EXPANDED DISTRIBUTION OF THE BAMBOO SPIDER MITE, *SCHIZOTETRANYCHUS LONGUS* (ACARI: TETRANYCHIDAE), AND PREDATION BY *NEOSEIULUS FALLACIS* (ACARI: PHYTOSEIIDAE)

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SCHIZOTETRANYCHUS LONGUS
NEOSEIULUS FALLACIS
BAMBOO
ORNAMENTAL

SUMMARY: *Schizotetranychus longus* Saito is a common pest of bamboo in Japan. We report its new occurrence in the Willamette Valley, Oregon, on bamboo. We assessed the ability of adult females of *Neoseiulus fallacis* (Garman), a native predaceous mite, to invade *S. longus* nests after construction times of 5 or 10 days. Frequency of predators in nests decreased from 5 to 10 days, although the predator laid most of its eggs in nests irrespective of construction time. In choice tests, spider mite webbing was more attractive to *N. fallacis* than eggs, but similar to feces. Predators searched more in proximity to feces than eggs, but resting sites were equally common near both. Survival, activity and reproduction of *N. fallacis* when given excess of mixed life stages of *S. longus*, *Tetranychus urticae* Koch, pollen of *Tulipa gesneriana* L. or *Pseudotsuga menzesii* (Mirbel), or no food were measured by holding single adult female *N. fallacis* for 7 days. Survival, activity, oviposition and immature production of predators were alike for both spider mites, but lower (or higher activity) with pollens or when starved. To see if *N. fallacis* would suppress *S. longus* under normal growing conditions, predators were added to infested *Sasaella hidaensis* (Makino and Uchida) var. 'Murai' plants, and mites were monitored thereafter for 5 weeks. *N. fallacis* significantly reduced levels of *S. longus* and the rates that it infested bamboo leaves; it nearly eliminated *S. longus* from plants at the end of the test.

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ZUSAMMENFASSUNG: Die Spinnmilbe *Schizotetranychus longus* Saito ist ein weitverbreiteter Schädling an Bambus in Japan und semi-tropischen Regionen Nordamerikas (Kalifornien, Georgia und Florida). Erstmals wird über das Auftreten dieser Art an Bambus im Willamette-Valley, Oregon, berichtet. Es wurde untersucht, ob adulte Weibchen der (in Oregon heimischen) Raubmilbe *Neoseiulus fallacis* (Garman) fähig sind, 5 oder 10 Tage alte Gespinste von *S. longus* zu durchbrechen und in deren Nester einzudringen. Mit zunehmender Gespinstdichte nahm die Anzahl der Raubmilben in den Spinnmilbennestern ab. Unabhängig von der Gespinstdichte legten die Raubmilben den Grossteil der Eier in den Nestern ab. In Wahlversuchen bevorzugte *N. fallacis* Spinnmilbengespinste und -kot gegenüber Spinnmilbeneiern. Nahrungssuchende Raubmilbenweibchen wurden häufiger in der Nähe von Spinnmilbenkot als in der Nähevon Spinnmilbeneiern gefunden, rastende Raubmilbenweibchen zeigten

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keine Präferenz. Die Überlebensfähigkeit, Aktivität und Reproduktion von einzeln gehaltenen adulten *N. fallacis* Weibchen wurde mit den Beutetieren *S. longus* und *Tetranychus urticae* Koch bzw. mit Pollen von *Tulipa gesneriana* L. und *Pseudotsuga menzesii* (Mirbel) über einen Zeitraum von 7 Tagen gemessen. Als Kontrolle wurden Weibchen ohne Nahrung gehalten. Der Prozentsatz an überlebenden Weibchen, Aktivität, Oviposition und Nachkommenszuwachs waren gleich hoch mit beiden Spinnmilbenarten als Nahrung, jedoch geringer (und die Aktivität höher) mit Pollen bzw. ohne Nahrung. Um zu testen, ob *S. longus* unter natürlichen Bedingungen durch *N. fallacis* bekämpft werden kann, wurden die Raubmilben an spinnmilbenbesetzten Bambuspflanzen, *Sasaella hidaensis* (Makino & Uchida) var., Murai', ausgesetzt und das Räuber/Beute Verhältnis über einen Zeitraum von 5 Wochen kontrolliert. *N. fallacis* reduzierte sowohl die Populationsdichte der Schadmilben, als auch die Anzahl der durch *S. celarius* befallenen Blätter signifikant. Gegen Versuchsende war *S. longus* beinahe vollständig von den Pflanzen verschwunden.

