

CHILOCORUS STIGMA (COLEOPTERA: COCCINELLIDAE) AND OTHER

PREDATORS OF BEECH SCALE IN CENTRAL NEW YORK¹

Mark Mayer² and Douglas C. Allen³

Abstract.--The twice-stabbed lady beetle Chilocorus stigma (Say), was studied in two infestations of beech scale, Cryptococcus fagisuga Lind., to elucidate predator biology and to determine the predator's effect on scale populations. C. stigma is univoltine in north-central regions of New York and its seasonal occurrence is well synchronized with that of C. fagisuga. The predator was most abundant in dense scale populations and exhibited a numerical response at high scale densities. The effectiveness of C. stigma was limited by the propensity of adults to disperse following eclosion, its apparent failure to feed on all life stages of the scale, mortality during the beetle's pupal stage and high rate of host reproduction. Four species of mites were also noted as predators of C. fagisuga.

INTRODUCTION

Beech bark disease first appeared in North America during the 1890's when the beech scale, Cryptococcus fagisuga Lind., was introduced from Europe on a species of ornamental beech, Fagus sylvatica L. The disease results when C. fagisuga initially infests the stems of American beech, Fagus grandifolia Ehrh. and a fungus, Nectria coccinea var. faginata Lohman, Watson and Ayers then penetrates the bark through feeding wounds. Scale populations alone evidently have little impact on the health of the tree, but in conjunction with Nectria, moderate to heavy scale populations may kill trees within 3-5 years. Presently, extensive areas of dead beech pervade northern hardwood forests in the northeastern United States.

This disease has generated more concern in recent years because modern kiln drying methods have enhanced the value of beech, whose wood is used for flooring, plywood, dowels, shuttles, containers and furniture. Beech is also an important pulpwood species

and makes excellent fuelwood. Spread of the disease south and west from its initial point of entry in Nova Scotia has encouraged research on the ecology (Houston 1975; Houston et al. 1979) and management of infested stands (Filip 1978). However, relatively little information about the twice-stabbed lady beetle, Chilocorus stigma (Say), a native coccinellid predator of the beech scale, is available, and other natural enemies of C. fagisuga have received only cursory attention.

C. stigma was first associated with populations of C. fagisuga by Ehrlich (1934) who noted the presence of C. stigma (identified as C. bivulnerus Muls.) in beech scale-infested sample plots in Nova Scotia. Ehrlich reviewed the European literature and reported several vague references to other insects and arachnids that were thought to be predators of beech scale. Brown (1934) suggested that C. stigma was the only predator in New England that had potential to control populations of beech scale.

The general biology of C. stigma was first investigated by Girault (1907), who determined that the beetle oviposited in bark cracks, crevices, and under loosened bark on scale-infested apple trees. Marlatt (1902) and DeBoo and Weidhaas (1976), on the other hand, reported that the beetle oviposited beneath scale secretions and predominantly fed

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²Forest Entomologist, New Jersey Dept. of Agriculture.

³Professor of Forest Entomology, State University of New York, College of Environmental Science and Forestry, Syracuse, NY.

on immature scales. Muma (1955) indicated that oviposition occurred on the leaves, trunk, fruit and twigs of Florida citrus trees. He found that adults and all four instars voraciously fed on adult scales. C. stigma has been recorded as a predator of 18 species of scales, 7 species of aphids, and one species of coccinellid (Thompson and Simmonds 1965).

DeBoo and Weidhaas (1976) examined C. stigma in central New York as a predator of pine needle scale, Phenacaspis pinifoliae (Fitch). The coccinellid colonized moderately and severely infested Scotch pine (Pinus sylvestris L.) in naturally regenerated stands, but was absent on sparsely infested trees. Lady beetles aggregated on trees that harbored the greatest number of scales, but only in stands that had a large number of infested trees. In areas with small isolated infestations, the beetles did not remain (or reproduce) on scale-infested trees and did not significantly reduce scale density. DeBoo and Weidhaas hypothesized that alternate prey on nearby plants prevented C. stigma from congregating on trees infested with pine needle scale. Monocultures (plantations) of Scotch pine resulted in high numbers of pine needle scale, which subsequently supported abundant natural enemies that eventually controlled this host.

The objectives of the present study were to (1) determine the biology of C. stigma, (2) to evaluate the effect of C. stigma on populations of C. fagisuga, and (3) to identify other predators of C. fagisuga.

