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Potentials and prospects of the Integrated Pest Management of *Ceroplastes destructor* Newstead (Hemiptera: Coccidae) in citrus orchards in South Africa

Abstract - The white wax scale, *Ceroplastes destructor* (Hemiptera: Coccidae), has become a common pest in some citrus orchards in the Western and Eastern Cape Provinces of South Africa over the past six to eight years. A study over three consecutive years on the biology of *C. destructor* and the seasonal abundance of its natural enemies indicated that there is a temporal synchrony between the population densities of the susceptible scale stages and some of its natural enemies, showing that the scale-natural enemy association contained a density-dependent regulatory mechanism. Parasitoids and predators acted as density-dependent mortality factors during the pre-ovipositing female stage. Bioassays of some of the insecticides commonly used for the control of red scale and false codling moth indicated that most are highly detrimental to one of the major parasitoids of *C. destructor*. This could represent one of the reasons for the increase in the distribution and densities of *C. destructor* over the past decade. Our study has also indicated that the sex ratio of *Aprostocetus* (= *Tetrastichus*) *ceroplastae* (Girault), a dominant primary endo-parasitoid of *C. destructor*, reared from early third-instar was male-biased while that of parasitoids reared from mature adult female was slightly female-biased. The implication of this for a possible mass rearing of *A. ceroplastae* and biocontrol of *C. destructor* is discussed.

Key words: *Aprostocetus ceroplastae*, *Ceroplastes destructor*, *Citrus reticulata*, density-dependence, parasitoids, predators

INTRODUCTION

The white wax scale, *Ceroplastes destructor* Newstead, is a univoltine and polyphagous species with three nymphal instars and an adult female (Cilliers, 1967; Wakgari & Giliomee, 1998; 2000). Males are unknown and reproduction is by parthenogenesis (Qin & Gullan, 1994). Wakgari & Giliomee (1998; 2000) have discussed its phenology in South Africa. Based on the localities where its type species was originally designated, *C. destructor* is believed to have originated in Africa (Zeck, 1934; De Lotto, 1965; Snowball, 1969; Smith, 1970). Indeed, a cladistic analysis of

the phylogeny of the scale insects by Qin *et al.* (1994) predicted that *C. destructor* is a native of the Afrotropical region. *Ceroplastes destructor* is now a cosmopolitan species.

Ceroplastes destructor has only been considered as a minor indigenous pest of citrus and deciduous fruit orchards in South Africa in the past (Cilliers, 1967). A complex of natural enemies has kept its population densities at a non-economic level in South African orchards for a long time (Cilliers, 1967). Cilliers (1967) and Snowball (1969) have recorded more than 21 hymenopteran parasitoids attacking *C. destructor* in South Africa. However, since 1994, the population density of *C. destructor* has surged in the Western Cape Province of South Africa in certain *Citrus reticulata* (Blanco) orchards probably because of changes in citricultural and/or pest control practices that had taken place in the recent past. Wakgari (2001) reported the seasonal dynamics and the effectiveness of natural enemies in regulating populations of *C. destructor* in South African orchards. In this study, the present species composition of natural enemies of *C. destructor*, their temporal variation in abundance and their susceptibility to insecticides were assessed in order to contribute towards more rational orchard spraying schedules and development of an effective integrated management system for *C. destructor*.

MATERIALS AND METHODS

Sampling

Sampling was carried out in four commercial *C. reticulata* orchards in the Western Cape Province from June 1997 to January 2000. Twenty trees in two rows of 2.5m apart were marked from each of the study orchards, subject to the presence of an identifiable number of scales. Each sample tree was about 4m apart. The experimental rows and two guard rows from the facing rows of the experimental trees were not sprayed with any insecticides during the study period. Triflumuron (Alsystin[®]) is usually applied twice in December against false codling moth (*Cryptophlebia leucotreta* (Meyrick)), and parathion and ultracide are applied once in August against red scale (*Aonidiella aurantii* (Maskell)). A corrective spray against red scale is also applied in October. The sampling population included all developmental stages: three nymphal stages designated as L1, L2 and L3; pre-ovipositing females (POF) and ovipositing females (OF). Sampling units were comprised of 4-6 infested twigs, 20 cm long and 3-5 mm in diameter, each bearing at least 10 leaves, from each sample tree. The twigs with their leaves were sampled at bimonthly intervals and taken to the laboratory for population census and parasitoid rearing.

