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CONSERVATION OF TWO PREDATOR SPECIES FOR BIOLOGICAL CONTROL OF *CHRYSOPHTHARTA BIMACULATA* (*COL. : CHRYSOMELIDAE*) IN TASMANIAN FORESTS

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Chrysophtharta bimaculata (Olivier) (Coleoptera : Chrysomelidae) is a major defoliator of regeneration eucalypt trees in Tasmania causing a significant reduction in height and diameter increment of trees which reduces wood volume per hectare. A study to conserve and enhance the efficiency of coccinellid species chiefly *Cleobora mellyi* (Mulsant) (Coleoptera : Coccinellidae), and the cantharid, *Chauliognathus pulchellus* (Macleay) (Coleoptera : Cantharidae), for the biological control of *C. bimaculata* was conducted in young regeneration forests in southern Tasmania from 1991-92. Cantharid adults and coccinellid adults and larvae feed on *C. bimaculata* eggs and, to a lesser extent, young larvae. The study found that coccinellids were more active throughout the egg and early (1st and 2nd) stage of *C. bimaculata*. The cantharid, however was active only during the egg stage of the prey and then disappeared from the plantation. The coccinellids were therefore the most useful predators, but their population declined when the prey reached the 3rd and 4th stages. As shortage of food may account for this decline, supplementary food was provided in the form of sucrose sprays or sugar granules at a feeding station. This resulted in the retention of both predators and particularly the coccinellids and enhanced their efficacy.

KEY-WORDS : biological control, cantharid, supplementary food, coccinellids.

Eucalypt plantation silviculture in Australia and, in particular, Tasmania is being developed as a means of relieving pressure on native forests. Defoliation of nine year old *Eucalyptus regnans* (Muell) for example, resulted in a loss over two years of 22 m^3/ha or \$275/ha (De Little, 1989). Such damage, when repeated and compounded over time, represents a significant loss to the forestry industry.

In Tasmania, the adults and larvae of chrysomelid beetle, *Chrysophtharta bimaculata* (Olivier), (Coleoptera : Chrysomelidae) is one of the prominent defoliators of *E. regnans, E. obliqua* (Muell) and *E. delegatensis* (Baker) forests and exotic *E. nitens* (Muell) plantations (Greaves, 1966). The effects of defoliation can results in a significant reduction of height and diameter increment and, in turn wood volume per hectare.

Currently, outbreaks are either uncontrolled with consequent growth loss, or they are sprayed by either the biological insecticide Novodor (*Bacillus thuringiensis*) which has low

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persistence, or chemical insecticides. Applications are costly and chemical insecticides have potentially adverse environmental effects, including destroying the beetles natural enemies.

A control program that minimises pesticide use through integration with other forms of control, especially predation by natural enemies of *C. bimaculata,* is therefore a desirable alternative. This requires an understanding of the predator/prey systems and how they operate under natural conditions in the plantation ecosystem.

De Little (1979) studied the life system of *C. bimaculata* and identified coccinellids, mostly *Cleobora mellyi* (Mulsant) (Coleoptera : Coccinellidae), and the cantharid *Chauliognathus pulchellus* (Macleay) (Coleptera : Cantharidae), as the main predators of the beetle. He reported that predator numbers declined along with prey density, but did not indicate at which stage in the life cycle of the prey this decline occurred. It was possible that predator numbers declined at a specific stage in the life cycle of the prey when they no longer served as food for the predators. If there was such a relationship, at what stage in the prey's life cycle does decline in predator numbers occur and how could the decline in predator numbers be prevented during that point in time to enhance their efficiency. The aim of this study was to identify those stages in the life cycle of the prey where predator numbers decline and to determine methods of conserving and enhancing the efficacy of these predators.

MATERIALS AND METHODS

STUDY AREAS

Prior to beetle emergence in the spring, six sites containing aerially sown 3 year old *E. regnans* regeneration were chosen in southern Tasmania of a size which allowed a 1 km transect to be established for subsequent population census purposes. Two of these, Riawunna Road (44°50' S, and 146°55' E, with an altitude of 250 m above sea level and mean daily temperature of 14.9 °C) and Peak Rivulet Road (44°40' S, 146°50' E, with an altitude of 125 m above sea level and mean daily temperature of 17.2 °C) were significantly attacked and selected for intensive sampling in 1991/92. Temperature values were obtained each week at each site using. Maximum and Minimum thermometers (Brannan thermometers, Cumberland) throughout the study.

POPULATION ASSESSMENTS

Sampling unit

The sample unit consisted of current season's growth. This was distinguished from the other shoots by its lighter reddish colour and thinner texture (De Little *et al.,* 1990). The sample unit comprised the distal 0.3 m of lateral branches of individual trees (De Little, 1979).

Sampling system

Following hibernation *C. bimaculata* have a dispersal generation which initially attack, feed and deposit eggs on host trees which are in the direction of movement as they move across a plantation.

A transect was marked across a feeding and oviposition front at each study site and a shoot sample randomly selected from the outer branches of each of 40 infested trees.