MATERIALS AND METHODS

The study sites at Wanakena, New York (St. Lawrence County) and Tully, New York (Cortland County) consisted of mature beech, eastern hemlock, Tsuga canadensis (L.) Carr, sugar maple, Acer saccharum Marsh, red maple, Acer rubrum L., and yellow birch, Betula alleghaniensis Britton. To determine the response of C. stigma to different densities of C. fagisuga at Wanakena, as well as to facilitate observations, 12 beech trees 10-20 m tall that represented a range of C. fagisuga densities were selected for population measurements. The four most heavily infested trees were sampled weekly from June through October, 1979 (n = 17-19 obs./tree) and the remainder were examined biweekly (n = 8-9 obs./tree).

Sample trees were divided into 1 m vertical segments and each meter was subsectioned into 10 cm x 10 cm squares. This was accomplished by marking every 10 cm around the circumference of the tree at each meter

height. Two strings, one meter long and subdivided into 10 cm units, were vertically attached to the 10 cm marks around the circumference of the tree. A ladder and tree trimmer's apparatus were used to climb each tree and sample 360° around the bole.

The number and position of Chilocorus were determined within each 10 cm sq. Populations of C. fagisuga in each sq were arbitrarily classified as light, medium, and heavy (DeBoo and Weidhaas 1976), based on five subsamples that were obtained by placing the mouth of a vial (2 cm dia.) on an ink pad and then pressing the ink-coated rim onto the tree. Counts were made of the number of adult scales within the circle. The sample unit was 3.14 sq. cm of bark, and an average of 1-10 scales, 11-25 scales and 25+ scales per sample were regarded as light, medium and heavy populations, respectively.

Adults and pupae of C. stigma were easy to recognize. The last three instars were distinguished by size; color was used to identify first instars. The dorsal midline of the thoracic and abdominal regions and much of the dorsum of the first abdominal segment of instars II-IV are light cream to white (Muma 1955). First instars are uniformly dark gray and approximately 1 mm long. Second instars are 2.5 to 3.5 mm long, the third instar is 4.0 to 5.0 mm long, and fourth instars are 6.0 mm or longer. Whenever identification of instars was questionable, setaceous dorsal and lateral processes, the senti (sic Gage 1920), were examined.

RESULTS AND DISCUSSION

Periodic examination of beech boles made it possible to (1) determine temporal changes in populations of C. stigma; (2) estimate population density by mapping the scale infestation; (3) examine the relationship between changes in the scale and predator populations and; (4) observe the effect of physical variables on the scale and beetle populations. Also, this approach enhanced the probability of finding other predators and/or parasites of C. fagisuga, because a large total area of tree bole was systematically examined throughout several 24 hr periods.

Effect of C. fagisuga density on populations of C. stigma

There was a significant positive correlation between the density of C. stigma and that of its prey. While the correlation ($r = 0.75$, $p = .05$) between scale density and predator density is encouraging from a natural control standpoint, it is important to examine

the within-tree distribution of the predator population at different host densities. In other words, predator abundance should be viewed in terms of the proportion of total bark surface area occupied by an infestation level (i.e., light, medium or heavy) (Fig. 1). Initially, as the proportion of bole area occupied by each infestation level increased, the proportion of predators found in that area also increased. However, the data indicate that beetles do not readily establish themselves on trees that are lightly infested. This may account, in part, for the fact that sparse scale colonies are capable of rapid numerical increases over a relatively short period. Apparently, the predator concentrates on trees, or portions of trees, where the host is easily found (i.e., dense populations). The decrease in predator density when 15% of the infested area contained a medium scale density, and the increase in predator density where 30% of the bark area was lightly infested (Fig. 1) probably are a result of sampling error. Also, there could be a limit to the number of predators that will occur on an infested area of bark at a given time. This limit may have little to do with the carrying capacity of the food base, but rather with *Chilocorus* itself. Predator density may be determined by other mechanisms, irrespective of the fact that more than enough prey are available.

