First Record of *Pulvinaria urbicola* (Hemiptera: Coccidae), a Potentially Damaging Scale Insect, on Christmas Island, Indian Ocean

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Abstract

Pulvinaria urbicola, a pulvinariine soft scale was recorded for the first time on Christmas Island (Indian Ocean) in June 2011. A broad host plant generalist, *Pu. urbicola* excretes honeydew and is commonly tended by ants, including invasive *Anoplolepis gracilipes* and *Pheidole megacephala*. *Pu. urbicola* is implicated in dieback of forest dominated by *Pisonia grandis* (Nyctaginaceae) on many Indo-pacific islands. Here we report the first records of *Pu. urbicola* on Christmas Island, describe the potential impacts of the association of this trophobiont with introduced ants, and outline management options. *Pu. urbicola* represents a threat to stands of *Pi. grandis*, potentially threatens the forest dominant *Pi. umbellifera*, and could exacerbate supercolony formation and impacts of the yellow crazy ant *Anoplolepis gracilipes*. Christmas Island is now the closest land area with a *Pu. urbicola* infestation to Cocos (Keeling) Islands and Pulu Keeling National Park and, therefore, it is likely the most probable steppingstone for any future introduction.

General Background

Pulvinaria urbicola. *Pulvinaria urbicola* Cockerell (Coccidae) is a soft scale insect, probably native to the West Indies. It is now widespread across the tropical Atlantic, Indian and Pacific Ocean islands, and occurs in Central America, Cuba, southeastern United States, and Israel. *Pu. urbicola* is an extreme host plant generalist reported to attack dicot, monocot, and fern plant species in 68 genera and 33 families (Scalenet; http://www.sel.barc.usda.gov/scalenet/scalenet.htm; accessed 18 July 2011). Maturing *Pu. urbicola* females develop cottony, prominent white egg sacks (ovisacs) in which the females lay the eggs (Figure 2A). The ovisacs contain several hundreds of eggs up to about 1000 eggs per female (Smith and Papacek 2001a). The eggs then hatch into 'crawlers', the mobile first instar scale insects. The crawlers disperse by walking to other parts of the host plant but passive aerial dispersal probably plays an important role in the colonization of new host plants. Crawlers of many scale insects are known to travel from host to host by wind (Hanks and Denno 1993). Long distance dispersal may occur by birds. Smith and Papacek (2001a) suggested that *Pu. urbicola* probably arrived to islets of the Coral Sea by sea birds although direct evidence is lacking. After crawlers settle on a host plant, they start feeding on plant sap. They will then develop into second and third instar, third instar being the adult insect. Smith and Papacek (2001a) estimates a 2-month life cycle from crawler emergence to the emergence of the next crawler generation. On Christmas Island, the life cycle was observed to be between 6 and 7 weeks in the laboratory and in the field (G. Neumann, unpublished data).

Pu. urbicola excretes honeydew and is usually associated with ants (Table 1). One of the most common attendants is the invasive big-headed ant, *Pheidole megacephala* Fabricius (Myrmicinae), but a number of ant species, including the invasive yellow crazy ant, *Anoplolepis gracilipes* Smith and the pennant ant, *Tetramorium bicarinatum* Nylander readily attend *Pu. urbicola.* Association with mutualistic ant partners, which provide protection from natural enemies and hygiene, is believed to trigger *Pulvinaria* population explosions and maintain scale insect numbers at outbreak levels. The strong positive relationships between abundance of *Pu. urbicola* and *Ph. megacephala*, and between *Pu. urbicola* abundance and leaf damage to *Pi. grandis* (Gaigher et al. 2011) are consistent with this view. Immature, crawler stages of *Pu. urbicola* are carried by yellow crazy ant workers on Bird Island (Hill et al. 2003) so are probably redistributed and locally dispersed by tending ants.

