Biology of *Stethorus siphonulus* Kapur (Coccinellidae: Coleoptera), a Predator of Spider Mites, in Hawaii[1, 2]

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Stethorus siphonulus, a tiny ladybird beetle, was described by Kapur in 1948 from a specimen collected in 1939 from Penang, Malaya. This species has been in the Hawaiian Islands for many years but was misidentified and referred to as *Stethorus vagans* (Blackburn) (Fullaway, 1922; Swezey, 1927; Williams, 1931; Krauss, 1944; Raros, 1972). The true identity of the species of *Stethorus* that has been in Hawaii for possibly 70 years was established only recently, February, 1973, by E.B. Britton of the C.S.I.R.O. *S. siphonulus* was apparently among the several undetermined species of coccinellids introduced into the Hawaiian Islands during 1894 by Koebele (Perkins, 1925). Besides the brief notes of its recovery, nothing is known about the biology of this species.

In recent years, we have observed large numbers of *S. siphonulus* preying on spider mites such as *Tetranychus cinnabarinus* (Boisduval), *Tetranychus tumidus* Banks, and *Eutetranychus banksi* (McGregor) in Hawaii. In view of this increased occurrence and the recent emphasis on the biological control of spider mites, it was deemed desirable to obtain as much information on the life history and feeding habits of this seemingly important predator.

MATERIALS AND METHODS

A greenhouse culture of *S. siphonulus* was established from adults collected on papaya, *Carica papaya* L., in an orchard at Kaaawa, Oahu, Hawaii in March, 1970. In order to study the life history of this species, 25 mated females from the greenhouse culture were caged on a papaya leaf heavily infested with *T. cinnabarinus* in the laboratory at temperatures and humidities of 27-32°C and 50-60%, respectively. As the females oviposited, 66 eggs were transferred into individual cages made from 60 x 15 mm plastic Petri dishes. Within each cage, the egg was placed on a filter paper which overlaid a layer of cotton in the bottom of the cage. Just prior to hatching a section of papaya leaf with many individuals of *T. cinnabarinus* was placed in the immediate proximity of each of the

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eggs. In 16 out of the 66 individual cages, the papaya leaf sections were changed daily. The number and the stages of *T. cinnabarinus* present on each leaf section were recorded before placing them in each cage and counted again before removing them in order to determine the feeding capacity and habits of the different larval instars of *S. siphonulus*. The layers of filter paper and cotton lining the bottoms of the cages were moistened periodically with Hoagland's solution in an attempt to maintain the turgidity of the leaf sections for as long as possible but as the *S. siphonulus* emerged and commenced feeding on the mites, frequent replenishment of the existing leaf sections with fresh sections containing more mites became necessary. All of the *S. siphonulus* confined within the individual cages were examined at least 4 times daily for 14 days to record the date and time of eclosion of the eggs, molting of the larvae, death of the larvae if any, and emergence of the imagos.

Upon emergence of the imagos, 20 females and 20 males were removed from their individual cages, paired, and then each pair was held separately throughout their life in lantern cages. The remaining 16 adults were held individually in their original cages. A small papaya leaf with its petiole submerged in Hoagland's solution and heavily infested with all stages of *T. cinnabarinus* was placed in each of the 20 lantern globe cages for food and ovipositional substrate. Papaya leaf sections with *T. cinnabarinus* like those provided to the larvae were supplied to the 16 individually held adults throughout their life but only the numbers of the mites eaten each day during the first 5 days after emergence were recorded. The paired as well as the unpaired *S. siphonulus* adults were observed several times daily to obtain such informations as pre-mating period, frequency of mating, preovipositional period, fecundity, feeding habits, longevity, etc.

In addition to the life history study in the laboratory, population counts of *S. siphonulus* were made at several localities on Oahu and its behavior under field conditions closely observed.

Results and Discussion

The life stages of *S. siphonulus* include the egg, 4 larval instars, pupa, and adult. Their measurements and durations are presented in Tables 1 and 2 and descriptions of them follow:

Egg (Fig. 1A): The egg is elliptical, light orange when freshly laid and grayish black before hatching. It is deposited singly in a colony of spider mites with its long axis lying parallel to the leaf surface. It hatches within 2 to 3 days after deposition. The eggshell is opaque white and has a fine reticulate pattern on the outer surface. It remains adhered in situ for several weeks after hatching.

