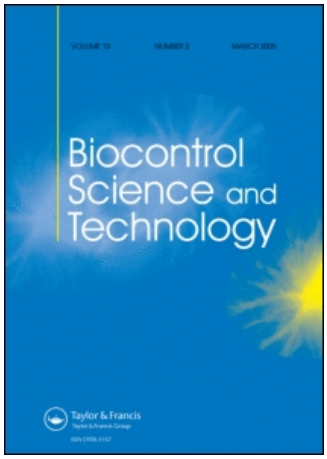

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Biology and Prey Range of *Cryptognatha nodiceps* (Coleoptera: Coccinellidae), a Potential Biological Control Agent for the Coconut Scale, *Aspidiotus destructor* (Hemiptera: Diaspididae)

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Cryptognatha nodiceps *Marshall is an important natural enemy used in biological control programmes against* Aspidiotus destructor *(Signoret), an introduced pest of coconut in many countries. In order to increase our understanding of* C. nodiceps*, the present study to quantify aspects of the developmental, reproductive and feeding biology under constant environmental conditions (26 ± 2°C, 55–65% RH) was carried out. In addition, methods for culturing the scale and the beetle were developed. The average duration of development was 19.2 ± 0.1 days for males and 19.6 ± 0.2 days for females. Female longevity and lifetime fecundity was 35.6 ± 5.1 days and 141.0 ± 35.6 eggs, respectively. Life table statistics were as follows: reproductive rate, 9.99, intrinsic rate of increase, 0.09, finite rate of increase, 1.1, doubling time, 7.8 days and generation time, 41.1 days. Studies on feeding biology showed that* C. nodiceps *was oligophagous. The coccinellid fed and reproduced on prey species in two families, Diaspididae and Coccidae. Adults also fed on the coconut whitefly* Aleurodicus cocois *(Curtis) (Aleyrodidae) but no reproduction occurred on this prey. Aphididae, Psyllidae and Pseudococcidae were not fed upon.*

Keywords: *Coccinellidae,* Cryptognatha nodiceps*, Diaspidae,* Aspidiotus destructor*, biology, prey range, biological control*

INTRODUCTION

Cryptognatha nodiceps Marshall (Coleoptera: Coccinellidae) is an important biological control agent of the coconut scale *Aspidiotus destructor* (Signoret) (Diaspididae: Hemiptera), a serious pest of coconut in many tropical and subtropical countries of Asia, Africa, the

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Caribbean, Florida (USA) and the Pacific. Urich (1914) first recorded the coccinellid preying on *A. destructor* on coconut in Trinidad. Around the same time, *C. nodiceps* was also reported from Guyana, attacking both *A. destructor* and early stages of the coconut whitefly, *Aleurodicus cocois* (Curtis) (Bodkin, 1914, 1917) (Aleyrodidae). Over the years, *C. nodiceps* has been used successfully in several classical biological control programmes, particularly against *A. destructor*, beginning with Fiji in 1928 (Taylor, 1928). In recent years, however, serious outbreaks of the scale have occurred on Tuvalu and neighbouring islands (Pranish Prasad, pers. comm.). Anecdotal evidence seemed to suggest that *C. nodiceps* may have become extinct and consideration was being made to re-introduce the coccinellid into Fiji.

Many changes have occurred in how classical biological control programmes are undertaken since the last introduction of the coccinellid to Fiji. These have been mainly due to concerns about potential impacts of introduced agents on non-target organisms. Against this background, it is necessary to have adequate knowledge on the biology and ecology of any potential agent to allow informed decision-making. Additionally, reliable laboratory culturing techniques are required. Thus, the main objective of the present study was to improve our understanding of *C. nodiceps* by elucidating salient elements of the coccinellid's developmental and reproductive biology, and to generate experimental data on its prey range under laboratory conditions. Techniques for culturing *C. nodiceps* were also developed.