Pisonia grandis. *Pisonia grandis* forests are distributed pantropically, especially on oceanic islands. This vegetation community has a limited distribution and is threatened worldwide (Batianoff 1999). In Australia, most *P. grandis* forest is located in the Great Barrier Reef islands (~190 ha – Batianioff 1999) and on Pulu Keeling in the Cocos-Keeling Islands in the northeaster Indian Ocean (~95 ha). National Park comprises a large fraction of the reserved *Pi. grandis* forest in Australia across the Pacific and Indian Oceans. *Pi. grandis* forests are structurally and functionally important to these island ecosystems, providing nesting and roosting habitat for a range of seabirds (e.g. boobies, noddies, frigatebirds), regulating understorey vegetation structure and as valuable source of organic material (Smith et al. 2004, Handler et al. 2007). As *Pi. grandis* stands are rare and declining in their native range (Kay et al. 2003), and as they are threatened in the Seychelles (Samways et al. 2010), Palmyra Atoll (Krushelnycky and Lester 2003; Handler et al. 2007), and the Great Barrier Reef (Smith and Papacek 2001), their conservation is of great importance. Pulu Keeling National Park, for example, is the largest rookery of the Red-footed Booby in the Indian Ocean. Nesting birds and *P. grandis* may even have a special relationship where *Pi. grandis* trees provide nesting areas while seabirds provide some level of long distance dispersal for the tree by carrying the sticky seeds of *Pi. grandis* (Burger 2005). *Pi. grandis* flourishes in habitats where the trees receive large amounts of guano and suggested that *Pi. grandis* may have evolved special adaptations to the very high levels seabird-derived N levels in its habitat (Fosberg 1994; Schmidt et al. 2004). This would suggest a highly interdependent relationship between the birds and the tree. Degradation of *Pi. grandis* forest would has implications for these seabirds and potentially degrade the conservation value of the National Park.

Impacts of Pu. urbicola *on* Pi. grandis *forest*. One major threat to *Pi. grandis* forests is dieback. As a phloem-feeding insect, *Pu. urbicola* primarily affects its host plants by consuming photosynthate which would otherwise be used in maintenance, growth, and reproduction by the host plant. Although populations of *Pu. urbicola* are normally kept under control by its natural enemies, this insect can become a serious pest in island ecosystems where its natural enemies are absent. Build-up of *Pu. urbicola* populations often causes tree stress and mortality in *Pi. grandis* across the Indo-Pacific region (Table 1). This can result in substantial forest dieback. *Pu. urbicola* infestations destroyed significant proportions of *Pi. grandis* stands on several islands on The Great Barrier Reef. On Coringa Atoll in the Coral Sea, 80% of the *Pi. grandis* forest was lost in approximately 6 years; 65% of *Pi. grandis* trees were killed on Tyron Island in the Capricornia Group 3 years after the first record of infestation. Defoliation and death of mature trees occurred also on Bird Island (Seychelles) due to heavy *Pu. urbicola* infestation. On the Eastern islet of Palmyra Atoll in the Central Pacific, >50% foliage loss was recorded in 2002 less than a year after the first record of *Pu. urbicola* outbreak (Table 1).

The causes of dieback are complex but invasive tramp ants and honeydew-secreting Hemiptera are implicated in recent episodes of *Pi. grandis* dieback in at least four separate regions: Seychelle Islands in the western Indian Ocean (Hill et al. 2003, Gaigher et al. 2011), Palmyra Atoll in the Line Islands, Central Pacific (Krushelnycky and Lester 2003), Coringa-Herald Cays in the Coral Sea (Smith et al. 2004), and Tryon Island in the Capricorn-Bunker Group of the Great Barrier Reef (Kay et al. 2003) (Table 1). In each of these instances, dieback was associated with outbreaks of the introduced scale insect *Pu. urbicola* in association with a variety of invasive tramp ant species, including the yellow crazy ant (*Anoplolepis gracilipes*), the pennant ant (*Tetramorium bicarinatum*), and the African big-headed ant (*Pheidole megacephala*).

These ant-scale insect associations can result in positive population-level effects that increase and diversify impacts, including dieback of host trees (O'Dowd et al. 2003). *Pi. grandis* forests provide important nesting habitat for seabirds across the Indo-Pacific (Batanioff 1999). The loss of seabird nests on infested *Pi. grandis* stands was described as an effect of the weakening branches due to *Pu. urbicola* infestation. The outbreak was also associated with higher rates of branchfall which, in turn, resulted in the opening of the canopy and loss of shaded areas (Depkin 2002). This opening of the canopy can lead to a shift from closed canopy to open shrubland and loss of nesting sites for seabirds, an issue of concern across the Indo-Pacific region (Table 1).

