Airborne Dispersal of San Jose Scale, *Quadraspidiotus perniciosus* (Comstock) (Homoptera: Diaspididae), Crawlers Infesting Apple[1]

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ABSTRACT The aerial dispersal of San Jose scale, *Quadraspidiotus perniciosus* (Comstock), crawlers within the apple tree canopy and between trees was positively correlated with the seasonal abundance of crawlers on the bark. Airborne crawlers were significantly more abundant within the upper portions of the canopy and in the northeast and southeast quadrants. These data supported observations on variations in crawler density by location on the host and suggested that wind direction may have affected the distribution of crawlers dispersing aerially within the trees. The magnitude of aerial dispersal between trees was related to the levels of airborne dispersal within the canopy and the distance to the infested source.

The San Jose scale (SJS), *Quadraspidiotus perniciosus* (Comstock), is currently a major economic pest attacking fresh and processing apple varieties in New York State. Although the literature on SJS is abundant, little information is available on dispersal of this species. Both the active ambulatory dispersal and passive airborne dispersal of 1st-instar crawlers contribute to the spread of SJS populations and infestation of the fruit (Gentile and Summers 1958). Active dispersal of crawlers during the brief mobile period before settling is limited to the area surrounding the point of emergence from the female (Gentile and Summers 1958) and, except in cases of direct contact between hosts, is restricted to the tree on which parturition occurs (Melis 1943). The importance of passive aerial dispersal is less well known, but this mode of transport is often implicated in the spread of SJS infestations between hosts and orchards. SJS crawlers, as other diaspidids, are well adapted morphologically for aerial transport (Beardsley and Gonzalez 1975). Greenhouse studies have confirmed that SJS can become windborne in air currents in excess of 1 m/sec (Mathys 1953), but airborne dispersal in the field has not been experimentally documented.

Studies of aerial dispersal in other species of the Coccoidea have demonstrated the potential role of passive airborne dispersal of crawlers in the short- and long-range spread of infestations (Beardsley and Gonzalez 1975). Reports (Rabkin and Lejeune 1954, Brown 1958, Hoelscher 1967, McClure 1977) have differed as to whether the deposition of wind-dispersed crawlers was greater over long distances (between 7.6 and 15 m) or at short distances within and beneath infested trees. According to Cornwall (1960) and Greathead (1972), crawlers, once airborne, behaved as inert particles, since movements aloft could not be self-directed. In short-range aerial trapping experiments, these authors determined that the density of crawlers dispersing in the wind was often inversely related to height within the crop canopy. These trapping data, however, were not compared with variations in population density distribution on the infested hosts. Investigations of long-range aerial dispersal (Brown 1958, Greathead 1972, McClure 1977) have shown that crawler displacement is generally greatest in the direction downwind from an infested source. However, Timlin (1964) trapped comparable numbers of *Parlatoria pittospori* Maskell crawlers both windward and leeward of an infested shelter belt and suggested that daily variations in wind direction may be as important as the influence of prevailing wind in the spread of scale infestations.

A preliminary field study (Mague 1982) demonstrated that there was no significant reduction in the percentage of SJS-infested fruit at harvest when crawlers walking over the bark had been mechanically excluded from access to the fruit. This indicated that aerial dispersal of crawlers was an important factor contributing to crop infestation by the SJS and may have functioned in population spread within and between hosts.

The objective of this study was to monitor the seasonal aerial dispersal of crawlers and to identify differences in aerial crawler densities at various locations within the apple tree canopy and between trees.

Materials and Methods

During 1981, crawler aerial dispersal studies were conducted in four untreated, 35-year-old 'Rhode Island Greening' apple trees located in a commercial orchard in Sodus, Wayne County, N.Y. The trees were planted on seedling rootstock at a spacing of 7.6 by 7.6 m and were ca. 4.5 m high. All trees were heavily infested with SJS and had received routine insecticidal and fungicidal applications before the 1981 season.

