

## EFFECT OF THE BIOLOGICAL CONTROL AGENT *NEOSEIULUS CALIFORNICUS* (ACARI: PHYTOSEIIDAE) ON ARTHROPOD COMMUNITY STRUCTURE IN NORTH FLORIDA STRAWBERRY FIELDS

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### ABSTRACT

Field experiments were conducted during the 2006-2007 growing season to determine the effect of the predatory mite, *Neoseiulus californicus* (McGregor) on arthropod community structure when released as a biological control agent for the twospotted spider mite, *Tetranychus urticae* Koch, in north Florida strawberries (*Fragaria* × *ananassa* Duchesne). Releases of *N. californicus* were conducted at approximately 1-month intervals from Dec 2006 to Feb 2007 to compare effects of predator release times on arthropod community structure. Evaluations of community structure were conducted 3 times during the growing season. The Shannon-Weaver index of diversity was used to quantify differences among release and non-release plots. Our results indicate that the release of *N. californicus* does not affect the arthropod diversity in the strawberry system studied. The generalist feeding behavior of *N. californicus*, coupled with a high level of richness and diversity in the strawberry ecosystem, may diffuse the measurable effect of *N. californicus* releases on the arthropod community structure. This makes *N. californicus* a desirable biological control agent for management of twospotted spider mite in strawberries while preserving arthropod diversity.

**Key Words:** biological control, arthropod assemblage, strawberry ecosystem, twospotted spider mite, pest management

### RESUMEN

Experimentos de campo fueron establecidos para determinar el efecto del acaro predador, *Neoseiulus californicus* (McGregor), en la estructura de las comunidad de artrópodos cuando es liberado como control biológico de la araña roja, *Tetranychus urticae* Koch, en Fresas (*Fragaria* × *ananassa* Duchesne) en el norte de la Florida. Liberaciones de *N. californicus* se realizaron en intervalos de un mes desde Diciembre 2006 hasta Febrero 2007, para comparar los efectos del tiempo de liberación de los predadores en la estructura de la comunidad de artrópodos presentes. Evaluaciones de la estructura de las comunidades se realizó tres veces durante la temporada de producción. El índice de Shannon-Weaver fue usado para cuantificar las diferencias entre los lotes donde se hicieron las liberaciones y los lotes de control. Nuestros resultados demuestran que la liberación de *N. californicus* no afecta significativamente la diversidad de artrópodos en el sistema de fresas estudiado. El comportamiento alimentario generalista de *N. californicus* y el alto nivel de riqueza y diversidad del sistema de producción de fresas, puede dispersar el efecto cuantificable de *N. californicus* en la estructura de la comunidad. Esta característica hace que *N. californicus* sea un controlador biológico importante para el manejo de la araña roja en fresas, al mismo tiempo que se conserva la diversidad del sistema.

Translation provided by the authors.

Twospotted spider mite, *Tetranychus urticae* Koch (TSSM), is a key pest of strawberries (*Fragaria* × *ananassa* Duchesne) in north Florida. High populations of TSSM can reduce foliar and floral development thereby decreasing the quality and quantity of mature fruit (Rhodes et al. 2006). Twospotted spider mite populations have become resistant to most acaricides due their short life cycle and high fecundity (Huffaker et al. 1969; Williams 2000; Cross et al. 2001; Stumpf & Nauen 2001; Sato et al. 2004). Outbreaks of TSSM have become more frequent over the last few decades

due to increased use of pesticides in modern cultural practices. As a result, more growers are utilizing biological control as an alternative to chemical management (Huffaker et al. 1969; Escudero & Ferragut 2005; Rhodes et al. 2006). However, little is known about the non-target effects of biological control releases on beneficial arthropods in the strawberry ecosystem.

Phytoseiid mites have been found to be highly effective predators in controlling TSSM (Zhi-Qiang & Sanderson 1995). Two of the most commonly used phytoseiids are *Phytoseiulus persimi-*

lis Athias-Henriot and *Neoseiulus californicus* (McGregor) (McMurtry & Croft 1997; Cloyd et al. 2006). Oatman et al. (1972) found that although *P. persimilis* was effective in controlling TSSM, it is a type I specialist predator of *Tetranychus* species and tends to decimate TSSM populations, altering the arthropod complex (McMurtry & Croft 1997). However, Colfer et al. (2004) found that releases of generalist species of phytoseiid mites such as *N. californicus* do not affect the diversity or abundance of arthropod populations.

As a type II generalist, *N. californicus* has a broad diet range that includes not only various arthropods, but also plant sap, honeydew, and pollen (McMurtry & Croft 1997). *Neoseiulus californicus* can adapt to fluctuations in prey populations, providing stable pest suppression over time (Croft et al. 1998; Castagnoli et al. 1999; Escudero & Ferragut 2005; Greco et al. 2005). Rhodes et al. (2006) observed that *N. californicus* was able to maintain more consistent control of TSSM populations compared with *P. persimilis* throughout the season in north Florida strawberry fields. The ability of *N. californicus* to survive on a broad array of food sources contributes to its stability and may mitigate its effect on community structure and other beneficial arthropods (Jones 1976; Powers & McSorley 2000; Cross et al. 2001; Rhodes et al. 2006).