Parasitoid rearing

Two methods were employed to rear parasitoids from field-sampled materials. Firstly, twigs infested with each of susceptible scale stages (L3 and POF) were separately enclosed in emergence boxes of various dimensions in an incubator at 27

°C and 60 ± 5% RH. The boxes were made up of corrugated carton and were similar to those described by Bedford (1968). In the second method, scales from infested twigs were overturned with needles and sorted into stage categories before placing each stage separately into glass tubes of varying sizes. The tubes were then covered with cotton wool and maintained in an incubator at the temperature and RH indicated above. The emerging adult parasitoids were recorded daily and some stored in 70% ethyl alcohol until identification and others provided with bee honey until used for chemical bioassays. Predators were collected directly from the field using forceps or sometimes hand picked and identified in the laboratory.

Effects of scale stages on body sizes of Aprostocetus ceroplastae (Girault)

Sample units bearing early third-instar nymphs, late third-instar nymphs, young and mature adult female stages were separately enclosed in emergence boxes or tubes and emerging parasitoids were separately stored in 70% ethyl alcohol. The body length of *A. ceroplastae*, reared from the different host stages at different times of the year, was measured under a stereomicroscope equipped with a micrometer eyepiece. *Aprostocetus ceroplastae* was used as an indicator species because of its predominance. It was sexed based on descriptions given by Ben-Dov (1972) and Prinsloo (1984). Factorial analysis of variance was used to examine the effects of host stages, sampling periods and parasitoid sexes on body length of *A. ceroplastae*.

Temporal variations in mortality and density-dependence

Mortality from parasitism and disease was determined by dissecting about 100-250 randomly selected scales susceptible to parasitism and disease, i.e. third-instar nymphs (LIII) and pre-ovipositing females (POF) (young and mature females), under a stereomicroscope at bimonthly intervals. Because of their agility, most predators are not amenable to easy collection. However, they usually leave behind signs of predation in the form of host remains and/or body punctures on the dorsum of their hosts. Percentage predation was thus determined from direct counts of the white remains of the spiracular bands, and scale covers with chewed edges or ragged holes in them in each sample unit at bimonthly intervals. Parasitoids or predators attacked no other developmental stages other than the third-instar and adult female. The density dependency of parasitism, predation and disease was determined by correlating the average number of the bimonthly samples of scales that died of each mortality factor with the total number of scale population on which they acted (Neilson & Morris, 1964; Varley & Gradwell, 1970; Varley *et al.*, 1973).

Bioassay of insecticides against Ceroplastes destructor and Aprostocetus ceroplastae

A contact bioassay of a dry film of insecticides (Table 1) deposited on glass plates was conducted in a series of aluminium cages to determine their possible adverse effects on *A. ceroplastae* in the laboratory (see Wakgari & Giliomee, 2001 for details).

Table 1 - Insecticides tested against adult *Aprostocetus ceroplastae* in the Western Cape, South Africa.