All of the 66 eggs obtained from mated females and used in making the life history study hatched; however, none of the eggs from unmated

TABLE 1. *Body measurements of the different life stages of* Stethorus siphonulus Kapur.

		Range (mm.)		*Mean ± S. D. (mm.)*	
Stages	*N*	*Length*	*Width*	*Length*	*Width*
Egg	66	0.30-0.36	0.18-0.27	0.33 ± 0.02	0.21 ± 0.02
Larva*					
First instar	63	0.60-1.05	0.24-0.33	0.83 ± 0.10	0.27 ± 0.02
Second instar	60	0.84-1.14	0.24-0.39	1.02 ± 0.69	0.31 ± 0.03
Third instar	58	1.11-1.80	0.42-0.54	1.46 ± 0.21	0.46 ± 0.03
Fourth instar	56	2.04-2.34	0.60-1.28	2.18 ± 0.08	0.80 ± 0.20
Pupa	56	1.00-1.80	0.80-1.07	1.50 ± 0.14	0.95 ± 0.05
Adult	56	1.02-1.50	0.78-1.14	1.33 ± 0.07	0.99 ± 0.06

*Measurements taken prior to molting to the next instar or stage.

TABLE 2. *Durations of the different life stages of* Stethorus siphonulus Kapur *when reared in the laboratory at* 27-32°C *and at* 50-60% *relative humidity.*

Life Stages	*N*	*Range (Days)*	*Mean ± S. D. (Days)*
Egg	66	2.0-3.2	2.9 ± 0.4
Larva	56	5.6-7.7	6.8 ± 0.5
First instar	63	1.7-3.6	2.0 ± 0.3
Second instar	60	0.8-1.8	1.0 ± 0.2
Third instar	58	0.8-2.3	1.2 ± 0.4
Fourth instar	56	1.8-3.6	2.6 ± 0.5
Pupa	56	2.1-3.7	3.0 ± 0.2
Adult	56	27.0-36.0	31.0 ± 2.0
Males	29	27.0-35.0	29.8 ± 1.7
Females	27	30.0-36.0	32.4 ± 1.4

females hatched or showed indications of development. They shrivelled soon after deposition.

Larva (Fig. 1B): The larva is tiny, fusiform and grayish black when newly emerged and yellowish brown when fully grown. The 4 to 8 strong serrate setae that arise from the 3 pairs of protuberances located medially, mediolaterally and laterally on the dorsal surface of each of the abdominal segment and the many scattered strong serrate setae on the thorax give the larva a spiny appearance. Located on the dorsal surface of the thorax are several irregular black areas which are very noticeable on the fully grown larva.

The first instar larva emerged head first through a longitudinal slit about one-half the length of the egg made on the upper surface of the eggshell. It remained motionless near the eggshell for about an hour and thereafter wandered about in the immediate vicinity in search for food. After feeding for about 2 days, the first instar larva stopped moving, affixed itself to the leaf surface by its caudal segment, and remained inactive for about 2 hours. Subsequent to this time, the second instar larva

