Methods for quantifying spider density and migration in cereal crops

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Summary

A method of using combined D-Vac suction and hand-searching to assess spider density in a cereal crop is described. Hand-searching helped to correct the biased estimates resulting from suction sampling. D-Vac extraction efficiency of surface-dwelling spiders was variable between sites. Spiders were found to aggregate in weedy areas of the crop as the season progressed. A description is also given of a caging method used to measure spider migration.

Introduction

Much present interest centres around the reduction in use of pesticides and an increased reliance on natural predators (including spiders) in the field. However, in order to achieve this, careful ecological studies are required to determine those factors controlling predator numbers (Sunderland, 1992). An essential prerequisite for these studies is the development of reliable sampling methodology, including methods for estimation of density (e.g. Duffey, 1989).

Many methods have been used to assess the abundance of spiders in crop systems, including pitfall trapping, hand-searching, suction sampling and Tullgren funnel extraction (Toft, 1989; De Keer & Maelfait, 1987; Yeargan & Cothran, 1974; Duffey, 1962). However, accurate measurements are difficult and can be time-consuming. Pitfall trapping, suction sampling and ground-searching are all unsuitable for spider density estimation in cereals if used in isolation (Duffey, 1980; Sunderland et al., 1987; Topping & Sunderland, 1992). One approach is to use a number of complementary techniques on the same unit of ground (e.g. Dinter & Poehling (1992) removed vegetation, for laboratory sorting, before suction-sampling the area below the excised vegetation). In a study of predators in winter wheat Sunderland et al. (1987) used a combination of suction sampling followed by ground-searching and finally pitfall trapping to determine density. These methods, although extremely accurate, were very labour intensive and could not be used for regular sampling if time was limited.

One cause of changes in spider density in cereal fields can be migration. Many common cereal species are thought to be highly migratory (Duffey, 1956), and this is likely to form an important component of their population dynamics. However, this migration has never been adequately quantified because previous studies have relied on indices of aerial movement (e.g. Duffey (1956) used sticky traps).

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This paper describes two techniques used in a population dynamics study of spiders in a cereal crop: a combination of D-Vac suction-sampling (Dietrick, 1961) and ground-searching for assessing density, and a caging method for measuring the changes in density resulting from the processes of immigration and emigration (net migration).

Methods

Sampling sites

Sampling was undertaken during 1990 in a field of winter wheat (cv. Pastiche), on a chalk with flints soil; during 1991 sampling was conducted in a field of winter wheat (cv. Riband) on a silty brick earth soil. The surface of the chalk soil was very particulate and weed cover was more even than at the silty brick earth site. Both fields were treated with agrochemical applications (fertiliser and fungicides), following normal farming practice; insecticides were not required in either year.

Density sampling

The density sampling was used for a population dynamics study of spiders in winter wheat (Sunderland & Topping, 1993). Sampling entailed a combination of suction sampling and ground-searching, based on the methods of Sunderland et al. (1987). The sampled area was not pitfall-trapped to extinction, after ground-searching, therefore this method was likely to under-estimate total spider density (see Sunderland et al., 1987). However, if careful destructive searching is employed, this error is likely to be less than 5% and can be considered negligible.

To take a sample, an area of 0.5 m^2 was delimited by a 35 mm deep steel ring. The area inside the ring was then thoroughly sampled with a suction sampler by repeatedly raising and lowering the suction head within the delimited circle for a period of two minutes. The sampling head was modified by the addition of a 1 m long steel tube (Fig. 1). This modification prevented the
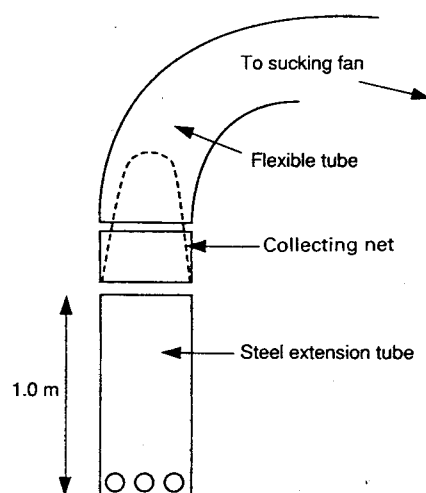

Fig. 1: Modifications to the head of a suction sampler to allow live samples to be taken from tall crops.

spiders being crushed between the crop and the net. This was found to be a problem when sampling without the extension tube in a tall crop (>0.7 m). A secondary benefit was a reduction in the degree of flattening of the crop, which might otherwise have decreased air-flow through the vegetation and thus decreased extraction efficiency. Immediately following the suction sampling the delimited area was destructively hand-searched for spiders for a period of ten man-minutes.