Active Ingredient	T. name	Formu.	Dose 100 l H ₂ O
Methidathion	Ultracide	420 g/l EC	150 ml
Methomyl +	Lannate	200 g/l SL	120 ml
Mineral oil (heavy narrow range)	BP Cipron	835 g/l EC	300 ml
Methyl-parathion	Penncap-M	240 g/l SC	100 ml
Profenofos	Selecron	500 g/l EC	100 ml
Prothiofos	Tokuthion	960 g/l EC	50 ml
Fenoxy carb	Insergar®	250 g/kg WP	25 g
Pyriproxyfen +	Nemesis®	100 g/l EC	30 ml
Mineral oil (heavy narrow range)	BP Cipron	835 g/l EC	300 ml
Triflumuron	Alsystin®	480 g/l SC	20 ml

RESULTS

Variations in parasitism and predation

Seven primary and three secondary parasitoids, as well as four predator species were reared from LIII and POF scales (Table 2). *Aprostocetus ceroplastae* was the dominant parasitoid species, accounting for 78.9% of the total number of the primary parasitoids reared, followed by *Anicetus nyasicus* (Compere) (8.8%). Among the predator species *Cydonia runata* F. and *Coccidophaga* (= *Eublemma*) *scitula* (Rambur) were predominant. The Cape white-eye bird (*Zosterops pallidus* Swainson) was observed feeding on scales while the honeybee (*Apis mellifera* L.) removed the wax cover in their corbiculae and exposed scales to desiccation. Although there was an overlap of the different developmental stages of *C. destructor* (Fig. 1), parasitoids and predators attacked only third-instar nymphs and adult female stages. *Ceroplastes destructor* had one discrete generation per year in the Western Cape Province of South Africa.

Aprostocetus ceroplastae was the dominant species throughout the susceptible host stages whereas *Anicetus nyasicus* and the other parasitoids seemed to be active for only a limited period during the year (Fig. 2). *Anicetus nyasicus* attacked mostly the adult scales rather than the other developmental stages. On the contrary, both *Coccophagus* spp. and *Euxanthellus* sp. were active during the LIII and young adult host stages. *Apanteles* sp. was recorded from July to November of 1998 and 1999 as a parasitoid of *C. sciitula* whereas *Elasmus* sp. was reared only in 1999 (June – October). The latter was probably a secondary parasitoid of *Apanteles* sp. (G. Prinsloo, personal communication). There was a temporal synchrony between density of the susceptible host stages and the level of parasitism and predation (Fig. 3).

Table 2 - Parasitoids and predators reared/collected from third-instar nymphs and adult female stages of *Ceroplastes destructor* on *Citrus reticulata* from June 1997 to December 1999 in the Western Cape, South Africa.

Species name	Family	% of total
Primary		
<i>Aprostocetus ceroplastae</i> (Girault)	Eulophidae	78.9
<i>Anicetus nyasicus</i> (Compere)	Encyrtidae	8.8
<i>Anicetus</i> sp.	Encyrtidae	1.6
<i>Metaphycus</i> sp.	Encyrtidae	4.5
<i>Coccophagus atratus</i> Compere	Aphelinidae	1.8
<i>Coccophagus catherinae</i> Annecke	Aphelinidae	1.6
<i>Euxanthellus</i> sp.	Aphelinidae	1.6
Others	-	1.2
Secondary		
<i>Marietta leopardina</i> Motschulsky	Aphelinidae	55.8
<i>Marietta connecta</i> Compere	Aphelinidae	5.5
<i>Cheiloneurus</i> sp.	Encyrtidae	38.7
Predators*		
<i>Coccidophaga scitula</i> (Rambur)	Noctuidae	high
<i>Exochomus flavipes</i> Thunb.	Coccinellidae	low
<i>Cydonia runata</i> F.	Coccinellidae	high
<i>Nephus</i> sp.	Coccinellidae	medium

* relative abundance; data from Wakgari (2001).