Numbers of *C. bimaculata* stages (including adults) were recorded at weekly intervals by visual counts from November, 5^{th} 1991 to April, 13^{th} 1992 at Riawunna Road and November, 11^{th} 1991 to March, 19^{th} 1992 at Peak Rivulet Road. Four emergence traps were established in each of the two sites. The traps were inverted circular litter traps fitted with Sarlon mesh. Ten pupae were placed in each trap (0.45 m diameter × 0.10 m high). Life tables for the insect were constructed from egg to adult following the method of Varley & Gradwell (1960). At the end of a given generation, the sum of the absolute numbers of individuals entering a stage was divided by the number of lateral shoots sampled from 40 trees in that generation to express the density of each stage as numbers per shoot per generation. All density estimates were converted to $\log_{10}$ values to calculate specific stage mortalities (k_i's). The k_i value was the difference between the $\log_{10}$ density of two successive stages. The successive mortalities were : k_e : egg mortality ; k_1 to k_4 : mortality of first to fourth stage larvae respectively. Total generation mortality K was calculated by summation of all k_i's within a generation.

Populations of *C. mellyi* and *C. pulchellus* were assessed visually on each of the 40 trees at weekly intervals and records taken on the numbers of coccinellid adults and larvae, and cantharid adults per tree. The numbers of *C. bimaculata* eggs, 1-2^{nd}, and 3-4^{th} stages per shoot were compared with those of coccinellid (adults and larvae) and also *C. pulchellus* adults per tree to determine changes in abundance of the predators in relationship to the prey.

RESPONSE OF PREDATORS TO SUPPLEMENTARY FOOD SUPPLY

Effect of feeding station

The study was conducted at the Peak Rivulet Road site during the 1991–92 season. A weather proof feeding station, in the form of an elevated, roofed platform was devised and used to provide food in the form of granular sugar to the predators. The cage consisted of a wooden frame measuring 50 × 50 cm covered with a curved roof of a clear weather proof plastic (Handiglaze clear flexible sheet) to fit the same dimension. The cage was fixed onto a wooden pole of height 1.80 m and diameter 1.25 mm secured firmly in the soil. The food source was provided on a small plastic tray placed under the roof. In the forest the gathering of three or four individuals of either of the predator species in presence of food may produce aggregation of that species. To aggregate the predators in the feeding station therefore, four adults of each of the predator species, *C. mellyi* and *C. pulchellus,* were starved for 24 h and then introduced into the station food tray. Food was supplied continuously to the predators until the plantation was attacked by *C. bimaculata* overwintering adults when feeding was discontinued.

The effect of the feeding station on predator numbers was assessed by randomly selecting 20 infested trees within 5-10 m of the feeding station, then 20, 40, 60, 80, 100, 500 and 1,000 m away from the station at weekly intervals and numbers of coccinellid larvae, adults and cantharid adults were recorded per tree. Egg predation was assessed from 20 saplings (1-3 m high) from each of the 20 trees at weekly intervals and numbers of *C. bimaculata* eggs (predated and unpredated) were recorded at each sampling date.

Analysis of variance was used to analyse the data and Duncan's multiple range test to compare the means.

Effect of sucrose spray

The experiment was conducted in the *E. regnans* and *E. obliqua* regeneration plantation at Riawunna Road in summer 1992 when the *C. bimaculata* population at the site consisted mainly of 3rd and 4th stages. The experimental design was a randomised complete block with five replications of two treatments. Each replicate was 10 × 10 m and contained 20 trees. One treatment was sprayed with 25 % sucrose solution (Suwanbutr, 1990) using a knapsack sprayer delivering 420 ml solution per minute to provide food for the predators. The second was left unsprayed to assess the effect of food shortage. Spraying was done at weekly intervals for 11 weeks.

The effect of the food spray on coccinellids and cantharids was assessed at weekly intervals by randomly selecting 40 trees from each treatment (8 trees/replicate) and records were taken of the numbers of larvae (in the case of coccinellids) and adults. Analysis of variance was used to analyse the data and Duncan's multiple range test to compare the means of numbers on both sucrose sprayed and an unsprayed plots.

TABLE 1

Life tables for C. bimaculata *at Raiwena and Peak Rivulet study sites, 1991-92 showing k - values of successive stages calculated by the Varley and Gradwell (1960) method*

Study sites	Riawenna Road	Peak Rivulet Road	
Generations	1	1	2
No. of eggs per shoot	356.80	541.000	332.800
k (e)	0.382	0.590	0.370
1st stage larvae/shoot	147.800	139.000	141.600
k (1)	0.014	0.178	0.171
2nd stage larvae/shoot	143.200	92.200	95.600
k (2)	0.282	0.246	0.730
3rd stage larvae/shoot	74.800	52.400	17.800
k (3)	0.111	0.728	1.104
4th stage larvae/shoot	58.000	9.800	1.400
k (4)	1.064	0.690	0.146
Pupa	—	—	—
Adult	5.000	2.000	0
Total generation mortality (K)	1.853	2.432	2.521

RESULTS

POPULATION STUDIES

Trends in *C. bimaculata* oviposition obtained in this study (figs. 1 and 2) show two distinct oviposition peaks at both study sites. At the Riawunna Road site, 29 days (i.e. 4.14 weeks) separated the two egg peaks (fig. 1). In contrast 64 days (i.e. 9.14 weeks) separated the two egg peaks at Peak Rivulet Road (fig. 2). The emergence traps set up at both study sites caught emerging adults at Peak Rivulet Road two weeks before the second egg peak was recorded but at Riawunna Road the second egg peak was recorded long before the emergence traps caught adults. Table 1 summarizes the life tables of *C. bimaculata* for one generation at Riawunna Road site and two at Peak Rivulet Road. The total generation mortality in generation 1 was higher at Peak Rivulet than at Riawunna Road even though predator numbers at the latter was lower. The result was higher adult numbers

