

BIOLOGICAL CONTROL OF *PULVINARIA URBICOLA* (COCKERELL) (HOMOPTERA: COCCIDAE) IN A *PISONIA GRANDIS* FOREST ON NORTH EAST HERALD CAY IN THE CORAL SEA

D. Smith¹, D. Papacek², M. Hallam³ and J. Smith¹

¹ Queensland Department of Primary Industries, PO Box 5083 SCMC, Nambour Qld. 4560, Australia

² Citrus Consultant, 28 Orton Street, Mundubbera Qld. 4626, Australia

³ Consultant, 25 Shumack Street, Weetangara ACT 2614, Australia

Email: Dan.Smith@dpi.qld.gov.au

Summary

During 1993-2000 the soft scale insect *Pulvinaria urbicola* (Cockerell) caused complete destruction of a 16 ha *Pisonia grandis* R.Br. forest on Coringa South West Islet in the Coringa-Herald National Nature Reserve 400 km off the north-east coast of Queensland, Australia. In March and August 2001, scale surveys on a nearby cay, North East Herald, showed a worrying increase in numbers. Releases of the natural enemies *Cryptolaemus montrouzieri* (Mulsant) and three parasitoids - *Coccophagus ceroplastae* (Howard), *Euryischomyia flavithorax* (Girault) and *Metaphycus luteolus* (Timberlake) were made in August 2001. *C. montrouzieri* quickly increased to very high numbers on the pulvinaria scale and the percentage of infested leaves dropped from 25% in August to 8% in December 2001 to 0.01% of leaves by August 2003. All three parasitoids established and parasitism was evident on 30% of infested leaves after nine months. By 2004, *C. ceroplastae* was the dominant parasitoid and is expected to play an important role in maintaining the scale population at its current low level.

Keywords: pulvinaria scale, *Pisonia*, Coral Sea, biological control

INTRODUCTION

The Coringa Herald National Nature Reserve consists of three pairs of isolated cays or islets in the Coral Sea at 16°23' - 17°11'S and 149°00' - 150°30'E, 440 km off the north-east coast of Australia. The cays are the Herald Cays (North East Herald and South West Herald), the Coringa Islets (South West and Chilcott) and the Magdelaine Cays (North West Magdelaine and South East Magdelaine). They are vegetated (except for North West Magdelaine) by about 24 plant species. These comprise grasses like *Sporobolus virginicus*, *Portulaca oleraceae*, the legume *Canavalia rosea*, short herbaceous shrubs like *Achyranthes aspera*, *Boerhavia* spp. and *Tribulus cistoides*, taller shrubs like *Agusia argentea* and *Abutilon indicus*, vines like *Ipomoea* spp., and trees like *Cordia subcordata* and *Pisonia grandis* (Anon. 2000).

Before 1990 there was approximately 16 ha of *P. grandis* (*Pisonia*) on Coringa South West Islet, a similar area on North East Herald Cay and about 2 ha on South East Magdelaine Cay. *P. grandis* grows on these cays to about 15 m in height and produces a cool shady closed canopy forest (with very little undergrowth) in the central part of the cay. Walker (1991) estimated that up to 200 ha of *Pisonia* forests occurred in conservation reserves in the Great Barrier Reef region of Australia most of it in the Capricornia Cays National Parks off Gladstone. In the Coral Sea, *Pisonia* helps support large seabird rookeries of red

footed boobies, least and great frigate birds, sooty tern and black noddy. Nesting birds disperse *Pisonia* seed but regrowth from broken limbs seems to be the main means of reproduction and spread of *Pisonia* especially after cyclone damage (Cribb and Cribb 1985).

Pulvinaria urbicola (Cockerell) was first described in Jamaica (Ben-Dov 1993) but has almost worldwide distribution throughout the Austro-Oriental Region (Papua New Guinea, Solomon Islands, Queensland and Northern Territory, Caroline Islands, Cook Island, Fiji, Hawaii, Mariana Islands, New Caledonia, Vanuatu, Western Samoa and in Central America, West Indies, Cuba, Galapagos Islands, Southern USA and Israel). It has a wide host range and in Australia is recorded from maidenhair fern *Adiantum diaphanum*, capsicum *Capsicum annum*, tomato *Lycopersicum esculentum*, blackberry nightshade *Solanum nigrum*, dahlia *Dahlia pinnata*, dianthus *Dianthus* sp. and lantana *Lantana camara*. Other known hosts include guava *Psidium guajava*, frangipanni *Plumera obtusa*, taro *Colocasia* sp., pineapple *Ananas comosus*, milk thistle *Sonehus oleraceus*, cobblers peg *Bidens pilosa* and cape gooseberry *Physalis peruviana* (Quin and Gullan 1992). It has been recorded causing limb death on yellow bells *Telcoma stans* in Papua New Guinea (Quin and Gullan 1992). The life cycle takes about two months during summer and four to five generations occur annually. Adult females each produce up to 1000 eggs contained in a prominent

