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Effectiveness of single-thread webs as insect traps: Sticky trap models

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Summary

Single-thread sticky traps placed in coffee plantation understorey captured a minimum of 4 insects/thread-day, about 80% of which were small Diptera and Hymenoptera. Variables which influenced trapping success were, in decreasing order of importance: time of trapping activity, thread size, thread orientation. More insects were caught during the day on all traps; thick threads caught somewhat more insects than thin ones; vertical threads caught more insects by day and horizontal threads caught more by night. Single-thread traps caught fewer total insects, but more insects per thread, than multiple-thread traps. A 10-fold increase in thread length resulted in only a 4 to 6-fold increase in captures (comparing single- and multiple-thread traps). Single-thread traps did better than expected on the basis of thread length alone. Two alternative hypotheses are presented to explain the capture success of single-threads, taking into consideration the ways in which insects perceive and respond to traps and/or webs.

Introduction

In each of the major families of web-building spiders there occur some species which construct webs with reduced capture areas. Examples of extreme web reduction – use of only one or a few sticky threads – can be found in the Uloboridae (*Miagrammopes*), Araneidae (*Mastophora, Kaira, Celaenia* and *Dicrostichus*) and Theridiidae (*Phoroncidia*) (Gertsch, 1955; Marples, 1955; Lubin *et al.*, 1978). Whereas *Mastophora* (Eberhard, 1977a), *Kaira* (M. K. Stowe, pers. comm.) and probably *Celaenia* and *Dicrostichus* (McKeown, 1952) and *Phoroncidia* (Eberhard, 1981) use chemical attractants to draw certain insect prey to their "webs", *Miagrammopes* does not, and its reduced web is thus a simple interception trap for airborne insects (Lubin *et al.*, 1978).

One might expect reduced webs such as those of *Miagrammopes* to be less effective traps than multiple-thread orb webs typical of other uloborids. In comparison with an orb web, a reduced web has (1) a shorter length of sticky thread, (2) a smaller total area of trapping surface and (3) a larger "mesh" size. All of these attributes might be expected to reduce trapping efficiency by reducing the probability of an insect intercepting the sticky elements.

We explore here the problem of the effectiveness of reduced webs as traps for flying insects, using sticky traps as models. Trap effectiveness may include a number of parameters, not all of which may be of equal importance to the spider (see Lubin, 1973 and Chacón & Eberhard, 1980 for discussions of trapping strategies of webs). Here we compare the numbers, sizes and taxa of arthropods trapped (1) per unit time and (2) per unit length of thread. The variables tested are the number of sticky threads (single-thread vs. multiple-thread traps), thread diameter (thin vs. thick), orientation of threads with respect to the substrate (horizontal vs. vertical), and trapping time (day vs. night).

Methods

In Papua New Guinea, *Miagrammopes* sp. 1[1] build webs consisting of 1-6 sticky threads, oriented at varying angles to the substrate, but usually not horizontal. Webs were found in overgrown coffee plantations in the grounds of the Wau Ecology Institute in Wau, Morobe Province (1200 m elevation), most

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[1] Specimens have been deposited with B. D. Opell, Virginia Polytechnic Institute and State University, Blacksburg, Va. for identification.

(the latter were perhaps insect parasites that were dislodged when their hosts struggled to escape from the traps), while the largest included Tipulidae (Diptera: Nematocera) 18-22 mm total body length, Asiloidea (Diptera: Brachycera) 7-17 mm, Fulgoroidea (Homoptera) 9 mm, Reduvioidea (Heteroptera) 10 mm and Lycidae (Coleoptera) 7-8 mm. Large scarab beetles, moths and butterflies, large cicadas, hunting wasps and apid bees were frequently seen in the coffee plantation but were rarely caught in the sticky traps.