The relationship between the density of *C. stigma* and total bark area occupied by *C. fagisuga* infestation categories (Figs. 2-5) further support the hypothesis that high beetle density is associated with high host density. The figures indicate that heavy infestations (H) were usually associated with

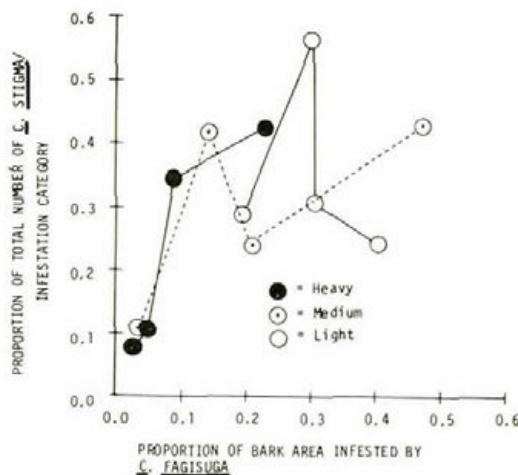


Fig. 1. Distribution of total *C. stigma* population in relation to proportion of scale-infested bark in 3 infestation categories (n = 4 trees).

a higher predator density than the medium infestations (M), which in turn supported more predators than did the light infestation (L). This relationship is typical of a predator with well developed searching behavior and host finding capabilities. *C. stigma* was able to locate prey colonies even when a small proportion of the bole was infested. The data indicate that the density and distribution of *C. stigma* on beech boles was influenced by the density and distribution of *C. fagisuga*. Even though a light infestation occupied a relatively large total bark area, the beetle density in that category was usually lower than that in the next highest infestation category.

Life history of *C. stigma*

C. stigma overwintered as an adult in the duff. Adults at Tully, New York were first observed feeding on beech scale on a warm day (max. 13°C) in early March. For example, during one day of observation they remained on the lower bole until the temperature increased (max. 13-14°C) at which time they moved up the tree several meters. In late afternoon adults descended and eventually dropped into the duff. Adults often congregated on the lower boles of trees, and mated during mid-April and early May at Tully and Wanakena, respectively.

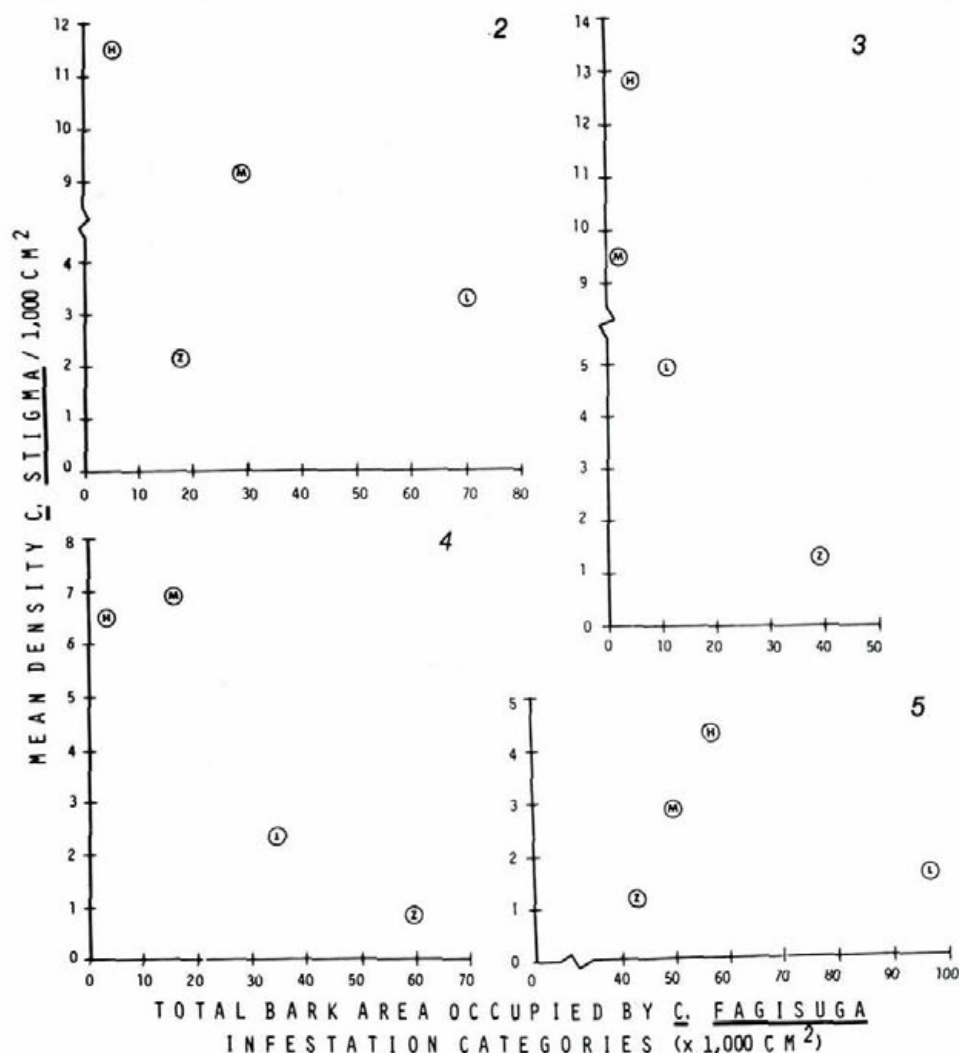
Oviposition by *C. stigma* was first observed at Tully in late April. The scale oviposited in bark fissures, some of which were caused by another scale, *Xylococcus betulae* Pergande. The last first instar was observed on 15 August (first instars were difficult to see because they were camouflaged on the gray beech boles) and second instars were observed four weeks later. The last second instar was noted on 13 October. Most third- and fourth-instars disappeared the first week in October, and larvae that did not pupate by October did not survive. Adults were most numerous on 20 June and 9 August. During this period only 8 of 21 median weekly temperatures were above 16.7°C. At median temperatures below this, *C. stigma* larvae require 12 weeks or longer to complete one generation (Muma 1955).