(5.0 per shoot) as Riawunna Road and 2.0 at Peak Rivulet Road. The mean daily temperature at Peak Rivulet Road was 17.9 °C and that at Riawunna was 14.9 °C. The difference in temperature may explain the variations in generation mortalities at the two sites. The number of eggs per shoot at Peak Rivulet Road was higher in generation 1 than in 2. However the total generation mortality was not significantly different ($P > 0.05$).

Densities of *C. bimaculata* population over time were compared with those of its predators and are given for Riawunna Road (fig. 1) and Peak Rivulet Road (fig. 2). Coccinellids, mostly *C. mellyi* adults and larvae, and adults of *C. pulchellus* fed on *C. bimaculata* eggs and to a lesser extent on larvae. The results indicated that the dates of occurrence of the coccinellids (fig. 1) overlapped with the egg and 1^{st} and 2^{nd} stages of *C. bimaculata* at Riawunna Road but the *C. pulchellus* population (fig. 1) did not overlap with any of the stages of the prey at this site indicating that coccinellids were the major predators at this site. The cantharids were abundant at this site in November but disappeared in December three weeks before the *C. bimaculata* new population attacked the plantation (fig. 1). The coccinellid (both adults and larvae) population at Riawunna Road declined rapidly from 12.0 per tree when the prey population was in the 1^{st} and 2^{nd} stage of its life cycle to 2.0 per tree (83.3 % reduction) when the prey reached the 3^{rd} and 4^{th} larvae (fig. 1).

The results at Peak Rivulet Road are shown in fig. 2. The coccinellids again were the important predators of *C. bimaculata* eggs and 1^{st} and 2^{nd} stage larvae in generations 1 and 2 (fig. 2). There was a 75 per cent reduction of the coccinellid population at Peak Rivulet Road as the prey population developed through to 3^{rd} and 4^{th} stage larvae. In contrast to the situation at Riawunna Road study site, *C. pulchellus* was involved in the predation of *C. bimaculata* eggs in generation 1 but not in 2 because the cantharids had disappeared from the plantation six weeks before the prey's second egg peak was recorded (fig. 2). In general the coccinellid population at Riawunna Road was significantly higher ($P < 0.05$) than at Peak Rivulet Road.

EFFECT OF FEEDING STATION

Aggregation of the predators inside the feeding station was successful with the cantharids but not with the coccinellids (fig. 1). However, coccinellid adults were seen flying in and out of the station to feed. Besides these two insects, European wasps, *Vespula germanica* (F.) and honey bees *Apis mellifera* (L.) were also found in the station feeding on the sugar. This required frequent replacement of sugar in the station. Although abundant European wasps and bees did not aggregate in large numbers and take over the entire station.

The effect of providing supplementary food in a feeding station on predator numbers in relation to predation of *C. bimaculata* (eggs and larvae) is given for two generations in figs. 3 and 4. Predation of *C. bimaculata* eggs in generation 1 was highest (38 per cent) just around the feeding station (0–1 m away from the station) (fig. 3). This was followed by 22.5 and 20 per cent egg predation at 20 and 40 m respectively away from the feeding station. The lowest egg predation of 10 per cent was recorded at 1 000 m from the feeding station. Food was provided in the feeding station only in generation 1 to enable predators to spread thereafter thus egg predation and adults in generation 2 did not follow the same trend as in (fig. 3). Percentage egg predation and coccinellid numbers in generation 2 were highest 80 m from the feeding station (fig. 3). A significant positive relationship ($r^2 = 0.96$ for cantharids and $r^2 = 0.97$ for coccinellids) was established between percentage egg predation and predator numbers in generation 1 at various distances away from the feeding station (fig. 4a and b). The relationship between egg predation and coccinellid numbers in generation 2 though positive, $r^2 = 0.46$, explained less of the variability than in generation 1 (fig. 4c).