Plexiglas plates (10 by 5 by 0.2 cm), oriented vertically, were used to trap airborne crawlers. A 10-cm^2 area on each side of the plates was coated with petroleum jelly, which captured small-bodied insects, such as scale crawlers, but was not sufficiently viscous to trap larger insects that might have obliterated the impacted crawlers. The nongreased top portion of the plate was inserted into a no. 4 Boston bulldog clip (Hunt Mfg. Co., Statesville, N.C.) that had been suspended from a tree branch with vinyl rope. Clip and rope surfaces were similarly coated with petroleum jelly so that only air-

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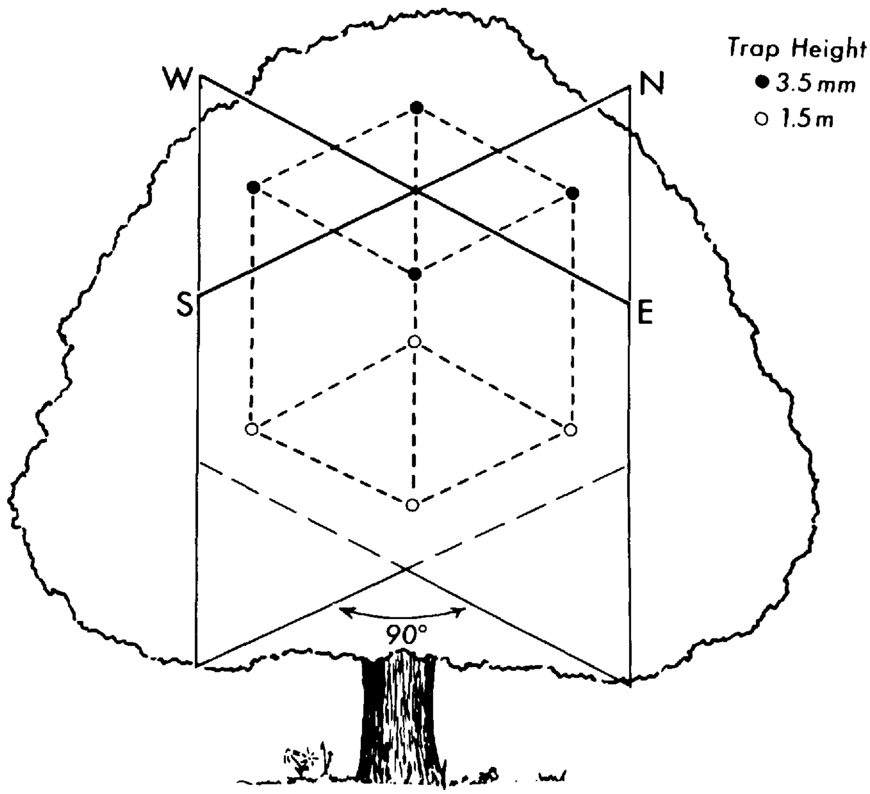

FIG. 1. Placement of aerial plate traps within the tree canopy.

borne crawlers were captured on the plate. As a further precaution, all plant parts that might have accidentally come in contact with the trap during movements in the wind were removed.

To evaluate crawler aerial dispersal within the tree canopy, each of the four trees was divided visually along the primary compass coordinates into NE, NW, SE, and SW quadrants (Fig. 1). Two traps were suspended in each of the four quadrants: one plate at a 1.5-m height and the second at 3.5 m. Traps were hung ca. 1 m inside the canopy surface.

To study aerial dispersal between the four infested trees, vinyl ropes were suspended between adjacent pairs of trees at 1.5- and 3.5-m heights. Three plates were attached with clips to each of the eight ropes, with one trap suspended halfway between the drip lines of the adjacent trees. The other two traps were hung 0.5 m away from opposite sides of the center trap (Fig. 2).

The aerial plate traps remained in the field from first crawler emergence on 15 June through 30 September. Each week, the plates were removed and taken to the laboratory, where the crawlers were counted under a magnifying lamp. The traps were then cleaned, regreased, and placed in the field the following morning. Crawler counts on each of the 15 observation dates represented totals captured in 6 days. Trap catches were analyzed by analysis of variance for differences among trees, dates, quadrants, and heights for within-tree traps, and for locations, dates, and heights for between-tree traps. When variance ratios were significant ($P = 0.05$), treatment means were separated with multiple t tests.