Evidence for one generation a year was strengthened by the temporal distribution of *C. stigma* life stages in the more northerly Wanakena (Fig. 6), indicating only one peak abundance for each stage. If there were two generations a year at Wanakena, there should be two peaks. Admittedly, the data do not cover early spring, but pupae would have been present prior to July if there were two generations a year. DeBoo and Weidhaas (1976), who also worked in central New York,

recorded two distinct populations for all life stages. The first generation occurred from late July through August. No pupae were observed at Wanakena until July and large numbers of them did not appear until August. Climatological records from Oswego, NY, the weather station closest to where DeBoo and Weidhaas did their study, indicated that 16 of 24 median weekly temperatures approximated 16.7°C. This lends further support to the hypothesis that their population of *C. stigma* was bivoltine.

Interestingly, the hosts in Muma's study, Florida red scale, *Chrysomphalus aonidum* (L.) (=ficus Ashmead), and purple scale, *Lepidosaphes beckii* (Newman) have three generations a year, as did the local

population of *C. stigma*. On the other hand, in New York, *P. pinifoliae* and *C. stigma* each had two generations a year (DeBoo and Weidhaas 1976). Hemlock scale, *Fiorinia externa* (Ferris), in Connecticut is univoltine, as is the local population of *C. stigma* (McClure 1979). This association between the voltinism of predator and prey is most likely related to temperature, rather than to the number of prey generations. However, it is highly probable that *C. stigma* is able to synchronize its development with that of the most suitable (=abundant) host. Coccinellids display close synchrony with their prey, especially on sedentary hosts (Hagen 1962). The coccinellids reproduce when populations of their prey are increasing and hibernate when the prey is dormant.



Figs. 2-5. Mean density of *C. stigma* in relation to total bark area infested by *C. fagisuga*. Each Fig. represents a single tree (H = >25 scales; M = 11-25 scales and L = 1-10 scales/sample unit).

Biology and behavior of *C. stigma*

Adult *Chilocorus* (Fig. 7C) moved from tree to tree in search of prey which apparently were located tactilely or visually. Some coccinellids locate their prey by means of prey odor (Hodek 1967), but this has never been established for the Chilocorini; other species apparently rely on visual cues (Allen et al. 1970; Stubbs 1980). Approximately half of the beetles' time was spent apparently resting (and possibly digesting prey) and the remaining time was spent searching for prey and feeding. Adults rested for a few minutes to hours, probably in response to temperature and hunger level. As long as the maxillary palpi remained in contact with the prey, the beetles fed until the prey was consumed or the

beetle was sated. Hourly observations of marked beetles for a 24 hr. period indicated that adults were diurnal and relatively quiescent at night.