There are many natural enemies capable of suppressing TSSM populations (Oatman et al. 1985). However, their use in biological control has been limited due to their generalist feeding preferences. Field studies conducted between 1964-1980 in southern California identified 9 phytoseiid mite species and several species of insects within the families Thripidae, Cecidomyiidae, Coccinellidae, Staphylinidae, Anthocoridae, Lygaeidae, Chrysopidae, and Hemerobiidae as natural enemies of TSSM (Oatman et al. 1985). Rondon et al. (2004) conducted laboratory studies evaluating the big-eyed bug, *Geocoris punctipes* Say, minute pirate bug, *Orius insidiosus* (Say), and the pink spotted lady beetle, *Coleomegilla maculata* De-Geer, as predators for TSSM. They found that while they feed on TSSM, they preferred other phytophagous insects, thereby limiting their utility as successful biological control agents.

Conserving a robust ecosystem is essential to sustain the myriad of natural enemies that contribute to a sustainable integrated pest management (IPM) program. In this study, field experiments were conducted to determine the effect of releasing *N. californicus* as a biological control agent for TSSM on the arthropod complex in strawberry fields, and evaluated with the Shannon-Weaver index ( $H'$ ) (Shannon 1948). Our hypothesis was that inundative releases of *N. californicus* to control TSSM in strawberries will not negatively impact other key natural enemies and arthropod diversity in the strawberry system. If so, *N. californicus* could be released as part of an

IPM or biological control program in north Florida strawberry while preserving non-target beneficial arthropods.

## MATERIALS AND METHODS

A preliminary study was conducted during 2005-2006 (Jan to Mar) to assess the accuracy of sample methods and level of diversity in the strawberry system. The main study was conducted during the 2006-2007 (Oct to Mar) growing season to evaluate the effect of predatory releases at 3 phenological periods: foliar, floral, and fruit development.

### Field Preparation

The field experiment was located at the University of Florida Plant Science Research and Education Unit in Citra, Florida (82.17°W, 29.41°N). Sixteen research plots of 53.29 m<sup>2</sup> with a bare ground buffer of 11 m between plots were planted with strawberries, variety 'Festival', during the first week of Oct 2005 and 2006 in raised beds covered with 6-mil black plastic mulch. Strawberry plants were fertilized through the drip irrigation system once per week with 18.5 kg of ammonium nitrate (Southern States Cooperative, Inc., Richmond, VA) and 32.7 kg of muriate of potash (Southern States Cooperative, Inc., Richmond, VA) per ha. Nitrogen was increased in Feb to 27.1 Kg/ha of ammonium nitrate to accommodate increased nutrient demand during fruit development. Fungicides were applied 3 times per week in rotation to all experimental plots throughout the season to combat *Botrytis* fruit rot (*Botrytis cinerea*) and anthracnose fruit rot (*Colletotrichum acutatum*). The fungicides used were Abound® (azoxystrobin) (Syngenta Crop Protection, Greensboro, NC), Topsin® (thiophanate) (Cereagri, Inc., King of Prussia, PA), Aliette® (aluminum tris) (Bayer Crop Science, Research Triangle Park, NC), and Serenade® (*Bacillus subtilis*) (Agraquest, Davis, CA). No insecticides or acaricides were applied to the research plots. Preparation and management procedures are described in detail in Fraulo & Liburd (2007).

The experimental design used was a randomized complete block with 4 treatments and 4 replications. *Neoseiulus californicus* (Koppert Biological Systems, Romulus, MI) was released in all treated plots at the recommended rate of 1-2 predators per square meter. Viability was assessed by observing 20-30 predatory mites in a Petri dish with a dissecting binocular microscope (10-20×) (Leica MZ12.5, McBain Instruments, Chatsworth, CA) for 15 min before each release to ensure that the mites were vigorously active. The treatments included releases of *N. californicus* as follows: (1) in the "early" season at foliar development, 4 weeks after planting (WAP), (2) during

the "mid" season at floral development, 8 WAP, (3) "late" in the season at fruit development, 12-16 WAP, and (4) "no release" untreated control.