The suction sample was returned to the laboratory for storage at 9°C and subsequent live-sorting of spiders.

Sets of fifteen density samples were taken at intervals of one to three weeks between March and October 1990 and again between March and September 1991. All samples were taken at least 60 m from the field boundary, with the placement of each sample following a pre-determined plan to avoid sampling the same area twice. Maximum Likelihood Procedure, MLP (Ross, 1987) was employed to compare the fit of the Poisson and negative binomial distributions to the density samples for each date in order to test for significant aggregation of the sampling data. Comparisons between catches were performed using arc-sine transformations for percentages.

During July and August 1991 a visual assessment of the weed cover of each density sample area was made and a note made, immediately before sampling, of those samples from high (>75%) or low (<10%) cover.

The efficiency of live-sorting of the D-Vac samples was investigated by careful sorting, under the microscope, of the remaining portion (after live-sorting), of 31 randomly selected samples. The efficiency of storing samples at 9°C was also investigated by storing 30 D-Vac samples, from the 1991 sample site, in three randomly selected groups of ten. The first group was sorted immediately, and the other two groups stored for 48 and 72 h respectively before sorting.

Migration measurement

Ten circular 0.5 m² × 1 m tall cages were constructed out of steel rings supported by reinforcing mesh. These were covered with mesh with 3 × 2.5 perforations mm⁻² (too small to allow the passage of first instar linyphiid spiderlings) (Fig. 2). The cages were placed randomly
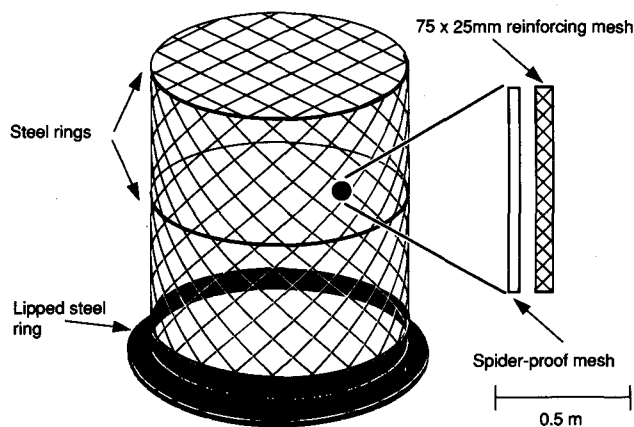

Fig. 2: The design of spider-proof field cages.

over undisturbed areas of crop following density sampling. In order to seal the cages any vegetation protruding from under the cages was removed and the bases sealed with sufficient compacted soil to prevent entry or exit of spiders. Spider density inside the cages was assessed by density sampling immediately upon removing the cages, on the same day that the field density was next measured. Cages were used between March and September 1991.

The net migration occurring between samples was measured by comparing the mean cage density with the mean field density. Any differences were attributed to migration since mortality and recruitment were assumed to be unaffected by such a short period of caging. Thus, net migration can be given as field density minus cage density.

Results

Density sampling

Density samples provided a total of 3004 adult spiders and 7772 juveniles comprising 51 species (Tables 1, 2). Species composition of both sites was very similar and typical of agricultural land, with high densities of *Oedothorax* spp., *Erigone* spp. and *Lepthyphantes tenuis* (Blackwall). The largest differences were noted in the density of *Meioneta rurestris* (C. L. Koch). This was the most abundant species in 1990 but only eighth most abundant in 1991.