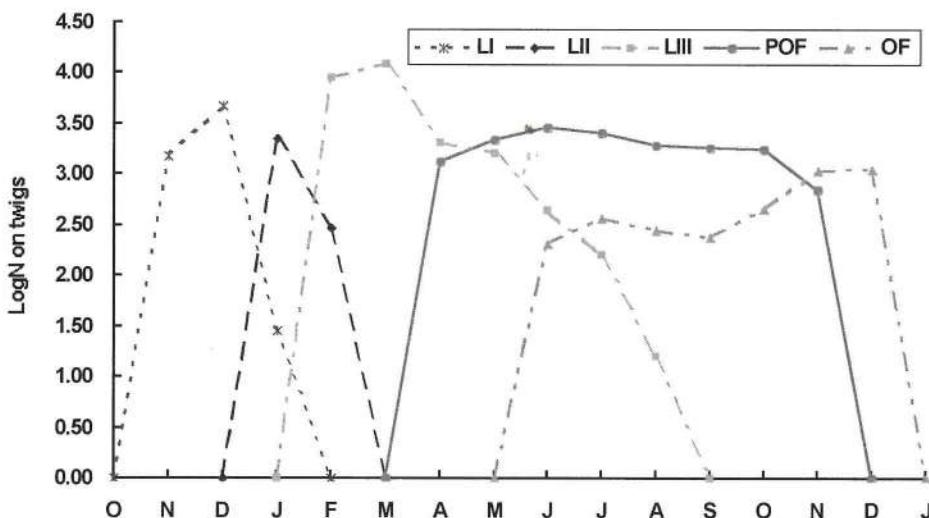


Fig. 1 - General phenology of *Ceroplastes destructor* on *Citrus reticulata* in the Western Cape, South Africa.

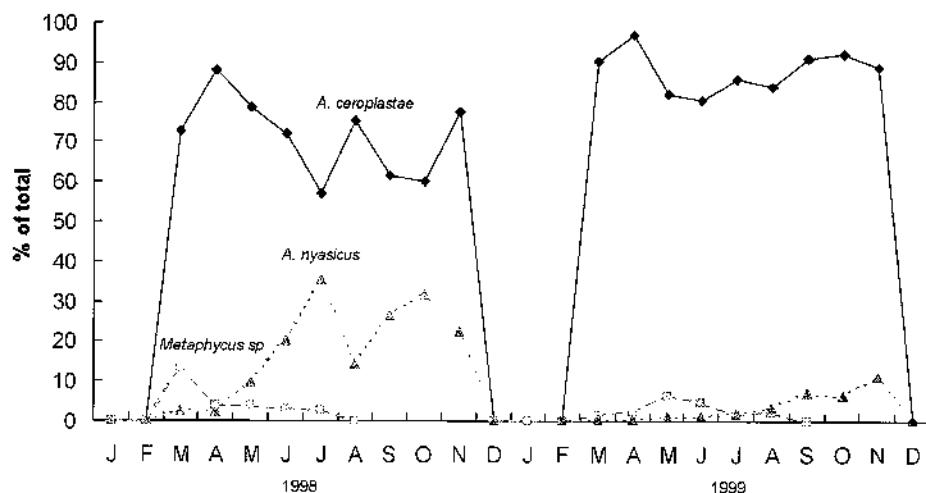


Fig. 2 - Seasonal variation in abundance of three primary parasitoids reared from *Ceroplastes destructor* during 1998 and 1999 in the Western Cape, South Africa.

Effects of scale stages on *A. ceroplastae*

The body length of *A. ceroplastae*, reared at different times of the year from the LIII and POF scale stages varied significantly between scale stages ($F_{1, 112} = 122.06$; $P < 0.0001$), parasitoid sexes ($F_{1, 112} = 212.39$, $P < 0.0001$) and sampling periods ($F_{1, 112} = 68.82$; $P < 0.0001$). The host stage also had a significant effect on the proportion of emergent male and female *A. ceroplastae*, and there was a strong correlation between host and parasitoid body sizes (Table 3). The number of female *A. ceroplastae* reared

Table 3 - Mean body length (mm) (\pm SEM in parenthesis) and sex ratio of *Aprostocetus ceroplastae* ($N = 15$ of each sex/time) and mean body size (length and width in mm) of dewaxed third-instar nymphs and adult female stages of *Ceroplastes destructor* from which *A. ceroplastae* was reared at three times of the year during 1998 and 1999 in the Western Cape, South Africa.