#### Preliminary Study

Field preparations for the preliminary study are described above and in Fraulo and Liburd (2007). The goal of the preliminary study was to determine an appropriate sample size and to evaluate diversity with the Shannon-Weaver diversity index. Data were collected at 12 WAP, during the "late" season of the 2005-2006 field season to assess the overall effect of *N. californicus* on the arthropod assemblage in the strawberry field. One yellow sticky Pherocon® AM Trap (YST) (Trécé, Inc., Adair, OK), 28 cm × 23 cm surface area with 56 squares of 6.45 cm<sup>2</sup> (1 in<sup>2</sup>) forming a grid on the board was hung on a garden stake 30 cm above plants. Each trap was placed in the center row of each of the 24 treatment plots. Traps were collected weekly for 5 weeks and placed into Zipper Seal Storage Bags® (American Value, Dolgencorp, Inc., Goodlettsville, TN) and transported to the Small Fruits and Vegetable IPM Laboratory at the University of Florida, Gainesville, FL to be examined under a dissecting microscope (10-20×) (Leica MZ12.5, McBain Instruments, Chatsworth, CA). To develop a sub-sample protocol, 3 YSTs were randomly chosen from all samples and each of the 56 one-inch squares on each trap was examined to determine the arthropod families found per square. The families observed on each square of the YST were counted and compiled into a comprehensive list, and recorded. A cumulative frequency distribution was plotted for each square to determine the optimal sub-sample size. These data were used to create a sub-sampling scheme for data analysis in the main study. The frequency tables of the families with their key taxonomic characteristics were recorded and used for primary identification during the main study.

#### Main Study

We evaluated the effect of *N. californicus* by sampling at 1-month intervals 2 weeks after each release date, based on the homogeneity of the preliminary results, field observations, and previous research by Garcia-Mari & Gonzalez-Samora (1999). Arthropod sampling was conducted during the 2006-2007 field season at (a) 2 months after planting ("early" season), (b) 3 months after planting ("mid" season), and (c) 4 months after planting ("late" season). Individuals were identified to family or genus depending upon the level of functional variation within the taxon, based on notes from the preliminary study described above and previous research (Jones 1976; Cross et al. 2001; Arevalo et al. 2006; Klein et al. 2006). The number of individuals present from each taxon

was collected by the method described in the preliminary sampling, identified, and recorded. Unknown taxa were identified at the Department of Plant Industry, Gainesville, FL. Data were collected throughout the season and compared to determine the effect of *N. californicus* releases on arthropod assemblages in the field within each distinct period.

We employed 4 sampling methods in order to increase the probability of encountering a higher diversity of taxa and to avoid bias, as follows: (1) *In situ* (visual inspection), (2) foliar sampling, (3) pitfall traps, and (4) yellow sticky traps.

*In situ* Sampling. Twenty-four strawberry plants from the interior rows of each plot were visually inspected once weekly for 2 weeks during each sample period. The visual inspection consisted of a scan for 30 s for each plant. This enabled us to sample the larger arthropods occurring in the field including macro-hymenoptera, hemiptera, and coleoptera.

Foliar Sampling. Four young trifoliate leaves from the inside of the plant crown and 4 old trifoliates from the outer-crown were taken randomly from each treatment plot. Samples were conducted weekly for 2 weeks after each of the 3 predatory releases. The leaves were placed in a ziplock bag and transported to the laboratory where they were visually inspected under the dissecting binocular microscope for leaf-dwelling and minute arthropods.

Pitfall Traps. Traps were constructed of white polypropylene deli containers 14 cm deep and 10.5 cm in diameter (Fabri-Kal Corp., Kalamazoo, MI) filled with 0.15 L of 10% dish soap and water solution. The traps were placed in the soil under the black plastic mulch in one of the 2 center rows of each treatment plot to capture cursorial soil arthropods and soil dwellers (Southwood 1966). The traps were left in the field for 48 h each week for a 2-week period after each of the 3 predatory releases.

Yellow Sticky Traps. One trap per plot was placed in one of the 2 center rows at foliar height, approximately 30 cm above ground to capture winged arthropods. The YST were left in the field for 48 h each week for a 2-week period after each of the 3 predatory releases. In the laboratory, a proportion of each trap surface area was observed for analysis based on results of the preliminary samples.

#### Statistical Analysis

The arthropod assemblages among treatments in both the YST and pitfall traps throughout the season were analyzed with a Non-Metric Multidimensional Scaling (NMS) ordination with PC-ORD 4 (Kruskal 1964). This method is well-suited for describing patterns in community data and does not assume normality (McCune & Grace 2002).

The ordination was conducted by the Sørensen distance measure (McCune & Grace 2002) with a random starting configuration. The autopilot setting on medium thoroughness was used to determine the dimensions of the ordination (McCune & Grace 2002). Fifteen runs with real data with 200 iterations were used. To assess the strength of the ordination, the Monte Carlo option with 30 runs of randomized data was selected. Data were square-root transformed if the correlation of variation among rows and columns were greater than 50% (McCune & Grace 2002) and outliers were removed to strengthen the structure of the data. Rare families that were present in numbers too low to be included in the ordination were recorded in a comprehensive list for each treatment and were included in diversity calculations. All taxa found were included in the calculation of the Shannon-Weaver diversity index and results among treatments were compared by analysis of variance (ANOVA) followed by mean separation with LSD test (SPSS 2004). To convert the results of the Shannon-Weaver index into a true diversity measure, the exponential of the entropy value was calculated (Jost 2006), as follows:

$$D = \exp\left(-\sum_{i=1}^s p_i \ln p_i\right) = \exp(H')$$

where  $p_i$  = the proportional abundance of taxon.  
 $D$  = true diversity measure.