Relative densities of SJS crawlers on the bark of the study trees were assessed during the season by using the direct-count sampling method (Mague and Reissig, in press). Crawlers on 100-cm^2 of bark on the main tree limbs (>5 cm in diameter) in each of the four quadrants and at each of the two heights corresponding to aerial plate trap placement with the trees were counted. Counts were taken weekly from 16 June through 30 September. Direct-count data were analyzed as previously described for aerial trap catches. Mean crawler abundance, measured by direct counts and aerial traps within and between trees, was plotted vs. cumulative degree-days (Baskerville and Emin 1969) above 10°C from 1 March for the 1981 season.

The percentage of SJS-infested fruit and the mean number of SJS per fruit were determined in a random sample of 10 fruit from each quadrant in both the upper and lower canopies on 10 September. Significant ($P = 0.05$) differences between treatment means for trees and quadrants were determined by Waller and Duncan's multiple range test (Waller and Duncan 1969).

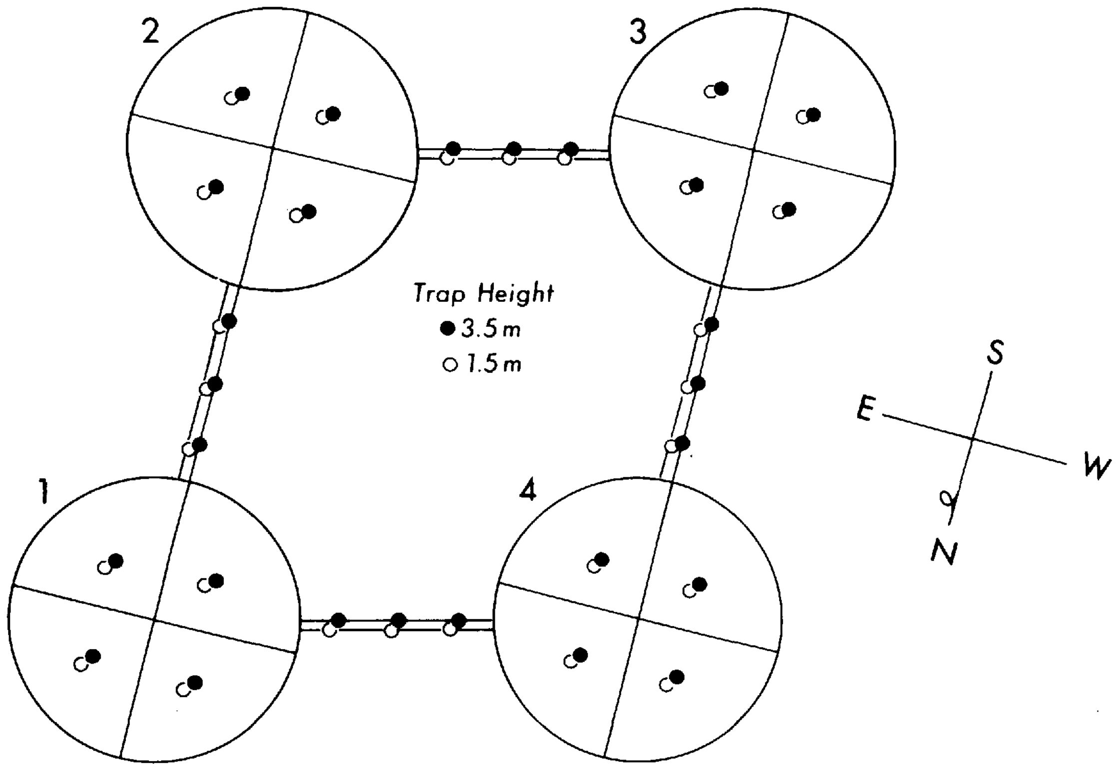

FIG. 2. Placement of aerial plate traps between trees in the study plot.