Efficiency tests demonstrated that there was no significant loss of specimens after 72 hours of storage (immediate sorting $\bar{x} = 25.4$, 95% c.l. = 4.67, cf. after 72 hours $\bar{x} = 24.8$, 95% c.l. = 4.47). The efficiency of sorting was measured as 98.1% (95% c.l. 91.4–100%). Thus we conclude that overnight storage followed by live-sorting of the D-Vac samples will recover approximately 95% of spiders sampled.

Spider numbers were low at the beginning of the season in both years. Numbers then increased until harvest when a 60% decline in population density occurred (Fig. 3). Standard errors for the density estimates were variable and generally higher in the later part of the season. This appeared to coincide with high summer temperatures and a marked aggregation in the population in both years as the season progressed (low k, Table 3). Analysis of the five sets of density samples during the period 9 July 1991 to 5 August 1991 showed spiders to occur at higher densities in the weedy (mainly Gramineae) areas of the crop ($\bar{x}_{high\ cover} = 67.42$, SE = 13.98, $\bar{x}_{low\ cover} = 19.52$, SE = 2.26, $n = 5$).

Using arc-sine transformations, the proportion of spiders caught by D-Vac sampling was shown to be different in the two years. In 1990 the D-Vac samples yielded 81.1% (95% c.l. 72.8–88.7%, $n = 19$) of the juveniles and 54.1% (95% c.l. 45.9–62.1%) of the adults captured compared with 94.3% (95% c.l. 92.7–95.8%, $n = 18$) and 79.2% (95% c.l. 74.1–83.9%) during 1991.

There were also differences in the composition of the hand-search and D-Vac samples (Tables 1, 2). The

D-Vac captured 33.1% (95% c.l. 19.3%–46.9%, n = 19) (1990) and 71.6% (95% c.l. 62.6–81.6%, n = 18) (1991) of the ground-living linyphiids (subfamily Erigoninae) compared with 76.1% (95% c.l. 69.9–82.2%, n = 19) and 92.4% (95% c.l. 90.5%–94.3%, n = 18) of the largely vegetation-dwelling subfamily Linyphiinae. In 1991 there was also a general trend towards lower catches of erigonines in the D-Vac, as the crop developed. The D-Vac component of the total samples taken after harvest in September contained 85% of the erigonines compared with 59% in the preceding two months and 86% in May when the crop was in the early stem-extension growth stage. These large differences suggest that the D-Vac was operating at a lower efficiency for the ground-living spiders.

Estimating net migration

No evidence was found to indicate that spiders could escape from or enter the cage once it was installed. Mean

