 2·96 ± 1·4 scorpions (which are either in search of mates or new burrow sites) were found on substrate surface in each transect· Of these 0·92 ± 5.55 were dead (due to predation)· Predation on scorpions living in burrows was significantly lower compared to scorpions found above ground (χ^2 = 17·22, P < 0·01, df = 1)·

3·1f *Burrow transformation :* After nearly two years, 19% of the marked burrows were transformed into nests with multiple openings (figure 2) by August 1987· In 1988, 28% of the burrows had transformed in to bests (table 2)· 53% of the marked burrows did not change.

The average width of large burrows was 3·82 ± 0·35 cm and it was inhabited by adult (n = 14)· Eight per cent of such burrows had two adults (male and female) cohabiting (table 2)· Excavations made during November and December 1986 showed the presence of many immatures and an adult in a single burrow (with no lateral openings) (table 2)· By early 1987, some individual burrows had several lateral openings (corresponding to the size of immatures, table 2)· All the lateral tunnels were connected to the main tunnel, the nest architecture was as shown in figure 2· These nests did not change further except for an increase in the width of the lateral openings (mean size from 1·36 to 2·56 cm width) by 1988· The size of the lateral tunnels were in correspondence to the size of immatures· These nests had an adult and ,two broods of immatures (table 2)· The mean size (CL) of the first and second brood differed significantly (t= 8·78, P < 0·01, df = 13) (figure 3).

Table 2. Contents of burrows which starts with single entrance in December 1985, and which were dug up at later dates

Date	N	Number of entrances	Size of entrance/s (cm)	No. of scorpions present	Size* of scorpion/s
May–	9	1L	3·6 ± 0·44	1	3·51 ± 0·1
July,	5	1L	3·8 ± 0·33	2	3·77 ± 0·2
Nov–	4	1L	3·87 ± 0·36	1A +	3·49A
Dec 1986				11·41 ± 1·7N	0·78 ± 0·11N
July and	12	1L +	3·7A	1A +	3·57A
Aug 87		5·3S	1·27 ± 0·2	9·1 ± 2·07N	1·51 ± 0·22N
July and	7	1L +	3·85A	1A +	3·86A
Aug 88		5·9S	2·36 ± 0·2	14·2 ± 2N +N1	
				5·2N	2·7 ± 0·2N
				9·85N1	1·46 ± 0·1N1

L, Large burrow entrance belonging to adult; A, adult; S, small burrow entrance; N nymphs of first brood; Nl, Nymphs of second brood; *, size of the cephalothorax·

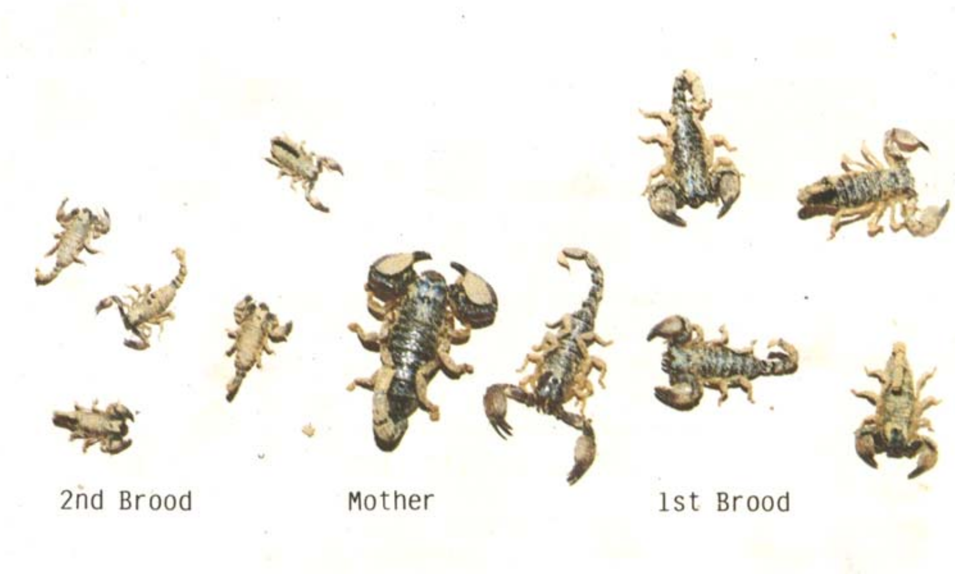

Figure 3. The mother scorpion with the first and second brood.

3.1 g *Foraging:* In a large nest between 5 and 7 scorpions foraged from 1900 to 0500 h· Each scorpion foraged by waiting at an opening of the nest· The adult always occupied the largest opening of the nest and the immatures the lateral openings· The excavations of such nests showed the presence of significantly larger number of scorpions in each nest compared to the number of openings of the nest [(x = 5·11 + 1·2) (t= 7·94, P < 0·01, n = 19), mean = 13·5 ± 3·1, including one adult].