Results and Discussion

Peak periods of aerial dispersal coincided with increased crawler densities on the bark during late June and late August (Fig. 3). Within-tree trap catches were highly correlated with direct-count samples (r = 0.88). Airborne dispersal between infested trees, although less closely related to crawler activity inside the canopy, was also highly correlated with direct counts (r = 0.81) and within-tree aerial trap catch (r = 0.76). Throughout the season, mean aerial dispersal within the canopy varied from 1.6 to 20 times greater than that between trees.

Crawler densities on the bark were not significantly different, based on direct counts by tree quadrant; however, populations were slightly higher on the eastern sides of the trees (Table 1). A significantly greater number of crawlers were recorded in the upper limbs of the trees. This supported the work of Morgan and Angle (1969), who observed that SJS infestations were concentrated in the tops of the trees where insecticidal coverage is poor and where SJS maturation is more rapid. Since our study was conducted in a commercial block, the data may have reflected a density distribution influenced by more thorough spray coverage in the lower regions of the trees in previous years. However, a behavioral component could not be discounted, since SJS crawlers tend to migrate upward on a vertical plane and their dispersal range is temperature-dependent (Gentile and Summers 1958). In the field, SJS crawlers were most active before 1200 h on sunny days (Mague 1982). Therefore a light- or temperature-related response, which has been documented in other diaspidids (Beardsley and Gonzalez 1975), may at least partially explain the higher crawler densities in the SE quadrant and at the 3.5-m height.

The mean numbers of crawlers trapped on aerial plates within the trees differed significantly among tree quadrants and were generally related to corresponding crawler densities on the bark in each quadrant (Table 1). Throughout the season, greater numbers of crawlers were airborne in the eastern side of the canopy, particularly in the NE quadrant. Since prevailing winds in western New York during the summer were typically from the south and west, their influence may have contributed to aerial trap catch in the eastern quadrants.

Height within the tree canopy also significantly affected aerial plate trap catch. During the season, greater numbers of crawlers were trapped at the 3.5-m height, which was consistent with direct-count observations on density. However, the ratio of crawlers trapped at the 3.5-m height compared with the 1.5-m height was reduced from that observed by direct count, which implied that a greater number of the crawlers trapped in the lower canopy had dispersed downward from the tops of the trees. These data did not agree with earlier studies

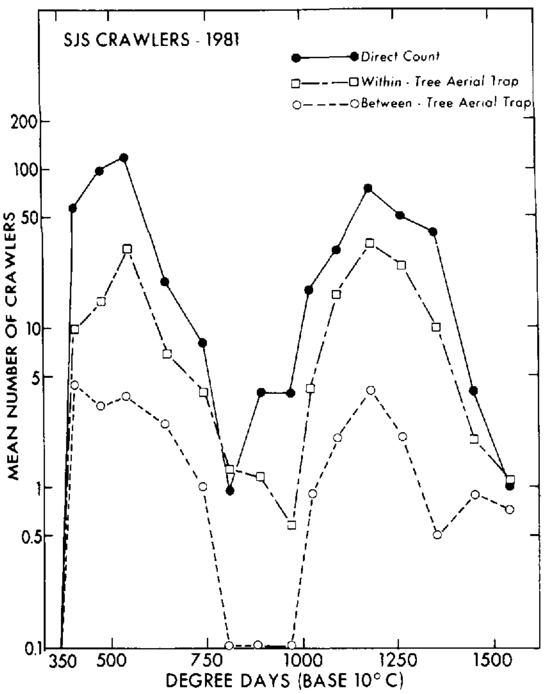

FIG. 3. Seasonal abundance of SJS crawlers as assessed by direct count (mean number per 100 cm²) and aerial plate traps within and between trees (mean number caught over 6 days/200 cm²) vs. degree-day accumulations (base 10°C from 1 March) for Sodus, N.Y., in 1981.

(Cornwall 1960, Greathead 1972) on other species of Coccoidea in cacao and sugarcane, where aerial dispersal of crawlers was inversely related to height. This difference may have been related to variations in population distribution over the hosts, dissimilarities in canopy structure, or higher wind speeds which increased horizontal transport.

