Comparison of Dispersion and Regression Indices for *Tetranychus cinnabarinus* (Boisduval) (Acari: Tetranychidae) Populations in Cotton

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ABSTRACT Dispersion indices, including Green's coefficient of dispersion (Cx), the standardized Morisita's coefficient (Ip), mean crowding ($\mathring{m}$), Lloyd's "patchiness index" ($\mathring{m}/m$) and variance/mean ratio (s^2/m), as well as Iwao's regression of m against the mean and Taylor's regression of log variance against log mean, were calculated for populations of female *Tetranychus cinnabarinus* (Boisduval) infesting cotton. Comparisons show that Cx, Ip, and $\mathring{m}/m$ as well as slopes from the regressions all indicated that the population was slightly aggregated. The variance/mean ratio fluctuated considerably more than other indices examined, which, when coupled with a strongly dependent relationship with the mean, suggested that this index may be less reliable than previously thought.

AN IMPORTANT characteristic of resource exploitation is the distribution of individuals among resource units. Many field studies designed to detect changes in insect distribution on plants have recently been questioned because of a dependent relationship between indices of dispersion and the mean density (m), which generates statistical artifacts instead of biologically significant effects (Myers 1978). The best measures of dispersion, as evaluated by Myers (1978) with computer-generated patterns of egg dispersion at different population densities, are Green's (1966) coefficient, Cx, and the standardized Morisita's coefficient, Ip (Smith-Gill 1975). These indices are not correlated with m and are therefore considered the best candidates for use when analyzing actual changes in distribution of organisms with changes in m. The variance/mean ratio (s^2/m) is only weakly correlated with m, but mean crowding ($\mathring{m}$) (Lloyd 1967) is highly dependent on m and is therefore not considered useful as a measure of clumping. The regression of $\mathring{m}$ on m described by Iwao (1968) and Iwao and Kuno (1971) has not been compared with the other techniques by Myers (1978) but is considered to be valid.

Trumble et al. (1983) used Green's Cx, Lloyd's "patchiness index" ($\mathring{m}/m$) (Lloyd 1967), and the regression of $\mathring{m}$ against m to document seasonal variation in the spatial dispersion patterns of aphids on strawberry. Conclusions were analogous for all techniques, indicating that although $\mathring{m}/m$ may be influenced by density, this index is nonetheless in close agreement with Cx and Iwao's regression. Additionally, statistical artifacts generated by ignoring changes in dispersion during the course of a season have been documented. These findings prompted us to compare various indices of dispersion by using counts of females of the spider mite *Tetranychus cinnabarinus* (Boisduval) on cotton. Our specific objectives were to (1) determine the seasonal dispersion patterns of *T. cinnabarinus* on cotton, (2) attempt to repeat Myers' (1978) findings with a large data set collected in a field situation, and (3) determine the effect on mite distribution of pesticide applications for the pink bollworm, *Pectinophora gossypiella* (Saunders).

Materials and Methods

All experiments were conducted during the 1982 and 1983 field seasons on Deltapine 61 variety of cotton at the Imperial Valley Field station, near El Centro, Calif. In 1982, treatments were replicated four times in a randomized-block design. Each replicate contained eight 38-m rows with 96-cm centers. In 1983, treatments were replicated eight times in a randomized-block design. Each replicate contained eight 19-m rows with 96-cm centers.

Pesticides were applied weekly when cotton bolls susceptible to pink bollworm (bolls that are 14–21 days old) were present. Applications were made with a John Deere Hi-Cycle 600 Sprayer dispensing 225 liters/ha. In 1982 there were six treatments: an organophosphate (Shell monocrotophos 5E, 0.56 kg [AI]/ha); a carbamate (Upjohn U-56295 85WP, 0.73 kg [AI]/ha); three pyrethroids (FMC cypermethrin 2.5E, FMC-54800 0.8EC, and Bayer FCR-1272 1.67EC, all at 0.04 kg [AI]/ha); and an untreated control. Only three treatments were compared in 1983: cypermethrin 2.5EC and FMC-54800 2EC, both at 0.05 kg (AI)/ha, and an untreated control. In both years, treatment effectiveness was assessed by counting the number of adult female mites on the upper 16 mainstem node leaves

