Feeding behavior of *Scymnillus horni* (Coleoptera: Coccinellidae) on the Elongate Hemlock Scale, *Fiorinia externa* (Hemiptera: Diaspididae)

Yingping Xie[1], PL Lambdin[2] & C Lynch[2]
[1]College of Life Science and Technology, Shanxi University, Taiyuan, 030006, China; [2]Dept of Entomology and Plant Pathology, University of Tennessee, Knoxville, TN 37996, USA.

Abstract: The feeding behavior of the coccinellid predator *Scymnillus horni* (Gordon) on the diaspidid scale insect *Fiorinia externa* Ferris was assessed. *S. horni* searched for prey by tapping its antennae on the infested needle and moving in one of four recognition patterns (random, zigzagged, circle or combination of these patterns). The predator preferred to feed on male scales in all developmental stages compared to the female stages. The medial and posterior sections of the tests were most frequently damaged by *S. horni*. Rarely was the entire scale insect consumed by the predator. The average consumption rate was 4.1 (0-9) prey daily, with predators consuming 27 to 54 prey during a 10-day observational period. There appeared to be a trend for greater damage and a higher consumption rate as the number of potential prey increased. Adult predators survived from 32 to 45 days under laboratory conditions.

Key words: *Scymnillus horni*, *Fiorinia externa* Ferris, predation behaviour, consumption.

Introduction

The invasive elongate hemlock scale (EHS), *Fiorinia externa* Ferris, has expanded its range into the southern Appalachians and now threatens eastern hemlock, *Tsuga canadensis* L., dominated forest. Over 300 insect species have been documented to be associated with eastern hemlock in the southern Appalachians, several of which are highly dependant on this host tree for survival (Buck *et al.*, 2005; Dilling, 2007). *Scymnillus horni* Gordon is a coccinellid native predator distributed along the eastern United States from Florida to Virginia, and in Indiana and Ohio in the central U.S. (Gordon, 1985). Isolated populations of this species also are found in Louisiana at Caddo Parish, East Baton Rouge Parish, and Rapides Parish (Chapin, 1974; Gordon, 1985; Muma *et al.*, 1961). In a recent search for natural enemies of EHS, this predator was one of six predators recorded at EHS-infested sites in eastern Tennessee and western North Carolina (Lynch *et al.*, 2006). Our objective was to assess the behavior and consumption of *S. horni* on EHS to determine its potential as a biological control agent.

Materials and methods

Predators were collected using beat-sheets from EHS-infested eastern hemlocks at Lynnhurst Cemetery in October, 2006 through January, 2007. Each of the four tests conducted consisted of 10 adult predators individually placed in Fisherbrand® plastic Petri dishes (6 cm diam., 0.8 cm high) for 10 successive days and maintained in the laboratory at 21°C, 50~60% RH, with 16:8 (L:D) h photoperiod. EHS-infested needles were placed in the Petri dishes daily to assess predation behavior and consumption. Test 1 was replicated five times for two prey densities (6-10 and 11-15 prey per dish) to evaluate if prey densities influenced feeding behavior. Food was withheld from each predator for a 24 h prior to initiating the test. Each Petri dish containing a predator was placed on top of an Easi-Grid® system for observation. A piece of Whitman® filter paper (4.25 cm diam.) with one drop of water from a plastic pipette (1 ml) for moisture was placed in each Petri dish. Also, an eastern hemlock branch with either 6-10 gravid female scales and nymphs or 11-15

gravid female scales and nymphs was placed 22 mm away from the predator in the center of the dish to evaluate the time required for predators to recognize the prey source. Tests were designed to assess predator impact on 1) the immature and adult stages, 2) immature male and female stages, 3) the second instar female, and 4) the adult female stage. Specimen number, number of prey offered, location of attack, total prey consumed, and percent of scale attacked were recorded for each test. Observations on searching and feeding behavior for each predator also were recorded and ANOVA on data were conducted (SAS 2005).

Results and discussion

In test 1, each predator was provided with 6-10 specimens (immatures, adult male and female EHS) daily for 10 successive days to assess consumption, while test 2 used 11-15 specimens. When 6-10 specimens were provided, the 10 predators consumed a total of 406 EHS, with an average daily consumption rate of 4.1 (2.7-5.4) (Table 1).