## RESULTS

### Preliminary Study

Sub-sampling procedures demonstrated that 28 squares on the YST consistently included at least 90% of the arthropod families recorded (Fig. 1). Therefore, 28 squares (47% of the trap area, excluding borders) were observed for analysis in the main study. The Shannon-Weaver index indicated no significant differences in level of diversity among any of the treatments in the preliminary study ( $F = 0.5$ ;  $df = 3, 12$ ;  $P = 0.69$ ).

### Main Study

Arthropod community structure following releases of *N. californicus* for biological control of TSSM was analyzed during various periods throughout the growing season. The NMS ordination conducted following releases of *N. californicus* during “mid” season sampling showed a weak community structure and did not provide any groupings of the data related to the treatments imposed (Fig. 2). A similar lack of structure was observed in ordinations for the “early” and “late” sampling dates (data not shown). In the “early”

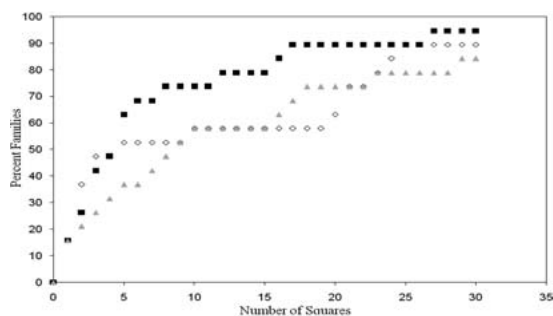


Fig. 1. Distribution frequency used in the preliminary trial to calculate optimal sub-sample size for squares on yellow sticky card trap (YST).

season (Dec) we compared the plots treated with *N. californicus* releases and untreated plots (without *N. californicus* releases). The arthropod assemblages found in pitfall traps showed a weak structure (axis 1,  $P = 0.13$ ; axis 2,  $P = 0.13$ ; axis 3,  $P = 0.32$ ) indicating that *N. californicus* releases did not have a significant effect on the arthropod assemblages. When data were square-root transformed and outliers were removed, the NMS ordination remained non-significant (axis 1,  $P = 0.13$ ; axis 2,  $P = 0.29$ ; axis 3,  $P = 0.48$ ). Results from NMS ordination of the YST also were not significant (axis 1,  $P = 0.52$ ; axis 2,  $P = 0.68$ ; axis 3,  $P = 0.48$ ). The coefficient of variation was low (39.17%) indicating that transformation of data has no effect on data structure.

During the “mid” season (Jan) no significant differences were recorded in assemblages collected in the pitfall traps (axis 1,  $P = 0.29$ ; axis 2,  $P = 0.26$ ; axis 3,  $P = 0.26$ ) by the NMS ordination. Yellow sticky traps also showed no significant differences among treatments (axis 1,  $P = 0.29$ ; axis 2,  $P = 0.13$ ; axis 3,  $P = 0.23$ ). Transformations were not recommended as it did not affect data structure.

In the final NMS ordination, no significant differences among treatments were found in the late season (Feb), for pitfall trap data (axis 1,  $P = 0.13$ ; axis 2,  $P = 0.16$ ; axis 3,  $P = 0.32$ ). When outliers were removed from the data set results remained non-significant (axis 1,  $P = 0.13$ ; axis 2,  $P = 0.16$ ; axis 3,  $P = 0.13$ ). Yellow sticky traps showed no differences among arthropod assemblages with introduction of *N. californicus* (axis 1,  $P = 0.52$ ; axis 2,  $P = 0.71$ ; axis 3,  $P = 0.71$ ). Removing outliers did not affect data structure (axis 1,  $P = 0.29$ ; axis 2,  $P = 0.32$ ; axis 3,  $P = 0.58$ ).

The true diversity index based on the Shannon-Weaver index (“D”) showed a significant effect on arthropod diversity in the YST in the “early” season ( $F = 5.35$ ;  $df = 3, 12$ ;  $P = 0.01$ ), but not in the pitfall traps ( $F = 0.3$ ;  $df = 3, 12$ ;  $P = 0.83$ ). “Mid” season YST and pitfall traps showed no significant effect on diversity ( $F = 1.3$ ;  $df =$