There was considerable day-to-day variation in the numbers of insects trapped, with a marked decline in numbers on days 4 and 5. This decline was significant for experiments I, II and III ($p < 0.001$; χ^2 test comparing captures on days 1-3 and 4-5 with expected values based on total captures). The variation in number of captures on days 1-3 was significant only in experiment II ($p < 0.01$; χ^2 test). It seems unlikely that the small numbers of insects removed by the traps during the first 3 days significantly reduced the populations of flying insects. Perhaps some insects learned the locations of the traps and were able to avoid them. In order to avoid this additional source of variation, experiments IV and V were run for 3 days only. Day-to-day variation within the 3-day trapping period was significant only in single-thread traps in experiment V ($p < 0.001$; χ^2 test).

Thread size: experiments II and III (Table 2)

Thin sewing threads trapped somewhat fewer insects than did thick monofilament threads. Although the difference was significant only in experiment II ($0.02 < p < 0.05$; t-test), it was con-

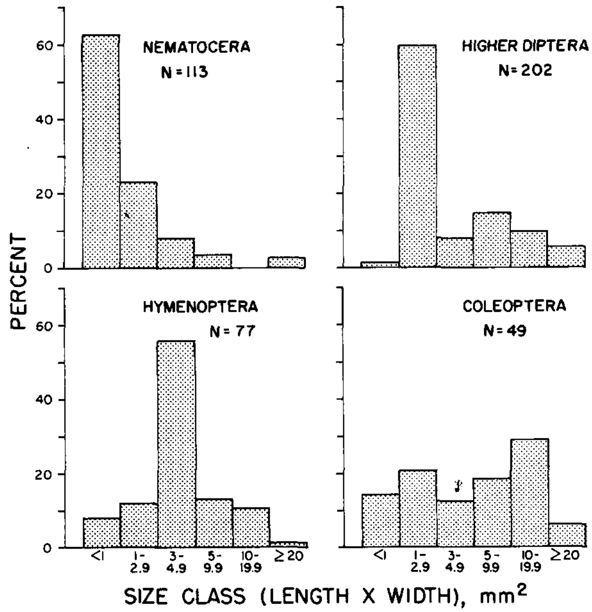

Fig. 3: Frequency distribution of sizes of Nematocera, higher Diptera, Hymenoptera and Coleoptera trapped on 2 lb test monofilament (experiment I).

sistent in both day and night captures and may reflect a real difference in trapping success of thin and thick threads.

Significantly more higher Diptera were trapped on thick threads than on thin ones (experiment II: $p < 0.01$; experiment III: $p < 0.001$; χ^2 tests), but the numbers of Nematocera trapped were not significantly different. In experiment III, thick threads trapped more small insects of all taxa (< 3 mm^2) than did thin threads ($0.02 < p < 0.05$; χ^2 test). In both experiments somewhat more large insects

Experiment/ Orientation	Multiple-Thread Traps		Single-Thread Traps		
	No. Insects	Insects/Thread-Day	No. Insects	Insects/Thread-Day	
IV/Vertical					
Day	572	1.9 ± 0.7	110	3.7 ± 2.6	$p < 0.01$
Night	178	0.6 ± 0.3	26	0.9 ± 1.0	n.s.
V/Horizontal					
Day	359	1.2 ± 0.5	98	3.3 ± 2.3	$p < 0.001$
Night	201	0.7 ± 0.5	46	1.5 ± 1.9	$p < 0.02$

Table 3: Total numbers of insects and numbers per thread per day trapped on paired multiple- and single-thread traps during the day and night, with threads oriented vertically (experiment IV) and horizontally (experiment V). p values refer to t-test comparisons of insects/thread-day in multiple- and single-thread traps.

($\geqslant 10\ mm^2$) were trapped on thick threads, but these differences were not statistically significant.

Time of day: experiments III, IV and V (Tables 2, 3, Fig. 4)

In all experiments, many more insects were trapped during the day than at night (Tables 2, 3). The differences were highly significant in experiment III (monofilament and sewing thread: $p < 0.001$; t-test) and in experiments IV and V for both multiple-thread (MT) and single-thread (ST) traps (vertical, MT: $p < 0.001$, ST: $p < 0.01$; horizontal, MT and ST: $p < 0.01$; t-tests).