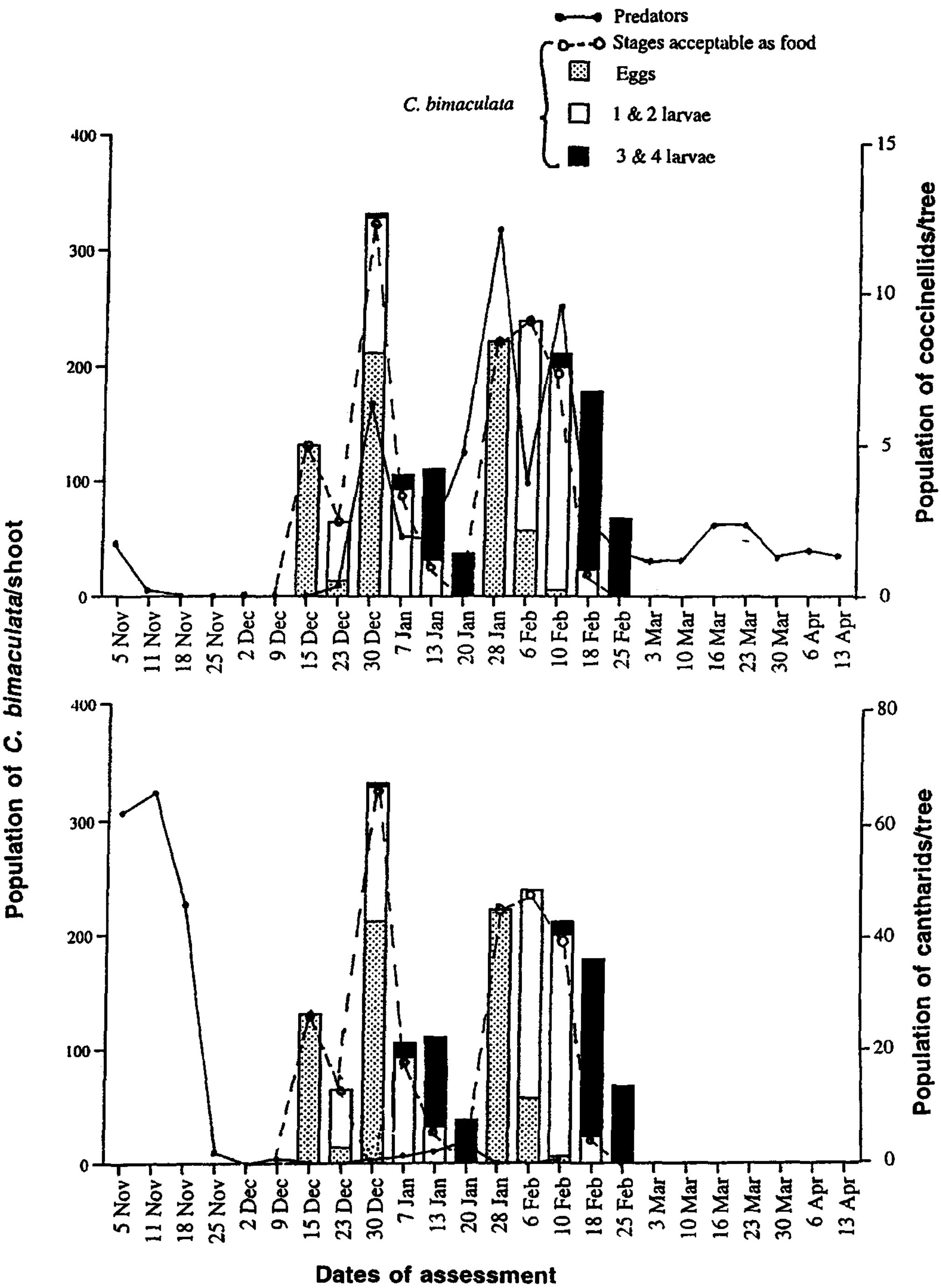

Fig. 1. Densities of *Chrysophtharta bimaculata* population over time compared with those of its predators (viz coccinellids, mostly *Cleobora mellyi* and the cantharid, *Chauliognathus pulchellus*) at Riawunna Road, South Tasmania, 1991–92.