white egg sac up to 8 mm in length. The eggs hatch into mobile 'crawlers' which tend to move up to the light and congregate in large numbers at the top of the tree where they drop off into air currents and are dispersed over hundreds of metres to fresh hosts. Where there are heavy infestations it is possible that crawlers would also crawl on to nesting or resting seabirds and be dispersed in this manner (Dekle 1965).

A heavy infestation of *P. urbicola* defoliating *Pisonia* was first noticed on Coringa Islet by Australian National Parks and Wildlife staff in 1991. By 1997, 80% of the 16 ha forest on Coringa Islet had been destroyed. By 2001 the forest was totally destroyed and the former area is now covered mostly by grasses, herbaceous species and vines. A similar result occurred on Tryon Island in the Capricorn Cays where excessive scale numbers were first noticed in 1993 resulting in an 87% destruction of the *Pisonia* forest (O'Neill *et al.* 1997).

P. urbicola is not regarded as a serious pest of crops or ornamentals on mainland Australia possibly because it is usually controlled by several wasp parasitoids - *Coccophagus ceroplastae* (Howard), *Euryischomyia flavithorax* Girault and Dodd and *Metaphycus luteolus* Timberlake (Malipatil *et al.* 2000). Predatory coccinellids like *Cryptolaemus montrouzieri* (Mulsant) and scale pathogens like *Verticillium lecanii* (Zimmerman) are also important (Smith *et al.* 1997). Collections of *P. urbicola* in the Capricornia Cays off Gladstone from 1993-2002 found as many as fifteen wasp parasitoids, with *C. ceroplastae* dominating but *C. montrouzieri* and *V. lecanii* scarce (Anon. 2003). From 1993-2002, seven wasp parasitoids were collected from *P. urbicola* on Tryon Island with *C. ceroplastae* the most common and occasional specimens of *C. montrouzieri*. Parasitism (mainly by *C. ceroplastae*) reached 90% in most of the Capricorn Cays (like North West Island and Heron Island) but was less than 13% on Tryon Island (Smith and Papacek 2001a). By 1999 the scale infestation on *Pisonia* leaves on Tryon Island had dropped to 5% of leaves infested (down from 80% in 1994). This also coincided with significant increase in parasitism (R. Elder pers. comm. 2003). The reason for the relative inactivity of natural enemies on Tryon Island during the 1990s is not known. Possible reasons include: the scale reaching the island ahead of its natural enemies which then took 5-6 years to locate and contain the infestation; natural enemies on the island dropped to extremely low levels due to host scale fluctuations; or that the introduced coastal brown ant *Pheidole*

megacephala (Fabricius) seriously disrupted the natural enemies (Anon. 2003).

Initial surveys of *P. urbicola* in the Coringa-Herald Islets in March and July-August 2001 showed a total absence of parasitoids and of coccinellid predators like *C. montrouzieri*. The main ant species were *Tetramorium sp.* and *Monomorium sp.* (Smith and Papacek 2001a, b). In this study, assessments were made of scale levels on *Pisonia* on North East Herald Cay on ten occasions from March 2001 until April 2004. Levels of natural enemies were recorded particularly after release of three parasitoids species and of *C. montrouzieri* in August 2001.

MATERIALS AND METHODS

North East Herald Cay

Scale monitoring. North East Herald Cay was visited ten times and assessments made of pulvinaria scale levels, ants, other significant pests and natural enemies on 18 March, 8 August, and 18 December 2001, on 16 March, 23 August and 29 November 2002, 1 April, 17 August and 10 December 2003 and 3 April 2004. To select trees and leaves for sampling (for scale, ants and natural enemies), use was made of 11 existing seabird monitoring transects across North East Herald Cay (averaging 360 m in length each traversing the 15 ha *Pisonia* forest west to east at about 100 m intervals). Every 60 m (30 m in March 2001) along the transect, three trees were randomly selected and from each tree, one upper canopy leaf (cut down with an extended pruning tool at 3-4 m) and one lower canopy leaf (<2 m high) was collected. For each leaf sampled the following were recorded: leaf blade length (cm); number of scales touching the midrib (recorded as first, second and third instar); adults with egg sacs on the whole leaf and the number of these (adults with egg sacs) that were spent (dead); ant species on the leaf; larvae, pupae, and adult ladybirds on the leaf; parasitoid adults on the leaf; the number of obviously parasitised scale and other relevant insects eg. hawk moth (eggs, larvae or pupae). Detailed stereo microscopic assessments were made on randomly collected scales - 3200 in March 2001 and 2500 in April 2004. In 2001, the percentage of live first, second and third instars (adults) were calculated together with the percentage of parasitised, predated and diseased scales. In 2004 a similar assessment was made but only on second instar scales.