Although fewer of all insect taxa were trapped at night than during the day, the reduction in numbers of flies was proportionally larger than that in other groups. In all traps, the percentage of both nematocerans and higher dipterans was lower during the night than during the day (Fig. 4). In contrast, beetles, hemipterans and spiders made up a proportionally larger part of the captures at night. Other insects such as winged termites and Neuroptera were more abundant, whereas Hymenoptera occurred in about the same frequency. Most of the spiders trapped were dispersing immatures ($< 1\ mm^2$) or adult males.

Number of threads: experiments IV and V (Table 3, Figs. 4-6)

Although multiple-thread traps captured many more insects than did single-thread traps, significantly fewer insects were trapped *per thread* in multiple-thread traps than in single-thread traps (Table 3). This applied to both vertical- and horizontal-thread traps during the day and to horizontal-thread traps at night (vertical, day: $p < 0.01$; horizontal, day: $p < 0.001$, night: $p < 0.02$; t-tests). The same trend held for vertical-thread traps at night,

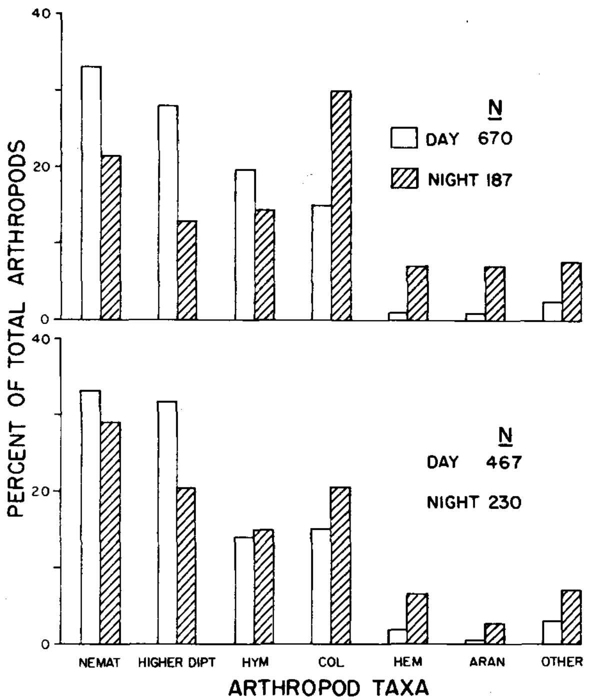

Fig. 4: Percentage of arthropods trapped during the day (open bars) and night (closed bars) on traps with threads oriented vertically (above) and horizontally (below). Data from multiple- and single-thread traps were combined.

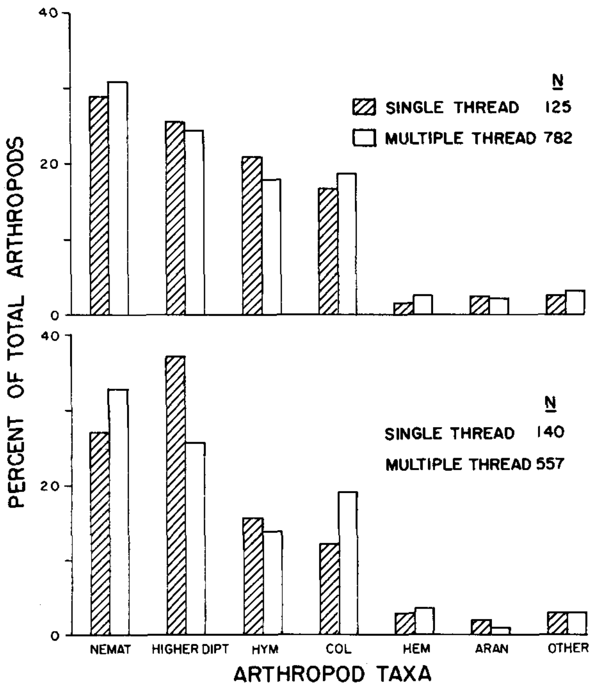

Fig. 5: Percentage of arthropods trapped on single-thread traps (shaded bars) and multiple-thread traps (open bars) with threads oriented vertically (above) and horizontally (below). Day and night captures were combined.

but the difference was not statistically significant.

