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DISCOVERY OF ISOLATED PATCHES OF *ICERYA PURCHASI* BY *RODOLIA CARDINALIS*: A FIELD STUDY

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The discovery of isolated patches of prey by the natural enemies of the cottony-cushion scale *Icerya purchasi* Maskell was tested in the field on potted plants of *Acacia baileyana* and citrus between November and February in South Australia. The survival of scales to adults in patches in the 4 fortnightly releases (cohort sets) was not significantly different between location-1 (under an *Acacia* tree harbouring scales and its natural enemies) and location-2 (about 500 m away from the nearest host plant of the scale). The temporal distribution of mortality in the scale cohorts was described by the Weibull model. The proportion of scales surviving at the 2 locations (on the 3^{rd} & 6^{th} fortnight) was not significantly different suggesting that the total effect of all the mortality factors on the scales at the 2 locations was the same.

The trends in prey patches destroyed in time could be explained from the period of activity of the natural enemies in the field. *Rodolia cardinalis* (Mulsant) had discovered the prey patches within a fortnight of the release of scale crawlers. The results substantiate earlier reports that *Rodolia* can find and destroy isolated scale colonies.

KEY-WORDS: *Icerya purchasi, Rodolia cardinalis,* searching, prey patches, Weibull model.

The foraging strategies of animals, and especially insects, are strongly influenced by the complex spatial structure of the environment. The natural distribution of prey are aggregated on a series of spatial scales, like "clumps-within-clumps"(**Heads & Lawton,** 1983). A predator is believed to perceive the environment at 3 hierarchical levels: the habitat, the patch, and finally the prey (**Hassell & Southwood,** 1978). The degree of clumping at any hierarchical level would depend on the size of the prey population. As prey become scarce, the numbers of both, the individuals per patch and patches per habitat, would decline while the average distances between individuals and between patches would increase. If a predator is the key mortality factor, it must be efficient in finding isolated patches of scarce prey in order to maintain the scarcity of the prey and prevent its own extinction.

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Both *Icerya purchasi* Maskell (*Homoptera: Margarodidae*) and *Rodolia cardinalis* (Mulsant) (*Coleoptera: Coccinellidae*) are relatively rare in Australia (**DeBach,** 1974; **Prasad,** in prep.), their supposed native land. The beetle, which has reputation for several successes in biocontrol over a century, is believed to be primarily responsible for the low numbers of scales in Australia as well. Considering the monophagous nature of *Rodolia* (**Quezada & DeBach,** 1973), the almost sedentary nature of its larval stages, and the obscure occurrence of scales in South Australia, *Rodolia* adults must be finding patches of prey on trees which are often spread far apart. Though the beetle's potential to find and destroy isolated patches of prey has been inferred from its numerous successes in biological control (**Quezada & DeBach,** 1973), there is no direct experimental evidence to substantiate this hypothesis. The following field experiment was designed to test the search-and-destroy ability of the natural enemies of *Icerya,* especially *Rodolia.*

MATERIALS AND METHODS

Potted plants of *Acacia baileyana* Ferdinand von Mueller and citrus were placed at 2 locations. Location 1 was under a large *Acacia* tree with natural population of *Icerya* and its natural enemies. Location 2 was an isolated area about 500 m away from the nearest known host plant of the scale, and so presumably as far away from any natural population of the scale or its natural enemies. Three patches of prey, generated by releasing crawlers in clip-on-leaf cages, were present on 4 potted plants of each species at each location. Starting from 20th November, 1981, each of the 4 fortnightly releases formed a cohort set. Thirty crawlers were released per patch in cohort set 1, 20 crawlers per patch in cohort set 2 and 3, and 10 crawlers per patch in cohort set 4. After 4 days, the cages were removed and the numbers of crawlers settled recorded.

The numbers of scales surviving and the natural enemies present on each patch were recorded every fortnight. Observations were terminated when all the surviving scales began producing crawlers. The almost sedentary nature of the scales facilitated in following individual scales through the experiment.