INTRODUCTION

Establishment of an exotic pest may depend on the absence of native predators that are adapted to it (GOEDEN & LOUDA, 1976). Also, changes in local environmental conditions caused by a pest can improve microclimates or retard predators, and thereby enhance its establishment. *Schizotetranychus longus* Saito is a pest of bamboo in Japan (SAITO, 1990b). Upon finding a feeding site, this spider mite builds a densely webbed nest within which it reproduces. SAITO suggested that the dense webbing and fecal deposits of *S. longus* may protect it from predators (SAITO, 1983), although webbing of some spider mites is attractive to many predaceous phytoseiid mite species (SCHMIDT, 1976). SAITO (1990) reported feeding and adaptations of *Typhlodromus (Amblyseius) bambusae* Ehara, a native phytoseiid associated with *Schizotetranychus* species in Japan and concluded that it had coevolved with *S. celarius* to feed and maneuver within the nest of the pest. No studies to date have reported any endemic phytoseiids in the USA that are associated with *S. longus*.

Recent inspections of bamboo revealed infestations of an unknown spider mite in the coastal-temperate regions of Oregon and Washington USA, where ornamentals are widely grown. Preliminary observations of the pest indicated that it was *S. longus*. We sought to confirm this identification and, in the absence of *T. bambusae*, to measure the ability of a native phytoseiid mite to exploit the nest habitat and suppress this spider mite. In temperate-humid areas of the USA, *Neoseiulus fallacis* (Garman) is widely released on ornamentals and other crops to control spider mites (PRATT & CROFT, 1998). Objectives of this study were to measure: 1) propensities of *N. fallacis* to enter the nest of *S. longus*, 2) attractiveness to *N. fallacis* of webbing, feces or eggs of *S. longus*, 3) ability of *N. fallacis* to reproduce on *S. longus* and 4) whether *N. fallacis* could suppress *S. longus* on bamboo plants under normal growing conditions.

MATERIALS AND METHODS

Identification of S. longus *and predator mite cultures*

Initially, an unknown spider mite was collected from commercial bamboo near Coos Bay and Portland, OR, USA. Adults of both sexes were mounted on glass slides and sent to Z. Q. ZHANG, Landcare Research, Auckland, New Zealand for identification. Predators for releases (*N. fallacis*) had been collected from crops in the Willamette Valley, Oregon (HADAM *et al.*, 1986). These cultures had been held for six years or more with yearly additions of field-collected mites. Predator cultures were held at 25 (± 5)°C, 16:8 L:D (light:dark), and 75–95% RH, and fed mixed life stages of the common spider mite, *Tetranychus urticae* Koch, three times per week. Only gravid female predators were selected for use in tests. To adjust for possible dissimilar levels of hunger among predator mites, all *N. fallacis* adult females were held without food for 24 hours just prior to feeding experiments (below).

Invasion of nests by N. fallacis *and attraction to products of* S. longus

To quantify the ability of *N. fallacis* to enter webbed nests of *S. longus*, 2.5 × 2.5 cm arenas were created on bamboo leaves (underside up) using a water-soaked cotton barrier (SAITO, 1990a). To allow nest construction, 3–4 *S. longus* adult females were added to each of 16 arenas held at 25 (± 1)°C, 75 (± 10) RH, and 16:8 L:D. We randomly selected 8 arenas and placed a single gravid *N. fallacis* on each after 5 days of nest construction. The other 8 arenas received a single female *N. fallacis* after 10 days. Sites of entrance of the predator into the nest, resting locations of *N. fallacis* and number and sites of predator eggs were measured at 2, 4, 6, 8, 10, 12, 24, and 36 hours after transfer of predators. Mode of entrance was scored as either entering via existing openings on either side of the nest or boring an entrance into the nest through the webbing. To compare frequencies of these two binomial measured attributes, we used a binomial test with the null hypothesis frequency of 0.5. A *P*-value <0.10 was considered evidence that the null hypothesis was false.

To test attraction and arrestment of *N. fallacis*, dual choice arenas were used (SCHMIDT, 1976). Arenas consisted of 2 × 2 cm tile substrate ringed with water-soaked cotton and replicated 18 times (MACRAE & CROFT, 1993). *S. longus* eggs, webbing or feces were removed with different forceps from bamboo leaves [*Sasaella hidaensis* (Makino and Uchida) var. 'Murai'] and placed near two diagonal corners and the other *S. longus* product pair was placed near the remaining two corners. Treatments were eggs vs. webbing, webbing vs. feces or eggs vs. feces. Unlike *T. urticae*, *S. longus* defecates outside the nest and any mixing of fecal pellets and webbing can be avoided. A single *N. fallacis* adult female was placed in the center of each arena and location of the predator while searching or resting and number and location of predator eggs were monitored at 1–12, 24 and 36 hours after transfer of the predator. To compare relative attractiveness of the spider mite products, we used a binomial test and significant levels as before.