Single-thread traps caught a smaller proportion of Nematocera and a higher proportion of higher Diptera than did multiple-thread traps (Fig. 5). Likewise, single-thread traps caught a smaller percentage of Coleoptera. These differences were more pronounced in horizontal-thread traps than in vertical-thread traps.

Single-threads caught a smaller percentage of both very small (< 1 mm) and very large (⩾ 10 mm) flies in the vertical-thread traps, but somewhat greater or equal percentages of small flies in horizontal-thread traps (Fig. 6). Large flies trapped by multiple-thread traps were predominantly Tipulidae (5-7.5 mm body length) and Asiloidea (8-17 mm).

Thread orientation: experiments IV and V (Table 3, Figs. 4-6)

Traps with threads oriented vertically and horizontally were tested at different times and are not, therefore, strictly comparable. However, as the traps were located in the same positions in both experiments and the two experiments were only 3 weeks apart, both falling in mid-wet season, we feel justified in making limited comparisons between them (Table 3).

Vertical threads caught significantly more insects during the day than did horizontal threads ($p < 0.01$; t-test), while horizontal threads caught somewhat more insects at night ($0.02 < p < 0.05$; t-test) (multiple-thread and single-thread traps combined). Flies comprised a smaller proportion of the total captures on vertical than on horizontal threads (Fig. 4). Nonetheless, vertical traps captured significantly more small flies (< 1 mm^2 than did horizontal-thread traps ($p < 0.001$; χ^2 test). Vertical-thread traps caught a higher percentage of beetles at night and Hymenoptera during the day than did horizontal-thread traps.

Discussion

Thread diameter

Thin threads trapped somewhat fewer insects than did thick threads, suggesting that any increase in the visibility of thick threads was offset by other factors. Chacón & Eberhard (1980) found more

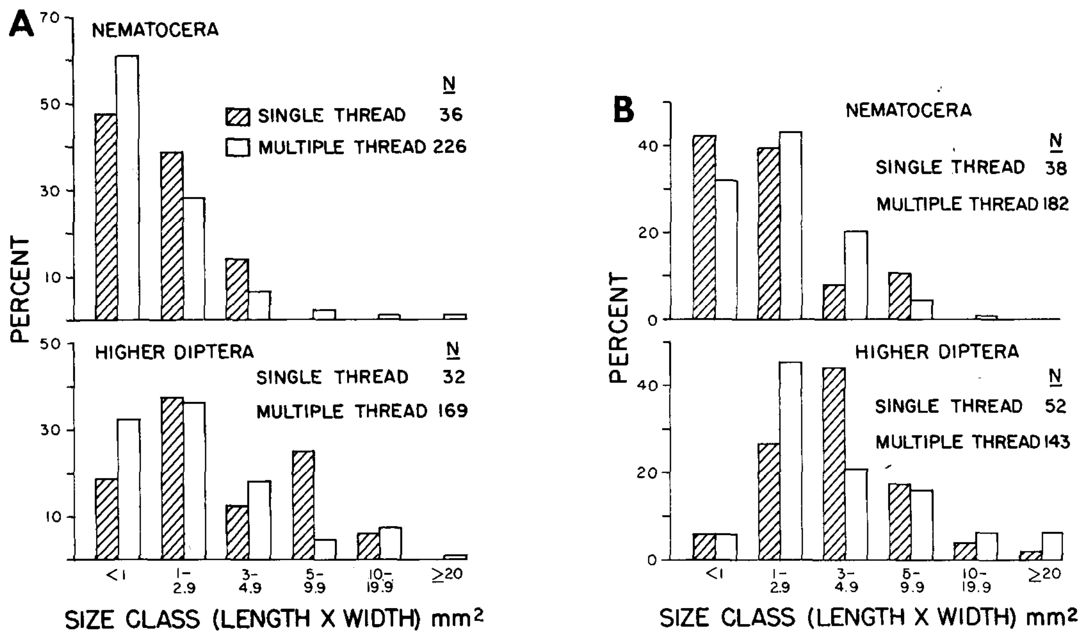

Fig. 6: Frequency distribution of sizes of Nematocera and higher Diptera trapped on single-thread (shaded bars) and multiple-thread (open bars) traps with threads oriented vertically (A) and horizontally (B). Day and night captures were combined.