RESULTS

SURVIVAL OF SCALES AT THE TWO LOCATIONS

The numbers of scales surviving were summed up across patches and across plants of the same species for each location and cohort set combinations for each fortnight. The proportions of scales surviving gradually declined in each subsequent fortnight in all the cohorts (fig. 1). Except for the 3rd and 4th cohort set on *Acacia* at Location 1 in which > 40 % scales survived to adults, in all other cohort sets only < 10 % scales survived to adults by the 12th week.

The Weibull time-to-failure model, which can be used to describe survivorship data from animal populations (**Pinder** *et al.*, 1978; **Hogg & Nordheim,** 1983), was fitted to the survival data for each cohort (fig. 1). Kolmogorov-Smirnov and χ^2 tests suggested good fit of the model. The shape (c) and the scale (b) parameters of the Weibull distribution were estimated by Linear Regression Method (**Hahn & Shapiro,** 1967). The shape parameter describes the distribution of mortality with age, and both parameters can be used to compare different sets of survivorship data (**Lawless,** 1982). The shape parameters were very similar across locations, especially on citrus (fig. 1), which suggests that the survival-

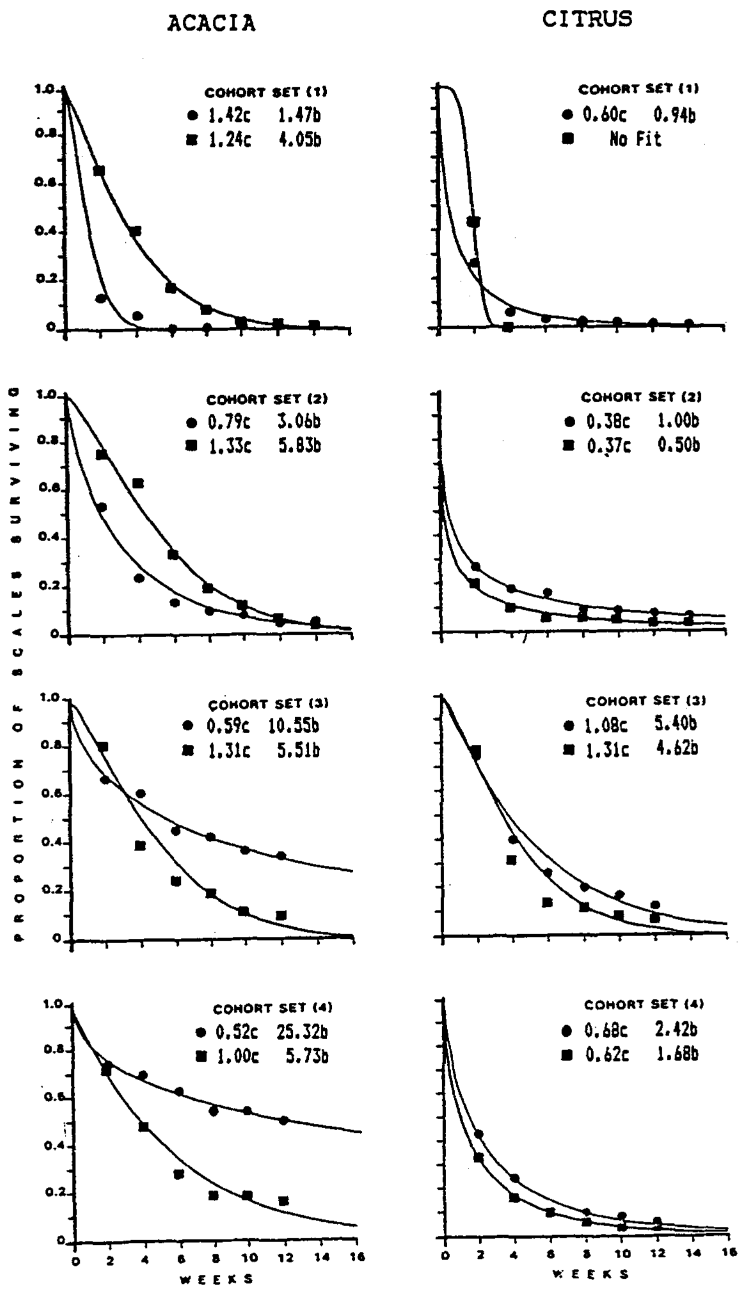

Fig. 1. The proportion of settled crawlers that survived over 16 weeks on *Acacia* and on citrus after each of 4 releases (cohort sets) at location 1 (●) and location 2 (■). The curved lines represent the fitted Weibull curve, with shape parameters (c) and scale parameters (b).

rates of the scales on citrus were not different at the 2 locations. The estimates of the Weibull parameters from the different cohorts could not be compared statistically due to presence of single values only.