Table 1. Daily consumption of *Fiorinia externa* by *Scymnillus horni* when provided with two prey regimes:

Test 1: 6-10 immature and adult prey daily

Beetle	Day											
No.	1	2	3	4	5	6	7	8	9	10	Tl	Avg
1	4	3	5	5	5	4	6	5	6	2	45	4.5
2	3	5	5	9	9	6	3	6	5	3	54	5.4
3	9	3	4	3	4	6	4	6	4	4	47	4.7
4	3	3	3	5	3	3	3	4	3	0	30	3.0
5	3	3	3	3	3	3	4	3	5	3	33	3.3
6	5	2	4	5	4	4	4	7	7	5	47	4.7
7	2	3	3	7	1	2	3	4	1	1	27	2.7
8	5	1	5	4	4	2	2	3	6	1	33	3.3
9	4	3	3	7	6	3	5	3	7	8	49	4.9
10	3	2	5	5	4	3	4	6	4	5	41	4.1
											406	4.06

Test 2: 11-15 immature and adult prey daily

Beetle	Day											
No.	1	2	3	4	5	6	7	8	9	10	Tl	Avg
1	7	2	5	8	8	4	6	8	8	3	57	5.7
2	12	8	6	6	6	7	11	12	6	8	82	8.2
3	7	4	6	7	7	4	6	5	3	7	56	5.6
4	3	5	2	4	4	4	7	5	7	6	47	4.7
5	8	3	6	11	5	4	12	14	14	5	82	8.2
6	8	8	6	4	5	2	8	6	5	3	55	5.5
7	2	4	3	3	10	7	3	3	7	4	46	4.6
8	4	8	5	3	4	7	9	9	11	6	66	6.6
9	9	4	7	6	9	6	7	9	4	5	66	6.6
10	2	7	5	1	6	5	6	4	6	9	51	5.1
											608	6.08

There appeared to be a trend for a higher consumption rate as the number of potential prey increased (Table 1). In test 2, the average daily consumption rate per beetle increased from 4.1 to 6.1 (4.6-8.2) prey either damaged or killed per day. The range of prey eaten daily per beetle ranged from 1-14.

In test 1, where a range of scale insect stages were offered, the predators fed more often on the immature than on the adult stages. It was also noted that newly-developed adult males, still within their scale covers, were attacked and eaten. A test was therefore designed consisting of needles with only immature male EHS and needles with only second-instar females to determine any preference in the beetle's predatory behavior and consumption (Table 2).

Table 2. Feeding preference of *Scymnillus horni* when offered either 20-25 immature male or female *Fiorinia externa* daily.

Beetle No.	2nd instar sex	Day											
		1	2	3	4	5	6	7	8	9	10	Total	Average
1	♀	2	0	1	1	0	1	1	1	4	2	13	1.3
	♂	6	3	7	6	9	3	5	5	11	5	56	5.6
	T1	8	3	8	7	9	4	6	6	15	7	69	6.9
2	♀	3	2	1	0	4	0	4	3	1	3	21	2.1
	♂	7	9	15	6	5	7	9	7	7	5	77	7.7
	T2	10	11	16	6	9	7	13	10	8	8	98	9.8
3	♀	3	3	5	1	3	0	2	1	2	1	21	2.1
	♂	7	10	10	6	6	3	7	5	8	7	69	6.9
	T3	10	13	15	7	9	3	9	6	10	8	90	9.0
4	♀	0	1	2	0	1	0	0	2	4	7	17	1.7
	♂	3	5	1	4	8	6	9	6	4	3	49	4.9
	T4	3	6	3	4	9	6	9	8	8	10	66	6.6
5	♀	6	2	1	4	2	2	2	4	2	6	31	3.1
	♂	11	5	11	9	6	1	9	12	14	15	93	9.3
	T5	17	7	12	13	8	3	11	16	16	21	124	12.4
6	♀	3	2	3	3	1	0	3	3	0	3	21	2.1
	♂	12	10	18	7	6	6	10	7	4	4	84	8.4
	T6	15	12	21	10	7	6	13	10	4	7	105	10.5
7	♀	1	1	0	2	8	1	1	1	3	8	26	2.6
	♂	3	3	2	4	4	4	2	7	12	5	46	4.6
	T7	4	4	2	6	12	5	3	8	15	13	72	7.2
8	♀	2	1	0	1	0	3	2	3	2	1	15	1.5
	♂	8	19	11	5	7	4	9	7	12	6	88	8.8
	T8	10	20	11	6	7	7	11	10	14	7	103	10.3
9	♀	5	7	1	3	1	3	2	1	2	1	26	2.6
	♂	8	9	9	5	18	7	4	7	3	5	75	7.5
	T9	13	16	10	8	19	10	6	8	5	6	101	10.1
10	♀	1	7	8	3	1	2	0	1	3	5	31	3.1
	♂	11	9	2	3	8	11	9	3	3	8	67	6.7
	T10	12	16	10	6	9	13	9	4	6	13	98	9.8
T												926	9.26
%	♀											23.97♀	
	♂											76.03♂	

When immature male or female EHS were provided, the 10 predators damaged or consumed a total of 926 scale insects, of which 76% were males and 24% were females. During the ten-day period, an individual predator damaged or consumed a mean of 22.2 (13-31) second-instar females or 70.4 (46-93) second-instar males (Table 2), suggesting a strong preference for immature males.