insects on threads with more adhesive, attributing the increase to a greater restraining ability of stickier threads. In the present study, monofilament threads had larger trapping surfaces than thin sewing threads and this may have had the same effect as having more adhesive in increasing the ability to restrain insects once they struck the threads. The fact that thick threads trapped more higher Diptera (larger and stronger flying insects than most Nematocera) than did thin threads lends support to this hypothesis.

Monofilament and sewing threads were clearly distinguishable to the human eye, the former being at least 3 x the diameter of the latter. Whether this difference was distinguishable to flying insects remains unknown. Even the thin sewing thread was considerably thicker than a *Miagrammopes* capture thread. Possibly once threads exceed a certain size they are regarded alike by visually orienting insects.

Time of trapping

Somewhat surprisingly, many more insects were trapped during the day than at night. One might expect that webs and web models alike would be less visible at night to most insects and that, consequently, nocturnal captures would be higher than diurnal ones. Possibly there were fewer insects in general flying at night than during the day. Other data, however, suggest that this was not the case: *Cyrtophora moluccensis* (Doleschall), an orb-weaving spider which is active both day and night in the same area as the sticky traps, captured about 20% more insects at night than during the day (Lubin, unpublished). *Miagrammopes* webs in this area are nocturnal, but whether this is related to insect abundance or activity patterns, to risks of predation, or to physiological factors (water balance or thermoregulation) is not known. The sticky trap data alone suggest that *Miagrammopes* webs ought to operate successfully during the day, and indeed, many species of *Miagrammopes* are diurnal (Lubin *et al.*, 1978), including at least two other species in Papua New Guinea.

Although moths constitute a primarily nocturnal group of flying insects, very few were trapped in the sticky traps (0.004% of the total 2511 arthropods). Similarly, a vertical, plastic-sheet sticky trap placed in the understorey of a nearby coffee plantation caught only 1.7% moths out of 3533 insects trapped in a year's census (Robinson & Robinson, 1973). By comparison, window traps set out in the same area caught 23.1% moths (Robinson & Robinson, 1973) and ones placed near webs of *C. moluccensis* (in more exposed locations) captured 8.3% moths (Lubin, unpublished).

These observations suggest that sticky traps are unsuitable for trapping moths, whether they be highly visible plastic sheets or thin sticky threads. This is probably due to the nature of the sticky substance and to the fact that moths can shed their scales readily (Eisner *et al.*, 1964). Indeed, we often found sticky threads with moth scales on them (and no moths), suggesting that moths which encountered sticky trap threads escaped by shedding their scales. Contradictory results were obtained by Chacón & Eberhard (1980) from sticky-thread traps set at night in an open field, where Lepidoptera comprised the fourth most abundant group of insects trapped (approximately 7% of 3407 insects). As the same adhesive was used in both studies, this high rate of capture may reflect a very great abundance of moths in the open field habitat rather than a difference in trap effectiveness.

Moths were a major component of the prey of certain other spiders found in the same habitat as *Miagrammopes*, comprising 37.6 and 23.6% respectively of the diets of *Cyrtophora moluccensis* and *Nephila maculata* (Fabricius), both orb-weavers that are active during the day and at night. Other nocturnal moth specialists were abundant including the ladder-web spider, *Tylorida* sp. (Robinson & Robinson, 1972) and *Pasilobus* sp. (Robinson & Robinson, 1975). Unlike these nocturnal araneids, *Miagrammopes* caught few, if any moths (Lubin *et al.*, 1978 and unpublished observations), perhaps because moths do not stick to cribellate silk. Indeed, moths offered to *M. simus* Chamberlin & Ivie in Panama escaped readily from the capture threads, whereas other insects remained firmly stuck to the silk (Lubin *et al.*, 1978). In this respect, sticky-thread traps may be good models of cribellate webs.