Analyses of variance were conducted on arcsine transformed data on percent survival to test the influence of cohort sets, host plant species, and locations on the survival of the scales. Data for the 3rd and 6th fortnight were selected for 2 separate analyses of variance. The plants were "pseudoreplicates" within each "plot" (location) (**Hurlbert,** 1984). Furthermore, the interactions between plant species, locations and cohorts were not significant, so their S.S. were pooled with the S.S. for the plant species × locations × cohorts and the subsequent pooled error M.S. with 10 d.f. was used to test the main effects.

The Anova for the 3rd fortnight (table 1) showed that the effect of host plant species was significant ($P > 0.05$), and that for the 6th fortnight (table 2) showed that only the effect of cohort sets was significant ($P > 0.05$). The effect of location was not significant in both the 3rd and 6th fortnight indicating that the survival of the scales remained unaffected by their either being close to the source of natural enemies (Location 1) or away from it (Location 2). The total effect of all the mortality factors on the scales at both the locations were, therefore not different. However, the survival of scales on *Acacia* was apparently different between the 2 locations in cohort sets 3 and 4 (fig. 1). This is possibly not due to natural enemies (see below).

TABLE 1

Anova on the Arcsine transformation of percentage of the settled scales surviving on the 3rd fortnight after their release on plants

Source	D.F.	S.S.	M.S.S.	F	P
Cohort sets	3	5,167.02	1,722.34	3.25	> 0.05
Plant Species	1	2,907.23	2,907.23	5.49	< 0.05
Locations	1	16.39	16.39	0.03	> 0.05
Experimental Error (*)	10	5,296.64	529.66		
Sampling Error	48	17,843.73	371.74		
Total	63	31,231.02	495.73		

(*) Experimental error used in the estimation of "F" statistic (**Cochran's** Normality test statistic = 0.24; $P > 0.05$).

TABLE 2

Anova on the Arcsine transformation of percentage of the settled scales surviving on the 6th fortnight after their release on plants

Source	D.F.	S.S.	M.S.S.	F.	P.
Cohort sets	3	3,451.94	1,150.65	2.14	< 0.05
Plant Species	1	1,464.69	1,464.69	2.72	> 0.05
Locations	1	105.96	105.96	0.20	> 0.05
Experimental Error (*)	10	5,390.06	539.01		
Sampling Error	48	18,096.11	377.00		
Total	63	28,508.77	452.52		

(*) Experimental error used in the estimation of "F" statistic [**Cochran's** Normality test statistic = 0.16; $P = 0.76$ (approx.)].

IMPACT OF NATURAL ENEMIES

Numbers of natural enemies observed

One adult beetle was seen feeding on scales at Location 1 on citrus on the 1st fortnight (table 3). Eggs and larvae of *Rodolia* were also found at Location 2 on both *Acacia* and citrus on the 1st and 2nd fortnight which indicates that female beetles had discovered the scales within a week of their release. After destroying their parent prey patch, *Rodolia* larvae may have wandered away in search of other prey patches and straved on not finding prey.

TABLE 3

Numbers of different stages of Rodolia cardinalis *observed on patches of scales on plants of* Acacia *and* citrus *at location 1 and 2 during the 1st and 2nd fortnight (F1 & F2) after the release of crawlers. No predators were recorded on other fortnights*

Plant	Patch	Acacia		Citrus	
		F1 4.12.81	F2 18.12.81	F1 4.12.81	F2 18.12.81
*Location 1**					
(4)	2	0	0	1 A	0
Location 2					
(1)	1	0	0	1 @	0
	2	0	1 #	0	0
	3	0	0	2 @	0
(2)	1	1 @	0	1 @	0
	2	0	0	0	0
	3	2 @	0	0	0
(3)	1	0	0	1 @	0
	2	0	0	2 @	0
	3	0	0	3 $	0
(4)	1	0	0	0	0
	2	0	0	0	0
	3	1 @	0	1 @	0
Totals		4	1	11	0

* = Zeroes for all other plant/patch combinations.
A = Adult.
$ = eggs.
@ = 1st instar larva.
# = 2nd instar larva.