First instars searched for food soon after eclosion. Searching appeared random and feeding occurred only when the prey were contacted with the maxillary palpi. Thereafter, the larvae slowed down and conducted a more thorough search of the surrounding area by moving in a circular pattern and frequently changing direction. The small size of first instars allowed them to search bark fissures that were inaccessible to later instars. Beech scales within the fissures were utilized with little competition from later instars. Larvae in bark openings

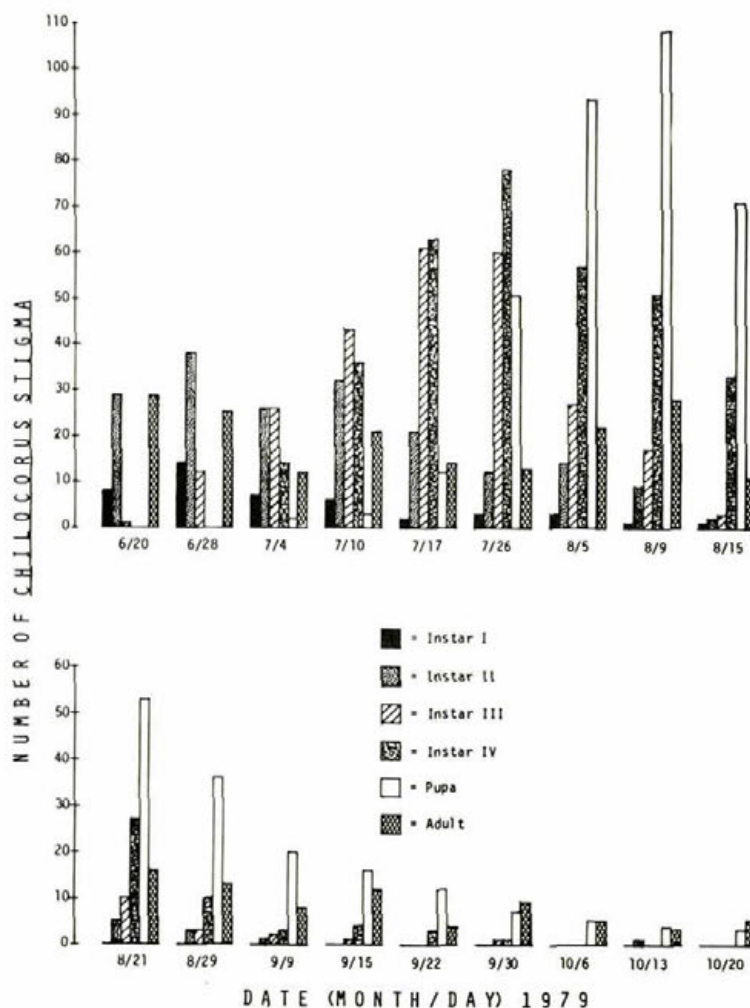


Fig. 6. Temporal distribution of *C. stigma* life stages, Wanakena, New York.

were difficult to detect and are probably better protected from the weather and predators than are older larvae. Larvae spent more time moving and feeding than the adults and rested 10-25% of the time. It took longer for a first instar to consume prey than it did for other instars, because prey size was large relative to the predator. The first instars fed by working their way through the waxy secretion of the scale. When contacted, a scale was pierced by the predator's mandibles and the scale's body fluids were withdrawn. Once first instars located an area with abundant prey, they rarely left.

Second instars behaved much like first instars except the former were more mobile when not feeding.

Because of their larger size, third instars covered more area as they searched for prey. During this stage, prey seeking was more involved: larvae moved 10-20 cm over the tree bole in a limited zigzag pattern. If no prey were encountered within this distance the larvae turned around and sometimes retraced their original trail. Why larvae stopped going in one direction and proceeded in another is not known. They did this on all bark types, oftentimes walking over scale colonies in the process. Feeding did not commence until the maxillary palpi contacted a scale, at which time larvae masticated prey with the mandibles and did not use their mouthparts in a piercing-sucking manner. The eggs of *C. fagisuga* were occasionally eaten. Sometimes only part of a scale was consumed before another one was attacked. The larvae were not observed feeding on the scale crawlers and seemed to prefer more sedentary hosts.

Behavior of fourth instars (Fig. 7A) conformed to that of the third except the former were more mobile and searched a larger area. As fourth instars approached pupation, their zigzag search pattern became disorganized. Once an appropriate spot was found the larvae became quiescent for one to three days before pupation.

The gregarious pupae of *C. stigma* (Fig. 7B) were found on the main bole, under branches, and in other sheltered areas. The reason why larvae selected particular areas for pupation was not revealed until trees were climbed during a rainstorm. Pupae beneath tree limbs and other protected areas on the main bole were not exposed to stem flow. Rain, especially a heavy downpour, is usually intercepted by the tree crown and then flows down the main branches; thence down the bole. In almost all cases, pupae were found in island-like refugia that were protected from runoff.