Releases of natural enemies

Four species of natural enemies were released on North East Herald Cay beginning in July-August

2001. The ladybird *C. montrouzieri* was reared in the 'Bugs for Bugs' Insectary, at Mundubbera, Queensland. Ladybirds were transported to North East Herald as adults, 500 per ventilated plastic tub (16 x 12 x 4 cm) sustained by a moist honey-water pad. The parasitoids *C. ceroplastae* and *E. flavithorax* were reared on *P. urbicola* in 1 m high tubs of *Pisonia* plants at Nambour while *M. luteolus* was reared on soft brown scale *Coccus herspiridum* Linnaeus at 'Biological Services Insectary', Loxton, South Australia. These were transported to North East Herald Cay as adults in 500 cm³ plastic tubs. *C. ceroplastae* was also transported as juveniles in parasitised scale. Male *C. ceroplastae* are hyperparasitic on juvenile female *C. ceroplastae* (G.Walter pers. comm. 2001) so to obtain viable establishment, emerging adults must be released over a period of at least 1-2 weeks.

Approximately 40000 *C. montrouzieri* adults were released between 30 July and 10 August 2001 mostly on North East Herald Cay. Initially a release was made into a 2 m long cloth mesh sleeve cage over a heavily infested *Pisonia* limb. However, the beetles were heavily attacked by ants (*Tetramorium sp.*) and all subsequent releases were made into open trees in scale-infested areas. These areas (totaling 0.65 ha) were treated with ant bait (Amdro[®] (hydramethylnon) or Presto[®] (fipronil on fishmeal) both broadcast at 2.5 kg ha⁻¹) prior to release.

A total of 2000 *C. ceroplastae* (reared in a glasshouse at Nambour) were transported to North East Herald Cay, half released on 31 July 2001 into three 2 m long sleeve cages and the rest on 7 August into two more of these cages. The cages were removed on 9 August. Live scale on twigs of *Pisonia* were left in a 2 L plastic container (with drainage holes) suspended with nylon string from a shaded branch near two cages. A smear of petroleum jelly on the string excluded ants. The twigs had been treated with a mixture of benomyl and avermectin to kill any fungal pathogens or mites respectively and all leaves had been removed and carefully screened for any other insects. The scales on the *Pisonia* twigs were heavily parasitised with *C. ceroplastae* that would emerge over the next 3 weeks.

A second round of natural enemy releases was made from 17-21 December 2001. A total of 7000 adult *C. montrouzieri* was released on 18 December in five areas of North East Herald Cay where there was noticeable scale activity. Ants were again suppressed using baits. Five thousand *M. luteolus* were released on North East Herald Cay at the northern end where there was most scale. About 500 *C. ceroplastae*

adults were released at the northern end and eight ant-proofed tubs (of scale infested twigs as in July) were hung in the trees together in this area (Smith *et al.* 2001).

Other islets - observations on scales and hawk moths and releases of natural enemies

South East Magdelaine Cay. Observations were made at similar times as on North East Herald but there were no visits in August or December 2001 or in April 2004. The *Pisonia* occurs in two patches of about 1 ha each and these were carefully traversed searching for scales. Two thousand *C. montrouzieri* adults were released in March 2002.

South West Herald Cay. This cay was visited on the same number of occasions as North East Herald Cay. There is no *Pisonia* on Southwest Herald Cay but the herbaceous vegetation, particularly *A. aspersa* was found to be heavily infested with pulvinaria scale resulting in many dead patches. No *C. montrouzieri* or parasitoids were released in August 2001 when the first releases were made on North East Herald Cay (10 km to the NE). Three thousand *C. montrouzieri* were released on South West Herald Cay on 18 December 2001 but the beetle was found to be established at this date presumably having been colonised from nearby North East Herald.