Table 1. Dispersion indices for the distribution of adult female *T. cinnabarinus* on cotton, 1982

Date	m	s^2/m	$\overset{*}{m}$	$\overset{*}{m}/m$	Cx	Ip
29 June	1.53	16.003	16.534	10.798	0.103	0.550
6 July	1.63	13.114	13.739	8.455	0.078	0.538
13 July	2.43	7.657	9.084	3.743	0.029	0.514
20 July	7.28	21.543	27.824	3.821	0.029	0.515
27 July	13.12	19.851	31.965	2.473	0.015	0.507
3 August	33.09	62.363	94.456	2.854	0.019	0.010
9 August	97.31	229.830	326.142	3.352	0.024	0.512
17 August	32.21	143.166	174.374	5.414	0.046	0.523
24 August	11.16	55.881	66.042	5.917	0.053	0.526
30 August	4.94	52.683	56.619	11.472	0.113	0.556
6 September	8.58	109.062	116.638	13.600	0.137	0.568
13 September	4.96	62.534	66.489	13.419	0.140	0.570
20 September	17.39	62.088	78.478	4.513	0.046	0.523
28 September	17.66	78.637	95.300	5.396	0.048	0.524
3 October	24.98	57.493	81.472	3.262	0.024	0.512
10 October	45.84	75.636	120.479	2.628	0.018	0.509
17 October	86.40	116.739	202.136	2.334	0.020	0.510

m, Mean; s^2, variance; $\overset{*}{m}$, mean crowding; $\overset{*}{m}/m$, Lloyd's "patchiness index"; Cx, Green's coefficient of dispersion; Ip, standardized Morisita's coefficient.

on 96 plants per week: four plants per plot in 1982, three plants per plot in 1983.

Because herbivores are often segregated by host plants occurring as distinct units, we chose the individual cotton plant as the sampling unit. This is consistent with the concept of the "natural habitat unit" proposed by Patil and Stiteler (1974) as a basis for sampling agricultural crops grown in a continuum.

The mean, variance/mean ratio, mean crowding [$\overset{*}{m} = m + (s^2/m) - 1$], Lloyd's "patchiness index" ($\overset{*}{m}/m$), Green's coefficient of dispersion [$Cx = (s^2/m - 1)/(\Sigma x - 1)$], and standardized Morisita's coefficient (see Smith-Gill 1975, for details) were calculated for each sampling date in 1982 and 1983. Regressions were then generated to determine the relationship of each index to m. In addition, the regression equations of $\overset{*}{m}$ on m and log s^2 on log m (Taylor 1965) were calculated for each sampling date in both years. The Proc GLM procedure of Statistical Analysis Systems (SAS) (Helwig and Council 1979) was used to compute all regression equations.

Results and Discussion

During 1982, there were two peaks in the mite population (Table 1). Initially, the mean number of female mites per plant increased rapidly from 0.10 to 97.31 per plant and then decreased to 4.93. Population density then increased in mid-September, again reaching a level of 86.40 per plant. These increases and decreases were independent of chemical treatments for the pink bollworm; previous research has suggested such fluctuations may

Table 2. Dispersion indices for the distribution of adult female *T. cinnabarinus* on cotton, 1983

Date	m	s^2/m	$\overset{*}{m}$	$\overset{*}{m}/m$	Cx	Ip
6 June	0.57	4.841	4.414	7.705	0.071	0.533
13 June	0.07	1.226	0.298	4.093	0.038	0.493
20 June	0.03	1.653	0.684	21.884	0.326	0.603
27 June	0.31	5.478	4.790	15.329	0.154	0.573
4 July	0.26	2.511	1.767	6.915	0.069	0.528
11 July	0.16	1.661	0.817	5.231	0.047	0.513
18 July	0.09	1.140	0.234	2.497	0.018	0.489
25 July	0.60	15.906	15.511	25.673	0.262	0.629
1 August	0.52	6.749	6.270	12.039	0.117	0.556
8 August	0.79	3.330	3.122	3.944	0.063	0.526
15 August	1.75	10.899	11.649	6.657	0.059	0.529
22 August	3.68	42.405	45.082	12.260	0.118	0.558
29 August	5.97	35.989	40.958	6.862	0.061	0.530
5 September	9.15	51.652	59.798	6.538	0.058	0.529
12 September	16.65	76.625	92.321	5.546	0.047	0.524
19 September	30.33	65.722	95.056	3.134	0.030	0.515
26 September	18.48	27.417	44.897	2.430	0.015	0.507
3 October	42.54	46.736	88.278	2.075	0.011	0.506