MATERIALS AND METHODS

Rearing Techniques

Hosts. Three host materials were assessed for suitability in rearing the scale: coconut plants, pumpkin fruits and sprouting potato tubers. The choice of the last two was based on the observations of Ahmad and Ghani (1970). Young, naturally growing, 50–75-cm tall coconut plants were collected along the beach in Trinidad, potted in 30-cm diameter pots in a 1:1 topsoil and gravel/sand mixture and maintained in an outdoor rearing facility. They were watered twice weekly and fertilized alternately with urea and Nutrex® (N:P:K ratio 20:20:20) once a month. The plants took about a month to become established. Clean plants with two to three open fronds were used for culturing *A. destructor*. A rough-skinned pumpkin variety (local name 'crapaud-back'), 15–30 cm in diameter, was used after cleaning with a soft cloth moistened in 1% Chlorox®, followed by a gentle swob with a dry cloth. Clean potatoes were sprayed with gibberillic acid (100 ppm), dried and placed in a dark room in $30 \times 30 \times 2$-cm trays to encourage sprouting. When the sprouts were 2–3 cm long, the potatoes were used for rearing *A. destructor*.

Laboratory conditions. Insects were cultured in two controlled-temperature rooms maintained at $26 \pm 2^{\circ}$C and a relative humidity of $60 \pm 10\%$. In one room, pumpkins and potatoes were used for rearing *A. destructor* under natural light. Coconut plants were used in the second room had artificial lighting (12 h light:12 h dark).

Cages. Metal cage frames measuring $60 \times 60 \times 60$ cm and covered with a thin white nylon mesh cloth were used for pumpkins/potatoes. Sleeve cages, measuring $60–100 \times 40–60$ cm, of the same material were used for coconut plants.

Establishment and maintenance of A. destructor *cultures.* Field-collected coconut leaves harbouring *A. destructor* eggs and crawlers were observed under the microscope and all contaminants including parasitoids, coccinellids, mites, mealybugs and other scales were removed before the leaves were used to infest laboratory plants. The techniques used for infestation varied with the host. The procedure used to initiate cultures on pumpkins is described below.

Chicken wire mesh was cut into pieces measuring about 60×60 cm and wrapped around individual pumpkins placed on a 15-cm diameter plastic pot to form a shroud. The ends of

the flexible wire were brought together and tied tightly around the pot with a string. Field infested portions of the coconut leaves were cut into 3–6-cm length strips and placed on the shroud, with the infested side facing the pumpkin to allow hatching scales to drop onto the fruit. The infested leaf portions were left for 3–4 days and then transferred to another pumpkin. Each batch of leaves was thus used to infest two sets of pumpkins. Infested pumpkins were examined twice per week to remove any contaminants. Once 50–60 pumpkins were infested, field collections were stopped. The procedure for culture maintenance is described below. A two-shelf rack was constructed using dexion with the lower shelf being solid and the upper one being made of 2 × 2-cm heavy gauge wire. Clean pumpkins were placed on the lower shelf and infested pumpkins with eggs/crawlers were placed on the upper shelf. This allowed the crawlers to 'drop down' and infest the clean pumpkins below. About 25 sprouted potatoes placed in 30 × 30-cm trays were similarly infested. Clean coconut plants were infested by placing them horizontally on the lower shelf. After 1–3 days, the infested hosts were removed and examined for contaminants. The pumpkins were placed on a clean pot and transferred to the cages described above. Two trays of potatoes were placed in a similar cage. The coconut plants were individually covered with sleeve cages and placed under a light frame.

Establishment and maintenance of C. nodiceps *cultures.* Adults reared from unparasitized, field-collected larvae and pupae were used to establish cultures of *C. nodiceps*. Each adult was carefully examined under the microscope and sexed based on the method outlined by Taylor (1935). About 20–25 pairs were released on four heavily infested pumpkins, in a cage for 3–4 days for feeding and oviposition. The adults were then moved to another set of pumpkins for a similar period. This was continued until all the adults were dead. Females oviposited large numbers of eggs on the pumpkins. The first instar larvae were not visible to the naked eye. Larvae only became visible in the late second and early third instar stages, by which time the food source on the pumpkin had become depleted. About 20–40 larvae were then transferred manually with a fine brush onto heavily infested pumpkins. When the larvae pupated, they were collected and placed in 6-cm diameter Petri dishes for adult emergence. The emerging adults were used for culture maintenance, as described above.