Needles with only second-instar females were provided to assess the potential damage by *S. horni* to immature females (Table 3). In this test, 15-30 second-instar females were provided daily to each beetle. Of the 1,985 immature scales provided, 1,259 were attacked. Of these, the scale cover or body of 533 (42.3%) were partially consumed. In addition, 726 scales (57.7%) were killed. Each predator consumed an average of 7.3 (5.0-9.3) scales daily, while also damaging a further 5.3 (4.5-6.9). However, predators can potentially damage or kill up to 15 prey daily (Table 3).

Table 3. The number of second-instar EHS damaged or killed by *Scymnillus horni* when 15-30 scales were provided daily.

Beetle No.	D* or K	Day										Total		Average	
		1	2	3	4	5	6	7	8	9	10	D	K	D	K
1	D	11	2	2	13	6	2	7	7	2	8	60		6.0	
	K	4	4	6	6	5	7	7	10	10	4		63		6.3
2	D	14	4	3	6	3	2	1	7	14	6	60		6.0	
	K	8	6	5	10	12	6	11	11	7	4		80		8.0
3	D	6	2	1	2	5	2	9	2	7	10	46		4.6	
	K	14	7	6	7	8	3	12	7	10	12		86		8.6
4	D	7	0	0	2	1	0	5	11	4	6	36		3.6	
	K	14	11	9	12	6	2	10	9	9	11		93		9.3
5	D	2	3	3	13	4	2	3	5	5	9	49		4.9	
	K	10	10	5	5	5	5	9	10	14	4		77		7.7
6	D	7	2	1	5	6	4	4	7	15	8	59		5.9	
	K	6	8	6	9	8	6	7	4	7	8		69		6.9
7	D	8	2	2	9	0	2	11	6	7	10	57		5.7	
	K	9	3	4	5	9	5	10	8	3	2		58		5.8
8	D	13	3	0	4	3	1	2	6	5	8	45		4.5	
	K	7	6	5	10	4	7	13	3	10	7		72		7.2
9	D	8	8	8	4	7	5	9	5	7	8	69		6.9	
	K	6	6	5	5	3	3	6	3	8	5		50		5.0
10	D	9	10	1	7	9	2	5	1	13	4	52		5.2	
	K	5	4	5	7	14	8	10	6	10	9		78		7.8
T1	D	84	27	21	65	44	22	56	57	79	77	533		5.33	
	K	83	65	56	76	74	52	95	71	88	66		726		7.26

*D=damaged, K= killed.

Eastern hemlock needles infested with first and second instar and adult female EHS were also evaluated for injury by the predator (Table 4). Over a 10-day-period, the damage by the 10 predators consisted of: 32.2% to the adult female's test, 12.5% to the adult female's puparillum and 34.1% to the first and second instars, while 21.3% showed no damage.

Table 4. The attack behavior of *Scymnillus horni* on *Fiorinia externa.*

Beetle No.	Attack behavior of *Scymnillus horni*				
	No. EHS Provided	No damage	Adult Female Test	First-Second Test	Adult Female Puparium
1	33	9	13	10	1
2	35	5	8	10	12
3	31	7	13	7	4
4	35	7	7	16	5
5	32	12	6	13	1
6	31	5	14	7	5
7	27	1	13	10	3
8	37	9	14	11	3
9	32	9	8	11	4
10	27	4	7	14	2
T	320	68	103	109	40
%	100	21.25	32.19	34.06	12.50

Searching behaviour: Predators were able to locate the prey on the needles within the enclosed Petri dish in about two minutes. *S. horni* searched for prey by tapping its antennae on the needle while moving in one of four recognition patterns (random, zigzagged, circle or combination of these patterns). Once a prey was discovered, the predator moved back and forth over the prey, tapping the test with its antennae. Feeding involved using its mandibles to chew through the waxy test. The predator used its maxillary palps to better grasp the edge of the test while feeding. The attack and injury to the prey varied from minor chewing activity on the test (leaving areas visibly damaged) to total consumption of the prey. Sometimes, the predator abandoned the prey after it had dislodged the cover of the scales from the needle. In other cases, the beetle ate portions of the scale cover along with the scale insect's body. In most instances, the predator damaged only a portion of the body of the prey, leaving the scale cover primarily intact.