m, Mean; s^2, variance; $\overset{*}{m}$, mean crowding; $\overset{*}{m}/m$, Lloyd's "patchiness index"; Cx, Green's coefficient of dispersion; Ip, standardized Morisita's coefficient.

Table 3. Regression indices for the distribution of adult female *T. cinnabarinus* on cotton, 1982

Date	Iwao's regression			Taylor's regression	
	Intercept	Slope	r^2	Slope	r^2
29 June	−0.186	6.792**	0.67	1.764**	0.97
6 July	−0.044	4.980**	0.66	1.701**	0.96
13 July	−0.740	7.899**	0.81	1.689**	0.93
20 July	−0.284	4.818**	0.85	1.562**	0.93
27 July	0.281	2.859**	0.67	1.499**	0.93
3 August	0.249	2.283**	0.87	1.501**	0.95
9 August	0.546	1.952**	0.96	1.555**	0.98
17 August	1.620**	1.578**	0.88	1.489**	0.98
24 August	0.414	2.185**	0.75	1.357**	0.93
30 August	−0.039	2.920**	0.97	1.470**	0.97
6 September	0.787*	2.070**	0.91	1.459**	0.96
13 September	0.094	2.571**	0.90	1.434**	0.97
20 September	0.565	1.644**	0.90	1.403**	0.97
28 September	0.816*	2.148**	0.89	1.514**	0.97
3 October	1.637*	1.900**	0.81	1.501**	0.96
10 October	0.521	2.269**	0.94	1.545**	0.96
17 October	2.989**	1.643**	0.92	1.490**	0.96

Intercepts tested for significant difference from 0.0 and slopes tested for significant difference from 1.0, both by using Student's *t* test: * $P < 0.05$; ** $P < 0.01$.

be tied to the crop's physiology or climatic conditions (Sevacherian and El-Zik 1983).

In 1983, mite populations were smaller (Table 2). The early season population peak seen in 1982 did not occur in 1983. In late 1983, populations increased to an average of 42.54 per plant, still considerably lower than the density recorded in 1982.

Analysis of these data showed that dispersion indices of mites did not change significantly ($P > 0.05$) as the result of the use of pesticides for pink bollworm control, allowing the pooling of data from all treatments when comparing indices. Mollet and Sevacherian (1984) had previously found that the within-plant distribution of *T. cinnabarinus* was not significantly affected by pesticide treatments.

The coefficients Cx and Ip indicate that the populations were slightly aggregated throughout both seasons (Tables 1 and 2). Cx was consistently greater than 0.0; populations are considered random when $Cx = 0.0$ and aggregated when Cx approaches 1.0. Ip can range from 1.0 to −1.0, with dispersions considered aggregated at levels of 0.5–1.0. Levels of Ip greater than 0.5 were found on 32 of 35 sampling dates. Regressions of Cx and Ip against m showed that neither generated significant correlations at $P < 0.05$.

Although the regression of $\mathring{m}/m$ against m produced a significant ($P < 0.05$) correlation, results were similar to those of the other two indices (Tables 1 and 2). Indices greater than 1.0 are considered aggregated, with no upper limit to this index.