Scale stage	Third-instar				Adult female			
	Male		Female		Male		Female	
Parasitoid sex	Feb/Mar	Aug/Sept	Feb/Mar	Aug/Sept	Aug/Sept	Oct/Nov	Aug/Sept	Oct/Nov
Time	Feb/Mar	Aug/Sept	Feb/Mar	Aug/Sept	Aug/Sept	Oct/Nov	Aug/Sept	Oct/Nov
Length*	0.71 (0.03)	0.88 (0.02)	0.92 (0.02)	1.20 (0.03)	0.93 (0.03)	1.06 (0.02)	1.32 (0.03)	1.38 (0.04)
Sex ratio (M:F)	1:0.31	1:0.84	1:0.31	1:0.84	0.93:1	0.78:1	0.93:1	0.78:1
Length**			1.06 (0.07)	1.63 (0.10)			4.22 (0.13)	4.53 (0.13)
Width**			0.82 (0.02)	1.03 (0.08)			2.36 (0.07)	2.80 (0.11)
N			20	22			32	43

A. ceroplastae*; *C. destructor*.

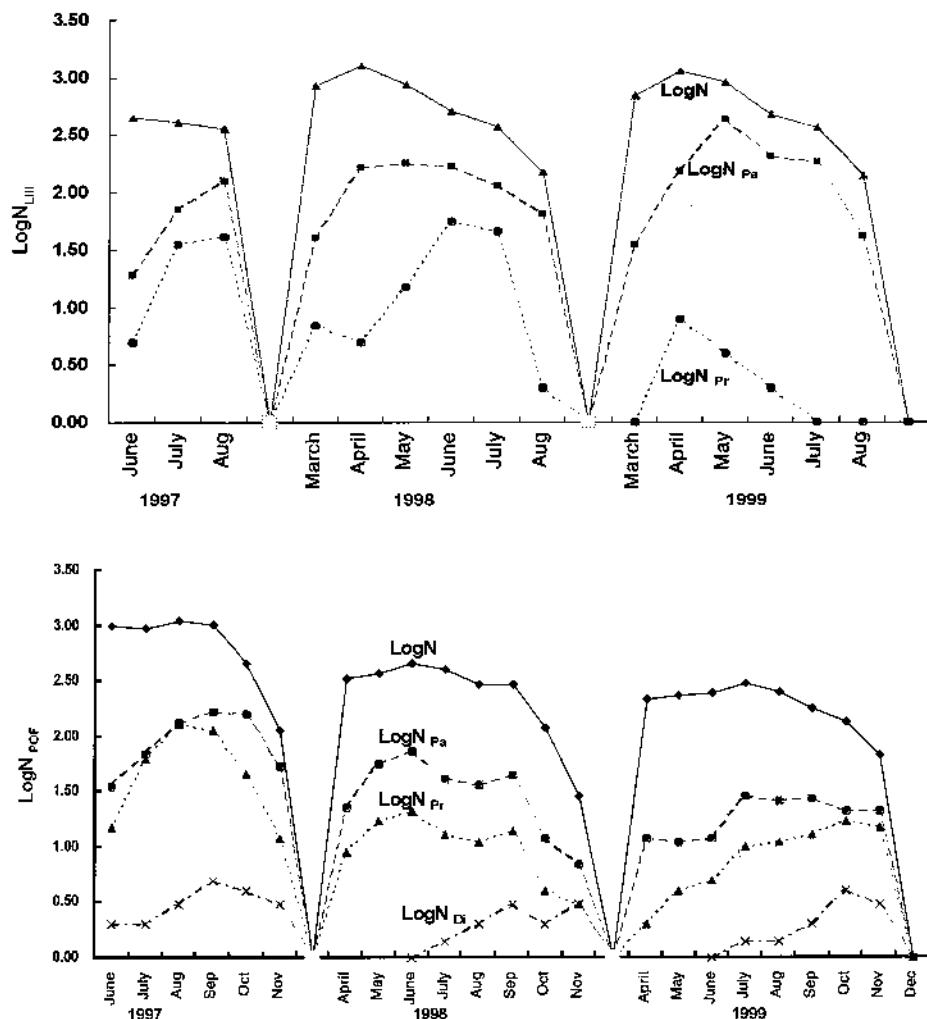


Fig. 3 - Fluctuation in mortality from parasitism, predation and disease of *Ceroplastes destructor* on *Citrus reticulata* from June 1997 to December 1999 in the Western Cape, South Africa. LogN = log of total number of scale; LogN_{Pa} = number died of parasitism; LogN_{Pr} = number died of predation; LogN_{Di} = number died of disease.

from the early LIII scales was about 31% of the total number of parasitoids reared from this stage. At the late LIII and POF (young and mature) scale stages, however, males and females of *A. ceroplastae* emerged in almost equal proportion.

Density-dependence

Mortality from parasitism and predation of POF scales was significantly positively correlated with the number of POF scales on which these agents acted (N_t) ($r = 0.68$ and 0.80 ; $P < 0.01$, respectively), indicating a density-dependent relation. However, the number of scales killed by disease was not significantly correlated with N_t at this host stage ($P > 0.05$), showing no evidence of a density-dependent relation. Although the correlation between the number of parasitized scale and N_t at the LIII stage was positive, the correlation coefficient was not significantly different from 0 ($P > 0.05$), showing that parasitism was not strongly density related at the LIII stage. The number of LIII scales died of predation was inversely related to N_t .

Effects of insecticides on *Aprostocetus ceroplastae*