	1990 Females		Males		Total	1991 Females		Males		Total	Grand Total
	D-Vac	Hand	D-Vac	Hand		D-Vac	Hand	D-Vac	Hand		
Clubiona brevipes Blackwall	0	0	0	0	0	1	0	0	0	1	1
Clubiona reclusa O. P.-Cambridge	0	2	0	0	2	0	0	0	0	0	2
Xysticus cristatus (Clerck)	0	1	0	0	1	0	0	0	0	0	1
Oxyptila sanctuaria (O. P.-Cambridge)	0	1	0	0	1	0	1	0	0	1	2
Euophrys frontalis (Walckenaer)	0	1	0	0	1	0	0	0	0	0	1
Pardosa amentata (Clerck)	0	2	0	1	3	0	0	0	0	0	3
Pardosa palustris (Linnaeus)	0	3	1	0	4	0	0	0	0	0	4
Pardosa prativaga (L. Koch)	0	0	1	0	1	0	0	0	0	0	1
Pardosa pullata (Clerck)	0	0	0	0	0	0	1	0	0	1	1
Trochosa ruricola (Degeer)	0	0	0	0	0	1	0	0	0	1	1
Theridion bimaculatum (Linnaeus)	5	3	2	0	10	4	3	4	1	12	22
Theridion pallens Blackwall	0	1	0	0	1	2	0	2	0	4	5
Enoplognatha ovata (Clerck)	2	1	5	1	9	3	0	1	0	4	13
Enoplognatha thoracica (Hahn)	0	0	0	0	0	0	0	0	1	1	1
Pachygnatha degeeri Sundevall	7	8	8	9	32	0	2	1	0	3	35
Walckenaeria acuminata Blackwall	0	0	0	0	0	1	0	0	0	1	1
Walckenaeria atrotibialis (O. P.-Cambridge)	0	1	0	0	1	0	0	0	0	0	1
Dicymbium nigrum (Blackwall)	0	1	0	0	1	5	0	0	0	5	6
Dicymbium tibiale (Blackwall)	0	1	0	0	1	0	0	0	0	0	1
Dismodicus bifrons (Blackwall)	3	4	3	1	11	0	0	0	0	0	11
Hypomma bituberculatum (Wider)	0	0	0	0	0	0	0	1	0	1	1
Maso sundevalli (Westring)	2	0	0	0	2	0	1	0	0	1	3
Pocadicnemis juncea Locket & Millidge	0	0	0	0	0	2	0	1	0	3	3
Oedothorax apicatus (Blackwall)	1	3	1	1	6	27	17	40	17	101	107
Oedothorax fuscus (Blackwall)	7	20	6	5	38	42	49	65	19	175	213
Oedothorax retusus (Westring)	8	14	6	5	33	20	17	26	10	73	106
Tiso vagans (Blackwall)	0	0	1	0	1	6	2	2	1	11	12
Microctenonyx subitaneus (O. P.-Cambridge)	1	0	0	0	1	0	0	0	0	0	1
Monocephalus fuscipes (Blackwall)	0	0	0	0	0	1	0	0	1	2	2
Gongylidiellum vivum (O. P.-Cambridge)	0	0	0	0	0	0	0	1	0	1	1
Micrargus herbigradus (Blackwall)	0	0	0	0	0	1	0	0	0	1	1
Micrargus subaequalis (Westring)	1	2	1	1	5	1	0	0	0	1	6
Savignia frontata (Blackwall)	0	3	0	0	3	1	1	0	0	2	5
Diplocephalus latifrons (O. P.-Cambridge)	0	1	0	0	1	0	0	0	0	0	1
Panamomops sulcifrons (Wider)	7	4	4	0	15	1	0	0	0	1	16
Milleriana inerrans (O. P.-Cambridge)	23	33	12	13	81	3	3	0	0	6	87
Erigone atra Blackwall	31	51	31	40	153	59	61	44	31	195	348
Erigone dentipalpis (Wider)	14	23	8	21	66	13	27	9	8	57	123
Erigone promiscua (O. P.-Cambridge)	22	34	10	14	80	38	30	10	14	92	172
Porrhomma microphthalmum (O. P.-Cambridge)	0	1	0	0	1	8	0	5	0	13	14
Agyneta conigera (O. P.-Cambridge)	0	1	0	0	1	0	0	0	0	0	1
Meioneta rurestris (C. L. Koch)	176	142	109	81	508	27	20	8	7	62	570
Meioneta simplicitarsis (Simon)	7	4	0	3	14	0	1	0	0	1	15
Centromerita bicolor (Blackwall)	0	1	0	1	2	2	6	0	0	8	10
Bathyphantes gracilis (Blackwall)	19	5	16	2	42	55	10	52	8	125	167
Bathyphantes parvulus (Westring)	0	0	0	1	1	0	0	0	0	0	1
Diplostyla concolor (Wider)	0	0	0	0	0	7	0	1	0	8	8
Lepthyphantes ericaeus (Blackwall)	2	0	0	0	2	2	0	0	0	2	4
Lepthyphantes insignis O. P.-Cambridge	1	1	0	0	2	0	0	0	0	0	2
Lepthyphantes tenuis (Blackwall)	138	83	172	41	434	182	34	209	31	456	890
Microlinyphia pusilla (Sundevall)	0	0	1	0	1	0	0	0	0	0	1
Totals	477	456	398	241	1572	515	286	482	149	1432	3004

Table 1: D-Vac suction and hand-search catches of adult male and female spiders in winter wheat from density samples during 1990 and 1991.