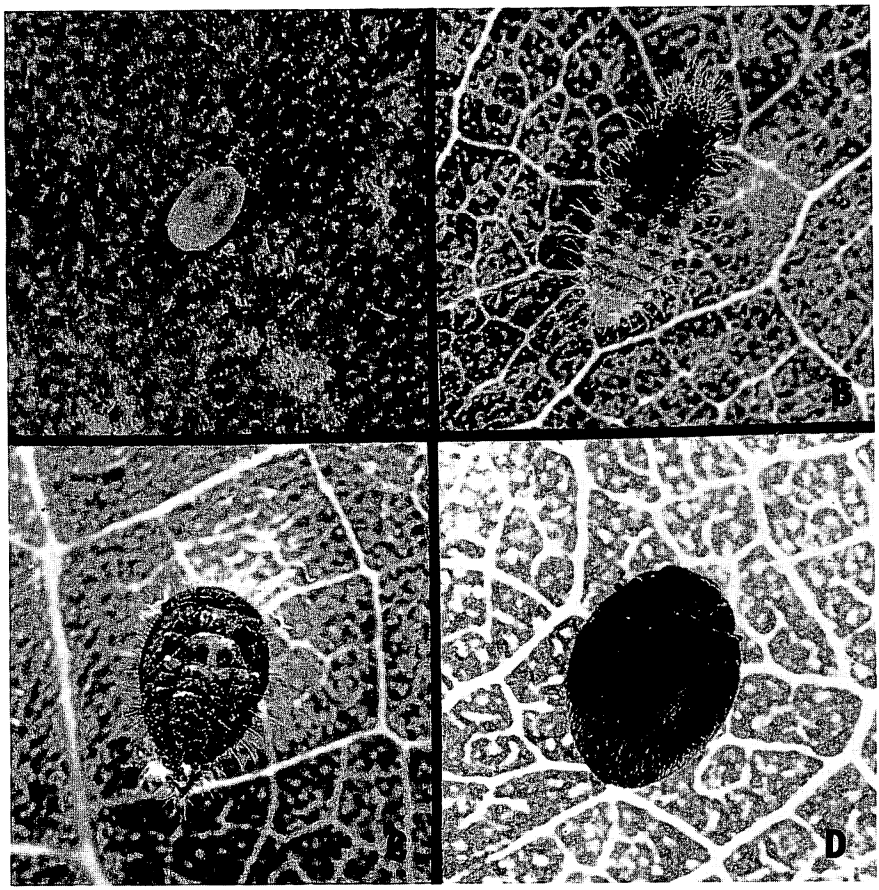

FIG. 1. Life stages of *Stethorus siphonulus* Kapur: A, egg; B, larva (fourth instar); C, pupa; D, adult.

emerged through a longitudinal slit made in the dorsal surface of the exoskeleton of the former instar. Like the eggshell, the grayish black exuvium of the first instar larva remained attached on the leaf surface for a long time. Larval activity during the second, third, and fourth stadia was about the same as that described for the first; however, with the passing of each stadium the larva became more aggressive, captured and fed on larger prey with greater ease, and wandered over larger area in search for food. The second stadium was of the shortest duration and the fourth the longest of the 4 stadia. Larval mortality was greatest during the first stadium (Table 2). About a week after hatching, 56 out of the 66 larvae that emerged from the eggs were fully grown and ready for pupation. In preparation for pupation the larva stopped feeding, attached its caudal segment to the surface of the leaf, and remained quiescent for 2 to 3 hours.

Pupa (Fig. 1C): The pupa is obovate, flattened, yellowish brown for the first 4 to 6 hours after pupation and uniformly black thereafter. The abdominal segments and wing pads are very prominent and excepting for the tenth abdominal segment which is covered by the exuvium of the fourth instar larva, the entire dorsal surface of the body has many white bristle-like setae scattered throughout.

All 56 larvae that successfully survived the egg and larval stages pupated and emerged in 3.0 ± 0.2 days. The entire developmental period from egg through the pupal stage was completed in 12.7 ± 0.7 days.

Adult (Fig. 1D): The adults are shortly oval and convex. The males are slightly smaller than the females. Their body color is yellowish brown as tenerals and uniformly black except for the antennae, legs, mouthparts, and the anterior margin of the clypeus which are yellowish brown as mature adults.

The adults emerged through a dorsal slit made in the pupal skin and remained motionless near it for 2 hours until the exoskeleton hardened. Soon thereafter they began to search actively for food. Of 56 individuals that successfully reached the adult stage, 27 were females and 29 males for a sex ratio of essentially 1:1. First mating occurred 3.3 ± 0.5 days after emergence. Females mated several times during their lifetime with the same males with which they were confined in the lantern cages. Each mating lasted about 1 to 3 minutes. Oviposition began 1.8 ± 0.7 days after initial mating, reached its peak about 3 weeks later, and ceased 6 days before the females died. One of the females laid as many as 7 eggs during a 24-hr period and each female laid an average of 170 ± 52.5 eggs during her life span of 32.4 ± 1.4 days. The males died 2 to 3 days sooner than the females.