Table 4. Regression indices for the distribution of adult female *T. cinnabarinus* on cotton, 1983

Date	Iwao's regression			Taylor's regression	
	Intercept	Slope	r^2	Slope	r^2
6 June	−0.331	4.018**	0.64	1.479**	0.92
13 June	−0.963	12.753**	0.99	1.966**	0.99
20 June	—	—	—	—	—
27 June	−0.200	5.103*	0.77	1.467**	0.98
4 July	−0.201	5.281**	0.69	1.458**	0.97
11 July	—	—	—	—	—
18 July	—	—	—	—	—
25 July	−0.162*	3.037**	0.96	1.383**	0.96
1 August	−0.546	7.933**	0.99	1.623**	0.97
8 August	0.207	3.592	0.21	1.312	0.81
15 August	−0.079	2.558**	0.72	1.292**	0.95
22 August	−0.059	2.241**	0.91	1.310**	0.95
29 August	0.021	2.588**	0.77	1.429**	0.97
5 September	0.517*	1.653**	0.85	1.345**	0.97
12 September	0.365	1.900**	0.93	1.406**	0.96
19 September	0.062	2.189**	0.95	1.469**	0.97
26 September	0.368	2.057**	0.84	1.417**	0.96
3 October	0.939*	1.948**	0.84	1.533**	0.96

Intercepts tested for significant difference from 0.0 and slopes tested for significant difference from 1.0, both by using Student's *t* test: * $P < 0.05$; ** $P < 0.01$.

The slightly higher values for $\mathring{m}/m$ as compared to Cx and Ip suggest a greater level of aggregation; however, the lack of an upper limit makes $\mathring{m}/m$ more difficult to interpret.

The s^2/m ratio fluctuated greatly, although this index always remained above 1.0, suggesting aggregation. Myers (1978) found s^2/m to be weakly correlated with the mean, but when we regressed s^2/m on m, a significant relationship ($P < 0.0001$) was found, indicating that s^2/m may be a poorer indicator of dispersion than previously thought.

Regressing $\mathring{m}$ against m produces the linear regression equation of $\mathring{m} = a + bm$. Iwao (1968) defined a as the "index of basic contagion" and described the basic unit of the population as an individual when $a = 0.0$ or a group of individuals when $a > 0.0$. In our study, the individual was the basic sampling unit because the intercepts were not significantly different from 0.0 for 27 of 35 sampling dates from both years (Tables 3 and 4). Also provided in this regression is a "density contagiousness coefficient," b, which distinguishes how the basic components of a population are distributed within their habitat (Iwao 1968). Distribution is random when $b = 1.0$ and becomes increasingly aggregated as b increases. We found values of b to be significantly greater than 1.0 for all sampling dates except one (8 August 1983), which was probably a result of the poor fit of the line to the data for that date ($r^2 = 0.21$).

Taylor's (1965) power law fit our data better, with r^2 values exceeding 0.90 on 31 of 32 dates, generally higher than the r^2 values produced with Iwao's (1968) analysis technique. Again, b was always significantly greater than 1.0 for all dates except 8 August 1983, indicating that *T. cinnabarinus* female populations remained effectively aggregated despite major density fluctuations.

These analyses demonstrate that Cx, Ip, $\mathring{m}/m$, and b determined from regressing either $\mathring{m}$ against m or log s^2 against log m are all in agreement that the population of *T. cinnabarinus* females on cotton was slightly aggregated on most sampling dates. This means that mites were found in disproportionately large numbers on some plants. Because substantial changes in dispersion occurred during the course of both seasons, regression values based on pooled data for all sample dates would not provide a biologically accurate evaluation of the within-field distribution. As mite populations expanded, more of the available niches were filled and the dispersions tended to be less aggregated. We view this as a biological process that is adequately explained by the statistics rather than as an artifact inherent in the statistics. Also, it was more difficult to interpret the comparison of population dispersions from one season to the next with the indices that do not have upper limits ($\mathring{m}/m$ and both b's) than it was for indices with upper limits (Cx and Ip). Cx and Ip were the most suitable indices for comparison of samples with disparate densities and, hence, unequal confidence limits. The s^2/m ratio fluctuated considerably more than other indices examined; this fact, combined with a strongly dependent relationship with m, suggests that this index may not be as reliable as thought previously.

We could not determine that any one index is best for all organisms under all circumstances. We recommend the use of more than one index to see if they agree with each other before drawing conclusions about the dispersion of a population.

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