Population fluctuations and prey consumption

Although larval populations were not readily estimated, abundance of sedentary pupae was easily determined. The number of new pupae and the dead or missing pupae on four sample trees were tallied weekly. The greatest number of new pupae were found on 5 August, 9 August and 15 August (Fig. 6). Pupal mortality (number dead or missing pupae ÷ total number of pupae) ranged from 18% to 29%. The average for the combined samples is 24.1%. Cause of mortality was attributed to two factors: (1) the nymph of a predaceous bug, *Podisus* sp. and (2) the fact that some pupae, even though sheltered, were still exposed to the elements and enough pressure may have been placed on the sucking disc to detach the insect.

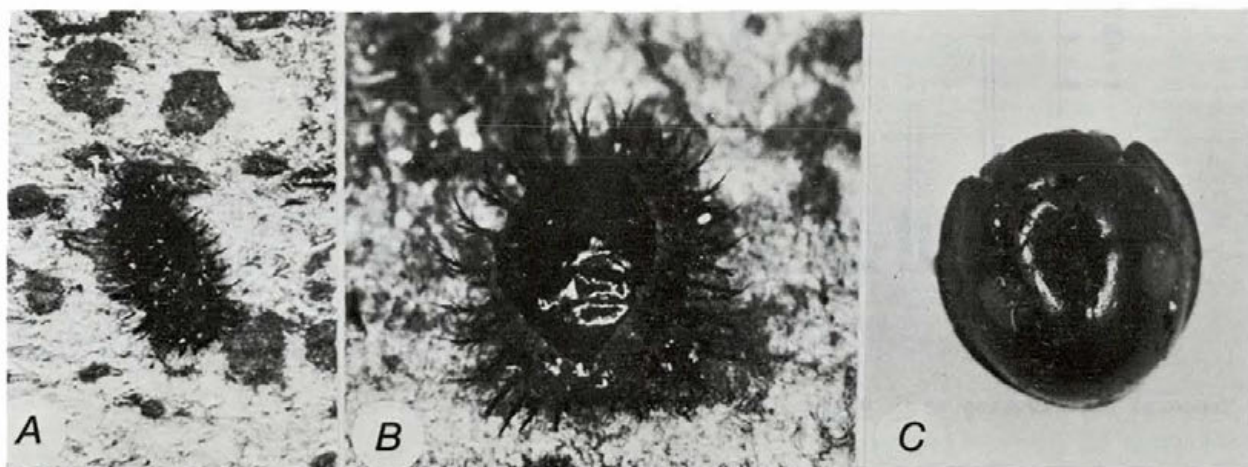


Fig. 7. Life stages of *C. stigma*: A, fourth instar; B, pupa; C, adult.

Feeding studies were undertaken with C. stigma to determine how many C. fagisuga each life stage of the predator consumed per day and over a period of 72 hr (Table 1). The feeding capacity of each stage was significantly ($p = .05$) greater than that of the preceding stage, except for adults, which consumed the same number of prey as fourth instars. All stages, except adults, consumed less on the first day than they did on succeeding days. Possibly the larvae required an adjustment period before they settled down to feed, and adults probably located the host more quickly than did larvae.

Table 1.--Beech scale consumption by Chilocorus stigma.

Life Stage	N	Average No. Prey Eaten ($\pm$ SD)	
		0-24 hrs	24-72 hrs
Instar I	13	6.5 $\pm$ 4.8	21.3 $\pm$ 10.4
Instar II	19	13.9 $\pm$ 5.9	33.9 $\pm$ 7.5
Instar III	20	23.8 $\pm$ 8.8	52.6 $\pm$ 21.7
Instar IV	19	30.4 $\pm$ 16.1	64.2 $\pm$ 18.3
Adult	20	30.8 $\pm$ 16.0	54.7 $\pm$ 17.3

Adults tended to disperse after eclosion and this behavior may prevent a buildup of C. stigma in areas where there are few prey. DeBoo and Weidhaas (1976) observed natural control by C. stigma in populations of pine needle scale in a monoculture of Scotch pine. When C. stigma dispersed under these conditions, the probability of finding alternative prey was low. Therefore, the beetle had a significant impact on scale populations in the monoculture due to lack of alternative prey and low dispersal losses. The northern hardwood forest is a relatively diverse community, however, and it probably offers a variety of prey, which may dilute the influence of C. stigma on beech scale populations. Even though C. stigma exhibited good host-predator synchronization and displayed an apparent numerical response to high prey density, the hosts' parthenogenetic mode of reproduction, apparent failure of the predator to feed on all host life stages, the tendency for adult C. stigma to disperse after eclosion and mortality during the pupal stage suggest that (1) this predator is an opportunist and (2) it has little potential for controlling populations of C. fagisuga.