Coringa Islet. This islet (75 km west of North East Herald Cay), was visited in March 2001 and March 2002. The former *Pisonia* forest had been totally destroyed (except for a lone shoot from a fallen stump). The herbaceous vegetation eg. *A. aspersa*, *P. oleracea* and *T. cistoides* were heavily infested with scale. In March 2002, 2000 *C. montrouzieri* adults and 1000 *M. luteolus* adults were released on pulvinaria scale on *A. aspera*. A release of 200 *C. ceroplastae* adults was also made and two ant-proofed plastic tubs set up to provide emerging adults for a further three weeks (as at North East Herald).

Willis Islet. This islet was visited in March 2002. There are no *Pisonia*, but herbaceous vegetation and capsicums and eggplants (in the weather station garden) were infested. *C. montrouzieri* adults (250) were released.

Other Pests

The only other significant pest problem observed on *Pisonia* was defoliation by the larvae of two species of hawk moth on North East Herald and South East Magdelaine Cays. A rating system was used on North East Herald Cay for assessing the damage: 0- nil; 1- slight <10%; 2- up to 25%; 3- up to 50%; 4- up

to 75% and 5- leaf totally destroyed.

The egg parasitoids *Trichogramma pretiosum* Riley and *Trichogramma carverae* Oatman and Pinto were released on North East Herald and on South East Magdelaine in March 2002. These were reared on *Sitotroga cerealella* (Olivier) eggs (Lepidoptera: Gelechiidae) in the 'Bugs for Bugs Insectary' at Mundubbera.

RESULTS

North East Herald Cay

The data collected for North East Herald Cay is summarised in Figures 1, 2 and 3. Figure 1 gives the average number of scales per cm of midrib and the percentage of infested leaves. It also shows the number of ants. Figure 2 shows the percentage of scale infested leaves; infested leaves with *C. montrouzieri* (larvae, pupae or adults); and infested leaves with parasitoids and/or parasitised scales present. Figure 3 shows average leaf lengths, monthly rainfall at Willis Island and the average hawk moth damage ratings on *Pisonia* leaves.

Scale monitoring. In March and August 2001 these were 23-25% of leaves infested, and an average 0.34-0.43 scales cm^{-1} of midrib (Figure 1). Ant populations (95% *Tetramorium sp.* and 5% *Monomorium sp.*) averaged one to six ants per leaf.

In March 2001, limb dieback and dead trees were common especially on the northern edges of the *Pisonia* forest. The scale infestation noticeably increased from March to August in some of the more heavily infested transects. There was a two-fold increase in transects 2 and 6 and seven-fold increase in transect 4.

By December 2001, only 8% of leaves were infested and there were 0.18 scales cm^{-1} of midrib. In March 2002, 14% of leaves were infested and there were 0.16 scales cm^{-1} midrib. Ant numbers at these two dates dropped to less than one per leaf.

In August and November 2002 and in April 2003 the infestation dropped to a lower level: 8.5, 8.5 and 5.3% of leaves infested and 0.3, 0.4 and 0.7 scales cm^{-1} of midrib respectively. In August and December 2003 the infestation dropped further to 0.01 and 0.02% of leaves infested and 0.1 and 0.2 scales cm^{-1} of midrib respectively. Ant numbers dropped to less than 0.5 ants per leaf. In April 2004, the percentage of infested leaves rose to 6.1% and there were 0.2 scales cm^{-1} of midrib.

Other pests

The only other significant pests occurring on *Pisonia* during the study were two species of hawk moth (*Hippotion velox* (Fabricius) and *Theretia sp.*).

