EFFECTIVENESS OF MALAISE TRAPS IN COLLECTING HYMENOPTERA: THE INFLUENCE OF TRAP DESIGN, MESH SIZE, AND LOCATION

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Abstract

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The influence of various aspects of Malaise trap design on efficiency in collecting various groups of Hymenoptera was compared using commercially available traps. The influence of fine and coarse mesh sizes and the importance of the incorporation of pan traps into the design were evaluated in two sampling periods in an old dune community at Pinery Provincial Park in southern Ontario. Numbers of individuals collected in Malaise trap heads and pan traps were presented for each paired comparison of mesh size (fine and coarse) and location (top and bottom of a hill) for various families of Hymenoptera. A graphical analysis of the normalized catch data for more inclusive groupings, *viz.* Symphyta, Aculeata, Ichneumonoidea, and microhymenoptera, was presented. The major results of these comparisons were as follows: (1) pan traps were an important component of efficient Malaise traps, especially for Aculeata and microhymenoptera; (2) coarse mesh was more effective in collecting Aculeata; (3) coarse and fine mesh were both effective in collecting Ichneumonoidea; and (4) fine mesh was more effective in collecting microhymenoptera. There was an interaction effect between the type of trap used and groups collected and it was not possible to maximize simultaneously the collection of all groups of Hymenoptera. The use of various mesh types and a trap design that incorporates pan traps was recommended.

Résumé

On a comparé l'influence de certaines caractéristiques du désign de pièges Malaise pour leur efficacité à collecter divers groupes d'Hyménoptères, en utilisant des modèles disponibles sur le marché. L'influence de la grandeur des mailles et l'importance de l'inclusion de bacs de piégeage ont été évalués lors de deux périodes d'échantillonnage dans une communauté avancée du type dune au Pinery Provincial Park, en Ontario. Les nombres d'individus collectés dans le haut des pièges Malaise et les bacs sont donnés pour chaque grandeur de mailles testée (fines, grosses), et chaque site de piégeage (bas et haut d'une colline), et ce pour diverses familles d'Hyménoptères. On présente une analyse graphique des données de capture normalisées pour des groupes plus inclusifs, soit les Symphyta, Aculeata, Ichneumonoidea et microhymenoptères. Les résultats de ces comparaisons se résument comme suit: (1) les bacs se sont avérés un élément important des pièges Malaise efficaces, particulièrement pour les Aculeata et les microhyménoptères; (2) les grandes mailles sont plus efficaces pour les Aculeata; (3) les mailles fines ou grandes sont également efficaces pour les Ichneumonoidea; (4) les mailles fines sont plus efficaces pour les microhyménoptères. On a noté un effet interactif entre le type de piège utilisé et les groupes collectés, et il semble impossible de maximiser simultanément la collection des tous les groupes d'Hymenoptera. On recommande l'utilisation des divers types de mailles et un désign de piège qui comprend des bacs.

Introduction

The rapid disappearance of pristine habitats, especially tropical rain forests, is now widely regarded as an ecological disaster of enormous scope and significance. The extinction of hundreds of thousands of species before they will become known to science is predicted (Lewin 1986). Systematists are now faced with the option of either embarking on salvage collecting operations or letting the raw materials of their science disappear

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forever. Today's collecting trips to many areas of the world may well be the last opportunities to collect biological specimens for posterity and the limitations of various collecting methods must be understood if we are to make the most of these opportunities.