Biology of *C. nodiceps*

Developmental biology. All insects used in the experiments on biology and prey range of *C. nodiceps* were reared on *A. destructor* on pumpkins. Leaf discs of coconut harbouring large numbers of adult *A. destructor* were placed in 5-cm diameter Petri dishes on moist filter paper. Ten to 15 ovipositing adult *C. nodiceps* were released on the leaf discs for 24 h. The leaf discs were then observed under a microscope and the covering of the scale carefully removed to locate the eggs, which were removed with a fine paintbrush. Each egg was placed individually on a new coconut leaf disc harbouring mixed stages of *A. destructor.* The leaf disc was then placed on moist filter paper in a 3-cm diameter Petri dish and observed daily for egg-hatch. When the eggs hatched, development of the larvae was followed through to pupal stage. In total, 56 eggs were set up for this study. Data on survival and moulting were recorded daily and the leaf discs were changed on alternate days, ensuring an abundant supply of food. Once pupae were formed, they were detached from the leaf and placed individually on a dry filter paper in a Petri dish. The date of emergence and sex of the emerging adults was recorded.

To determine the rate of feeding in *C. nodiceps*, observations were made on 12 larvae from the above experiment. The number of prey consumed from emergence to the prepupal stage was recorded for each larva. Non-ovipositing adult *A. destructor* were counted prior to being provided to the larvae on leaf discs for feeding. The leaf discs were changed every day and number of prey fed was counted and recorded. After each molt, the number of prey consumed by each instar was calculated. One larva died during development and two pupae

failed to develop. Feeding in nine adults (four males and five females) that emerged was similarly monitored for 7 days during which time no oviposition was recorded.

Morphological parameters of the various stages were measured under a dissecting microscope. For eggs and newly emerged adults, the length and width (at the longest and widest points respectively) were recorded. For larvae, the width of the head capsule of the various instars was measured immediately after each molt. Only the width of the pupa was recorded because of the remains of the ecdysed skin of the final instar at the distal end.

Reproductive biology. Sixteen newly emerged adults were paired. Each pair was released in a Petri dish containing a coconut leaf disc harbouring a large number of mixed stages of *A. destructor*. For the first few days, the adults were observed daily for periods of 30–60 min between 09:00 and 15:00 h to record mating; this was stopped once oviposition began. Leaf discs were changed every 2 days and the number of eggs recorded. Mortality of adults was recorded daily and dead males were replaced with mature males from cultures. The experiment was terminated when all the females were dead.

Means and standard errors were calculated for the data on developmental rates of various stages, longevity and fecundity of female *C. nodiceps*. The data on survival and egg production were used to compute life table parameters. Population growth parameters were computed according to methods described by Birch (1948). Thus the net reproductive rate, $R_o = \Sigma_0^\infty l_x m_x$ (where l_x and m_x are the cumulative daily survival and nymph production functions respectively); the intrinsic rate of increase $r_m = \Sigma e^{-r_m x} l_x m_x = 1$; mean generation time, $g = \ln R_o / r_m$; the finite rate of increase, $\lambda = e^{r_m}$; and doubling time, $DT = \ln(2)/r_m$.

Prey Feeding Tests

Potential prey species were selected in a similar way as is done during host specificity tests for weed biological control agents. This is based on the principle of centrifugal testing. Thus testing starts with closest relatives of the target host and continues with representatives of more distant taxa, e.g., subfamilies and families within the same order. Additionally, testing is also carried out against unrelated but valuable plants, either crop plants or ornamentals. A similar procedure was used to test the prey range of the predatory coccinellids, *Nephaspis bicolor* Gordon (Lopez *et al*., 1997) and *Scymnus coccivora* Ayyar (Peterkin *et al*., 1998). For *C. nodiceps*, test prey included members belonging to several closely related homopteran families (Coccidae, Aleyrodidae Aphididae, Psyllidae and Pseudococcidae).

Leaf sections of various host plants harbouring sufficient numbers of the prey species being tested were placed on moist filter paper in Petri dishes of 3-cm diameter. Hosts/host plants used and stages of prey tested are given in Table 1. Two types of controls were set up, the first comprising no prey but with water provided, and the second with no prey and no water. Ten replicates were set up on each prey species as well as of the two controls. The tests were conducted in two batches but similar conditions were maintained throughout.