The high levels of fruit infestation in the study plot at the time of fruit evaluation may have masked the more subtle effects of aerial dispersal in relation to crop damage (Table 1). There was no significant difference in the percentage of SJS-infested fruit between the upper and lower canopies; however, significantly greater numbers of scale-infested fruit in the tops of the trees. The percentages of infested fruit and number of SJS per fruit in each quadrant were similar.

Aerial dispersal of crawlers between trees was much lower than that within the canopy and did not differ with height (Table 2), in contrast to within-tree data. The magnitude of crawler aerial dispersal outward from an infested host was dependent upon the density of airborne crawlers within the tree canopy. Those traps between each pair of trees which were placed closest (0.5 m) to the host with greater within-tree plate catch (tree 3 or 1) trapped significantly greater numbers of airborne crawlers. Similarly, traps adjacent to trees where aerial dispersal within the canopy was lower caught fewer crawlers, in numbers comparable to traps located midway (1.5 m) between the trees. No directional component to aerial dispersal was apparent, since the mean total catch of the six traps between each pair of trees did not differ. This supported the observations of Timlin (1964), who demonstrated that prevailing wind direction was not the major factor influencing the direction of aerial dispersal of *P. pittospori* crawlers in apple orchards. The apparent unimportance of prevailing wind direction in airborne crawler movements may have been related to increased air turbulence around surface obstacles (Wellington 1945), such as trees, in the orchard setting.

This work supported the preliminary study (Mague 1982) that had suggested that airborne transport of SJS crawlers was important in dispersal to new sites of infestation. The low numbers of crawlers dispersing between trees, relative to the higher densities dispersing within the canopy, indicated that aerial movements between trees was not an important factor affecting fruit

Table 1. Mean SJS crawlers and fruit infestation by quadrant and height, Sodus, N.Y., 1981[a]

Quadrant	Crawlers[b]		Fruit (n = 20 fruit/quadrant per tree)		
	Direct count ($\bar{x}$/100 cm²)	Within-tree aerial trap ($\bar{x}$/200 cm²)		% Infested	$\bar{x}$ SJS/fruit[c,f]
NE	9.3A	19.4A		83.8AB	15.5B
NW	7.4A	5.7C		80.0B	14.8AB
SE	13.6A	14.4AB		86.3AB	32.7A
SW	5.7A	6.7BC		96.3A	24.3AB
Height (m)			Location in canopy	(n = 40 Fruit/location per tree)	
				% Infested[d,e]	$\bar{x}$ SJS/fruit[d,f]
3.5	15.1A	14.5A	Upper	92.5A	25.9A
1.5	3.0B	8.6B	Lower	83.8A	17.3B

[a] Means followed by the same letter are not significantly different at the 5% level, by tests listed in footnotes [b], [c], and [d] below.
[b] Multipe t test comparison.
[c] Waller and Duncan's BSD rule.
[d] Paired t test of means.
[e] Arc sine transformation before analysis.
[f] Log transformation before analysis.

Table 2. Comparison of aerial plate trap catch of SJS crawlers within and between trees, Sodus, N.Y., 1981

Tree no.	Within-tree aerial trap[a] (weekly $\bar{x}$ total crawlers/tree)	Between-tree aerial trap	
		Distance to tree 3 or 1 (m)	Trap catch[b] ($\bar{x}$ crawlers/200 cm^2)
3	250.5A		
1	70.4B	0.5	2.5A
2	28.9C	1.5	1.4B
4	20.4D	2.0	1.4B
		Trap height (m)	
		3.5	1.8A
		1.5	1.7A

[a]Means followed by same letter are not significantly different at the 5% level, by Waller and Duncan's BSD rule. Log transformation before analysis.

[b]Means followed by the same letter are not significantly different at the 5% level, by multiple *t* test comparison.

infestation. However, the potential of aerial dispersal in the spread of SJS within an orchard was demonstrated, which underscores the need for consideration of this factor in management programs for scale.

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