Perhaps the most effective means of obtaining specimens, and temporal and geographic distributional data (Evans and Owen 1965; Owen 1983), is the use of passive collecting methods. Malaise traps are commonly used but it is disconcerting how few comparative studies have been done to assess their collecting efficiency. With considerable foresight, Townes (1962) expressed some hesitation when he presented his design for a Malaise trap, fearing that the design might become frozen and not subject to further experimentation. This appears to have been the case. To date, most of the experimental work on trap design has been directed at determining the effectiveness of various baits in increasing the catch of horseflies and deerflies (Diptera: Tabanidae) (Steyskal 1981). Flight intercept traps also are commonly used to collect flying insects (Peck and Davies 1980; Masner and Goulet 1981). These are essentially Malaise traps without a collecting head but with a trough installed at ground level to collect the intercepted insects. Another method of passive sampling involves the use of pan traps (Southwood 1978). The attraction of insects to particular wavelengths of light has been incorporated to increase collecting efficiency; yellow is the preferred colour (Kennedy *et al.* 1961; Hollingsworth *et al.* 1970). With these various methods of collecting available it is unfortunate that there have not been more comparative studies of trapping efficiency.

Few studies exist on the relative collecting efficiency of different Malaise trap designs. Townes (1972) noted that the colour of various parts of the trap can have dramatic effects on the catch of Hymenoptera, but no detailed methods or raw data were presented so this effect must be regarded as conjectural. Matthews and Matthews (1983) compared two commercially available traps during a 4-week period and concluded that the Townes traps collected more insects, regardless of trap position or placement, than the Cornell trap. However, the trap designs were so different that it was difficult to determine the reasons for the differing efficiencies. Data were presented only for the major orders of insects, and not for less inclusive groupings.

We report here the results of a sampling programme designed to determine the factors affecting the efficiency of a particular style of Malaise trap in collecting Hymenoptera. Susceptibility to trapping is expected to vary within a single order of insects because of differences in behaviour related to factors such as body size, flight activity, sensory perception, and ecology. We have therefore analysed our trapping data separately for various taxonomic groups of Hymenoptera. Our experimental design addresses the specific question of whether or not it is possible to maximize simultaneously the catch of all groups of Hymenoptera. If so, the optimal design should be adopted as standard procedure for faunal surveys and salvage collection programmes. If it is not possible to maximize the catch, then the constraints and limitations of each trapping protocol should be understood to allow for a choice of the appropriate method or for the adoption of multiple methods.

Methods

This study was conducted at the Pinery Provincial Park in southwestern Ontario (Lambton County, 43°16′N, 81°50′W) during the summer of 1986. The traps were situated in a power line right-of-way through moderately dense woodland on an old sand dune system. The right-of-way was maintained by cutting and not by the application of herbicides. Areas of bare sand were not uncommon. Vegetation included beard grass (*Andropogon* sp.), poison ivy (*Rhus radicans* L.), and New Jersey Tea (*Ceanothus americanus* L.). The surrounding woodlands were predominantly oak (*Quercus* spp.).

Commercially available Malaise traps (Townes 1972) were used exclusively in this study (Golden Owl Publishers Inc., 182 Chestnut Rd., Lexington Park, MD, USA 20653).

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Pan traps were installed along the long axis of the traps. This design modification incorporates aspects of flight intercept and pan traps with the standard Malaise trap and allows for a comparison of these methods if insects collected in the pans are analysed separately from those collected in the Malaise trap head. The traps were identical except for the fabric used in their construction. ''Fine'' traps (Ft) were constructed with tricot warp knit polyester ''no-see-um'' netting with a maximum opening of about 0.8 mm (Figs. 1, 3). Note that the effective opening to a crawling or flying insect is much smaller due to the complexities of the mesh design. ''Coarse'' traps (Ct) were constructed with leno weave polyester netting with rectangular openings of about 0.8 mm (Figs. 2, 4). The Ft (Fig. 1) were uniform olive drab and the Ct were bicoloured with the lower panels black and the upper panels white (Fig. 2).

To determine the efficiency of the Malaise trap head in collecting insects intercepted by the trap, yellow pan traps were incorporated into the design. A comparison of the catch in the trap head and in the pans effectively compares the relative efficiency of traditional Malaise traps and flight intercept traps in collecting insects randomly encountering the traps or attracted by the yellow pans. The pan traps were painted potting trays (54 by 28 by 6.5 cm) and were installed along the major axis of the traps and recessed to ground level (Fig. 1). These were filled with tap water, with a small amount of detergent added to reduce the surface tension.