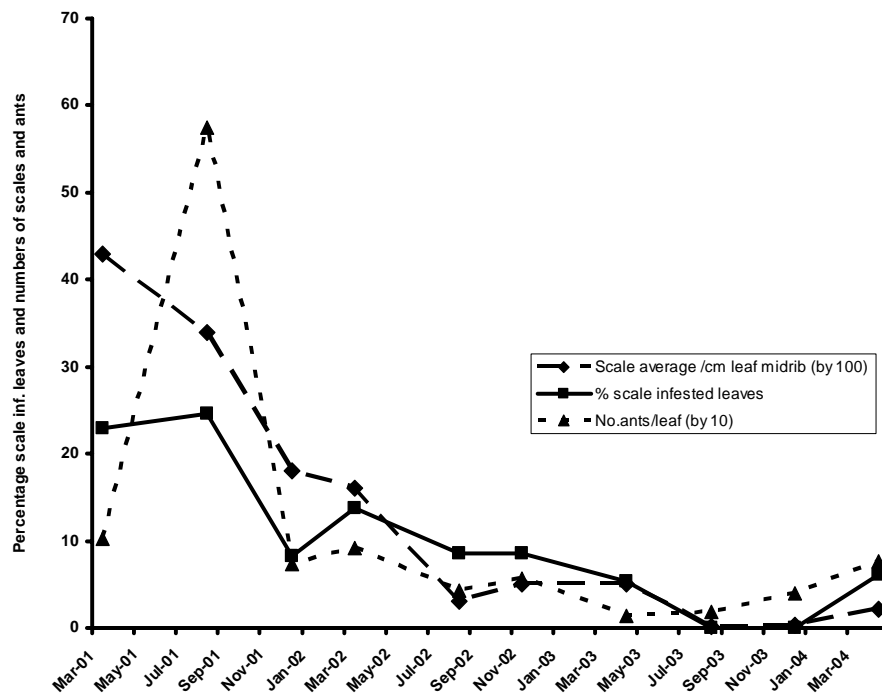


Figure 1. *Pulvinaria* scale levels on *Pisonia* leaves at North East Herald Cay, March 2001 to April 2004.

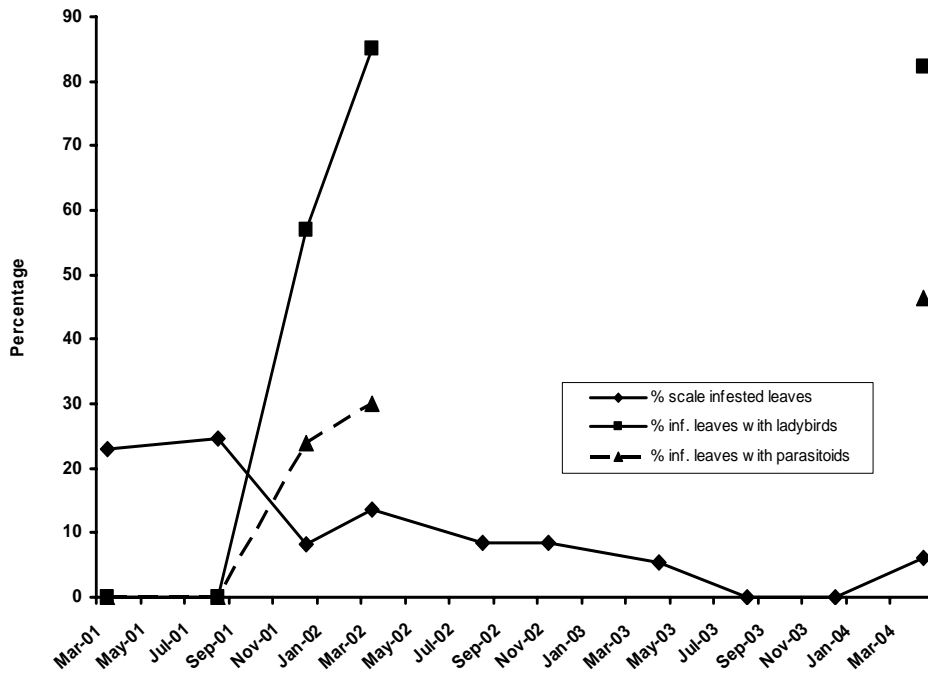


Figure 2. *Pulvinaria* scale levels on *Pisonia* leaves, predatory activity by *C.montrouzieri* and parasitic activity by *C.ceroplastae*, *E. flavithorax* and *M.luteolus* at North East Herald Cay, March 2001 to April 2004.
 Note: No data on percent infested leaves with ladybirds or parasitoids from March 2002 to March 2004.