Natural enemies of Pulvinaria urbicola. Natural biological control of *Pu. urbicola* can be achieved by several natural enemies, most importantly by a few parasitoids and a coccinellid beetle (Smith and Papacek 2001a; Waterhouse and Sands 2001).

Three hymenopteran parasitoids species are known to attack *Pulvinaria* species. *Coccophagus ceroplastae* Howard (Aphelinidae) is a small, black parasitoid considered to be the most important parasitoid of *Pu. urbicola*. It is widespread and attacks several other soft scale species. Another aphelinid wasp*, Euryischomyia flavithorax* Girault, is a small, brow and yellow parasitoid known to occur in Australia and attack *Pulvinaria* species. Its other hosts are in a few genera of soft scales. Lastly, an unidentified *Metaphycus* sp. (Encyrtidae) was found to attack *Pu. urbicola* on Queensland Islands (Smith and Papacek 2001a).

Cryptolaemus montrouzieri Mulsant (Coccinellidae) is an Australian native ladybird beetle most widely used in the biological control of mealybugs (Pseudococcidae). It is a generalist predator; both the larva and the adult feed on mealybugs and young soft scales. It is attracted to the waxy mealybugs and their waxy egg masses. This characteristic makes it a good control agent for *Pu. urbicola* as well: it will not only feed on the young scales but, more importantly, it is greatly attracted to its waxy ovisacs. Interestlingly, the beetle larva mimic mealybugs with waxy secretions. This may allow the larva to feed on mealybug prey even if tending ants are present; ants generally do not attack the larva. This ladybird beetle is credited with knocking down outbreaks of *Pu. urbicola* (Smith et al. 2004). The combination of *C. ceroplastae*, *Metaphycus* sp. and *C. montrouzieri* suppressed populations of *Pu. urbicola* on some islands of The Great Barrier Reef.

Pulvinaria urbicola on Christmas Island

Detection and distribution of Pu. urbicola. *Pu. urbicola* was first detected on *Pi. umbellifera* at two sites on Christmas Island on 1 June 2011; on the east coast approximately 1 km north of Dolly Beach and on the west coast approximately 0.8 km south of Martin Point (Figure 1; Figures 2A, D). Both of the infested areas were small (approx. 0.3 ha) and only a few trees were infested. Distribution of scale insects was extremely patchy among trees and also within trees with approximately 0.5% of leaves (500 leaves inspected in total) infested but with high densities on infested leaves (i.e., 200-300 scale insects/leaf). Approximately 2% of these scales were mature with ovisacs (white, waxy, sac-like structures containing eggs). Parasitism was not detected at either location. At both sites, yellow crazy ant tended the scales. The leaves with scales had at least one ant per mature scale insect and ant traffic was observed on the twigs leading to the infested leaves and some ants were observed carrying immature scale insects.

On 27 June 2011, a heavy infestation of *Pu. urbicola* was discovered on *Pi. grandis* on the south coast just southwest of the "Boulder" (Figure 1; Figure 2B). A rapid assessment of leaves collected from the lower canopy showed that 80% of trees (15 trees inspected in total) had some level of infestation with 5-60% of leaves of each tree infested. The number of mature female scales per infested leaf averaged 41 but variation was high. Approximately 85% of scale insects were mature with ovisacs present. Some fallen leaves with mature scales were also observed suggesting that scale-induced defoliation was occurring. No information is available on the levels of infestation in the high canopy or on the extent of the infested area. Tending by ants was only observed occasionally and at low level with the big-headed ant tending the scales. Although yellow crazy ants were found near this site, tending by this species was not observed. Parasitism rates were 0%.

On 3 July 2011, a large *Pi. grandis* stand near Tom's Point (on Egeria Track, southwest coast – Figure 1) was surveyed and a very high level of infestation was found (Figure 2C). Scale numbers were comparable to those at the Boulder Track site, except that at the center of the infestation (near Waypoint 39) all trees were infested. *Pu. urbicola* was not detected on *Pi. grandis* further southwest (near Waypoint 38). On leaves that could be collected directly from the trees, ~ 80% of scales were mature with ovisacs present. Although the canopy was still fully closed, many leaves with heavy loads of scale insects had fallen, suggesting that scale insect-induced defoliation could result in significant canopy loss. High densities of yellow crazy ant occurred on the ground at the site and foraging trails on the boles of *Pi. grandis* were apparent. It is likely that the yellow crazy ant was tending *Pu. urbicola* in the canopy. No parasitism of *Pu. urbicola* was detected.