The two traps were operated simultaneously across a power line right-of-way and separated by a distance of approximately 200 m. The ''top'' site (Ts) is at a slightly higher elevation than the ''bottom'' site (Bs). Ts was selected *a priori* as a better location for collecting flying insects. This site is at the crest of a small hill and at the confluence of two rights-of-way (Figs. 1, 2 [Note: both traps are visible in Fig. 1]).

The protocol involved two separate sampling periods: 1–6 June and 15–21 June. Traps were installed at each site for a period of 2 or 3 days and then disassembled and switched; during each sampling period both coarse and fine traps were used at both top and bottom sites. The same traps were used throughout the study. All specimens were collected before switching the traps, and the samples from the Malaise trap heads were kept separate from the pan traps. The specimens in the pan traps were collected using a fine mesh aquarium dip net.

Samples were sorted twice (once with a dissecting microscope) to remove all Hymenoptera. Ants (Formicidae) were omitted from our analyses for two reasons: (1) the synchronized swarming of alates would likely have resulted in high day-to-day variance in the numbers caught and this would not be expected for other taxa included in our analysis; and (2) proximity of the trap locations to individual ant nests would have biased the comparison of trap location. In fact, comparatively few ants were found in any of our samples. Specimens were identified to family level and were subsequently grouped into the suborders Symphyta (the sawflies), Parasitica (the parasitic wasps), and Aculeata (the stinging wasps). We subdivided the parasitic wasps into two groups generally thought to be ecologically and behaviourally distinct: Ichneumonoidea (Ichneumonidae and Braconidae), and microhymenoptera (remaining families). Compared with the microhymenoptera, ichneumonoids are usually larger and more active fliers. Passive movements are expected to be more important in microhymenoptera. In addition, there is some anecdotal information that these two groups of parasitic wasps may search for hosts in different microhabitats, with the smaller wasps, especially the Proctotrupoidea *sensu lato* (including Scelionidae, Diapriidae, and Platygasteridae), usually restricted to the narrow interface at ground level.

A standard normalization procedure was used to allow the comparison of the composition of samples without overemphasizing the differences in absolute numbers of specimens collected. In a study such as this, normalization helps correct for the influence of external factors such as weather, prevailing winds, and effective sample duration. The normalized catch is determined by setting the length of the sample vectors to unity. The

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FIGS. 1–4. Malaise trap design, construction, and location: 1, fine mesh trap at bottom site (Note: pan traps installed beneath and second trap in the distance at top of rise); 2, coarse mesh trap at top site; 3,4, photomicrographs of mesh types, scale line 0.5 mm: 3, fine (warp direction, vertical); 4, coarse (warp direction, horizontal).

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number of specimens collected of each taxonomic category (e.g. Symphyta, Aculeata) was divided by the sum of squares of all the values in the sample (Orlóci 1978: 46). For example, if the numbers of specimens collected in four groups for an individual sample were 5, 3, 2, and 4 (sum of squares = 54), the normalized values would be 5/sqrt(54), 3/sqrt(54), 2/sqrt(54), and 4/sqrt(54), or 0.6804, 0.4082, 0.2722, and 0.5443.

Voucher specimens and the samples that form the basis for these analyses are stored in the Department of Entomology, Royal Ontario Museum.

Results and Discussion

The raw data are provided as a means of evaluating the effectiveness of Malaise and flight intercept traps in sampling Hymenoptera; the number of specimens collected for various families and superfamilies and for the more inclusive groupings are provided in Table 1. For the total Hymenoptera data set a pairwise comparison of the 31 groups (two-tailed *t*-test, pooled variance, df = 30) indicates that more specimens were collected in the top than the bottom sites (means: Ts = 65.19, Bs = 30.68; $t = -2.31$, $p < 0.05$). There were, however, no differences between either the coarse and fine traps (means: Ct = 54.58, Ft = 41.26; $t = 0.85$, $p > 0.05$) or between Malaise trap heads and pan traps (means: heads = 60.55, pans = 35.32; $t = -1.62$, $p > 0.05$). Although almost twice as many specimens, on average, were collected by trap heads the extremely high variance in catch made these differences statistically insignificant using the *t*-test.