	1990 D-Vac	Hand	Total	1991 D-Vac	Hand	Total	Grand Total
Clubionidae	27	22	49	7	1	8	57
Thomisidae	11	1	12	6	0	6	18
Salticidae	1	0	1	0	0	0	1
Pisauridae	0	1	1	1	0	1	2
Lycosidae	29	46	75	23	19	42	117
Theridiidae	108	2	110	31	4	35	145
Tetragnathidae	168	38	206	26	1	27	233
Araneidae	5	1	6	18	13	31	37
Erigoninae	641	124	765	943	128	1071	1836
Linyphiinae	1347	217	1564	3550	212	3762	5326
Total	2337	452	2789	4605	378	4983	7772

Table 2: D-Vac suction and hand-search catches of immature spiders in winter wheat from density samples during 1990 and 1991.

cage density generally fluctuated around mean field density (Fig. 4). The composition of the density samples was also very similar (Table 4) with only *Porrhomma microphthalmum* (O. P.-Cambridge) occurring in disproportionate numbers in the cage samples. However, the attempt to use the caging method to assess migration was only partially successful owing to the very large spatial variation in density of spiders in the field (Fig. 4). Confidence limits for the estimate are given by:

$$1.96\sqrt{\mathrm{SE}^2_{density} + \mathrm{SE}^2_{cage}}$$

These values were particularly high between 17 July and 24 September when the spiders were significantly aggregated. Before this, net migration was apparently limited until 21 May; some net emigration probably then occurred between 21 May and 18 June.
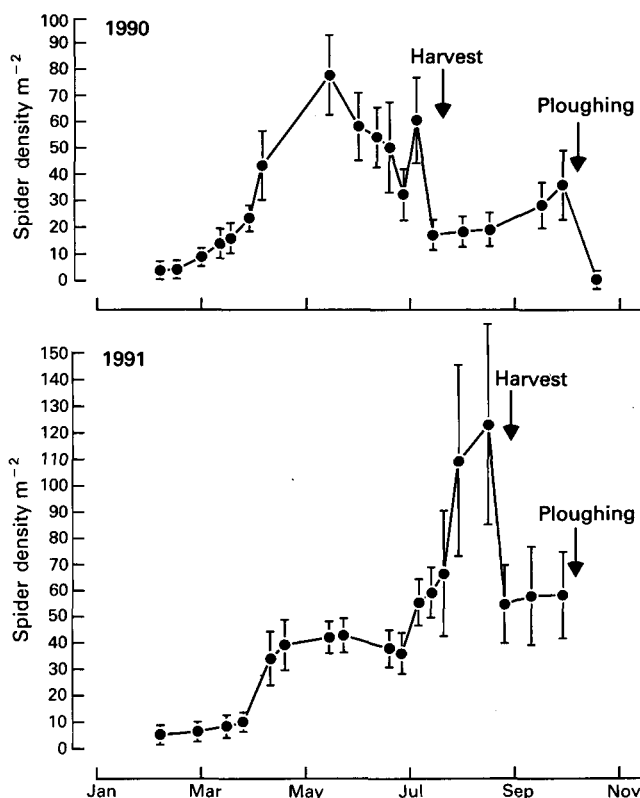
Discussion

Combining D-Vac and hand-search in a single sample ensures that any change in the efficiency of the D-Vac (perhaps associated with differences in vegetation structure as suggested by Duffey (1980)), will be compensated for by an increased catch in the hand-search. This was demonstrated during 1990 when the particulate soil surface provided refuges for a greater proportion of erigonine spiders than was the case in 1991, resulting in a much higher proportion of spiders caught by hand-searching. If density estimates had relied entirely on the D-Vac, there would have been an underestimate of 26.3% of the total catch in 1990 and 12.7% in 1991. The combination of the two techniques therefore allows a greater degree of standardisation of sampling between habitats than would be possible with either technique alone. In addition, the density estimation method used here was much less labour-intensive than that used by Sunderland *et al.* (1987) (3 man-hours for ten 0.5 m² samples cf. 9 man-hours for ten 0.1 m² samples).

Fig. 3: Mean spider density with 95% confidence limits.