One pair of mature, ovipositing adults was released in each Petri dish. Observations were made on the response of the coccinellids to the prey immediately after release and at other times when they appeared to have settled on the leaf discs to determine if settling and/or feeding occurred. The filter paper was kept moist and observations on adult survival were recorded daily for 6 days when the experiment was terminated. Leaves were changed or prey added as necessary, ensuring that there was always a sufficient supply of prey.

Data from the two trials were pooled for analysis. Survival data was analysed using the SPSS® statistical package (Norusis, 1993). For comparison of survivorship, the Kaplan–Meir technique was used, which allowed for analysis of censored data. Using this technique, the standard error of the cumulative proportion surviving at time k: $se(t_k) = S(t_k)\sqrt{\Sigma_{i=1}^{k} \frac{d_i}{n_i(n_i - d_i)}}$ where $S(t_k)$ is the cumulative survival probability, d_i is the number of deaths or censored cases at time t_i and n_i is the number of cases alive prior to

TABLE 1. Species used for the prey range tests for *Cryptognatha nodiceps*

Family	Species	Host plant	Arthropod prey stages
Hemiptera			
Diaspididae	*Aspidiotus destructor* (Signoret)	*Cocos nucifera* (coconut)	Mixed stages[a]
Diaspididae	*Aonidiella* sp.	*Coccoloba uvifera* (seagrape)	Mixed stages[a]
Coccidae	*Parlagena bennetti* Williams	Coconut	Mixed stages[a]
Coccidae	*Coccus viridis*	Seagrape	Mixed stages[a]
Aleyrodidae	*Aleurodicus cocois* Curtis	Coconut	Mixed immature stages[b]
Aleyrodidae	*Aleurothrixus floccosus* Maskell	*Psidium guajava* (guava)	Mixed immature stages[b]
Aleyrodidae	*Aleurocanthus woglumi* Ashby	*Citrus* sp. (citrus)	Mixed immature stages[c]
Aphididae	*Aphis gossypii* Glover	*Hibiscus rosa-sinensis* (hibiscus)	Mixed stages[a]
Aphididae	*Toxoptera citricida* Kirkaldy	Citrus	Mixed stages[a]
Pseudococcidae	*Maconellicoccus hirsutus* Green	Hibiscus	Ovisacs and third instars
Pseudococcidae	*Planococcus citri* (Risso)	Citrus	Third instars
Psyllidae	*Heteropsylla cubana* D.L. Crawford	*Leucaena leucocephala*	Mixed immature stages[b]
Coleoptera			
Coccinellidae	*Cryptognatha nodiceps* Marshall	Coconut	Eggs
Acarina			
Tetranychidae	*Tetranychus* sp.	Coconut	Mixed stages[a]

[a]Mixed adult and immature stages; [b]eggs and all immature stages; [c]eggs/early instars tested separately from later instars.

time t_i. To compare survival functions, the Breslow statistic was used and this is computed as follows: $U = \Sigma_{i=1}^{k} w_i - (O_i - E_i)$ where w_i, is the weight for the time point i, and k is the number of distinct time points. For the Breslow statistic (BS) the weights are the number at risk at each time point.

RESULTS

Rearing Techniques

Cultures of *A. destructor* readily established on pumpkins and coconuts, but not on sprouted potatoes. Each rearing cycle of *A. destructor* lasted about 30–35 days. Using the two-shelf method, the clean pumpkins were evenly covered with a layer of settled crawlers within 2–3 days. In each cycle, about 80% of pumpkins were used to rear *C. nodiceps*, while the remaining were used for culture maintenance of *A. destructor*. Only one or two generations of scales could be reared on both pumpkins and coconut plants. On hosts with high infestations covering almost the entire surface, only one generation of scales could be reared, but a second generation was possible on hosts with low to medium infestations.

Biology of *C. nodiceps*

Duration of development. Data on duration of development are given in Table 2. The egg stage lasted about 5 days. Each of the four instars and the pre-pupal stages lasted 1–3 or 1–4 days. The fourth instar was of the longest stage (2.7 days), followed by the first (2.1 days) and the prepupa (2.0 days). The duration of the larval and prepupal stages of both males and females was very similar, being 13.0 and 2.0 days, and 12.9 and 1.9 days respectively. The pupal stage, however, lasted slightly longer in females (4.8 days) than in males (4.2 days). This increase was also reflected in the overall duration of development (males, 19.2 days and females, 19.6 days).