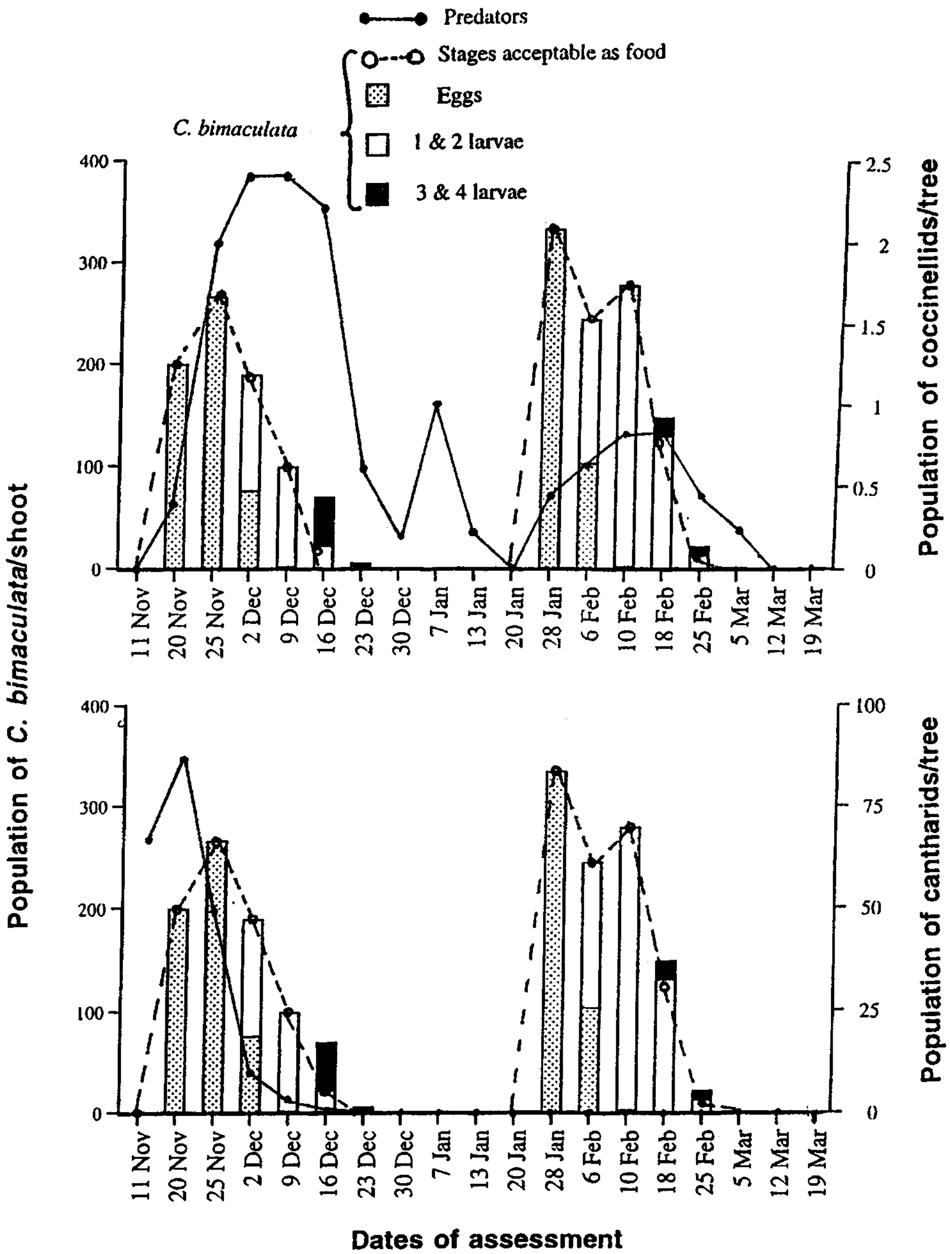

Fig. 2. Densities of *Chrysophtharta bimaculata* population over time compared with those of its predators (viz coccinellids, mostly *Cleobora mellyi* and the cantharid, *Chauliognathus pulchellus*) at Peak Rivulet Tasmania, 1991–92.

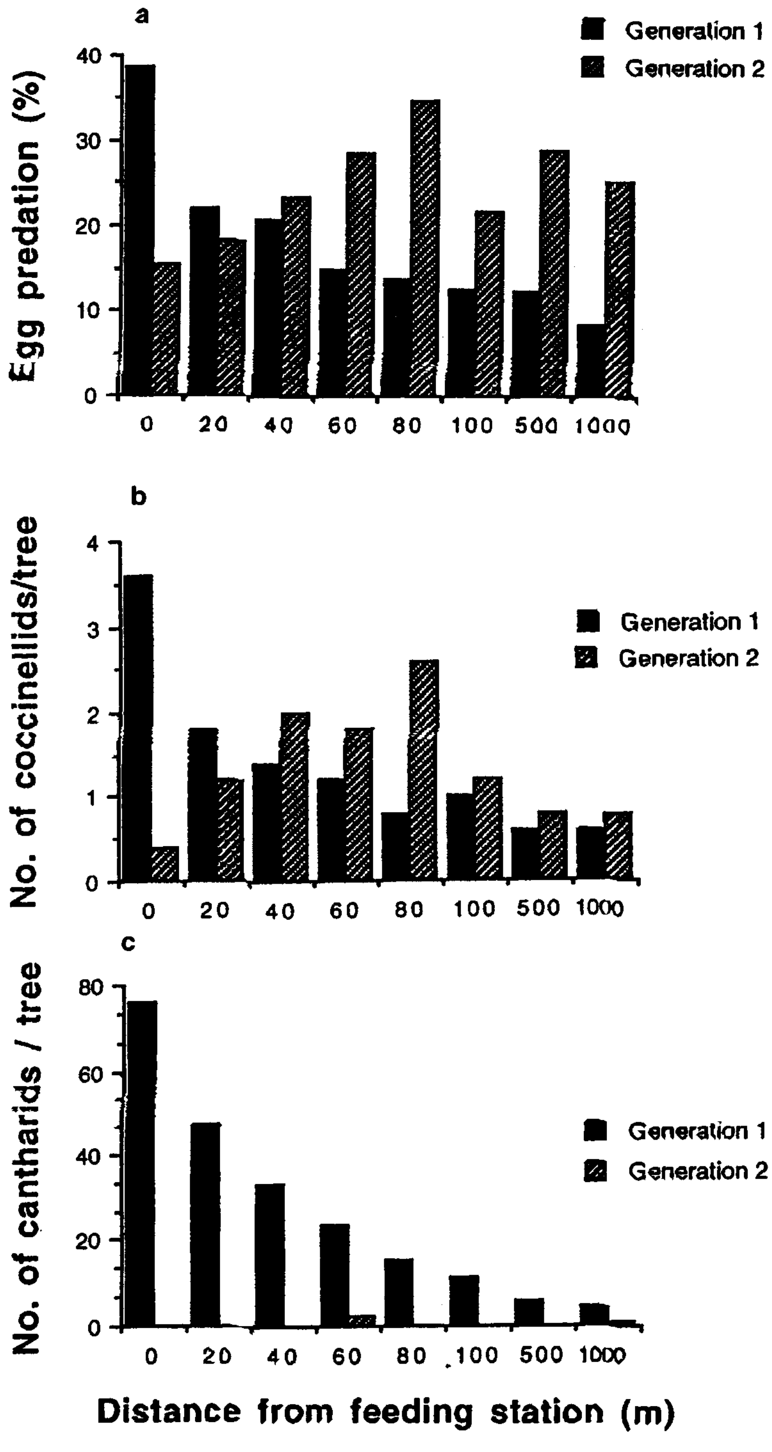

Fig. 3. Effect of supplementary food provided in a feeding station on predation of *Chrysophtharta bimaculata* eggs (a), and numbers of coccinellids, mostly *Cleobora mellyi* (b), and *Chauliognathus pulchellus* (c) at Peak Rivulet Road, 1991–92.