Flies, small parasitic wasps, beetles and, to a lesser extent, hemipterans made up the bulk of the nocturnal captures of sticky traps. The distribution of captures agrees well with the limited data on insects captured by *Miagrammopes* (Lubin *et al.*, 1978).

Number of threads

Perhaps the most unexpected result of the study was the fact that single-thread traps caught significantly more arthropods *per thread* than did multiple-thread traps. A 10-fold increase in the total length of sticky thread (by increasing the number of sticky threads) resulted in an increase in insect captures by only 5.9 times for vertical threads and 4.0 for horizontal threads.

The increase in effectiveness *per thread* of single-thread traps was apparently not the result of selective captures of a particular size class of insects, nor of any one taxon, although there was a trend for single threads to trap more higher Diptera and Hymenoptera than expected. The possibility that different insect species were trapped on single- and multiple-thread traps was not investigated.

Roth (1963) and Chacón & Eberhard (1980) found that traps with sparse (i.e., widely spaced) threads captured more insects per thread than did traps with dense threads. The latter authors suggested that increasing thread density increased the restraining or retention efficiency (by reducing the number of escapes), but not the efficiency of prey interception (see their fig. 9). We feel that this hypothesis, while theoretically accurate, does not explain the results of the present study because: (1) single- and multiple-thread traps present qualitatively different "obstacles" to airborne insects (unlike traps with different densities of threads) and (2) the threads in our multiple-thread traps were so widely spaced (gaps between threads were 3 x those of even the sparsest of Chacón & Eberhard's (1980) traps) that virtually all insects were trapped on only one thread and thus there could be no retention advantage to the multiple-thread traps. We suggest, instead, two alternative hypotheses for the increase in captures/thread on single-thread traps: (1) Single-thread traps were less conspicuous than multiple-thread traps, resulting in a greater number of insect interceptions/thread, or (2) single threads actually attracted insects to alight on them. Given the data at hand, we cannot distinguish between these alternatives, and indeed, both may be correct, but applicable to different groups of flying insects. For example, it is well known that some nematocerans hang from non-sticky elements of spider webs (Robinson & Robinson, 1976). Single threads might be more readily mistaken by such insects for non-sticky web elements than multiple threads, which resemble more closely a meshed web. However, reduced captures of Nematocera on single-thread traps as well as prey records from *Miagrammopes* webs (Lubin *et al.,* 1978) argue against this interpretation for both sticky traps and webs. Alternatively, insects which detect webs by visual, acoustical-mechanical (including detection of air-current deflections) or tactile cues may be more likely to detect and avoid multiple-thread traps (or webs) than single-thread ones. Considerable caution must be exercised, however, in generalising from sticky-thread traps to webs (J. Castillo, in prep.).

Both hypotheses suggested above are based on considerations of how flying insects perceive and respond to cues presented by web-like obstacles. The spiders' web is designed as a trap, not for inanimate moving objects, but for arthropods which are capable of altering their trajectories based on information obtained through highly developed sensory organs. The ability of some insects to detect and avoid webs has been documented (Turnbull, 1960; Lubin, 1974; Vollrath, ms.). In the design of traps for airborne insects, these attributes must be taken into account. Thus, the interception function (Chacón & Eberhard, 1980) of spider webs requires an arrangement of sticky elements in such a way as to (1) provide maximum impact surface and (2) render the web either invisible or, alternatively, attractive to potential prey. Web design may involve a compromise between these two aspects of the interception function.

There are, conceivably, other advantages to constructing reduced webs with one or few sticky threads, e.g. reducing the energetic cost of web construction both in terms of silk production and time spent in web building. The results of these experiments suggest that the loss in numbers of potential insect prey due to the reduction in trapping surface is at least partly compensated by an increase in captures per unit length of single-thread webs.