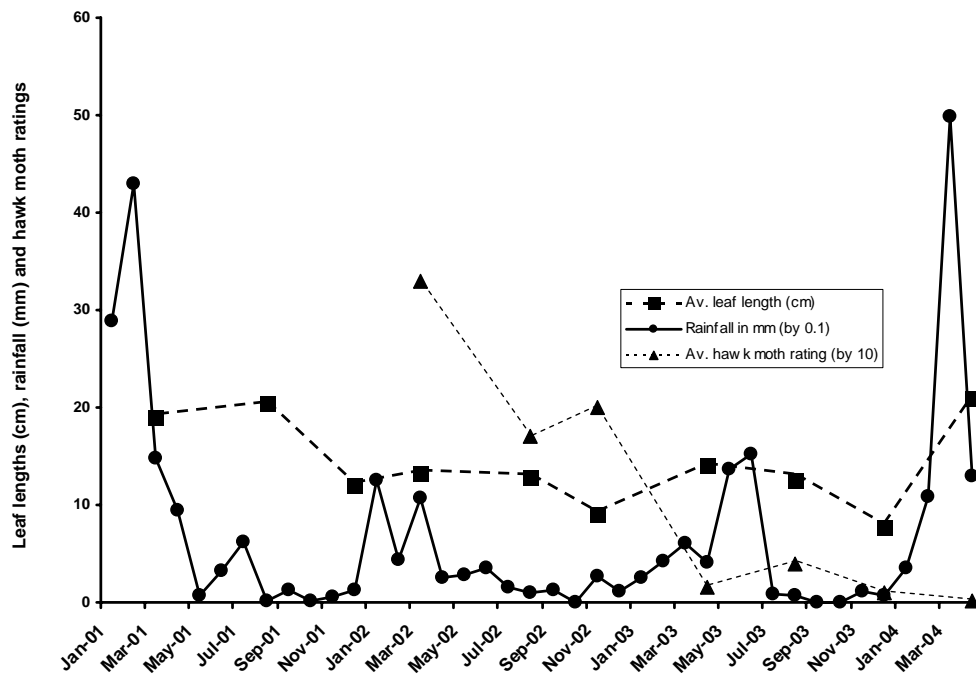


Figure 3. *Pisonia* average leaf lengths (cm) from March 2001 to April 2004 and average hawk moth ratings from March 2002 to April 2004 on North East Herald Cay and the average monthly rainfall (mm) at Willis Islet, January 2001 to April 2004.

During the March 2002 visit, hawk moth leaf destruction on North East Herald Cay was almost total with a much lower level of destruction on South East Magdelaine Cay. A similar amount of damage had been observed on South East Magdelaine Cay in March 2001. Damage ratings on North East Herald Cay dropped from an average 3.3 per leaf in March 2002 to less than two in August and November 2002. Levels have remained low (less than 0.5 rating) since that date (Figure 3).

Leaf lengths. Leaf lengths varied from an average of 19-20 cm per leaf in the first half of 2001 to 13 cm and less (as low as 9 cm) in 2002 and 14 cm and less (as low as 8 cm) in 2003. A high level of 21 cm was reached in April 2004 (see Figure 3). Figure 3 gives monthly rainfall data from January 2001 to February 2004 at Willis Islet 120 km to the North East of the Herald Cays (the only source of weather data in the area). The weather on Willis Islet is sufficiently similar to other islets in this region of the Coral Sea to use as an indicator of general rainfall (P. Jefferson pers. comm. 2004). The total rainfall for 2001 was 1095 mm, for 2002 - 441 mm and for 2003 - 491 mm. The hawk moth infestation of early 2002 in combination with a prolonged dry spell through 2002-03 (which slowed tree recovery) was the cause of the smaller leaves.

Releases of natural enemies

C. montrouzieri was released on North East Herald Cay in August 2001 (Figure 2). In the following three months to December 2001, beetle numbers rapidly increased until 57% of all infested leaves had larvae, pupae and/or adults present. Heavily infested leaves or twigs were commonly observed to be covered with scores of larvae and pupae. The egg-laying mature scales were particularly attractive to the predator. The percentage of infested leaves at this point had dropped from 25 to 8%. In March 2002 there was a slight resurgence of scale to 14% of leaves infested, but 85% of infested leaves had active *C. montrouzieri* present.

Less intensive monitoring of the scale population continued from August 2002 to December 2003 and it was not possible to collect similar quality data on the predators and parasitoids as with the first part of the study. The ladybird was observed to be still active even with the reduced scale infestation. In April 2004, clearer assessment of natural enemy levels was again possible and *C. montrouzieri* levels were at a high level (present on 82% of scale infested leaves) in response to a minor resurgence of the scale.

Parasitoids. In March 2001, the percentages of live - first, second and third instar scale was 98%, 99.6% and 99% respectively and there was no evidence of activity by any natural enemies. Parasitoids were first released in August 2001 on North East Herald Cay. In December 2001 some parasitoid activity was recorded (a few scales parasitised per leaf) on 24% of infested leaves - mainly by *M. luteolus* and some *E. flavithorax*. The most common species in the Capricorn Cays, *C. ceroplastae*, did not appear to have established. A concerted effort was made to establish this species in December 2001. This was successful and it was the most common parasitoid by March 2002. Of the 30% of infested leaves showing active parasitism, 14% had *C. ceroplastae*, 10% *M. luteolus* and 6% *E. flavithorax*. In April 2004, only *C. ceroplastae* was recovered, however, it was now present on 46% of scale infested leaves. Thirty percent of second instar scales were alive, 15% were parasitised with *C. ceroplastae*, 34% were eaten by *C. montrouzieri* and 21% had died from undetermined causes. The level of active parasitism by *C. ceroplastae* in live second instar scales (the stage most commonly parasitised by this species), ignoring dead and eaten scales, was 32%.