Feeding and ability of N. fallacis *to control* S. longus *on bamboo*

To measure the ability of *N. fallacis* to feed, reproduce and develop on *S. longus* we constructed 2.5 × 2.5 cm waterproof arenas ringed with a sticky material (Tanglefoot®, The Tanglefoot Co., Grand Rapids MI 49504) and replicated tests eight times (MONETTI & CROFT, 1997). Three adult female predators of about the same age were transferred to each individual arena and excess mixed life stages of *S. longus* were provisioned every 24 h. For comparisons, *N. fallacis* was also held with excess amounts of *Tulipa gesneriana* L. and *Pseudotsuga menzesii* (Mirbel) pollen grains. Arenas with mites and treatments were held at 25 (± 1)° C, 70 (± 5) RH, and 16:8 L:D for 7 days. Assessments of survivorship, activity (ambulation), oviposition per female per day, and production of immatures (larvae, protonymphs, deutonymphs) per female per day were measured every 24 hours. An index for survivorship of immatures was calculated on day 3–7 by dividing the number of immatures by the number of eggs present two days prior to the sampling of immatures (CROFT *et al.*, 1998). We compared our results with reported values for *N. fallacis* when held under identical conditions with the optimal prey *T. urticae* or no food (PRATT *et al.*, 1999). Means of each measured attribute and food type were compared by analysis of variance (ANOVA) and TUKEY's HSD.

Preliminary tests showed that *N. fallacis* would feed, reproduce and develop on *S. longus*. Because *N. fallacis* is often used to control pest mites in other ornamental plant systems, we were interested in the ability of *N. fallacis* to suppress *S. longus* on bamboo. In May, 1998, 10, two-year *S. hidaensis* 'Murai', of 64 (± 17.4) culms each, were potted in 4-liter plastic containers and inoculated with 50 (± 12) adult female *S. longus*. Plants were placed in a shaded nursery bed and randomly assigned either release of three adult female *N. fallacis* per plant or no predator release (control). By June 11, *S. longus* averaged 9.6 (± 3.1) colonies per plant and three adult female *N. fallacis* were released onto each plant (STRONG &

Nest Construction Period[a]	Attribute of *N. fallacis*[b]		Proportion	*P*-Value[c]
5 days	Observed location	Within Nest	0.65	
		On Leaf	0.35	0.08
10 days		Within Nest	0.47	
		On Leaf	0.53	0.72
5 days	Mode of Entrance	Natural Opening	0.33	
		Break-in	0.67	0.68
10 days		Natural Opening	0.73	
		Break-in	0.27	0.22
5 days	Egg Placement	Within Nest	0.85	
		Without Nest	0.15	0.02
10 days		Within Nest	1.00	
		Without Nest	0.00	<0.001

TABLE 1: Invasions of *Schizotetranychus longus* nests by the phytoseiid predator *Neoseiulus fallacis*.

[a] Duration of nest construction period after inoculation of 3–4 adult female *S. longus* onto a 2.5 × 2.5 cm arena. [b] Attributes of *N. fallacis* measured after introduction into colonies of *S. longus*. [c] *P*-value calculated from binomial test, null hypothesis frequency = 0.5.

CROFT, 1995). Infestation of new leaves after release (or non-release) of *N. fallacis* were estimated by marking each *S. longus* colony and scanning for new colonies every 7 days. The initially marked colonies of *S. longus* and 10 randomly selected (with replacement) uninfested leaves per plant were monitored for *N. fallacis* every 7 days. To adjust for sampling the same populations over time, data were analyzed by repeated measures ANOVA (VON ENDE, 1993).

RESULTS

Identification of S. longus

The unknown spider mite that was collected was *S. longus*. Although infestations by this pest on ornamental bamboo had been observed for about 5 years before this study was begun, this was the first taxonomic identification for these temperate-coastal regions of Oregon. Also, no phytoseiids were associated with *S. longus* within Oregon.