All the chemicals evaluated against adult *A. ceroplastae* caused high parasitoid mortality (Table 4). Methomyl, methidathion, methyl-parathion, profenofos and prothiofos caused 100% mortality of treated parasitoids in less than 6 hours of exposure. Methomyl was extremely toxic to the parasitoids, causing complete mortality within less than 30 minutes after treatment.

DISCUSSION

The number of parasitoid species reared during this study was significantly less than that reported by Cilliers (1967) and Snowball (1969). Although the reason/s for this is largely speculative, our study indicated that the susceptibility of *A. ceroplastae* (an indicator species used) to the various commonly used insecticides could represent

Table 4 - Total and corrected mortality of *Aprostocetus ceroplastae* treated with different chemicals in the laboratory at Stellenbosch, South Africa.

Treatment	% Mortality x hours after treatment						Corrected mortality
	3	6	12	24	48	96	
Pyriproxyfen	0	0	88.3	88.3	88.3	90.0	88.0
Fenoxy carb	0	0	91.7	91.7	93.3	93.3	91.9
Triflumuron	0	0	0	75.9	81.7	81.7	78.0
Methomyl	100.0	-	-	-	-	-	100.0
Methidathion	58.3	100.0	-	-	-	-	100.0
Methyl-parathion	90.0	100.0	-	-	-	-	100.0
Profenofos	66.7	100.0	-	-	-	-	100.0
Prothiofos	93.3	100.0	-	-	-	-	100.0
Control	0	0	0	0	15.0	16.7	-

Data from Wakgari & Giliomee (2001).

one of the reasons. One can also consider the possibility of local extinction of parasitoids, host plant varietal effect in the tri-trophic interactions (i.e. parasitoids/scale/plant) and localization in the distribution of parasitoids.

Parasitism and predation were restricted to the third-instar nymphs and adult female stages of *C. destructor* during the current study, although Cilliers (1967) reported rearing parasitoids from the second instar of *C. mimosae* and *C. destructor*. Ben-Dov (1972) has also reared parasitoids only from the third instar and adult females of *C. floridensis* in Israel. According to Lo & Chapman (1998) parasitism of *C. destructor* by *Euxanthellus philippiae* Silvestri was restricted to the third instar. This differs somewhat from the current result, where young adults of *C. destructor* were also affected by *Euxanthellus* sp. and other parasitoids.