Sawflies (Symphyta) were relatively uncommon during the sampling programme, comprising only about 4% of the Hymenoptera collected. For this reason it is not possible to make any generalizations about the relative effectiveness of the various Malaise trap designs for sawflies. Aculeata comprised 32% of the total catch. Sixty-four percent were Parasitica; about one-half (47%) were microhymenoptera. Ichneumonoidea constituted only about 17% of the specimens collected, and Ichneumonidae and Braconidae were equally represented.

Within the higher taxonomic categories there was a tendency for certain groups to be concentrated in either the Malaise trap heads or in the pan traps. In the Aculeata, for example, Sphecidae were equally represented in the trap heads and in the pans, indicating that either can be used to sample these wasps. However, Pompilidae were better represented in the pans than in the heads (seven of eight comparisons). A standard configuration of a Malaise trap would probably fail to collect many of the pompilids that were intercepted and would underestimate the abundance and probably the diversity of this family. Masner and Goulet (1981) note that parasitic microhymenoptera appear to be poorly represented in Malaise trap catches but our results suggest that there is considerable variability at the family and superfamily level. For example, Cynipoidea accumulate in the heads (seven of eight comparisons, one tie) whereas Diapriidae accumulate in pan traps (six of eight comparisons, one tie). Ceraphronoidea and Scelionidae also are represented better in pan traps (five of eight comparisons, in each case).

The data for the individual taxa were collapsed to four groups (Table 1) and these data form the basis for the graphical analysis (Fig. 5). For each sampling period, the number of specimens trapped in the heads and pans was compared for the four combinations of mesh size and trap location (Fig. 5*a–d*). A similar graphical analysis was made using the normalized data for the pooled taxa and is presented in Figure 5*e–h*.

This analysis indicates the importance of using a Malaise trap design that incorporates pan traps. This is particularly evident for Aculeata and microhymenoptera in which large numbers of specimens were caught in the pan trap sample (Fig. 5*a–d*). Ichneumonoidea were more effectively collected by the Malaise trap head than the pans; specimens were 3-fold more likely to be found in the head. In 25 of 32 comparisons using normalized data the Malaise trap head and pans give the same rank order of catch for the various treatments (mesh, location). Five of seven misses involve Ichneumonoidea, and the other two involve

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Table 1. Numbers of specimens of various taxonomic groups collected during the two sampling periods. Each sampling period used all combinations of mesh size (COARSE, FINE) and trap site (TOP, BOTTOM). In each comparison the Malaise trap head (Head) and pan traps (Pans) were treated separately