Another coccinellid, Calvia (= Anisocalvia) quatourdecimguttata var. similis Randall, purportedly feeds on C. fagisuga in New York and Pennsylvania, but we did not observe it on our study trees. C. stigma and C. quatourdecimguttata closely resemble each other; both are black with a

red spot on each elytra. The spots on C. stigma, however, are round and smaller than the squarish spots characteristic of C. quatourdecimguttata.

Acarine predators

Mites were the only other organisms that were observed feeding on beech scale. The most frequently encountered mite, Anystis sp. nr. kochi Oudemans (Fig. 8A) was very mobile and preyed on all stages of the scale, especially eggs and crawlers. Baker (1965) characterized Anystis spp. as general predators with non-specific prey preference, and he observed a species of Anystis preying upon another mite, Tydeus; we observed the latter preying on C. fagisuga eggs. Several Anystis molting chambers, craters in the bark covered with white papery silk, were examined and usually one large Anystis was found with several smaller protonymphs. Anystis appeared in late June and was present until the end of August. The silken chambers, which can be easily mistaken for beech scales, were first observed in early July. This species may be bivoltine because the mites were not noticed until June, and this would allow time for an earlier generation.

A second acarine predator, Tydeus sp., was difficult to observe because it was usually colorless, except after it fed when the gut turned gray. Tydeids were first observed on a section of infested bark that was placed under a dissecting microscope to look for scale parasites. Several tydeids were observed feeding on the eggs of C. fagisuga, but not on crawlers or adults.

Two erythraeid mites were encountered, Abrolophus sp. (Fig. 8B) and Leptus sp. (Fig. 8C). A few instances of scale predation were noted when attempts were made to study what were thought to be anystids, but were Abrolophus sp. instead. Erythraeids are predators in the adult, trito-, deuto- and protonymphal stages, and feed on a wide variety of prey. However, their larval stages are ectoparasitic. The larva of Leptus sp. was noted as an ectoparasite on Anystis sp. Of 37 anystids collected, 9 were parasitized by Leptus. No adult Leptus or nymphal Abrolophus were encountered.

One bdellid mite (Fig. 8D) was observed preying on C. fagisuga crawlers, but it could not be identified to genus because the palps were accidentally removed during mounting.