Date	1990 k	Sig. vs Poisson	Date	1991 k	Sig. vs Poisson
18 Apr.	6.88	NS	14 May	8.94	*
27 Apr.	No Fit	—	21 May	6.33	**
2 May	34.55	NS	11 June	No Fit	—
11 May	28.60	NS	18 June	No Fit	—
17 May	17.60	NS	3 July	5.13	NS
18 June	3.62	***	9 July	8.92	*
2 July	1.86	***	17 July	7.37	***
11 July	54.94	NS	23 July	11.14	**
17 July	7.83	*	29 July	2.60	***
24 July	2.16	***	5 Aug.	2.59	***
30 July	5.51	***	19 Aug.	1.62	***
7 Aug.	2.14	***	27 Aug.	1.76	***
21 Aug.	4.30	NS	9 Sep.	2.63	***
3 Sep.	2.73	***	24 Sep.	2.63	***
28 Sep.	2.11	***			
8 Oct.	1.19	***			

Table 3: The dispersion of spiders in density samples during 1990 and 1991. Samples from early in the season with low densities are omitted. k is from the negative binomial, p shows the significance of this distribution compared to the Poisson. Harvest dates 7 August 1990 and 21 August 1991. No Fit = unable to fit negative binomial. $*= p < 0.05$, $** = p < 0.01$, $*** = p < 0.001$.
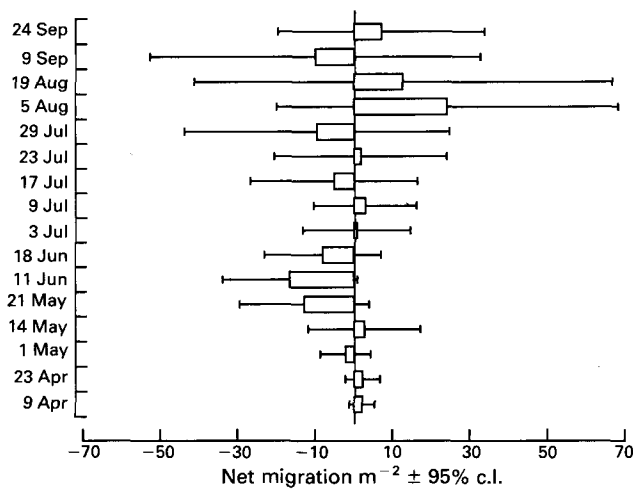
Fig. 4: Estimated net migration (field density − cage density) for total
spiders ± 95% confidence limits. Positive values suggest net
immigration.

Assessing net migration by caging was not viable with the number of samples taken and the spatial dispersion of spiders encountered. However, the caging design was successful as a method of containing spiders in the field for short periods and could be used as a method for measuring net migration in future studies if enough cages could be employed to reduce the sampling error, or if summer aggregation was not a problem.

Caged samples regularly revealed a number of specimens of *Porrhomma microphthalmum*, a species commonly encountered ballooning across the site but which was rare in the field density samples. Since spiders in this genus are often partly subterranean in habit (P. Merrett, pers. comm.), the cages may have prevented these spiders ballooning, leaving them on the surface to be sampled. Alternatively, the lower light levels in the cages may have tempted these spiders out of the ground.

For an ecological study, based on density sampling, to be successful, there are two main problems to be overcome. Firstly, density must be measured efficiently within each sample and secondly, the sampling procedure must cope adequately with the dispersion of organisms over the sampling site. The confidence limits of the density estimates obtained by this study were wide, largely due to the spider dispersion, rather than as a result of lack of sampling efficiency. This suggests that

Species	Field	Cages
Lepthyphantes tenuis	454	336
Erigone atra	185	101
Oedothorax fuscus	167	75
Bathyphantes gracilis	125	73
Oedothorax apicatus	99	61
Erigone promiscua	85	45
Oedothorax retusus	63	28
Meioneta rurestris	52	15
Erigone dentipalpis	46	17
Porrhomma microphthalmum	13	34

Table 4: The total catch of the ten most abundant spider species from field density samples and caged density samples.

the former may be a problem with spiders in cereal crops, especially since the dispersion of spiders can change during crop growth. The problem did not occur early in the season and may have been a response to decreased humidity in the crop, with spiders largely confined to the damper weedy areas. Alternatively, the weedy patches may have provided more food or websites. Consequently, this factor should be taken into account in future studies, perhaps by increasing the numbers of samples in July and August, or targeting samples at particular microhabitats within the field.

Acknowledgements

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