	Sampling period 1								Sampling period 2								
	1–3 June				4–6 June				15–17 June				18–21 June				
	COARSE BOTTOM		FINE TOP		COARSE TOP		FINE BOTTOM		COARSE BOTTOM		FINE TOP		COARSE TOP		FINE BOTTOM		
Taxon	Pans	Head	Pans	Head	Pans	Head	Pans	Head	Pans	Head	Pans	Head	Pans	Head	Pans	Head	Totals
SYMPHYTA	6	43	3	13	4	19	3	6	1	3			1	5	1		108
ACULEATA	17	68	35	31	117	117	20	44	37	63	16	39	93	207	14	39	957
Bethylidae					5		1		2		2		3		1		14
Dryinidae		3	2	7	1	9	1	2		17	1	16	1	64	4	6	134
Tiphiidae	4	10	4		46	15	3	8	3	2			16		2		113
Scoliidae					3							2	2				7
Mutillidae								1	1		1		1	2	1	1	8
Sapygidae		1		1		1	1			1							5
Chrysididae		9		4	5	4		2	1	1			2	3			31
Pompilidae	2	3	3	2	10	3	2	1	12	2	6		14	1	2	1	64
Vespidae		2	2	2	4	7		5		2			1	3		1	29
Sphecidae		3	4	4	4	6	3	4	2	6	1	3	13	17	1	10	81
Apoidea	11	37	20	11	39	72	9	21	16	32	5	18	40	117	3	20	471
ICHNEUMONOIDEA	5	76	23	91	36	62	5	6	6	20	17	13	25	62	5	49	501
Ichneumonidae	4	63	9	72	23	8	5	1	3	1	5		8	2	1	25	230
Braconidae	1	13	14	19	13	54		5	3	19	12	13	17	60	4	24	271
MICROHYMENOPTERA	14	47	55	180	99	94	48	103	45	31	157	137	151	119	36	90	1406
Ceraphronoidea		1	5	2	5	2	2	5	13		22	7	16	1		6	87
Scelionidae	1	2	6	16	19	2	7	9	10		35	21	56	6	13	6	209
Diapriidae		4	4	3	8	3	5	2	7		13	3	8	6	5	5	76
Platygasteridae	2	8	20	73	25	13	10	33	6	3	32	34	19	5	3	29	315
Proctotrupidae					2		1		1			2	6	5			17
Cynipoidea	1	11	2	20	5	24	3	3		10	5	13	5	31	1	5	139
Mymaridae	1		4	2	5		9	18	6	7	11	10	11	6	5	11	106
Chalcididae	2		2	3	3		1				3		5		3	1	23
Eurytomidae		3	3	4	5	19	1	2		6	4	20	4	10			81
Torymidae				1	3	2								1			7
Perilampidae			1		1				1							1	4
Eupelmidae				1	1	1		3					2	1		2	11
Ormyridae				4		1	1				1		1			1	9
Encyrtidae	1		1	8	7	1	4	4			5	8	7	16		9	71
Pteromalidae	3	12	4	22	4	13		15		3	2	6	2	6	4	3	99
Aphelinidae												3	2			2	7
Eulophidae	3	6	3	21	6	13	4	9	1	2	24	10	7	25	2	9	145
TOTALS	42	234	116	315	256	292	76	159	89	117	190	189	270	393	56	178	2972