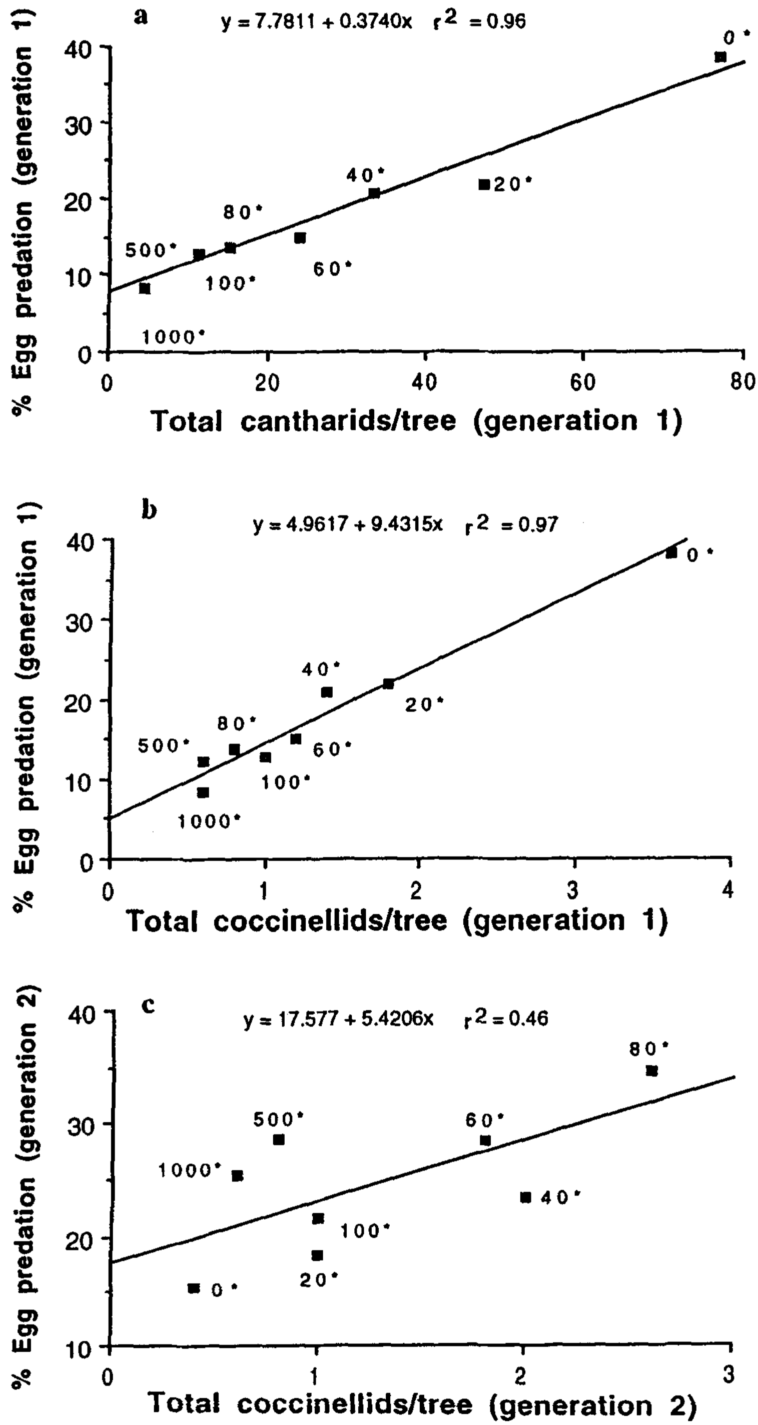

Fig. 4. Relationship between percentage predation of *Chrysophtharta bimaculata* eggs in two consecutive generations and numbers of *Chauliognathus pulchellus* (a), and *Cleobora mellyi* (b, c) taken at various distances from a feeding station.

* Indicates distance in metres from feeding station.

EFFECT OF SUCROSE SOLUTION SPRAY

Fig. 5 summarizes the effect of spraying trees each week with 25 % sucrose solution on coccinellid and cantharid numbers. The cumulative total number of coccinellid adults per tree from the sucrose sprayed plots was significantly higher ($P < 0.001$) than those from the unsprayed (fig. 5a). However the numbers of coccinellid larvae recorded from the sprayed and unsprayed plot did not differ significantly ($P < 0.05$) (fig. 5a). The cumulative total number of *C. pulchellus* per tree in sucrose sprayed plots was also significantly higher ($P < 0.05$) than those in unsprayed plot (fig. 5b). *C. pulchellus* adults were not recorded in unsprayed plots after March 3rd whereas in sprayed plots they remained until March 20th (fig. 5b).