Prey patches destroyed

The temporal distribution of the percentage of prey-patches destroyed gradually declined from cohort set 1 to cohort set 3, after which they increased in cohort set 4 (fig. 2). Thus, the total effect of all the mortality factors on patches of scales declined with time from cohort set 1 to 3 and then it increased again. The overlap in the period of activity of the natural enemies (from **Prasad** in prep.) with the duration of the experiment (fig. 3) also declined from cohort set 1 to cohort set 4, which suggests that the decline in the number

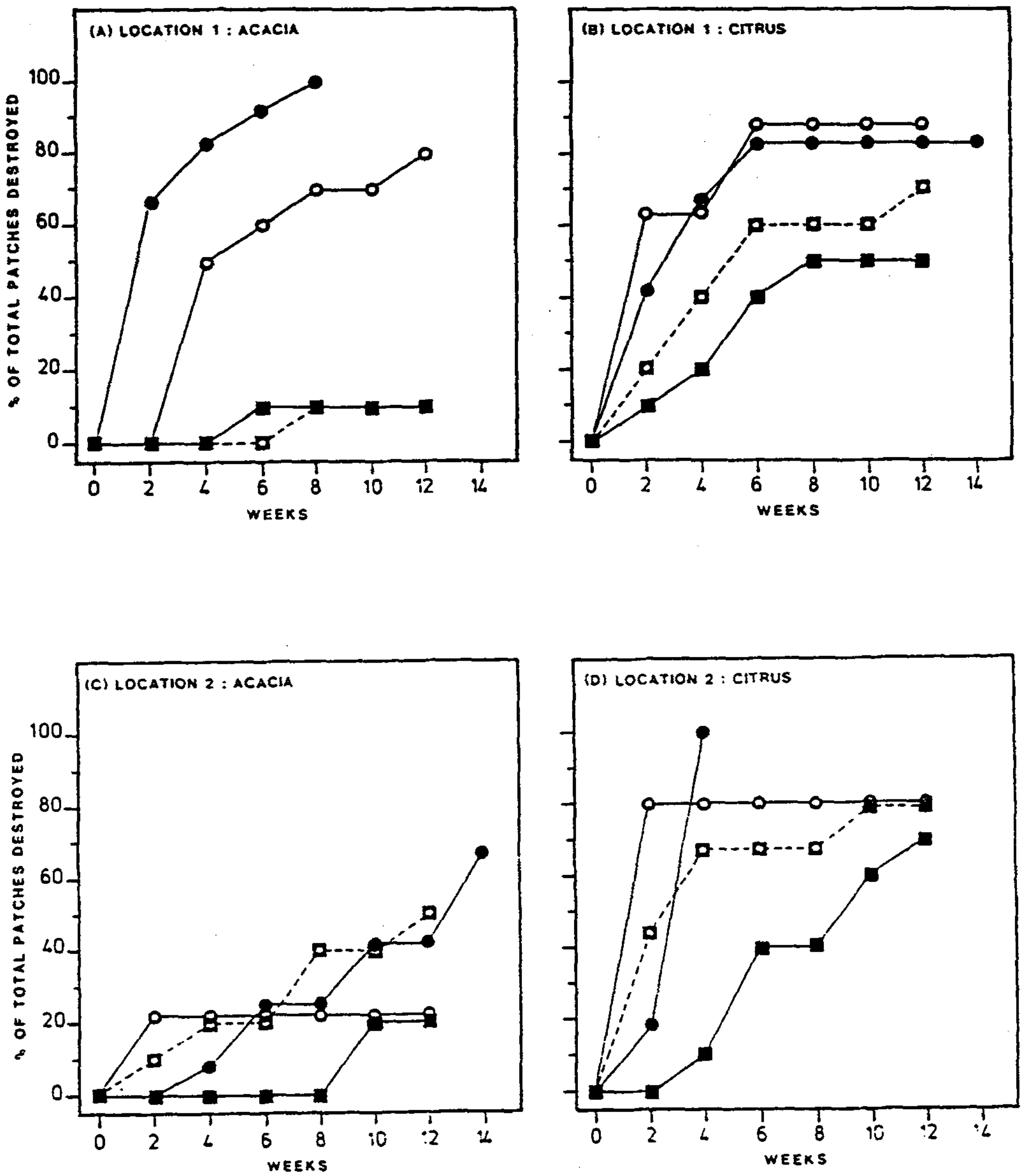

Fig. 2. Percentages of scale patches destroyed on plants of *Acacia* and citrus in 4 cohort sets at location 1 and location 2. Cohort set 1 (●), 2 (○), 3 (■), and 4 (□).