Cultivated, herbaceous plants on the island can also be attacked by *Pu. urbicola*. A pumpkin (*Cucurbita pepo* L.), collected near Lilly Beach (northeast coast),was brought in to the CINP at the end of June 2011 with several mature *Pu. urbicola*.

Pu. urbicola is now well established on Christmas Island (Figure 1). *Pi. grandis* has a patchy distribution in terrace forest on Christmas Island; in total, *Pi. grandis* forest probably covers about 20 ha, comprising about 15-20 percent of all *Pi. grandis* forest in the Indian Ocean Territories. *Pu. urbicola* appears to be distributed widely in *Pi. grandis* stands along the island terrace near the coast, although we have made no observations in *Pi. grandis* on much of the south and north coasts. The history of its arrival is unknown. It is difficult to estimate when the first introduction(s) to Christmas Island may have occurred. Under field conditions, immature *Pu. urbicola* are difficult to differentiate from other soft scale species that are present on the island. However, mature females of *Pu. urbicola* with their distinctive white ovisacs are very conspicuous and probably would not have gone undetected during earlier research on the island (e.g. Abbott 2004), although earlier research did not specifically target *Pi. grandis* stands. If so, an introduction or several introduction events happened sometime after 2003. Anecdotal evidence also suggests that *Pu. urbicola* was already present in 2009 when a significant loss of *Pi. grandis* canopy occurred approximately 1 km north of Egeria Point (near Tom's Point) on the coastal terraces (B. Tiernan, pers. comm.). Whether the defoliation was only due to the prolonged drought was not investigated and the scale insect was not identified. The following wet season was unusually long and lasted long into 2010. Scale numbers probably decreased and the insect remained undetected in 2010. With a return to more typical seasonal patterns in 2011, higher scale numbers may have increased the likelihood of detecting *Pu. urbicola*.

We can also only speculate about how *P. urbicola* was introduced to Christmas Island. Long distance dispersal by humans is the most likely pathway and the nursery trade (e.g. flowers) and foodstuffs (e.g. fruits and vegetables) are probably the most likely commodities with which *P. urbicola* would be associated. This is illustrated by interception records for *Pu. urbicola*. Between 1995-2005, *Pu. urbicola* was intercepted at U.S. ports of entry 19 times from 18 countries (http://www.sel.barc.usda.gov/scalekeys/softscales/key/soft_scales/media/html/Species/35Pulv_urbicola/1Pulv_urbicolaDesc.html; accessed 19 July 2011), consistent with the importance of human-assisted dispersal of *Pu. urbicola*. However, long distance dispersal of scale crawlers by seabirds is not impossible given the remote locations of the *Pi. grandis* stands with highest infestation levels and that these areas are all bird nesting locations (J. Hennicke, pers. comm.). Certainly, within-island spread of crawlers of *Pu. urbicola* is possible by both land and seabirds, especially if *Pu. urbicola* is at high densities.

Natural enemies of Pu. urbicola on Christmas Island. Presently, there is no evidence of parasitism in *Pu. urbicola* or significant predation at the known locations on Christmas Island. However, two parasitoids have been collected from the soft scales *Saissetia* sp. and *Coccus* sp. on the island (G. Neumann, unpublished results). They have been tentatively identified as *Coccophagus* sp. and *Metaphycus* sp. *Coccophagus* sp. was collected several times while *Metaphycus* sp. seems very rare. Both wasp species were reared from soft scales collected near Drumsite, and in the laboratory *Coccophagus* sp. successfully parasitized *Pu. urbicola* (G. Neumann, unpublished results). We are awaiting species identification, but this wasp may be *C. ceroplastae*, a known parasitoid of *Pu. urbicola*. *Metaphycus* sp. will be tested as specimens become available.

Potential Impacts on the Indian Ocean Territories

Below, we consider two potential impacts of the establishment of high-density *Pu. urbicola* populations on Christmas Island, and evaluate the threat posed by these infestations on Christmas Island for the Cocos (Keeling) Islands.