The predator rarely chose the adult female to attack compared with the immature stages, perhaps due to the density of the test. When a predator did attack a mature female, it often terminated the attack prior to inflicting severe damage to the scale insect. When the predator began to feed on the female prey, it chewed on the waxy cover until a small opening was created and then fed on the small waxy pieces of the removed cover. Also, the predator would initially insert its mouthparts and eventually its head into the hole to consume the body of the adult female or the eggs.

Predators often alternated chewing on the test (cover) and the body of the gravid females. Once an irregular hole had been chewed in the scale cover of a gravid female, the predator pulled some of the eggs out to eat. The medial and the posterior sections were most frequently consumed, although the entire scale's body was rarely consumed (X^2 = 73.092, df = 16, P < 0.0001). From 52 observations, *S. horni* damaged the scale cover of 9 prey on the anterior end, 14 medially, 11 posteriorly, 9 through the sides, 1 anterior-medially, and 5 posterior-medially, while only 3 specimens were completely consumed. When it was not feeding, the predator rested on the underside of the eastern hemlock branch where it was often observed cleaning its antennae and mandibles with its legs.

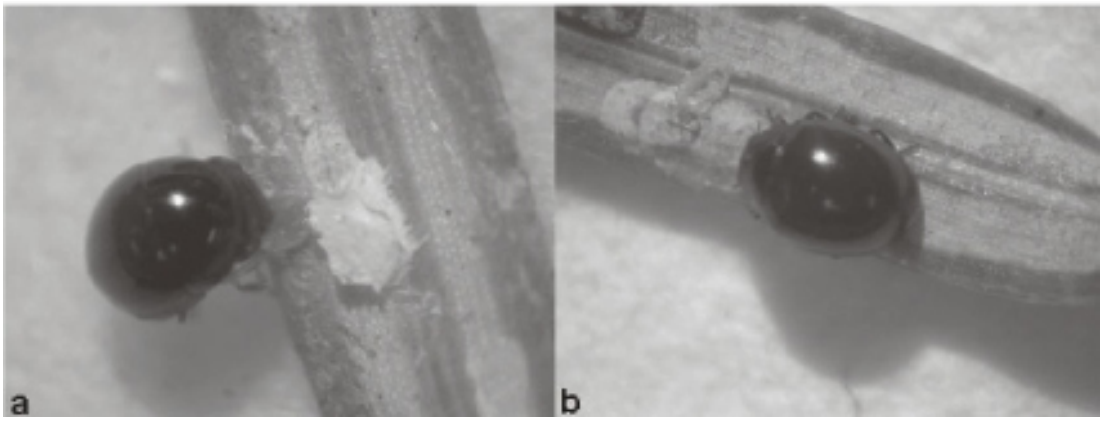

Figure. 1. *Scymnillus horni* feeding on a) cast exuviae of first-instar male and b) second-instar female *Fiorinia externa.*

This preference for males was consistent in all developmental stages (Fig. 1). In several instances, *S. horni* consumed the body of the scales as well as most of the waxy cover. When the beetle attacked second-instar or pupal males, it often managed to chew a hole through the test or dislodge the prey using its mouthpart, legs, and head to expose the scale's body.

The longevity of ten adult predators recorded from laboratory reared specimens collected on October 13, 2006 on eastern hemlocks at Lynnhurst Cemetery, Knoxville, TN was: 2 beetles living 32 days, one 39 days, four 43 days, and three 45 days. The average longevity was 41 days (SD=5.055). Because we do not know precisely how long these beetles had spent in the forest before they were collected, additional longevity tests are needed. A extensive longevity, at least of the adult stage, is anticipated based on the above data taken during the fall and winter months.

It would appear that the attack and feeding behavior of the beetle is influenced by the number of prey encountered. Based on these preliminary results, we found that the daily mean consumption increased from 4.1 to 6.1 prey per beetle when higher numbers of prey were available. Additional tests will be required to evaluate the consumption rate when even greater prey numbers are offered. During this observational period, we determined that the predator preferred to feed on male scales and the first- and second-instar female scales. However, the beetle also consumed adult female scales and their eggs. As such, the predator is capable of feeding on adult female scale insects to sustain themselves when immature stages of EHS are absent. Because *S. horni* is a native species well established in the area and has a rather high consumption rate and longevity, it may be considered a potentially effective biological control agent against elongate hemlock scale populations. More information is needed on the longevity and development of the immature stages of the predator and their consumption rate to fully assess the potential of this species.

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