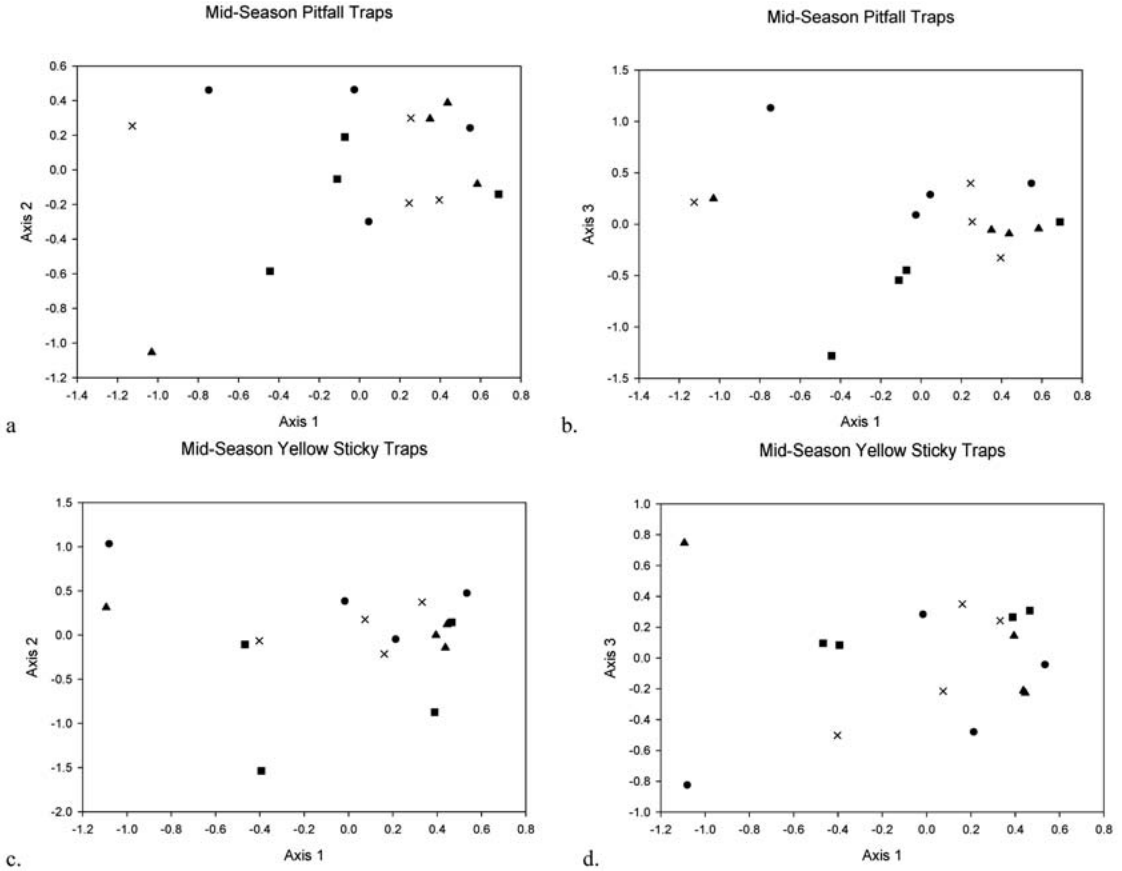


Fig. 2. Non-Metric Multidimensional Scaling (NMS) ordinations of arthropod communities in “mid” season pitfall traps (a, b) and yellow sticky traps (c, d) showing weak data structure along axis 1 and 2 (a, b), and axis 1 and 3 (c, d) with no significant differences ( $P < 0.05$ ) among treatments. ▲ = Early release; ■ = Mid-season release; ● = Late release; × = No Release (control).

3,12;  $P = 0.7$ ; and  $F = 0.3$ ;  $df = 3,12$ ;  $P = 0.57$ , respectively). Yellow sticky traps ( $F = 2.8$ ;  $df = 3,12$ ;  $P = 0.08$ ) and pitfall traps ( $F = 6.5$ ;  $df = 3,12$ ;  $P = 0.6$ ) also showed no significant difference among treatments late in the season (Tables 1 and 2).

Overall, the visual and foliar samples did not produce sufficient numbers of arthropods to conduct robust statistical analysis. However, they should not be dismissed because they revealed interesting phenological trends and important natural predators of strawberry pests. Early in the season thrips (*Frankliniella* spp.) and Chalcidoidea populations were significantly higher in the treated plots compared with the untreated plots ( $F = 4.81$ ;  $df = 1, 30$ ;  $P = 0.04$ ,  $F = 8.44$ ;  $df = 1, 30$ ;  $P = 0.01$ , respectively) During the “mid” season high numbers of *Pachybrachius* spp. and a dramatic decline in aphid population directly following an increase in syrphid abundance were observed (Tables 3, 4, 5, and 6). Foliar sampling indicated that as the season progressed, the abundance of Coccinellids increased in all treatment

plots (personal observation), as did six-spotted thrips *Scolothrips sexmaculatus* (Pergande) and Geocorid bugs *Geocoris* spp. Late in the season, numbers of taxa decreased, and an increase of *Bradysia* spp. (Sciaridae) was observed.