TABLE 2. Duration of development of immature stages of *Cryptognatha nodiceps*

	Duration of development		
Life stage	*N*	Range	Mean ± SE
Egg incubation	56	4–6	5.0 ± 0.05
First instar larva	50	1–3	2.1 ± 0.09
Second instar larva	50	1–4	1.5 ± 0.10
Third instar larva	50	1–3	1.7 ± 0.09
Fourth instar larva	49	1–4	2.7 ± 0.10
Total (larval stage)	49	12–15	13.0 ± 0.13
Prepupa	44	1–3	2.0 ± 0.11
Pupa	42	3–7	4.4 ± 0.11
Total (egg-adult)	42	17–23	19.4 ± 0.16

Size of stages. Eggs measured 0.50 ± 0.003 mm in length and 0.26 ± 005 mm in width. The width of the head capsule increased with each moult, measuring 0.16 ± 0.001, 0.25 ± 001, 0.35 ± 0.003 and 0.50 ± 0.003 mm, in the first, second, third and fourth instars, respectively. The values did not differ significantly between males and females even though females were generally slightly larger.

Reproductive biology. Mating occurred 4–5 days after emergence and matings were repeatedly observed throughout adult life. Life table parameters calculated from data on female fecundity and survival rates are presented in Table 3. Female adults lived for an average of 35.6 ± 5.13 days during which time they oviposited 141.1 ± 23.73 eggs after a preoviposition period of 7.9 ± 0.23 days. Eggs were invariably laid under the empty covering of the adult scale. Males were shorter-lived than females (20.7 ± 7.38 days).

Rate of feeding. Larval feeding rates increased considerably with each instar. Thus the second, third and fourth instars consumed 2, 12 and 20 times more than first instar (Figure 1). Males and females consumed similar number of hosts. Adults began feeding slowly one day after emergence and this gradually increased to an average of 19.3 and 22.3 scales per male and female, respectively, by day 7 (Figure 2).

Prey Feeding Tests

Absence of food led to cannibalism on the eggs within 24 h. Among the homopteran prey species tested, foraging was observed immediately after exposure of adult beetles to four coccid species: *Aspidiotus destructor*, *Aonidiella* sp., *Parlagena bennetti* Williams and *Coccus viridis* (Green) in 75–85% of the cases. On the other hand, adults were not attracted to the other prey because they did not forage on these species but moved to the top of the Petri dish, where they remained. After 7 days, 95–100% of beetles exposed to the four coccid

TABLE 3. Life table parameters for *Cryptognatha nodiceps*

Parameter	Estimate[a]
Female survival (days) (Mean ± SE)	35.6 ± 5.12
Fecundity (Mean ± SE)	141 ± 23.73
Net reproductive rate (R_0)	9.99
Intrinsic rate of increase (r_m)	0.0887
Generation time (G)	41.12
Doubling time (DT)	7.815
Innate capacity for increase (λ)	1.093

[a]Four of the 16 females set up died within a week of emergence most likely due to handling and were excluded from the analysis.