of prey patches destroyed through cohort sets 1 to 3 was, perhaps, due to a decline in the numbers of natural enemies in the field (fig. 3). The analysis of variance also showed that the numbers of scales surviving in the different cohort sets were significantly different, and there was better survival of the scales in the subsequent cohort sets (table 1).

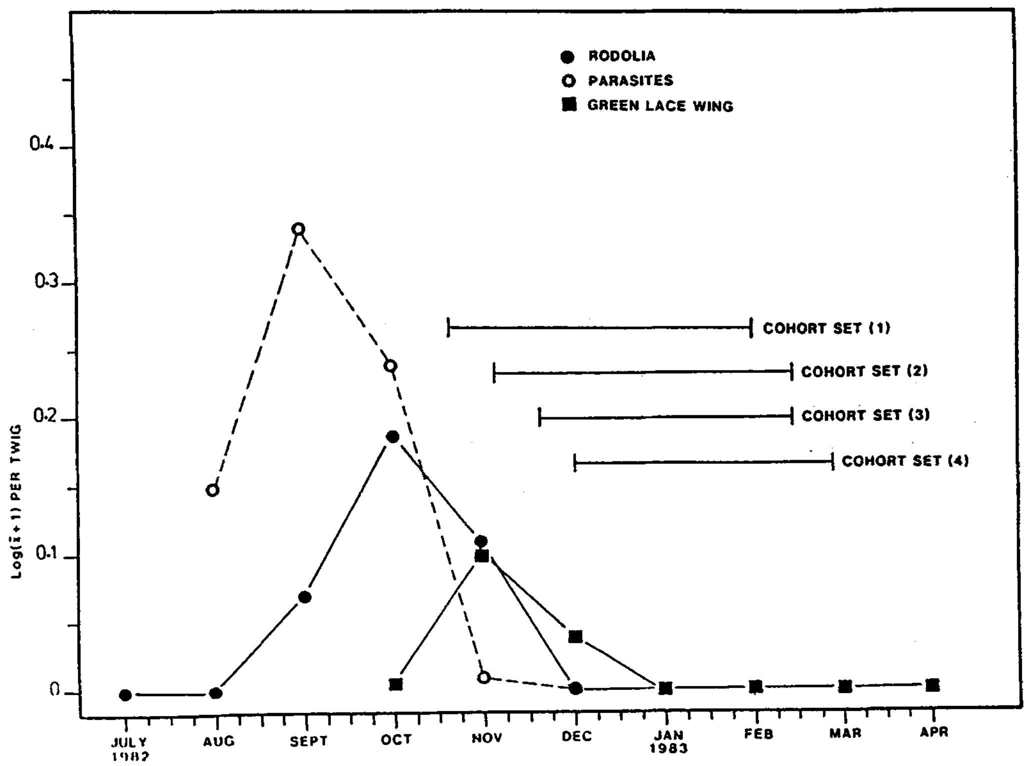

Fig. 3. The numbers of natural enemies estimated from population samples taken at monthly intervals (from **Prasad**, in prep.), plotted in relation to the time taken by the scales in cohort sets 1, 2, 3, and 4 to develop to adults.