FEEDING HABITS

The larvae and adults of *S. siphonulus* actively searched for food but their searching pattern seemed disoriented and at random. When

they came into contact with a prey, the larvae seized and pierced the eggshell or exoskeleton of the prey with their sickle-shaped mandibles and consumed only the internal contents by a series of sucking-regurgitation processes while the adults in most instances devoured the entire body of the prey. Neither the larvae nor adults of *S. siphonulus* seized and ate every *T. cinnabarinus* they contacted nor did the larvae always completely consume the internal contents of every prey they seized and ate. Although larvae of *S. siphonulus* fed on all stages of *T. cinnabarinus,* first and second instar larvae were too sluggish to readily overcome and feed on the active stages of *T. cinnabarinus.* During the first stadium, 61.7% of the *T. cinnabarinus* eaten were eggs, 27.3% larvae and nymphs, and only 11.0% adults. During the second stadium, 51.5% were eggs, 28.5% larvae and nymphs, and 20.8% adults. However, as third instars, *S. siphonulus* larvae were large and agile enough to cope with the more active and larger stages they contacted. During this stadium, the prey included 36.3% eggs, 41.3% larvae and nymphs, and 22.4% adults of *T. cinnabarinus.*

The time required to consume a single prey varied considerably but generally was dependent on the size of the predator in relation to the prey. For example, the third larval instar spent an average of 22.3 seconds to completely consume an egg while the fourth larval instar spent only 8.9 seconds. Also, the third instar predator spent about 72.6 seconds consuming a larva; 112.7 seconds on a nymph and 195.6 seconds on an adult of *T. cinnabarinus.* The adults needed about the same amount of time to devour the different stages of *T. cinnabarinus* as the fourth larval instar. Each *S. siphonulus* adult spent an average of 9.9 seconds to devour an egg, 52.5 seconds a larva, 80.9 seconds a nymph, and 210.9 seconds an adult.

S. siphonulus larvae and adults that had just fed on nymphs or adults of *T. cinnabarinus* remained idle for a longer time before seeking another prey than those that had fed on eggs or larvae. Larvae that ate more nymphs and adults during a given stadium did not complete that stadium any sooner than those that fed on eggs and larvae but ate fewer numbers of *T. cinnabarinus.* Although some larvae and adults of *S. siphonulus* fed on more of a particular stage than on another during a brief period, none of them fed exclusively on one stage of *T. cinnabarinus* throughout their entire larval or adult life.

Each larva consumed on an average of 199 ±64.5 *T. cinnabarinus* of which 46.7% were eggs, 33.3% larvae and nymphs, and 20.0% adults during its larval stage and each adult during its first 5 days of life devoured some 383.9 ± 138.7 *T. cinnabarinus* of which 41.7% were eggs, 36.6% larvae and nymphs, 21.6% adults. Since the adults continued to feed actively until a day or 2 before death at nearly the same rate as they did during the first 5 days, it was estimated that each *S. siphonulus* con-

sumed an average of more than 2,400 spider mites during its combined larval and adult feeding period of 34 to 44 days.

Adults of *S. siphonulus* were seen feeding on their own eggs on a few occasions. Out of the 4,184 eggs laid, only 62 were eaten by the adults. Cannibalism among the larvae of this species did not occur even though many individuals of various sizes were held together in a small area.

FIELD OBSERVATIONS

S. siphonulus was observed in close association with 3 species of spider mites, *T. cinnabarinus, T. tumidus,* and *E. banksi,* at several localities on Oahu, Hawaii. Although these 3 species of spider mites infest many different kinds of plants, *S. siphonulus* was found in close association with them most frequently on papaya *(C. papaya),* crown flower *(Calotropis gigantea* (L.) Ait.), croton *(Codiaeum variegatum* (L.) Bl. var. *pictum* (Lodd.) Muell.-Arg.), and coral tree *(Erythrina cristagalli* L.). It was conspicuously absent on plants with very pubescent leaves even though they were heavily infested by one of the abovementioned spider mites and occurred in the immediate vicinity of the preferred plants.