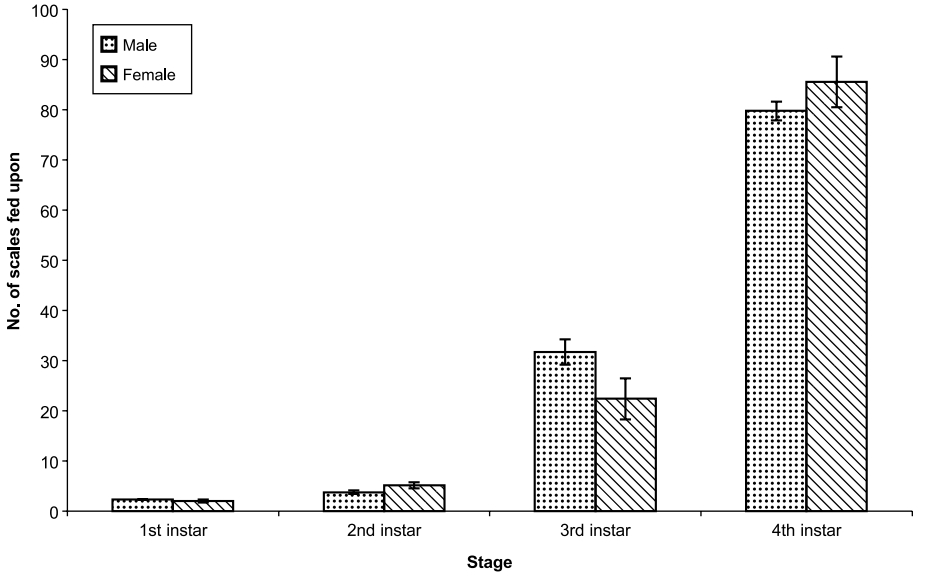

FIGURE 1. Feeding rates of immature stages *Cryptognatha nodiceps* on *Aspidiotus destructor*.

species above were still surviving. Survival on *Maconellicoccus hirsutus* Green and *Planococcus citri* (Risso) was 0 and 25%, respectively. Some feeding occurred on the two aphid species and *Tetranychus* sp., resulting in a survival of 10, 10 and 5%, respectively. Among the Aleyrodidae, some feeding occurred on *Aleurothrixus floccosus*, resulting in 15% survival, while none occurred on eggs and first instars of *Aleurocanthus woglumi* Ashby and all adult beetles died within 4 days of release. However, some feeding occurred when mixed stages of *Aleurocanthus woglumi* were provided, resulting in 5% survival at the end of 7 days. Survival on *Aleurodicus cocois* (40% on day 7) was the longest on a non-coccid species and

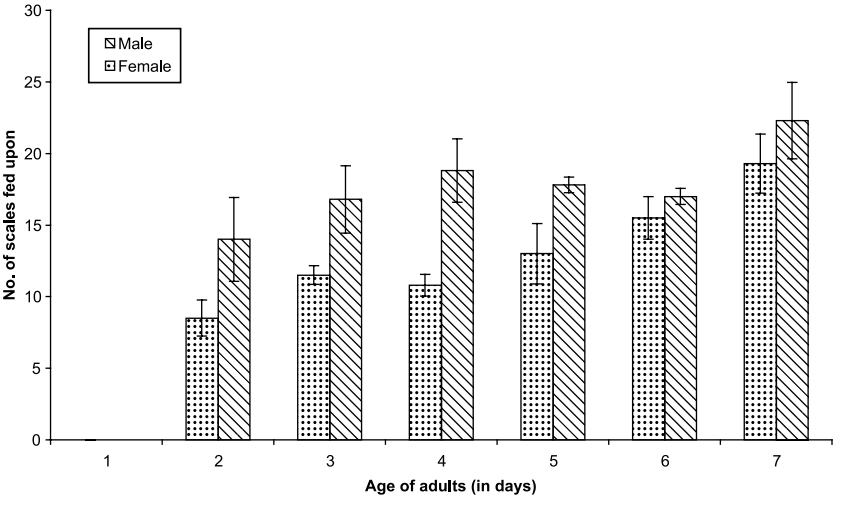

FIGURE 2. Feeding rates of adult *Cryptognatha nodiceps* on *Aspidiotus destructor* during the first seven days after emergence.

feeding was recorded consistently on this prey throughout the duration of the experiment. Results from the Kaplan–Meier survival analysis are depicted in Figure 3. Based on the Breslow Statistic, survival on all four coccids was significantly ($P < 0.05$) higher compared with all other prey as well as the two controls (Table 4). Survival on various prey tested was also significantly different ($P < 0.05$) compared to both control treatments, except *Aleurocanthus woglumi*, *Aleurothrixus floccosus*, *Heteropsylla cubana* D.L. Crawford, *Aphis gossypii* Glover, *Tetranychus* sp. and *M. hirsutus* (ovisacs), which were on par with control.

DISCUSSION

Simplified and effective techniques for maintenance of large cultures of *C. nodiceps* and its prey *Aspidiotus destructor* were developed. Both pumpkins and coconut plants were found to be good hosts for culturing *Aspidiotus destructor*. However, the use of pumpkin is recommended for large-scale production because it is more amenable to laboratory manipulation. No major problems were encountered, except that occasionally, an all-male population was produced, particularly on coconuts but the reason for this was unclear.