DISCUSSION

Ordination results confirmed the lack of treatment effects observed through the analysis of variance. If the treatments had affected community structure, points representing the same treatment would have clustered together in the ordination figures (Klein et al. 2006), but this was never observed. Ordination used to describe the community patterns and the measures of diversity both indicated that presence of *N. californicus* did not disrupt the natural ecology of the system. *Neoseiulus californicus* was released at several times during the season and persisted through the experiment, not disrupting arthropod assemblages while significantly reducing TSSM popula-

TABLE 1. MEAN ( $\pm$  SE) VALUES OF SHANNON-WEAVER DIVERSITY INDEX (D) FOR EACH SAMPLE PERIOD FOR YELLOW STICKY TRAPS.

Treatment	Sample date			
	Dec	Jan	Feb	Preliminary
Early	2.9 $\pm$ 0.16 c	9.4 $\pm$ 1.00	7.1 $\pm$ 0.68	8.6 $\pm$ 0.41
Middle	2.5 $\pm$ 0.20 b	8.6 $\pm$ 0.30	8.8 $\pm$ 0.91	8.7 $\pm$ 1.40
Late	3.9 $\pm$ 0.34 a	7.5 $\pm$ 0.66	5.7 $\pm$ 1.00	8.2 $\pm$ 0.14
No-release	3.1 $\pm$ 0.28 b	8.2 $\pm$ 0.53	6.3 $\pm$ 0.47	7.0 $\pm$ 0.95

Means with the same letter within columns are not significantly different ( $P < 0.05$ ) based on LSD test. Dates with no letters represent dates with no significant differences.

tions as observed in a related study (Fraulo & Liburd 2007). The Shannon-Weaver index on YST indicated a significant difference on community structure between treated and untreated plots in the “early” season. However, this effect was short lived and was non-significant for the remainder of the season. This early disruption may be due to sparse and clumped populations within arthropod communities at the beginning of the season and did not have a significant overall effect.

The majority of predators in the strawberry system are generalist feeders and *N. californicus* itself is a generalist predator. Feeding preference likely moderated the impact on the arthropod assemblage. Our results indicate that the release of *N. californicus* does not have a statistically significant effect on the assemblage and community functioning of arthropods in the strawberry system. Its release did not affect the balance and regulation of the natural ecosystem in our study. Generalist feeding behavior coupled with a high level of richness and insect diversity in the strawberry system may be key factors in reducing the effect of *N. californicus* releases on the structure of the strawberry system.

There were no overall non-target effects on natural enemies. Major insect families (Thripidae, Cecidomyiidae, Coccinellidae, Staphylinidae, and Lygaeidae) as cited by Oatman et al. (1985) and Rondon et al. (2004), were present throughout our study. Thrips (*Frankliniella* spp.) and

Chalcidoidea populations were present throughout the field early in the season. *Neoseiulus californicus* is a known predator of thrips. However, adult thrips migrate into flowering strawberry plants and take shelter within the styles of the strawberry flower where *N. californicus* cannot access them (Cross et al. 2001). Increased levels of the superfamily Chalcidoidea, which are parasitoids of thrips, were also observed in higher numbers in the plots with high numbers of thrips.

Aphids were abundant in all treatments during the “early” season and decreased throughout the season. Decreasing numbers of aphids in conjunction with increased numbers of Syrphidae are consistent with studies conducted in north Wales showing that Syrphidae can cause considerable reduction in aphid numbers (Cross et al. 2001). This function was not affected by the presence of *N. californicus*. Foliar sampling indicated that as the season progressed, the abundance of sixspotted thrips (*S. sexmaculatus*) and *Geocoris* spp. increased in all treatment plots (both are predators of TSSM).

Our findings from this and previous release studies demonstrate that releasing *N. californicus* in the field at the recommended rate of 1-2 *N. californicus* per m<sup>2</sup> when TSSM populations are low ( $\leq 70$ -80 TSSM per trifoliolate) provides season-long control of TSSM and does not disrupt other natural enemies of seasonal pests (Jones 1976; Fraulo & Liburd 2007). A one-time application of

TABLE 2. MEAN ( $\pm$  SE) VALUES OF SHANNON-WEAVER DIVERSITY INDEX (D) FOR EACH SAMPLING PERIOD FOR PITFALL TRAPS.

Treatment	Sample date		
	Dec	Jan	Feb
Early	5.4 $\pm$ 0.76	4.7 $\pm$ 0.77	3.8 $\pm$ 0.42
Middle	5.0 $\pm$ 0.44	3.7 $\pm$ 0.44	3.7 $\pm$ 0.09
Late	5.2 $\pm$ 0.62	3.7 $\pm$ 0.54	4.4 $\pm$ 0.37
No-release	5.8 $\pm$ 0.63	3.8 $\pm$ 0.46	3.9 $\pm$ 0.47

No significant differences ( $P < 0.05$ ) among treatments on any sampling date.

TABLE 3. CUMULATIVE NUMBER OF SPECIMENS FOUND IN YELLOW STICKY TRAPS DURING THE 3 SAMPLING PERIODS.