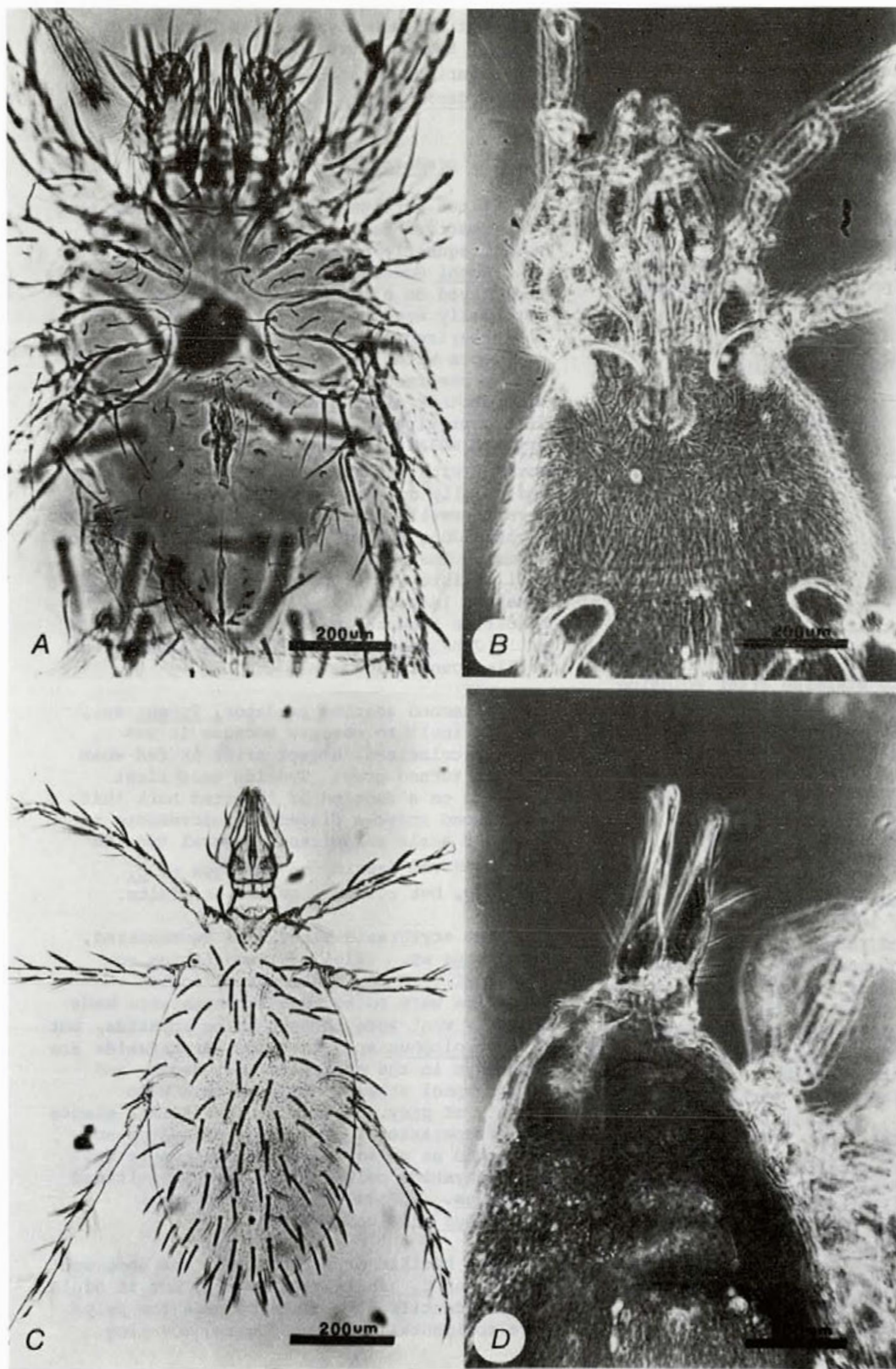


Fig. 8. Mite predators of *C. fagisuga*: A, *Anystis* sp.; B, *Abrolophus* sp.; C, *Leptus* sp.; D, a bdellid.

CONCLUSIONS

The occurrence of extensive beech mortality and flourishing populations of beech scale in North America are cogent evidence of the fact that indigenous natural enemies are not able to control this exotic pest. C. stigma was the most abundant, and usually the only, insect predator of beech scale that we observed in two forest stands in central New York. Parasitic and predaceous mites were frequently associated with immature scales, but apparently are not able to hold scale populations below damaging levels.

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RÉSUMÉ

La coccinelle stigma, Chilocorus stigma (Say), fut étudiée durant deux infestations de la cochenille du hêtre, Cryptococcus fagisuga Lind., pour en élucider sa biologie et déterminer son effet sur les populations de la cochenille. Dans la région centre-nord de New York, le C. stigma est univoltin et sa présence saisonnière est bien synchronisée avec celle du C. fagisuga. Le prédateur était le plus abondant dans les populations élevées de cochenilles et montrait une corrélation numérique positive aux hautes densités de celles-ci. L'efficacité du C. stigma était limitée par la progression des adultes à se disperser après l'éclosion, son attitude apparente à ne pas se nourrir de tous les stades de la cochenille, la mortalité observée durant le stade nymphal de la coccinelle et le taux élevé de reproduction de l'hôte. Quatre espèces d'acariens furent aussi notées comme prédateurs du C. fagisuga.

ZUSAMMENFASSUNG

Marienkäfer (Chilocorus stigma (Say.)) wurden in zwei Vorkommen der Buchenwollschildlaus (Cryptococcus fagisuga Lind.) hinsichtlich ihres Beuteverhaltens und der Auswirkung auf die Lauspöpopulationen untersucht. Chilocorus stigma bildet in den nördlichen Teilen Zentral-New Yorks eine Generation im Jahr. Sein jahreszeitliches Auftreten ist gut auf C. fagisuga abge-

stimmt. Die Marienkäfer treten in dichten Lauspöpopulationen - als zahlenmäßige Reaktion auf hohe Lausdichten - am zahlreichsten auf. Die Wirksamkeit von C. stigma gegenüber C. fagisuga ist begrenzt, da die Tiere offenbar nicht alle Entwicklungsstadien der Laus fressen, wegen der Mortalität der Käfer im Puppenstadium und wegen der hohen Reproduktionsrate der Läuse. Fünf verschiedene Milbenarten wurden ebenfalls als Fraßfeinde von C. fagisuga festgestellt.

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