Potential impacts on stands of Pi. grandis *on Christmas Island*. The association between dieback in stands of *Pi. grandis* and outbreak densities of *Pu. urbicola* are well documented in the Pacific and Indian Oceans (Table 1; see above). While it is tempting to infer causality, the factors responsible for dieback of *Pi. grandis* forest can be complex and, in addition to scale insect – ant association, have been attributed to a variety of factors including climate change, tree stress, and interactions among these factors (Batianoff et al. 2010). In other words, *Pu. urbicola* may be a 'passenger' rather than a 'driver' of dieback in these stands. On Christmas Island, stands of *Pi. grandis* could be sufficiently healthy and of low resource quality for scales that following an initial outbreak, local scale populations might collapse after defoliating host trees, which then recover. Given the degree and extent of dieback seen on many other islands (Table 1), this scenario seems unlikely.

Based on what is known from other localities and what we have observed already on Christmas Island, further spread of *Pu. urbicola* is expected. At the moment, the majority of observed scales are mature females with ovisacs. Adult female scales collected and brought into the laboratory started to release crawlers suggesting that they are also being released in the field. Given that a single ovisac can contain several hundred to a thousand eggs, we can expect a very high number of crawlers in this generation and the potential for population outbreaks of *Pu. urbicola*. High densities of scale insects can cause defoliation and even death of mature trees (Hill et al. 2003). In the absence of natural enemies of *Pu. urbicola*, populations on *Pi. grandis* could build up on Christmas Island to the point where tree dieback occurs, much like the rapid dieback of *Inocarpus fagifer* in yellow crazy ant supercolonies following sustained high densities of the lac scale *Tachardina aurantiaca* (O'Dowd et al. 2003). As has occurred on other oceanic islands (Table 1), rapid changes in *Pi. grandis* forest following *Pu. urbicola* population buildup could affect stand structure, understorey conditions, and nutrient cycling. In turn, this could influence nesting and roosting sites for seabirds.

Another important potential consequence of high-density *Pu. urbicola* infestation is an increased probability of unintended transfer to other localities on the island currently free of *Pu. urbicola*. High densities of scale insects may also facilitate further dispersal of crawlers by wind and birds both within and between *Pi. grandis* stands and speed spread and impact of *Pu. urbicola*.

Potential impacts on yellow crazy ant supercolony formation. With the saturation of *Pi. grandis* trees by *Pu. urbicola*, alternative hosts might be accepted in which case its impacts could extend. *Pu. urbicola* is a broad host plant generalist with host species occurring in genera with native species on Christmas Island (i.e. *Hernandia*, *Momordica*, *Ipomaea*, *Melochia*, *Premna*, and *Pisonia*), so it could spread to other native plant species on the island. Of particular concern is the detection of yellow crazy ant-tended populations of *Pu. urbicola* on *Pi. umbellifera*, a congener of *Pi. grandis* (see above, Figure 2A,D). Unlike *Pi. grandis*, *Pi. umbellifera* is a widespread, dominant tree in both terrace and plateau rainforest (Mitchell 1975). This could result in a new, significant source of honeydew for tending ants. It is not currently considered a main player in the dynamics of yellow crazy ant supercolonies, because it has not been recorded as hosting high densities of honeydew-secreting scale insects (Abbott 2004, G. Neumann unpublished results, Green & O'Dowd pers. obs.). However, *Pi. umbellifera* infested with *Pu. urbicola* have been found above the shore terrace at approx. 100 m ASL, and *Pu. urbicola* can easily be established on *Pu. umbellifera* seedlings under experimental conditions (Figure 3). Furthermore, the establishment of *Pu. urbicola* on *Pu. umbellifera* in rainforest across the island could increase the probability of supercolony formation by yellow crazy ant.
Potential implications for Cocos (Keeling) Islands and Pulu Keeling National Park. A rapid survey on Pulu Keeling in May 2011 found mealybugs (Pseudococcidae) as mutualistic partners for the yellow crazy ant but none of the "problem scales" known on Christmas Island (G. Neumann, unpublished results). The mealybug - yellow crazy ant association on Pulu Keeling is limited to coconut groves and to mixed coconut/*Pi. grandis* stands. No scale insects were found on *Pi. grandis*. In the event that *Pu. urbicola* finds its way to Pulu Keeling, it would encounter a preferred host plant (*Pi. grandis*) in presence of a known ant mutualist (Slip and Comport 2001; Hill et al. 2003, Gerlach 2004) and in the likely absence of significant natural enemies. *Pi. grandis* dieback could follow and degrade this largest stand of *P. grandis* in the Indian Ocean and affect the largest breeding ground of the Red-footed booby (*Sula sula*) in the Indian Ocean.