Peak numbers of parasitoids and predators were generally synchronized with peak numbers of the host stage susceptible to them, although a lag period of about one-month in appearance of parasitoids and predators was evident (see Wakgari, 2001). The level of parasitism and predation found here was far greater than that reported by Lo & Chapman (1998). This variation is probably attributable to the larger diversity of parasitoid and predator species that are associated with the indigenous *C. destructor* in South Africa. The overall scale mortality from parasitism and predation was generally density-dependent at the POF stage whereas mortality from disease appeared to occur randomly with no reference to changes in density of the host population. The apparent variation or fluctuation in parasitism and predation between generations however indicated that the regulatory effects of parasitoids and predators might not be strong enough to provide long term suppression of scales under the current citricultural practices (Wakgari, 2001). It is conceivable that the parasitoids could have rendered a better regulatory effect if interference by frequent spraying of orchards with broad-spectrum insecticides was limited (Wakgari & Giliomee, 2001).

More than 69 % of *A. ceroplastae* that emerged from the smaller early third-instar scale were males. Ben-Dov (1972) reared only male *A. ceroplastae* from third instar *C. floridensis*. This could be because *C. floridensis*, being a bivoltine species, is smaller in body size than *C. destructor*, which is univoltine in the Western Cape (Wakgari & Giliomee, 2000). Moreover, both male and female *A. ceroplastae* reared from the early third-instar stage were significantly smaller in body size than their counterparts reared from adult stage. Thus, only the late third-instar nymphs and young adult females would be appropriate for any possible rearing of *A. ceroplastae* because a comparable proportion of both male and female *A. ceroplastae* emerged from these stages.

All the insecticides evaluated against adult *A. ceroplastae* caused high parasitoid mortality. Of the three IGRs evaluated, triflumuron was slightly less harmful than fenoxycarb and pyriproxyfen, causing 78% mortality of parasitoids. Methomyl, methidathion, methyl-parathion, profenofos and prothiofos caused 100% mortality of treated parasitoids in less than 6 hours of exposure. Methomyl was exceptionally toxic to the parasitoids, causing complete mortality within less than 30 minutes after treatment. However, the detrimental effects of these products require validation in the field as their effects may be affected by climatic conditions. The results of our study

indicated that the wide-scale use of these chemicals in South African citrus orchards may have been responsible for the recent upsurge of *C. destructor* in the Western and Eastern Cape provinces through annihilation of *A. ceroplastae*. Therefore, proper timing of insecticide intervention is essential in order to maximize the contribution of extant natural enemies. However, in the field various pests occur together and the application of insecticides at different times in a season, often during active parasitization of *C. destructor*, appears routine. Under such conditions none of the chemicals tested here are compatible with biological or IPM programmes of *C. destructor* in citrus orchards. Furthermore, some IGRs have a long residual activity (e.g. Hattingh & Tate, 1995) and can interfere with the synchrony between pest species and their natural enemies in citrus orchards. They can lead to eradication of the entire population of the beneficial arthropods in the long term. Therefore, their persistence under field conditions must also be determined before their compatibility with citrus IPM systems can be established.

REFERENCES

BEDFORD E. G. C., 1968 - The biology of *Ceroplastes sinoiae* Hall, with special reference to the ecdysis and the morphology of the test - Entomology Memoirs, Department of Agriculture Technical Services, Republic of South Africa, 14: 1-111.

BEN-DOV Y., 1972 - Life history of *Tetrastichus ceroplastae* (Girault) (Hymenoptera: Eulophidae), a parasite of the Florida wax scale, *Ceroplastes floridensis* Comstock (Homoptera: Coccoidea), in Israel - J. Ent. Soc. Southern Africa, 35: 17-34.