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frequently on *Lucaena* sp. (a common plantation shade-tree), pine (*Pinus radiata*) and araucaria (*Araucaria hunsteinii* and *A. cunninghamii*). The sticky traps were all set in one such overgrown coffee plantation where webs of *Miagrammopes* were abundant.

Five series of tests were performed (see Table 1). In experiments I-III only single-thread traps were used, consisting of threads 50 cm long suspended from *Lucaena* branches and each weighted at the end with a ball of modelling clay (Fig. 1A). Threads used were 2 lb test nylon monofilament (experiments I-III) and fine nylon sewing thread (experiments II-III). The threads were coated with "Tack Trap" insect trapping adhesive (Osticon Co., USA) along 30 cm of their length, leaving a short, non-sticky portion at each end. Threads were left suspended *in situ* and coated at the beginning of each experiment, using a small piece of stiff plastic with a groove in it, dipped in the adhesive and drawn along the threads to produce a thin, relatively even layer of glue. Even with very small amounts of glue, however, some "balling up" of the sticky substance was inevitable.

In experiments IV and V both multiple-thread and single-thread traps were used and the design of the traps was modified. Traps consisted of a 40 x 40 cm frame made of galvanised fencing wire with 10 threads strung at 3 cm intervals (multiple-thread traps) or a single thread strung in the centre of the trap (single-thread traps) (Fig. 1B, C). Each thread was coated with Tack Trap along 30 cm of its length, as in experiments I-III. Paired traps were suspended

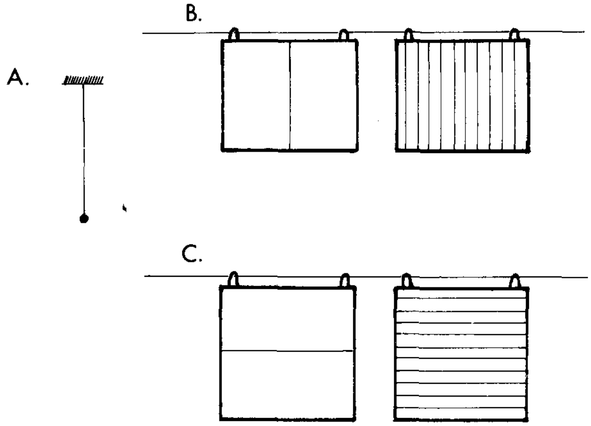

Fig. 1: Design of sticky traps: **A** Single-thread traps, experiments I-III. **B** Paired single-thread and multiple-thread traps, with threads oriented vertically, experiment IV. **C** Paired traps as in **B**, with threads oriented horizontally, experiment V.

about 1.7 m above ground from strings tied between *Lucaena* trees, with threads oriented either vertically (experiment IV) or horizontally (experiment V). These traps were not unlike those designed by Eberhard (1977b), except that we used thinner monofilament (2 lb test vs. 3 kg test) and the spacing between threads was greater.

Arthropods were removed from the traps using fine forceps, immersed in kerosene to dissolve the glue and then sorted to taxa, counted and measured. Insects were identified to order and Diptera were

Experiment	Dates	Trap Design and Arrangement	Collection Time	No. Trap-Days
I	8-12 Feb 1980	25 single-thread traps of 2 lb test monofilament.	0800	125
II	1-5 Mar 1980	10 pairs of single-thread traps, each consisting of one 2 lb test monofilament thread and one nylon sewing thread.	0800	50 per treatment
III	9-13 Mar 1980	10 pairs of single-thread traps, as in experiment II.	0700, 1800	40 per treatment
IV	16-18 Dec 1980	10 pairs of traps, each consisting of one multiple-thread and one single-thread trap, with threads oriented vertically. All threads were nylon sewing thread.	0600, 1800	30 per treatment
V	5-7 Jan 1981	10 pairs of traps, as in experiment IV, with threads oriented horizontally.	0600, 1800	30 per treatment

Table 1: Details of the design of sticky trap experiments.

her identified to Nematocera and "higher Diptera" (Brachycera and Cyclorrhapha). The rationale for this was that most nematocerans are small and delicate flies, whereas higher Diptera are more robust and fast-flying insects. Winged ants were distinguished from other Hymenoptera and Hemiptera were sorted to Heteroptera and Homoptera.