	Dec					Jan					Feb			
	E	M	L	NR		E	M	L	NR		E	M	L	NR
Acanaloniidae	2	1	2	1	Acanaloniidae	4	1	3	3	Aleyrodidae	—	4	—	—
Aleyrodidae	2	16	26	14	Aleyrodidae	2	17	3	1	Aphididae	6	6	1	3
Aphididae	383	643	579	539	Aphididae	12	10	5	11	Cecidomyiidae	4	6	8	1
Bethylidae	—	—	1	—	Tachinidae	5	8	2	3	Chalcidoidea	33	26	33	31
Bibionidae	—	5	5	—	Bibionidae	3	1	—	1	Chrysomella	2	2	2	—
Cecidomyiidae	11	10	6	9	Braconidae	2	1	3	5	Cicadellidae	7	2	1	7
Chalcidoidea	34	59	83	91	Cecidomyiidae	10	8	14	4	Coccinella ( <i>Hippodamia</i> spp.)	3	—	1	6
Chrysomelidae	—	—	—	1	Chalcidoidea	61	66	78	53	Drosophilidae	1	—	—	—
Cicadellidae	2	11	17	5	Chrysomelidae ( <i>Alticinae</i> spp.)	1	1	—	1	Ichneumonidae	3	8	4	4
Staphylinidae	—	2	—	—	Cicadellidae	3	3	4	2	Lepidoptera	1	—	—	—
Cucujidae	—	1	11	—	Coccinellidae ( <i>Hippodamia</i> spp.)	4	3	—	2	Muscidae	17	14	14	19
Dolichopodidae	7	17	4	3	Drosophilidae	4	1	2	1	Nitulidae	2	1	2	—
Drosophilidae	3	—	—	—	Ichneumonidae	4	—	3	—	Lygaeidae ( <i>Pachybrachius</i> spp.)	1	4	5	2
Ichneumonidae	—	—	4	4	Leiodidae	—	1	1	1	Phoridae	2	6	1	2
Lepidoptera	1	1	—	1	Dolichopodidae	2	4	4	5	Psychodidae	—	—	2	1
Muscidae	8	7	9	30	Lygaeidae ( <i>Pachybrachius</i> spp.)	3	6	—	1	Sciaridae ( <i>Bradysia</i> spp.)	52	48	94	48
Nitulidae	—	—	2	—	Muscidae	23	13	15	15	Staphylinidae	2	1	1	1
Phloeothripidae	3	2	4	3	Nitulidae	1	—	1	—	Syrphidae ( <i>Sphaerophoria</i> spp.)	3	2	1	1
Phoridae	3	16	7	7	Phloeothripidae	1	—	—	—	Thripidae ( <i>Frankliniella</i> spp.)	2	8	5	2
Platygatroidae	1	—	—	—	Phoridae	10	14	40	9	Araneida	1	1	1	3
Psychodidae	1	3	10	—	Psychodidae	5	2	—	1	Dolichopodidae	10	7	3	4
Sciaridae ( <i>Bradysia</i> spp.)	5	5	50	10	Sciaridae ( <i>Bradysia</i> sp.)	23	17	24	8	Tachinidae	2	4	4	2
Thripidae ( <i>Frankliniella</i> sp.)	39	39	—	23	Staphylinidae	—	2	1	—					
					Syrphidae ( <i>Sphaerophoria</i> spp.)	—	—	1	1					
					Thripidae ( <i>Frankliniella</i> spp.)	16	17	9	10					

E = early treatment, M = middle treatment, L = late treatment, and NR = no release.

TABLE 4. CUMULATIVE NUMBER OF SPECIMENS FOUND IN PITFALL TRAPS DURING THE 3 SAMPLING PERIODS.