DISCUSSION

The data on the survival of the scales and the presence of *Rodolia* on the patches at the 2 locations support the findings of earlier workers (**Quezada & DeBach**, 1973), that the beetle has the potential to search and destroy isolated patches of scales in the field. One may argue that there is only indirect evidence of the influence of natural enemies on the survival of the scales at the 2 locations and other tests are required to conclusively link the two together. To achieve this, the natural enemy exclusion method (**DeBach & Bartlett**, 1964) was incorporated in the design of the experiment, but many caged patches were accidentally destroyed. However, the influence of natural enemies on the survival of the scales throughout the year was conclusively demonstrated by a series of 12 (monthly) natural enemy exclusion experiments (**Prasad**, 1989). Even in the experiment reported here, within a fortnight of the start of the experiment (table 3), *Rodolia* adults had found the prey patches also at the isolated location 2, even when all the scales were in 1st instar. The gradual decline in the numbers of prey patches destroyed in the subsequent cohort sets, which was in tune with the decline in the natural enemy numbers in the field, also suggest the importance of natural enemies in the reduction of scale numbers.

From the results gathered, it is difficult to postulate exactly how the beetle finds patches of prey in the field, and whether it percieves the environment at the hierarchical levels (habitat, patch, and prey) as suggested by **Hassell & Southwood** (1978). Most Coccinellids are believed to search for their prey at random (**Banks,** 1957 ; **Dixon,** 1959 ; **Stubbs,** 1980 ; **Nakamuta,** 1983) to the extent that they have to bump onto their prey to notice them. If this is also true for *Rodolia,* then it is most likely that they will be unable to distinguish between habitat, patch and prey but would randomly land on a tree and move from leaf to leaf till they come across a prey. The beetle would then have to be extremely active and efficient to be able to find isolated patches of prey, especially when the numbers of its prey remain very low (**Prasad,** in prep.), and often spread far apart on bushes and trees.

In South Australia, it is still possible to find isolated bushes and trees completely laden with scales in one season and clean in another. Perhaps a few scales escape predation in one season and start a colony which builds up rapidly in the virtual absence of natural enemies. When such colonies are rediscovered, the scale numbers collapse due to heavy predation, later resulting in either dispersal and/or death of natural enemies themselves. For predators that have the capacity to reduce their prey population at a rate much faster than the latter can grow (e.g. *Rodolia*), the growth and existence of a prey patch is dependent on the duration for which it remains undiscovered. On the other hand, to be effective, the predator must be able to find more and more of these isolated prey colonies before their numbers grow to compensate for the rate of destruction by the predator. This kind of race between the predator and prey is partly responsible for their existing numbers.

Animals that are relatively scarce, are probably scarce because their natural enemies are very efficient. The corollary, that natural enemies which are able to find prey that are relatively scarce must be efficient searchers, should also be true. All other factors being equal, the level at which a prey population exists is thus likely to be a fine balance between the size of prey patch and the average distance between patches, on the one hand, and the efficiency with which the predator (if a key mortality factor) is able to first find these patches, and then prey within these patches, on the other.

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RÉSUMÉ

Découverte de colonies isolées d'*Icerya purchasi* par *Rodolia cardinalis* : Étude en plein air

La découverte de plages isolées de proies par les ennemis naturels de la Cochenille australienne *Icerya purchasi* a été testée en plein air sur plants d'*Acacia baileyana* en pots et sur *Citrus* entre Novembre et Février dans le Sud de l'Australie. La survie des Cochenilles comme adultes dans les colonies au cours des 4 émissions bi-mensuelles n'était pas significativement différente entre l'emplacement 1 (sous un *Acacia* hébergeant les Cochenilles et leurs ennemis naturels) et l'emplacement 2 (500 m environ au-delà de la plante-hôte de la cochenille la plus proche). La distribution temporelle de la mortalité dans les cohortes de Cochenilles était décrite par le modèle de Weibull. La proportion de Cochenilles survivant aux deux emplacements n'était pas différente significativement, ce qui suggérait que l'effet total de tous les facteurs de mortalité sur les Cochenilles était le même aux deux emplacements. Les tendances observées dans la destruction des colonies de proies pourraient être expliquées par la période d'activité des ennemis naturels en plein air. *Rodolia cardinalis* avait découvert les colonies de proies durant la quinzaine de l'émission des larves mobiles. Les résultats justifient les rapports antérieurs que *Rodolia* peut trouver et détruire les colonies isolées de Cochenilles.

MOTS CLÉS : *Icerya purchasi, Rodolia cardinalis,* recherche, colonies de proies, modèle de Weibull.

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