We measured maximum body length (including the wings, if folded) and width (excluding wings), using a dissecting microscope with an ocular micrometer calibrated at 0.2 mm intervals. Body size was calculated as length x width, giving a measure of the surface area (one side) of the insect. This measure was deemed more appropriate than a simple length measurement, since length alone would exaggerate the size of long, thin insects such as tipulid flies and emesine bugs, while underestimating the size of beetles and brachyceran flies.

Pairwise comparisons of the traps were tested with Student's t-test and comparisons of totals of all traps with a χ^2 test.

Results

Single-thread traps: experiments I-III (Table 2, Figs. 2, 3)

Single-thread sticky traps in experiments I-III captured 1473 arthropods, or 4.2-5.5 arthropods/thread-day (Table 2), more than half of which were flies (Fig. 2). Nematocera predominated in experiments II and III, while significantly more higher Diptera were trapped than Nematocera in experiment I ($p < 0.05$, t-test). Small drosophilid flies were caught in large numbers on some threads and accounted for more than half (53%) of the higher Diptera captured in experiment I. These flies occurred patchily in the vicinity of over-ripe coffee berries. Hymenoptera and Coleoptera were the next most numerous taxa trapped, comprising 15.5 and 8.6% of the total captures respectively, while all other arthropods combined made up less than 10% of the total captures. The latter included Lepidoptera (adults and occasionally larvae), Hemiptera, Blattoidea, Mantoidea, Orthoptera, Isoptera, Neuroptera, Araneae and Acarina. Most Hymenoptera trapped were small parasitic wasps; these accounted for 66-79% of the category "bees and wasps" in experiments I-III.

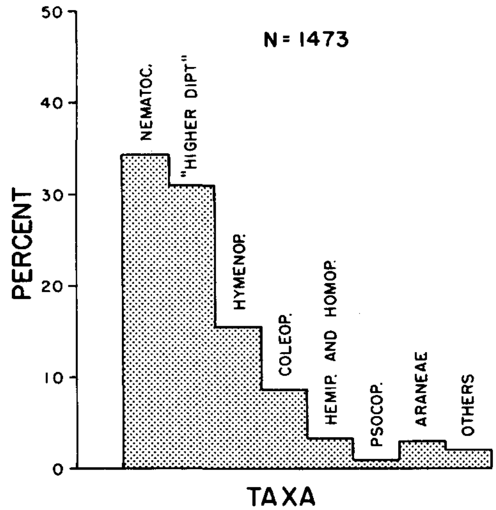

Fig. 2: Percentage of arthropods of different taxa captured on single-thread traps in experiments I-III combined.

The vast majority of arthropods trapped on single threads belonged to size categories less than 5 mm^2, and more than 80% of Nematocera and 60% of higher Diptera were less than 3 mm^2 (Fig. 3). Coleoptera tended to fall in larger size classes owing to their bulkier bodies. The smallest insects trapped were nematocerans and mites less than 1 mm in length

Exp.	Thick Threads		Thin Threads	
	No. Insects	Insects/Thread-Day	No. Insects	Insects/Thread-Day
I	516	4.2 ± 3.3		
II	237	4.8 ± 3.2	200	4.0 ± 4.0
III				
Day	219	5.5 ± 3.6	186	4.7 ± 2.7
Night	69	1.7 ± 2.4	46	1.2 ± 2.0

Table 2: Numbers of insects trapped on single-thread traps with thick (2 lb test monofilament) and thin (nylon sewing thread) threads: total numbers of insects in all traps combined and numbers of insects per thread per day (± 1 S.D.).