3.2 *Laboratory studies*

3.2a *Burrowing* : Scorpions lived longer kept on moist soil (without food) (23 days) than on dry soil (9 days)· Immatures of 0.5 to 1 cm (CL) attempted to dig but were unable to make tunnels in either moist or dry soil· In two nights scorpions of 1.5, 2.5, 3.5 and 3.5 cm (CL) dug tunnels with average widths of 1.3, 1.95, 2.6 and 3.6 to average depths of 3, 3.5, 4.2 and 6 cm, respectivley in moist soil· The scorpions dug very shallow tunnels (average depths of 0.6, 0.9, 1.3 and 2.1 cm, respectively) in dry soil·

3.2b *Feeding and food sharing :* The prey offered to the adult was caught and paralysed by stinging· The immatures (early instars) were unable to catch and sting prey· The adult chewed the prey for 15 to 35 min· At the end of feeding bout a finely masticated ball (5-8 mm diameter) was dropped· This premasticated food was later partially consumed by the immatures· A hungry colony (starved for a week) devoured prey "engroupe"·

3.2c *Cannibalism :* Neither hostility towards nest mates (from adult to immatures or among immatures) nor cannibalism was observed among·

3·2d *Communication :* The adult (mother) produced a "Buzz" sound when touched with the stick· This sound elucidated two types of responses from the immatures. The responses were (i) a sudden freezing (at the same spot) for a period of 5–20 s or (ii) quick running towards the adult, followed by freezing for a short interval.

3.2e *Foraging from the artificial nest:* The adult scorpion foraged repeatedly in the widest tunnel of the artificial nest· Five members of the first brood (Fl, F2, F4, F6 and F7 (χ^2 = 122.55, P < 0·001, df = 28) participated in the smaller openings number 2–5 (table 3)· The remaining two scorpions of the first brood (F3 and F5) and all scorpions of the second brood (S1-S2) were never observed in the foraging position at any of the openings (table 3)·

3.2f *Maternal care :* First instar immatures were observed resting on the back of the mother for 8–12 days· During this period, the mother became very aggressive when the container was touched or opened.

Table 3. Foraging pattern of different individuals of a colony of *H. fulvipes* kept in artificial nest with five entrances·

Identity of the scorpion	Tunnel entrances 1	2	3	4	5
Adult	16	0	0	0	0
F1	1	7	2	3	2
F2	1	2	3	1	12
F3	0	0	0	0	0
F4	0	0	0	6	0
F5	0	0	0	0	0
F6	0	2	3	5	5
F7	0	5	1	0	2
S1 to S6	0	0	0	0	0

F, Members of the first brood; S, members of the second brood·
Size of entrance 1, 3.6,..2–5; 2.0-2.5 cm wide

4. Discussion

Defense against predation is a major cause of group living in social insects and in other taxa (Alexander 1974)· In the present study defense against predation has favoured burrow life for *H· fulvipes·* The scorpion obtains maximum protection against predators in the burrows compared to open places·

The burrow life has certain disadvantages· In comparison to active predation strategies, sitting and waiting at the entrance of the burrow increases the degree of randomness in prey capture events (Shachak and Brand 1983)· The preferential burrowing by *H· fulvipes* below plants has decreased the randomness of the prey availability· The amount of food (prey) is an important factor for group living· It is more so for a scorpion, since the amount of available food is correlated to the degree of cannibalism (Polis 1985)· Increased food availability below the plants has probably reduced the cannibalism in *H· fulvipes·* The increased amount of food available and the loss of cannibalism is an important step for the group living of this species·

Some species of scorpions undergoes Inactivation during high temperature of the year (Shachak and Brand 1983; Vachon 1953)· Year round activity is essential for obtaining more food necessary to feed all the members of a colony· The burrows of *H· fulvipes* provided ideal microclimate for the year round activity· Living in burrows reduces the energetic costs to be spent on thermoregulation·

Many species of scorpions exhibit maternal care (Bloudsley-Thompson 1958; Krapf 1986; Polis and Lourenco 1986)· *H· fulvipes* showed maternal care by carrying offspring for 8–12 days on its back· The care is extended for a longer period (1–2 years) by providing shelter for the offsprings· If the offspring leave the maternal burrow after the second or third instar (*i·e·* by October and November) then they are exposed to risky environment (especially dry soil conditions)· They may only be able to dig shallow tunnel and thus die quickly· Moreover the inability of an early instar to excavate tunnels in such soils would make them a easy target for predators· Since predation is very high in the open areas, the risk of predation and the difficult to dig tunnel during winter and summer has forced the mother and offspring to live together for long durations·

Stridulation is observed in a few scorpion species (Pocock 1900; Bloudsley-Thompson 1958), and its function is not known· *H· fulvipes* "Buzzes" when disturbed· Effective communication, especially the production of alarming signals against approaching predators, are important for animals or birds foraging in groups (Ricklefs 1979)· Similarly the "Buzz" signal by adult *H· fulvipes* served as alarm signal for its offspring· This type of communication is unique among scorpions and is an important step towards sociality if we assume that communication is an integral part of sociality (Wilson 1971)·

The transformation of the adult burrow into a nest having different sized exit tunnels is of interest· The construction of lateral small tunnels is possible only by the members of the first brood and not by the· adult· The expansion of these tunnels occurred in the second year (in rainy season) corresponding to the size of the first brood (by now the second brood will be in early instars and are incapable of digging)· This can be considered as division of labour for nest expansion.

All the members of the colony went hungry when kept in the artificial nest. Every individual had equal opportunity to forage at different hours (table 3) yet only few (an adult and few of first brood) of the colony members participated in foraging· Openings were unoccupied during some observation periods (column total of table 3)· Members of the second brood did not participate in foraging as they are incapable of catching and stinging the preys· The repeated participation of few members of a colony represents division of labour for foraging among the members of a colony· The division of labour for foraging and nest construction is a wide spread phenomenon in social arthropods (Wilson 1971, 1975)·

All the members of a colony fed cooperatively on a single prey when hungry. Such cooperative feeding is also observed in *H. spinifer* (Krapf 1986)· Adult *H. fulvipes* also fed its offspring indirectly by dropping premasticated food in the nest. The repeated dropping of this food after each prey caught is an important step towards progressive provisioning, which is common in social insects (Velthuis 1986; Wilson 1971).

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