Duration of development of *C. nodiceps* in Trinidad was similar to that in Fiji, which ranged between 19 and 25 days and under crowded conditions with limited food supply, extended to 28 days (Taylor, 1935). Female *C. nodiceps* laid, on average, about five eggs per day, slightly higher than Taylor's (1935) estimate of four eggs per day. Oviposition occurred throughout life and ceased a few days prior to death.

Female egg laying behaviour in close proximity to hosts suggested a high degree of adaptation and prey specialization. Such adaptations are also found in other coccinellids known to have narrow prey ranges such as *Rodolia iceryae* Janson and *Nephaspis bicolor* Gordon (Kairo & Murphy, 1995; Lopez *et al*., 1997).

In predatory coccinellids, 'essential' foods support feeding and survival of developmental stages and egg production in adults (Majerus & Kearns, 1989). Many species can feed and survive on alternative 'accepted but inadequate' foods such as nectar, pollen and less suitable prey. Development and oviposition may, however, be prevented or reduced on these foods (Majerus & Kearns, 1989). Data from the present study suggests that *C. nodiceps* has a narrow prey range. While *Aspidiotus destructor* may be the preferred prey, survival of

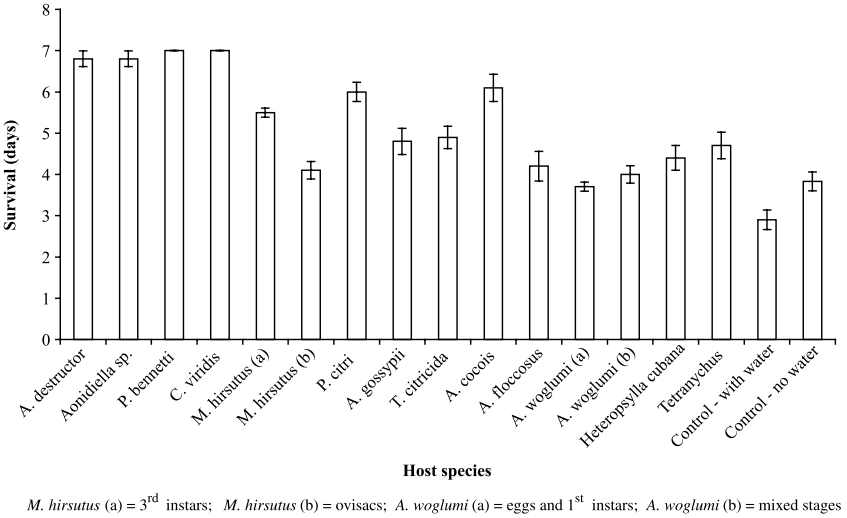

FIGURE 3. Survival patterns of *Cryptognatha nodiceps* fed on a range of prey over a 7-day period.

TABLE 4. Breslow statistics for comparison of survival of adult *Cryptognatha nodiceps* on 15 prey species, significant differences ($P < 0.05$) are marked with an asterisk

#Prey	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1																	
2	0.0																
3	1.0	1.0															
4	1.0	1.0	0.0														
5	28.2*	28.2*	35.9*	35.9*													
6	29.8*	29.8*	36.5*	36.5*	20.7*												
7	18.9*	18.9*	25.1*	25.1*	3.0	21.5*											
8	24.1*	24.1*	30.1*	30.1*	2.1	2.2	6.5*										
9	23.7*	23.7*	30.2*	30.2*	3.0	4.8*	6.6*	0.1									
10	11.9*	11.9*	16.4*	16.4*	6.6*	17.6*	1.0	7.5*	7.6*								
11	22.8*	22.8*	27.8*	27.8*	8.4*	0.0	10.7*	1.1	2.4	9.8*							
12	29.3*	29.3*	35.8*	35.8*	35.8*	1.3	33.0*	4.1*	11.1*	22.7*	0.3						
13	26.8*	26.8*	33.2*	33.2*	23.5*	0.1	22.5*	2.1	5.9*	16.9*	0.0	0.76					
14	27.1*	27.1*	33.7*	33.7*	11.1*	0.4	14.1*	0.5	2.0	12.5*	0.2	2.8	0.7				
15	22.1*	22.1*	27.8*	27.8*	4.7*	1.5	7.5*	0.04	0.4	7.6*	0.9	4.1*	1.8	0.4			
16	35.0*	35.0*	38.9*	38.9*	33.5*	8.7*	32.7*	13.8*	18.0*	27.9*	6.7*	5.0*	7.4*	10.3*	13.0*		
17	32.5*	32.5*	38.5*	38.5*	21.9*	0.3	24.1*	3.7	6.8*	20.6*	0.2	0.3	0.1	1.3	2.9	6.9*	