Other Islets

South East Magdelaine Cay the only other islet with a surviving *Pisonia* forest, was 75% defoliated by hawk moths in March 2001 and 25% defoliated in March 2002. A single site, lightly infested with pulvinaria scale was found in March 2002 and 2000 *C. montrouzieri* adults were released. The scale has not been detected on subsequent visits.

DISCUSSION

March and August 2001 scale levels on North East Herald Cay were very threatening and tree death was already evident in the worst affected areas where scale numbers had increased to hundreds per leaf. In 1997 the percentage of infested leaves on North East Herald Cay was only 2.2% with 0.003 scales cm⁻¹ of leaf midrib or a similar level commonly occurring in the Capricorn Cays (Anon. 2003). At the same time the infestation level on Coringa was 60% leaves infested and 0.45 scale cm⁻¹ of leaf midrib. By March 2001, the Coringa South West Islet *Pisonia* forest had been totally destroyed. On Tryon Island in the Capricorn Cays in 1993, 85% of leaves were infested and there were 4.3 scales cm⁻¹ of midrib. By 1997, 80% of this forest had been destroyed. A level of 25% of leaves infested and 0.43 scales cm⁻¹ of leaf in August 2001 at North East Herald Cay (with dieback already occurring) pointed to a similar pattern of destruction beginning as at Coringa South

West Islet and Tryon Island. In combination with the threatening scale levels, there was a complete absence of natural enemies such as coccinellids, lacewings, parasitoids or pathogens. Heavy infestations of the scale were also observed on the herbaceous vegetation of all the cays and islets with evidence of large dead patches particularly of *A. aspera* and again no sign of natural enemies. Scale infested twigs were covered with hundreds of ants (mainly *Tetramorium sp.*) as had occurred with coastal brown ant on Tryon Island (Anon. 2003).

The ladybird, *C. montrouzieri* established at the first release in August 2001 on North East Herald Cay. The adult beetles were attacked by *Tetramorium sp.* with dozens of ants swarming over individual beetles. Subsequently it was observed that neither larvae nor pupae of the ladybird were targeted by the ants. The baits Amdro® and Presto® were both effective. By December 2001, massive numbers of adults and larvae had reduced the scale population by 60% and stopped any further tree death.

C. montrouzieri is an extremely valuable native predator of mealybugs in eastern Australia and of soft scales as in the genus *Pulvinaria* that produce a large egg sac (Smith *et al.* 1997). Like many predatory coccinellids it could be expected to increase to large numbers when the host is abundant and decline to low numbers when the host is scarce. On North East Herald the scale did drop to very low levels during 2002-2003, however, the beetle did not die out and in April 2004, *C. montrouzieri* had responded quickly to the 2003-04 summer scale resurgence. Its role in bringing back the scale infestation on North East Herald Cay to non-damaging levels has been dominant. Releases were not made on Tryon Island in the Capricorn Cays as the beetle was already present, although in low numbers (Anon. 2003). There is no apparent explanation for why *C. montrouzieri* failed to respond to the increasing scale threat on Tryon Island.

The three parasitoids *C. ceroplastae*, *E. flavithorax* and *M. luteolus* were all successfully established on North East Herald Cay in 2001-02. Their impact by December 2001 and March 2002 was secondary to *C. montrouzieri* but not insignificant. In April 2004, only *C. ceroplastae* was detected but its level had significantly increased since 2002. Its active parasitism level of 32% is still well below the 90% occurring in the Capricorn Cays. In the Capricorn Cays parasitoids like *C. ceroplastae* keep *Pulvinaria* scale at non-damaging levels in most situations. It is expected that a similar balance will be established on

North East Herald Cay.

While it is likely that the *P. urbicola* infestation of the Capricorn Cays came by agency of birds or man over the 80 km from the Queensland coast, there is minimal tourist visitation to the Coringa-Herald group. Moreover, the 400 km distance from the coast would most likely rule out transfer on birds. It is possible that *Pulvinaria* scale could have originally been transported into the region on garden plants taken out to the Willis Islet weather station. Nesting seabirds then could have transported scale crawlers from infested vegetation to other cays.