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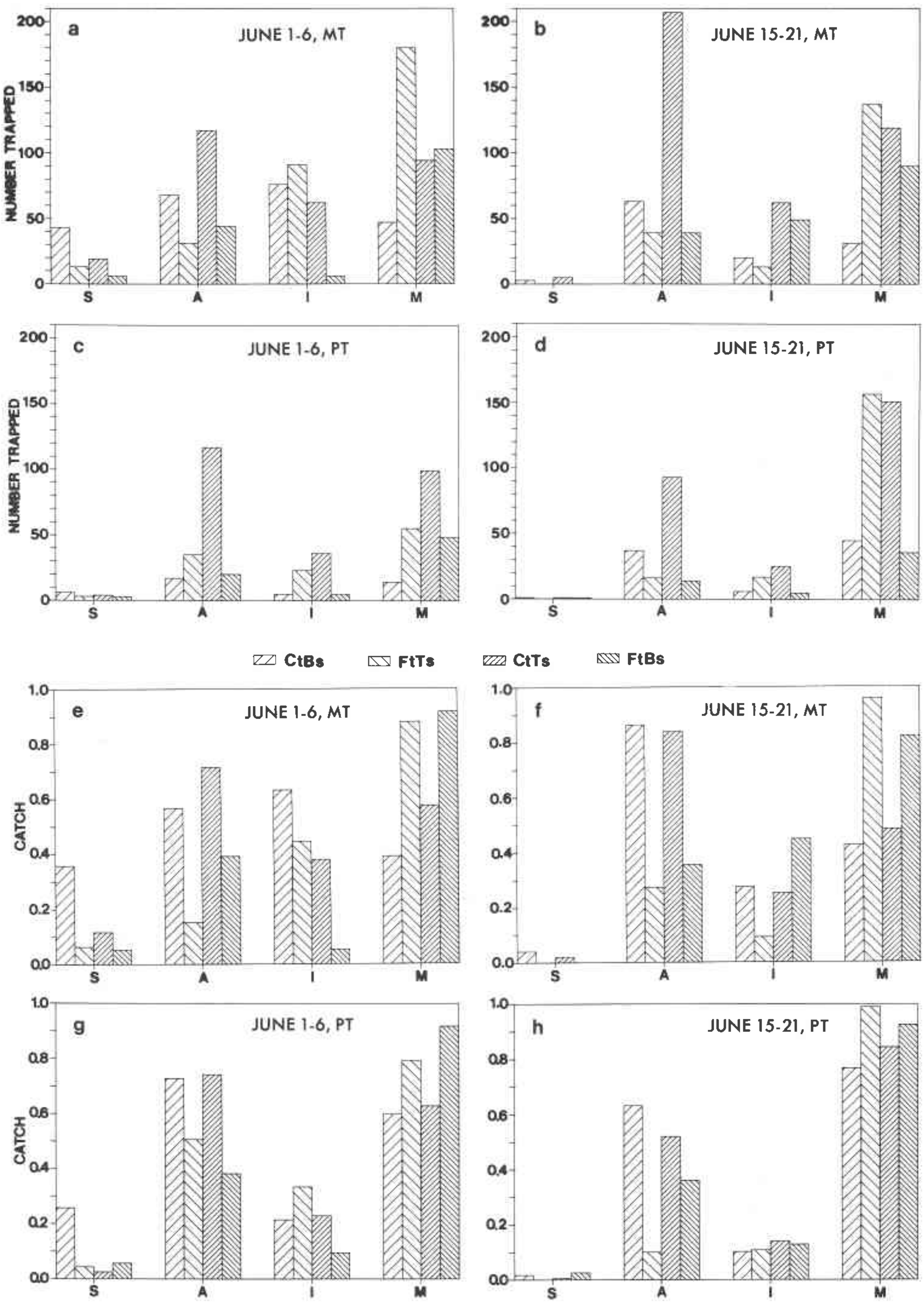

FIG. 5. Graphical analysis of Hymenoptera collected in sampling period 1 (1–6 June) and sampling period 2 (15–21 June): *a–d*, number of specimens collected; *e–h*, normalized catch. Abbreviations: MT, Malaise trap heads; PT, pan traps; S, Symphyta; A, Aculeata; I, Ichneumonoidea; M, microhymenoptera; Ct, coarse mesh traps; Ft, fine mesh traps; Ts, top site; Bs, bottom site.

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Symphyta. These results indicate that both heads and pans were effectively sampling the same populations of aculeates and microhymenoptera and that no bias at the family and superfamily level would be introduced by using only a single sampling method. For Ichneumonoidea there appears to be an interaction of treatment (mesh, location) and probability of a specimen turning up in either the heads or the pans and this could relate to differing flight activities and the probability that a wasp will end up in the head *versus* the pans. For example, if wasps were using the Ts flyways to move longer distances and at higher speeds, then they may either be better able to avoid a particular style of net (Ct or Ft) or, if intercepted by the trap, have an increased probability of ending up in either the head or pans. About equal numbers of microhymenoptera were collected in pan traps and Malaise trap heads. However, the normalized catch is greater for the pan traps. The explanation for this may be related to the small size of most of these wasps. The probability of an intercepted microhymenopteran making it to the collecting head may be much lower than the probability of it falling into the pans. For these reasons the use of flight intercept traps with insecticide have been advocated (Masner and Goulet 1981). Clearly, a collecting or sampling programme for the smaller parasitic Hymenoptera using Malaise traps is inefficient if it does not incorporate pan traps.