DISCUSSION

This study identified two distinct *C. bimaculata* generations at Peak Rivulet Road but only one at Riawunna Road. The two oviposition peaks during the spring-summer at Peak Rivulet Road represented eggs laid by females from two different generations of *C. bimaculata* adults but the two egg peaks at Riawunna Road were laid by females of the same generation. The 64 days between the two egg peaks at Peak Rivulet Road (fig. 2) was sufficient for the larvae of the first egg peak to complete their life cycle and become sexually mature and oviposit (de Little, 1979). In addition, the first generation *C. bimaculata* adults were recorded in emergence traps two weeks before the second egg peak and mating was observed in the plantation prior to the oviposition of the second egg peak. However the 29 day interval between the first and second oviposition peaks at Riawunna Road study site was not sufficiently long enough for adults from the first oviposition peak to have become sexually mature before the second peak occurred (de Little, 1979). The emergence traps established at Riawunna Road first contained adults from the first egg peak some four weeks after the second oviposition had occurred.

The results support the findings of Greaves (1966) but not those of de Little (1979) who considered *C. bimaculata* to be strictly univoltine. Carne (1966) reported that *Paropsis atomaria* may have more than a single generation per year in some seasons. The number of generations that *C. bimaculata* will complete per annum will possibly depend, apart from environmental conditions e.g. temperature, humidity, soil and host tree conditions, on the time when the host trees are attacked by the overwintered generation. If trees are attacked early in the season (i.e. early spring) and if prevailing environmental and host tree conditions are good, the species may complete two distinct generations in a year. Though the plantation at Riawunna Road was attacked 6 days before Peak Rivulet Road the insect had only one generation compared with two in the latter. In this situation environmental factors, especially temperature, might have played a significant role because Riawunna Road site is located at a much higher altitude than the Peak Rivulet site and the mean daily temperature was 14.9 °C compared with 17.2 °C at Peak Rivulet Road during the study period. As well as altitude Peak Rivulet has an easterly aspect compared with the northern aspect of Riawunna Road.

The results of the study also indicated that higher numbers of coccinellids and cantharids resulted in higher predation of *C. bimaculata.* The benefits of these two predators as potential biological control agents of *C. bimaculata* have not been fully utilized but this study has identified food shortage in the forest to be a factor that possibly limits predator numbers and efficiency. Most coccinellids adults and cantharids may have moved out of the forest during the period in search of oviposition and feeding sites when the host larvae became too large to be attacked. This may explain the 83 and 75 per cent reduction in