Invasion of nests by N. fallacis *and attraction to products of* S. longus

N. fallacis readily invaded nests of *S. longus* when webbing was minimal but was somewhat less invasive when webbing was denser (Table 1). When measuring the entrance into nests, *N. fallacis* used both natural openings and created new holes equally as often after 5 or 10 days of web construction. *N. fallacis* laid significantly more eggs within the nest than without, irrespective of the nest construction time (Table 1). When comparing attraction to prey products, *N. fallacis* was associated more with webbing than eggs either when searching ($P= 0.082$) or resting ($P= 0.052$). With feces and eggs, *N. fallacis* searched more near feces ($P=0.059$) although it was equally probable for them to rest among either product ($P=0.855$). Webbing and feces were equally attractive to *N. fallacis* when either searching or resting ($P=1.0$, 0.2 respectively).

Feeding and ability of N. fallacis *to control* S. longus *on bamboo*

N. fallacis survived equally well when held with either the optimal prey *T. urticae* or with *S. longus*, but significantly lower survival occurred when held with other treatments (Table 2). Activity of *N. fallacis* was similar between the two species of spider mites but significantly lower when with pollen or starved. Activity of *N. fallacis* was higher when with pollen as compared to the starvation treatment, which may be due to the increased morbidity and mortality of the predator near the end of the 7 d test (PRATT & CROFT, 1998). Oviposition rates and immature production were similar when held with either *S. longus* or *T.*

PREY	SURVIVORSHIP[a]	ACTIVITY[b]	EGG/FEMALE/DAY[c]	IMM./FEMALE/DAY[d]	INDEX[e]
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
T. urticae[h]	1.00 ± 0.04a[g]	0.17 ± 0.11a	1.78 ± 0.40a	1.15 ± 0.25a	1.86 ± 0.29a
S. longus	1.00 ± 0.11a	0.34 ± 0.09a	1.85 ± 0.22a	1.16 ± 0.11a	1.50 ± 0.22b
T. gesneriana	0.87 ± 0.09b	0.84 ± 0.10c	0.06 ± 0.04b	0.03 ± 0.03b	0.28 ± 0.30c
P. menzesii	0.89 ± 0.11b	0.67 ± 0.19bc	0.04 ± 0.04b	0.012 ± 0.02b	0.025 ± 0.07c
Starvation[h]	0.36 ± 0.07c	0.57 ± 0.13b	0.04 ± 0.03b	0.00 ± 0.00b	0.00 ± 0.00c
P-value[f]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

TABLE 2: Survival, activity, oviposition rates and immature production of *Neoseiulus fallacis* when held with unlimited numbers of prey-food over 7 d.

[a] Percent female survival after 7 days in arenas. [b] Percent female activity (ambulation) within arena per 1 min observation per d. [c] Eggs produced per female per d. [d] Mobile immatures produced per female per d. [e] Survivorship of immatures calculated on d 3–7 by dividing the number of immatures present by the number of eggs present 2 days prior to count. [f] Means of all tests were analyzed by ANOVA, d.f.=5, 42. [g] Means followed by different letters are significant at a=0.05 (TUKEY'S HSD). [h] From PRATT unpublished.

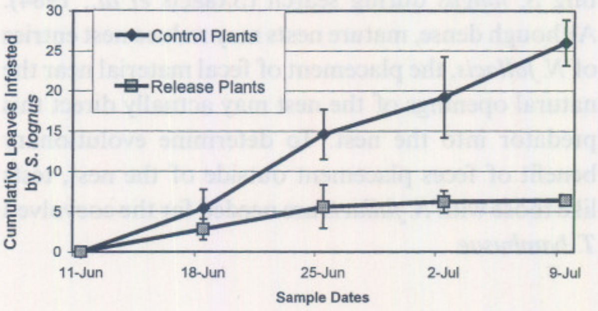

FIG. 1: Cumulative number of leaves per plant infested by *S. longus* after introduction of *N. fallacis* on June 11.

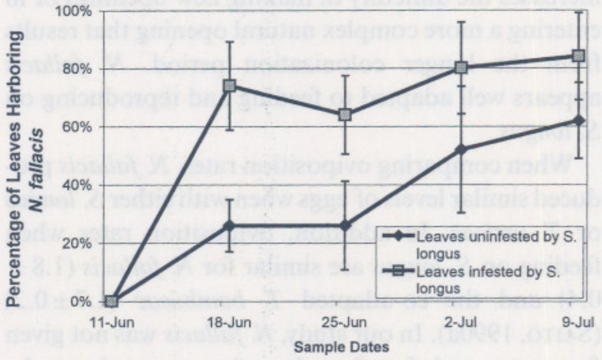

FIG. 2: Percentage of leaves harboring *N. fallacis* on either *S. longus* infested or uninfested leaves.

urticae but significantly lower when with pollen or in the starvation treatment. Immature *N. fallacis* had significantly greater survival when with *T. urticae* and the remaining treatments were ordered: *S. longus* > pollen = starvation.