The type of mesh used in the construction of the traps also influenced the catch of Hymenoptera. Aculeata, Ichneumonoidea, and microhymenoptera are differently represented in the two types of traps. The normalized data for the Aculeata show that regardless of trap location (Ts or Bs) the coarser, bicoloured traps have a higher catch. This result is replicated in both experiments and in both the pans and the heads. One possible explanation is that aculeates were better able to perceive and avoid the olive drab fine traps. This may be due either to the colour of the traps or to differences in airflow through the traps due to the different mesh sizes. Alternatively, aculeates may be more likely to escape from the uniform traps than from the bicoloured traps. In the present study there does not appear to be any strong association of the catch of Ichneumonoidea with either mesh type or trap location and Ichneumonidae and Braconidae are equally abundant. Ichenumonoidea comprise a far smaller proportion of the total sample than the 89% reported by Matthews and Matthews (1983), a study in which Ichneumonidae outnumbered Braconidae by 2:1. As most of the smaller Ichneumonoidea are braconids (e.g. Aphidiinae, Alysiinae), the differences in the relative abundance of braconids and ichneumonids could be simply due to the failure of the traps used by Matthews and Matthews (1983) (coarse mesh without pan traps) to collect microhymenoptera and smaller braconids. This does not appear to be the case because even when only the Malaise trap head samples from the coarser traps are considered, Ichneumonoidea only comprise about 22% of the sample (44% Aculeata, 27% microhymenoptera). These differences may be due either to seasonal or regional differences in the distribution and abundance of various groups of Hymenoptera or to procedural factors (e.g. the sorting procedures used in the earlier study may have missed smaller insects, thereby overestimating the proportion of Ichneumonoidea). The normalized catch data show quite clearly that fine mesh traps are more effective than coarse traps in catching microhymenoptera. In all four comparisons the fine traps resulted in a higher catch. The consistency of this result in both heads and pans indicates that mesh size is more important than the behaviour of the insects after entering the trap. Although some very small wasps may be able to fly unimpeded through the openings in the coarse net, many probably alight on the netting and are able to crawl through the openings to escape. The location of the trap did not have an important influence on numbers of specimens collected.

FIG. 6. Interaction of trap type and groups of Hymenoptera, normalized catch data: *a*, microhymenoptera and Aculeata; *b*, microhymenoptera and Ichneumonoidea. Open symbols, coarse mesh traps (Ct); closed symbols, fine mesh traps (Ft). Squares (□ or ■), top site (Ts); circles (○ or ●), bottom site (Bs). Malaise trap heads (MT) and pan traps (PT) are distinguished by a slash (/) through the symbol for pan traps.