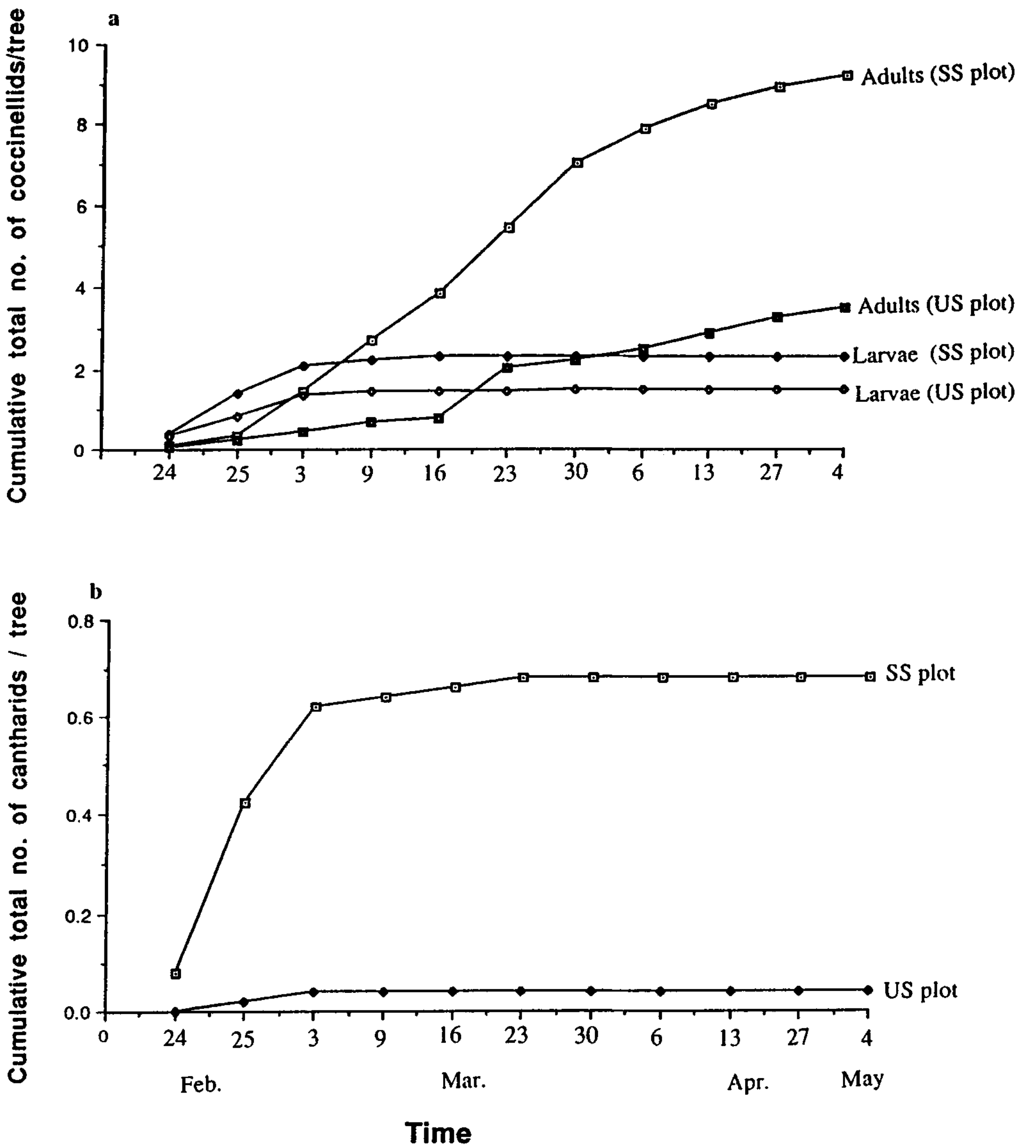

Fig. 5. Abundance of *Cleobora mellyi* (a) and *Chaulignathus pulchellus* (b) on sucrose sprayed (SS) and unsprayed (US) plots at Riawunna Road.

numbers of predator adults and larvae at Riawunna and Peak Rivulet Road respectively at peak densities of *C. bimaculata* late stage larvae.

The results of providing supplementary food in the form of either sucrose spray or granules indicated an increased number and efficiency of coccinellids and cantharids. Hocking (1967) found that the efficiency of *Rhyssa persuasoria* (L), an ichneumonid parasitoid of *Sirex noctilio* (F), was increased when females had access to carbohydrate in the form of sugar or honey. Ewert & Chiang (1966) demonstrated that sucrose sprays on corn plants concentrated coccinellid adults, and Schiefelbein & Chiang (1966) found that a 10 % sucrose solution significantly increased the number of coccinellid adults. In general sucrose solution and also artificial honeydew has been used successfully to concentrate adult lady beetles and lacewings in treated crops (Hagen *et al.*, 1971 ; Calson & Chiang, 1973 ; Ben Saad & Bishop, 1976a,b ; Suwanbutr, 1990). In this study 25 % sucrose spray concentrated coccinellid adults on trees. However, sugar granules placed in feeding stations at both study sites concentrated the cantharid, *C. pulchellus* but not coccinellids. It is possible that the high numbers of the cantharids at the station deterred the coccinellids from aggregating in the same feeding station. It is therefore suggested that future studies should attempt to aggregate different predators at different feeding stations. The effect of sugar sprays is limited by rainfall thus appropriate formulations have to be developed. Another potential problem of feeding stations was their invasion by European wasps and honey bees which rapidly consumed all the food in the station which therefore had to be replaced regularly. Their presence in high numbers could prevent beneficial insects from aggregating in the station. This could be prevented by covering the station with a grid or net of a size which prevents entry of wasps and bees but allows entry of coccinellids and/or cantharids.

In conclusion this investigation provides an additional example of the importance of conserving natural enemies in a crop system especially those systems directed towards monoculture. Provision of supplementary food in the form of sucrose sprays to trees and sugar granules in feeding stations sustained diversity and contributed to stability by retaining numbers of important predators.

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RÉSUMÉ

Conservation de deux espèces prédatrices pour la lutte biologique contre *Chrysophtharta bimaculata* (Col. : Chrysomelidae) dans les forêts de Tasmanie.

Chrysophtharta bimaculata Olivier (Col. Chrysomelidae) est un défoliateur important des régénérations d'eucalyptus en Tasmanie : il cause une forte réduction de l'accroissement en hauteur et en diamètre des arbres, réduisant ainsi le cubage de bois produit à l'hectare. En 1991 et 1992, une étude pour conserver et accroître l'efficacité de coccinelles, principalement *Cleobora mellyi* Mulsant (Col. : Coccinellidae), et d'une cantharide, *Chauliognathus pulchellus* (Macleay) (Col. : Cantharidae) comme agents de lutte biologique, a été faite dans les jeunes peuplements forestiers de Tasmanie du sud pour la lutte biologique de *C. bimaculata.* Les cantharides adultes et les adultes et larves de coccinelles se nourrissent des œufs de *C. bimaculata* et à un degré moindre, des jeunes larves. L'activité des coccinelles était la plus importante pendant le stade œuf et les premier et deuxième stades larvaires de *C. bimaculata.* Les cantharides n'étaient actives que durant le stade œuf de la proie puis disparaissaient de la parcelle. Les coccinelles étaient donc les prédateurs les plus utiles, mais leur population diminuait lorsque la proie atteignait les 3e et 4e stades larvaires. Comme le manque de nourriture pouvait être à l'origine de leur diminution, un complément de nourriture a été fourni sous forme de pulvérisation de saccharose ou de granules de sucre déposées à une station de nourrissage. Ceci a provoqué le maintien des populations des deux prédateurs, particulièrement des coccinelles, et a augmenté leur efficacité.

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