The introduction of *N. fallacis* into bamboo significantly reduced the infestation levels of *S. longus* (P=0.0002, F=42.87, d.f.=1,8) and the rate of population increase of the pest. Four weeks after predator releases were made, control plants without predators had a 3-fold increase of new pest colonies (Fig. 1). When infested versus uninfested leaves were compared, those with pest mites quickly reached 60% occupancy by *N. fallacis* after one week and then to above 80% towards the end of the test, whereas on uninfested leaves, predators only increased from 26% to 62% over the 4 weeks (Fig. 2). Clearly, the spatial distribution of *N. fallacis* was closely associated with that of the spider mite prey.

DISCUSSION

We report establishment of *S. longus* on ornamental bamboo in western Oregon, USA. Although this pest overwinters successfully in this region, its long-term survival over a cold winter or multiple cold winters is uncertain because, for the past 5 years, such severe winters have not occurred (unpublished weather records). However, as observed in these studies, *S. longus* seems to survive well in the semi-enclosed nurseries that are used to grow bamboo in the region. Also, contrary to earlier reports (YOUNG & HAUN, 1961), this pest is now of economic importance because of the reduction in marketability of spider mite-infested bamboo, and the potential for dissemination of the pest by nursery workers, plant collectors, and home owners is high. Also, the presence of this pest may hamper development of bamboo cultivation for other purposes within the region.

N. fallacis successfully invaded and preferentially oviposited within the specialized web nest of *S. longus*. These findings are consistent with *N. fallacis* being classified as a Type II specialist predator of spider mites that produce copious amounts of webbing (McMurtry & Croft, 1997). *N. fallacis* apparently is well adapted to entering nests of this pest via natural openings at ends of the nest structure or by making openings by brute force anywhere in the nest. The reason for a reduction of within-nest occurrence of *N. fallacis* after 10 days of nest building by *S. longus* is unclear. Possibly the denser webbing increases the difficulty in making new openings or in entering a more complex natural opening that results from the longer colonization period. *N. fallacis* appears well adapted to feeding and reproducing on *S. longus*.

When comparing oviposition rates, *N. fallacis* produced similar levels of eggs when with either *S. longus* or *T. urticae*. In addition, oviposition rates when feeding on *S. longus* are similar for *N. fallacis* (1.8 ± 0.4) and the co-adapted *T. bambusae* (1.7 ± 0.2) (Saito, 1990a). In our study, *N. fallacis* was not given free water and therefore the value reported may be conservative for oviposition when feeding on *S. longus* (unpublished data). Although others have reported that *N. fallacis* can do well when feeding on pollen (Zhang & Li, 1989), reproduction was negligible on the types that were assessed in this study. Again, this discrepancy may be because free water was not available to predators or that there are different nutritional values of pollens to *N. fallacis* (Pratt *et al.*, 1999).

Our results are relevant to control of *S. longus*. Dicke *et al.* (1990) suggested that attractiveness of mite products might be a useful indicator for selection of predators as biological control agents. In this study, *N. fallacis* was highly attracted to products of *S. longus*, it readily entered nests, it reproduced as well on *S. longus* as on *T. urticae*, and it reduced levels of *S. longus* on densely infested bamboo plants. These findings suggest that *N. fallacis* may be a good candidate for biological control of *S. longus* in temperate-humid climates.

To our knowledge, this is the first report that quantifies the attractiveness of a phytoseiid to tetranychid feces versus uncontaminated webbing. Before, Schmidt (1976) found that mixed webbing and feces were more attractive than eggs of *T. urticae* to *Phytoseiulus persimilis* Athias-Henriot. Using an olfactometer and *T. urticae* as the prey, Sabelis *et al.* (1984) found that feces were more attractive to *P. persimilis* than webbing (slightly contaminated with feces) and exuvia. We found that webbing and feces of *S. longus* were similarly attractive to *N. fallacis*, webbing was more attractive than eggs and, when searching, feces were more attractive than eggs. Our results do not support the hypothesis that webbing and feces may protect *S. longus* from phytoseiids (Saito, 1983). Rather, webbing and feces attracted *N. fallacis* and aided in locating *S. longus* during search (Sabelis *et al.*, 1984). Although dense, mature nests may reduce nest entries of *N. fallacis*, the placement of fecal material near the natural openings of the nest may actually direct this predator into the nest. To determine evolutionary benefit of feces placement outside of the nest, tests like those with *N. fallacis* are needed for the coevolved *T. bambusae*.

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