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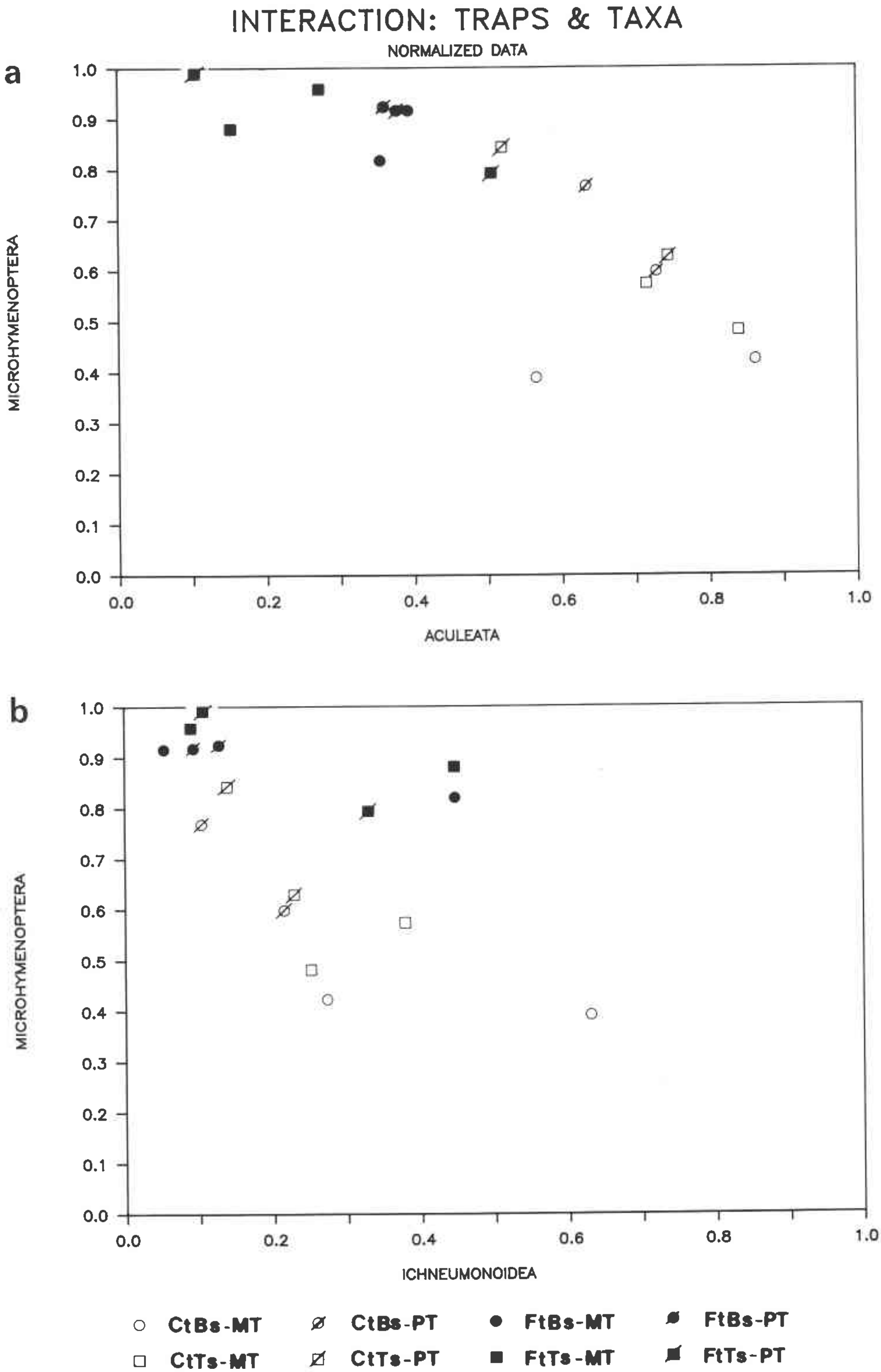

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As should be evident from this discussion, there appears to be an interaction between the type of trap used and the taxa collected. A change in netting from a concoloured trap of fine mesh to a bicoloured trap of coarse mesh will result in an increased catch of aculeates and Ichneumonoidea relative to microhymenoptera (Fig. 6). These effects were of such a magnitude as to override any effects of trap location. At least for the data presented herein, trap location is unimportant in determining the composition of the catch of Hymenoptera at the family level relative to the type of trap employed.

The definitive study of Malaise traps has yet to be done. This and earlier studies have demonstrated clear differences in the effectiveness of various trap designs. Causal explanations are more difficult to determine. The commercially available traps used in this study confounded the effects of mesh size and trap colour. For example, it is not possible to determine whether Aculeata are better represented in the coarser traps because of reduced airflow through the finer trap or reduced visibility of the trap as compared with the olive drab finer mesh fabric or because of an increased phototactic response of intercepted insects due to the bicoloured white-above design. A rather elaborate experimental design will be required to control for the effects of intrinsic variables such as colour, mesh size, and airflow through traps as well as extrinsic factors such as insect flyways, solar path, weather, and habitat variability.

This analysis of trapping efficiency does have clear implications for most sampling programmes (e.g. faunal surveys or general collecting) of Hymenoptera. First, pan traps are an important component of an efficient Malaise trap. Second, various types of mesh should be employed at least until it is possible to determine which aspects of mesh type (size, colour) are responsible for the variability in catch.

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