	Dec					Jan					Feb			
	E	M	L	NR		E	M	L	NR		E	M	L	NR
Chrysomelidae ( <i>Alticinae</i> spp.)	—	1	1	—	Aphididae	11	2	6	5	Aphididae	1	—	1	1
Aphididae	19	9	5	9	Cecidomyiidae	4	—	6	2	Braconidae	—	—	1	—
Apoidea	—	—	1	1	Chalcidoidea	1	2	1	—	Cecidomyiidae	—	—	—	1
Bibionidae	2	—	—	—	Cicadelidae	—	1	—	—	Chalcidoidea	1	1	—	—
Cecidomyiidae	8	7	7	17	Collembola	50	85	132	65	Chrysomellidae	—	—	1	—
Chalcidoidea	—	4	3	2	Gryllidae	1	—	—	—	Collembola	10	24	13	39
Chironomidae	—	2	—	—	Cucujidae	1	—	1	—	Formicidae	1	1	11	2
Cicadellidae	1	—	1	—	Drosophilidae	—	2	—	1	Lygaeidae ( <i>Geocoris</i> spp.)	4	1	—	8
Collembola	41	21	23	31	Formicidae	44	9	2	2	Sciaridae ( <i>Bradysia</i> spp.)	9	7	14	15
Cucujidae	1	—	—	—	Lygaeidae ( <i>Pachybrachius</i> spp.)	18	21	47	29	Staphylinidae	—	—	1	2
Drosophilidae	—	—	—	2	Miridae	1	—	—	—	Thripidae ( <i>Frankliniella</i> spp.)	1	—	—	—
Elateridae	—	—	1	—	Muscidae	—	—	1	—	Vespidae	—	1	—	—
Formicidae	35	26	6	42	Nitulidae	—	—	1	—	Araneida	3	1	1	—
Ichnueumonidae	—	1	—	—	Phoridae	—	—	1	—	Muscidae	—	—	2	—
Lepidoptera	—	—	—	2	Sciaridae ( <i>Bradysia</i> spp.)	4	2	1	2					
Miridae	1	—	—	—	Araneida	4	3	2	2					
Muscidae	2	2	—	—	Staphylinidae	1	—	—	—					
Mutillidae	1	—	—	—	Tettigoniidae	1	—	—	—					
Nematode	—	2	—	—	Thripidae ( <i>Frankliniella</i> spp.)	2	2	2	4					
Phloeothripidae	—	1	1	—	Scollidae	—	—	1	—					
Phoridae	2	3	2	2										
Sciaridae ( <i>Bradysia</i> spp.)	—	1	1	2										
Staphylinidae	3	1	1	1										
Tettigoniidae	—	2	—	—										
Thripidae ( <i>Frankliniella</i> spp.)	1	5	3	1										
Araneida	1	2	5	2										

E = “early” treatment, M = “mid” treatment, L = “late” treatment, and NR = no release.



TABLE 5. CUMULATIVE NUMBERS OF SPECIMENS RECORDED DURING VISUAL EVALUATIONS.

	Dec				Jan				Feb			
	E	M	L	NR	E	M	L	NR	E	M	L	NR
Tettigoniidae	3	1	3	3	—	—	—	—	4	7	2	4
Apoidea		6	9	5	—	—	—	—	0	1	3	2
Syrphidae ( <i>Sphaerophoria</i> spp.)	3	3	1	4	16	13	6	8	2	1	—	1
Araneida		—	—	1	2	1	8	4	2	—	—	—
Lepidoptera	1	1	1	1	—	—	—	—	—	—	1	—
Muscidae	1	2	2	2	—	—	—	—	1	—	1	2
Chrysomelidae	1	—	—	—	—	—	—	—	1	—	—	1
Coccinellidae ( <i>Hippodamia</i> spp.)	1	—	—	—	1	2	—	—	1	—	—	—
Lygaeidae ( <i>Tristicolor</i> spp.)	—	—	—	—	—	—	—	—	—	—	—	1
( <i>Pachybrachius</i> spp.)	—	—	—	—	8	2	6	12	1	—	—	1
Sciaridae ( <i>Bradysia</i> spp.)	—	—	—	—	—	—	—	—	52	28	39	14
Cicadellidae	—	—	—	—	—	—	—	—	—	1	—	—

E = "early" treatment, M = "mid" treatment, L = "late" treatment, and NR = no release.

TABLE 6. CUMULATIVE NUMBERS OF SPECIMENS RECORDED DURING THE FOLIAR EVALUATIONS.

	Dec				Jan				Feb			
	E	M	L	NR	E	M	L	NR	E	M	L	NR
Aphididae	43	64	28	40	—	1	4	4	1	1	—	—
Aleyrodidae	29	22	22	2	2	2	2	2	—	—	—	3
Thripidae ( <i>Frankliniella</i> spp.)	7	2	1	1	14	4	14	14	—	3	—	3
( <i>Scolothrips sexmaculatus</i> )	—	1	2	2	6	3	10	10	4	1	3	2
Chalcidoidea	—	—	1	—	—	—	—	—	—	—	—	—
Lepidoptera	1	—	—	—	—	—	—	—	6	6	2	9
Syrphidae ( <i>Sphaerophoria</i> spp.)	—	—	—	—	9	8	9	9	4	5	10	15
Lygaeidae ( <i>Geocoris</i> spp.)	—	—	—	—	—	—	—	—	3	—	—	9

E = "early" treatment, M = "mid" treatment, L = "late" treatment, and NR = no release.

*N. californicus* at the recommended rate would cost one-third the price of chemical treatments while having a non-significant effect on beneficials in strawberry. Although *N. californicus* is tolerant to many insecticides and fungicides (Easterbrook 1992; Croft et al. 1998; Escudero & Ferragut 2005; and Liburd et al. 2007), we do not recommend additional chemical applications as they may adversely affect other beneficials. We found that when released in the field, *N. californicus* is able to maintain consistent control of TSSM populations while maintaining an array of beneficials throughout the season in north Florida strawberry fields.

ACKNOWLEDGMENTS

We thank Elizabeth Boughton, Pedro Quintana-Ascencio, and H. Alejandro Arévalo for providing assistance with statistical analysis and critical reviews of the project.

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