Some of the eggs of *S. siphonulus* were deposited under concealed places such as beneath the exuviae of the spider mites and debris present on the leaf surface, but most of them were deposited in the open amongst the spider mites without apparent protection. All stages of *S. siphonulus* were observed feeding on colonies of *E. banksi* which normally occurs on the upper surface of the leaves of croton and coral tree and on colonies of *T. cinnabarinus* and *T. tumidus* on the lower surface of the leaves of papaya and crown flower, respectively. Only under unusually severe infestations did *S. siphonulus* and spider mites also occur on the opposite surface. Adults and fourth instar larvae of *S. siphonulus* were seen crawling off the leaves from which they had depleted the spider mites and crawling unto other leaves nearby. When disturbed, the larvae crawled at a faster rate to other parts of the leaves. The adults, on the other hand, seldom flew but exhibited the "death feigning" and dropped to the ground.

Monthly counts made of *S. siphonulus* and the 2 species of spider mites at Waimanalo, Kaaawa, and Manoa, Oahu for a year from November, 1970 have shown that populations of this beetle fluctuate with that of the spider mites. *S. siphonulus* was very scarce or absent during December, 1970 through February, 1971 when the populations of *T. cinnabarinus* and *T. tumidus* were low, and most abundant during June or July, 1971 when the populations of the spider mites were at their peak. For example, in the 30-leaf sample collected in December, 1970 from Waimanalo only 2 *S. siphonulus* were found and none were found in those collected in January and February, 1971. The infestation of the leaves by *T. cinnabarinus* for these 3 months averaged only 4.0% with 0.3 mite per 3.8 cm^2 of the lower leaf surface.

However, with the rapid increase in the population of *T. cinnabarinus* during spring to a peak density of more than 600 mites per 3.8 cm^2 in June, 1971, the population of *S. siphonulus* increased slowly during March-April, 1971; averaging 0.8 per leaf, and suddenly up to 18.0 per leaf in June, 1971. All stages of *S. siphonulus* were common in June but the eggs, larvae, and pupae outnumbered the adults. The 232 larvae and 67 adults present on 80.0% of the leaves were actively feeding on all stages of *T. cinnabarinus* and on some leaves there were indications that they had decimated the spider mites that were once there.

During the subsequent summer and fall months, the populations of the spider mites and *S. siphonulus* at all 3 localities fluctuated together very closely but the general trend was downward to the low winter population densities witnessed the previous year. The *S. siphonulus* population in October, 1971 was down to 2.6 per leaf and the infestation by *T. cinnabarinus* was 46.7% at Waimanalo. In November of the previous year, the *S. siphonulus* population at the same locality was 0.5 per leaf and the infestation was 33.3%.

Summary

Studies on the life history of *Stethorus siphonulus* Kapur in the laboratory at 27-32°C and 50-60% relative humidity showed that the duration of its egg stage is 2.9 ± 0.4 days, larval stage 6.8 ± 0.5 days, pupal stage 3.0 + 0.2 days, and the adult stage 29.8 ± 1.7 days for males and 32.4 + 1.4 days for females.

S. siphonulus adults mated several times during their life. The first mating occurred 3.3 ± 0.5 days after emergence and the females started to oviposit 1.8 ± 0.7 days thereafter. Each female laid 170 ± 52.5 eggs during her life.

During the larval stage *S. siphonulus* consumed an average of 199.4 ± 64.5 mites, and during the first 5 days of adult life it ate an average of 383.9 ± 138.7 mites.

The time spent by *S. siphonulus* to consume the contents of *Tetranychus cinnabarinus* (Boisduval) varied with: 1) the stage of the predator, 2) the stage of the host eaten, and 3) the time elapsed between feedings.

The searching pattern of *S. siphonulus* was random. The larvae fed on the internal contents of their prey by a sucking-regurgitation process while the adults usually consumed the entire body of the prey.

Cannibalism among the larvae of *S. siphonulus* did not occur but the adults ate some of their eggs.

Generally, the field population of *S. siphonulus* fluctuated with those of the 3 species of spider mites, *T. cinnabarinus, Tetranychus tumidus* Banks, and *Eutetranychus banksi* (McGregor). *S. siphonulus* were most abundant during the summer when these spider mites were most numerous and very scarce during the winter when the spider mite populations were lowest.

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