CILLIERS C. J., 1967 - A comparative biological study of three *Ceroplastes* species (Hemiptera: Coccoidea) and their natural enemies - Entomology Memoirs, Department of Agriculture Technical Services, Republic of South Africa, 13: 1-59.

DE LOTTO, G., 1965 - On some Coccidae (Homoptera) chiefly from Africa - Bulletin of the British Museum (Natural History) Entomology, 16: 177-239.

HATTINGH V., TATE B., 1995 - Effects of some field-weathered residues of insect growth regulators on some Coccinellidae (Coleoptera) of economic importance as biocontrol agents - Bull. Ent. Res., 85: 489-493.

LO P. L., CHAPMAN R. B., 1998 - The role of parasitoids and entomopathogenic fungi in mortality of third instar and adult *Ceroplastes destructor* and *C. sinensis* (Hemiptera: Coccoidea: Ceroplastinae) on citrus in New Zealand - Biocontrol Science and Technology, 8: 573-582.

NEILSON M. M., MORRIS R. F., 1964 - The regulation of European spruce sawfly numbers in the Maritime Provinces of Canada from 1937 to 1963 - Canadian Entomologist, 96: 773-784.

PRINSLOO G. L., 1984 - An illustrated guide to the parasitic wasps associated with citrus pests in the Republic of South Africa - Science Bulletin, Department of Agriculture, Republic of South Africa, 402: 1-119.

QIN T. K., GULLAN P. J., 1994 - Taxonomy of wax scales (Hemiptera: Coccoidea: Ceroplastinae) in Australia - Invertebrate Taxonomy, 8: 923-959.

QIN T. K., GULLAN P. J., BEATTIE G. A. C., TRUEMAN J. H. W., CRANSTON P. S., FLETCHER M. J., SANDS D. P. A., 1994 - The current distribution and geographical origin of the scale insect pest *Ceroplastes sinensis* (Hemiptera: Coccoidea) - Bull. Ent. Res., 84: 541-549.

SMITH, D., 1970 - White wax scale and its control - *Queensland Agricultural Journal*, 96: 704-708.

SNOWBALL G. J., 1969 - Prospects for biological control of white wax scale (*Gascardia destructor*) in Australia by South African natural enemies - *J. Ent. Soc. Australia (N.S.W.)*, 5: 23-33.

VARLEY G. C., GRADWELL G. R., 1970 - Recent advances in insect population Dynamics - *Ann. Rev. Entomology*, 15: 1-24.

VARLEY G. C., GRADWELL G. R., HASSELL M. P., 1973 - Insect population ecology. An analytical approach. Blackwell, Oxford.

WAKGARI, W.M., 2001 - The current status of the biocontrol of *Ceroplastes destructor* Newstead (Hemiptera: Coccidae) on *Citrus* and *Syzygium* in South Africa - *Biocontrol Science and Technology*, 11(3): 339-352.

WAKGARI W. M., GILIOREE J. H., 1998 - Description of the stages of the white wax scale, *Ceroplastes destructor* Newstead (Hemiptera: Coccidae) - *African Entomology*, 6: 303-316.

WAKGARI W. M., GILIOREE J. H., 2000 - Fecundity, fertility and phenology of the white wax scale, *Ceroplastes destructor* Newstead (Hemiptera: Coccidae), on *Citrus* and *Syzygium* in South Africa - *African Entomology*, 8: 233-242.

WAKGARI W. M., GILIOREE J. H., 2001 - Effects of some conventional insecticides and insect growth regulators on different phenological stages of the white wax scale, *Ceroplastes destructor* Newstead (Hemiptera: Coccidae), and its primary parasitoid, *Aprostocetus ceroplastae* (Girault) (Hymenoptera: Eulophidae) - *International Journal of Pest Management*, 47: 179-184.

ZECK H. E., 1934 - White wax scales of citrus (*Ceroplastes destructor*) - *The Agricultural Gazette of New South Wales* 45: 86-90.

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