Little is known on the history and movement of hawk moths found on *Pisonia*. Moderate to heavy defoliation appears to happen at least once every two to three years. On North East Herald in March 2002 almost complete defoliation occurred with masses of caterpillars falling to the ground and unable to complete their life cycle. Re-growth occurs providing there is adequate rainfall. A combination of defoliation by hawk moths and heavy scale infestation would be very damaging as most of the young new shoots would be targeted by the scale. No natural enemies of hawk moth larvae or pupae were observed. Ants (*Tetramorium sp.*) appeared unable to successfully feed on the hawk moth eggs and showed no interest in larvae or pupae. The *Trichogramma spp.* released during March 2002 were recovered from hawk moth eggs (with up to six parasitoids emerging from one egg) (Smith and Papacek 2002) but in April 2004 hawk moth levels were very low and only a single emerged egg was observed. There has been no opportunity then to gauge the long-term effect of the *Trichogramma* releases.

ACKNOWLEDGMENTS

We thank the Royal Australian Navy and the National Marine Unit of the Australian Customs Service for their generous assistance in transportation to and from the Coringa-Herald National Nature Reserve. Thanks also to other staff of the Commonwealth Department of Environment and Heritage: Matthew Whitting, Phil Domaschcz, Stefanie Pidcock and Clinton Dengate for logistical support. Thanks to Rod Elder formerly of Queensland Department of Primary Industries and John Olds and Alice Kay of Queensland National Parks and Wildlife Service for sharing experiences with the pests especially in the Capricorn Cays National Parks. Thanks especially to 'Bugs For Bugs Insectary' Mundubbera and also 'Biological Sources

Insectary' Loxton for supplying at no cost natural enemies for the releases.

REFERENCES

- Anon. (2000). Coringa-Herald National Nature Reserve and Lihou Reef National Nature Reserve Draft Management Plan. Environment Australia. 52 pp.
- Anon. (2003). The impact and distribution of the soft scale *Pulvinaria urbicola* in the *Pisonia grandis* forests off the Capricorn Cays National Park. Queensland Parks and Wildlife Service. 83 pp.
- Ben-Dov, Y. (1993). A systematic catalogue of the soft scales of the world. Sandhill Crane Press, Gainesville, Florida. 536 pp.
- Cribb, A.B. and Cribb, J.W. (1985). Plant Life of the Great Barrier Reef and adjacent shores. University of Queensland Press. 294 pp.
- Dekle, G.W. (1965). Florida Armoured Scale Insects. Florida Department of Agriculture and Consumer Services. 345 pp.
- Malipatil, M.B., Dunn, K.L. and Smith, D. (2000). An illustrated guide to the parasitic wasps associated with citrus scale insect and mealybugs in Australia. Department of Natural Resources and Environment, Agriculture Victoria and the Horticultural Research and Development Corporation. 152 pp.
- O'Neill, P., Olds, J. and Elder, R. (1997). Report on investigations of *Pulvinaria urbicola* infestations of *Pisonia grandis* forests, and masked and brown booby, populations in the Coral Sea. 25 November to 18 December 1997. Environment Australia Report.
- Quin, T.K. and Gullan, P.J. (1992). A revision of the Australian pulvinariine soft scales (Insecta: Hemiptera: Coccidae). *Journal of Natural History* **26**: 103-164.
- Smith, D. and Papacek, D. (2001a). Report on the levels of the scale insect *Pulvinaria urbicola* and its natural enemies on *Pisonia grandis* in the Coringa-Herald National Nature Reserve 16-23 March 2001. Report to Environment Australia. 25 pp.
- Smith, D. and Papacek, D. (2001b). Report on visit to the Coringa-Herald Nature Reserve 30 July-1 August 2001 with regard to the releasing of parasitoids and ladybird predators of the pest scale *Pulvinaria urbicola* on *Pisonia grandis*. Report to Environment Australia. 5 pp.
- Smith, D. and Papacek, D. (2002). Report on visit to the Coringa-Herald Nature Reserve 15-22 March 2002 with regard to the releasing of parasitoids and ladybird predators of the pest scale *Pulvinaria* on *Pisona grandis* and the assessment of biocontrol options for hawk moths. Report to Environment Australia. 11 pp.
- Smith D., Beattie, G.A.C. and Broadley, R. (Eds.) (1997). Citrus Pests and their Natural Enemies. Integrated Pest Management in Australia. Queensland Department of Primary Industries Information Series Q 197030. 272 pp.
- Smith, D., Papacek, D. and Smith, J. (2001). Report on visit to the Coringa-Herald Nature Reserve 17-21 December 2001 with regard to the releasing of parasitoids and ladybird predators of the pest scale *Pulvinaria* on *Pisonia grandis*. Report to Environment Australia. 6 pp.
- Walker, T. (1991). *Pisonia* Islands of the Great Barrier Reef. Part 3. Changes in the vascular flora of Lady Musgrave Island. *Atoll Research Bulletin* **350**: 31-41.