Prey species: 1. *Aspidiotus destructor*; 2. *Parlagena bennetti*; 3. *Aonidiella* sp.; 4. *Coccus viridis*; 5. *Maconellicoccus hirsutus* (third instar); 6. *M. hirsutus* (ovisacs); 7. *Planococcus citri*; 8. *Aphis gossypii*; 9. *Toxoptera citricida*; 10. *Aleurodicus cocois*; 11. *Aleurothrixus floccosus*; 12. *Aleurocanthus woglumi* (eggs/first instar); 13. *A. woglumi* (mixed stages); 14. *Heteropsylla cubana*; 15. *Tetranychus* sp.; 16. Control (water); 17. Control (no water).

95–100% and oviposition was recorded on at least three species of Diaspididae (*Aonidiella orientalis*, *Aonidiella* sp. and *P. bennetti*) and one species of Coccidae (*Coccus viridis*). Some feeding occurred on other Hemiptera, but survival of adults was very low on all except *Aleurodicus cocois*. Furthermore, no oviposition was recorded on any of the prey species tested including *Aleurodicus cocois*. Under field conditions, reproduction by *C. nodiceps* (as evidenced by presence of various developmental stages) was observed on *Aspidiotus destructor*, *P. bennetti* and *Aonidiella orientalis* Newstead (V.F. Lopez, unpublished data). During field surveys in Trinidad, *C. nodiceps* was never encountered on *M. hirsutus* and Aleyrodidae with these species when they occurred alone (Lopez & Kairo, 2003). However, species like *Aleurodicus cocois*, which attack similar host plants as *Aspidiotus destructor*, may be exploited for feeding by adult *C. nodiceps* but this prey will not support development of larvae. In Fiji, *C. nodiceps* was found to feed and survive, albeit reluctantly, on at least one alternative prey, *Pseudaulacaspis* (= *Diaspis*) *pentagona* Targioni & Tozzetti on mulberry, in the absence of *Aspidiotus destructor* (Taylor, 1935). In fact, the success of *C. nodiceps* in Fiji was attributed to this ability together with several other factors such as continuous breeding throughout the year with no serious natural enemies, voracious adult and immature stages and high longevity, fecundity and dispersal rates of adults (Taylor, 1935).

The successful introduction of *C. nodiceps* to Fiji has been repeatedly cited in the literature as an example of a highly successful classical biological control programme (DeBach, 1964; Hagen, 1974). Following this, the coccinellid was used against *A. destructor* and other diaspidids, with inconsistent results. For instance, it became established in Florida (Clausen, 1978) and Jamaica (Cock, 1985) but not several Caribbean islands (e.g., Grenada, St. Lucia) with comparable climatic and environmental conditions. In Principe, off the coast of West Africa, importation resulted in quick establishment and long-term control of *A. destructor* in the north but not in central and southern regions, possibly due to higher rainfall in the latter (Castel-Branco, 1956, 1972; Cochereau, 1965; Simmonds, 1960). Similar failures in Pakistan, French Polynesia (Rao *et al*., 1971) and Angola remain unexplained (Valles, 1965; Cock, 1985).

According to Obrycki and Kring (1998), 'coccinellids will continue to play a role in naturally occurring and human-assisted biological control and they will be considered for importation whenever a homopterous pest invades a new region'. Previous successful programmes reveal *C. nodiceps* as an effective biological control agent of *A. destructor*. However, the coccinellid has the potential to feed on prey species in at least two homopteran families. This is indicative of potentially undesirable effects on non-target species, even though it may also be biologically beneficial as it may allow the predator to survive when *A. destructor* populations are rare, as occurred in Fiji. This will need to be considered when assessing the risk of further introduction of the coccinellid. Field studies on the prey range of the coccinellid in areas where it has been introduced will be invaluable. However, based on previous successful use in biological control programmes, serious consideration should be given to introduction of the species in areas where *A. destructor* has been accidentally introduced.

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