The probability of human-assisted introduction of *Pu. urbicola* from Christmas Island to Pulu Keeling is very low because there is no direct human traffic between them. The scale would have to arrive first on West Island of the southern atoll, where there currently is only a handful of isolated *Pi. grandis* trees. However, current re-vegetation efforts on Cocos (Keeling) Islands (http://parksaustralia.govspace.gov.au/2011/07/22/revegetating-parts-of-cocos/; accessed 26 July 2011) to reestablish *Pi. grandis* might increase the both probability of establishment of *Pu. urbicola* in the southern atoll and jump dispersal to Pulu Keeling.

Furthermore, a direct pathway may exist for jump dispersal of *Pu. urbicola* from Christmas Island to Pulu Keeling. Pelagic seabirds, including the Red-footed Booby and Greater Frigatebird (*Fregata minor*) , can travel great distances between breeding colonies and bird movements between Christmas Island and Pulu Keeling are likely to occur (J. Hennicke, pers. comm.). Assuming an average travel speed of 16 km/h (*F. minor*) and 20-40 km/h (*S. sula*), a bird from Christmas Island could reach Pulu Keeling (approx. 970 km from Christmas Island) within 60 h and 24-49 hours, respectively. No information is available on the survival of crawlers travelling in the protective plumage of a bird by seabirds, but they can survive for days. Christmas Island is now the closest land area to Cocos (Keeling) Islands with *Pu. urbicola* infestation and, therefore, it is likely the most probable future origin of introduction.

Management options

Upon the detection of a new invasive species, the first option to consider by management is to 'do nothing'. This approach assumes a high level of confidence that the new invader will have no detectable (or very minor) ecological impacts, or that if initial impacts are large, the native community has sufficient resilience to rebound to its pre-invaded state once native natural enemies or other limiting factors bring the invader under some form of control. It further assumes that the novel invader will not contribute to existing invasions and exacerbate their impacts. Everything we know about *Pu. urbicola*, from elsewhere and from limited observations on Christmas Island, suggest that such assumptions are unwarranted. *Pu. urbicola* has been linked repeatedly with persistent forest dieback in *Pi. grandis* stands, could exacerbate yellow crazy ant supercolony formation and impacts on Christmas Island, and presents a possible risk to biodiversity values in the Pulu Keeling National Park. Below we canvas four options, which are not mutually exclusive, for management action.

1. *Monitoring and surveillance.* A simple but well-designed monitoring program could be developed to determine the status and dynamics of *Pu. urbicola* on *Pi. grandis*. Rapid survey of *Pi. grandis* stands has already led to discovery of new infestations of *P. urbicola* and estimated its distribution, phenology, abundance, damage levels to *P. grandis*, ant association, and abundance of natural enemies in the Capricornia-Bunker Group (Kay et al. 2003), Coral Sea atolls (Smith et al. 2004), and Palmyra Atoll (Krushelnycky and Lester 2003) for well over a decade. A similar standardized 'rapid survey' in *Pi. grandis* stands on Christmas Island could be incorporated as part of the overall ant management program and surveillance for *Pu. urbicola* could be included in the Island-wide Survey. Furthermore, CINP staff could target surveillance for *Pu. urbicola* on congeneric *Pi. umbellifera*, especially in the vicinity of stands of *Pi. grandis*.

2. *Improvement of within and between island quarantine.* The detection of infestations of *Pu. urbicola* has implications for intra- and inter-island quarantine. First, movement and sanitary protocols for CINP staff and other forest workers could be developed to minimize risk of spread of *Pu. urbicola* around Christmas Island. For example, to decease the probability of transporting crawlers, personnel working in and around known infestations (e.g. during the Island-wide Survey) could avoid visiting other, susceptible uninfested sites within 24 hours and clothing changed. Should nursery workers visit infested sites, movement should be "one way" – from nursery to field, but not back to nursery, to avoid infecting nursery stock. Furthermore, plants in the nursery should be checked periodically for *Pu. urbicola* infestation and treated chemically if necessary.

   Second, any increase in the distribution and abundance of *Pu. urbicola* on Christmas Island could increase the risk of spread to the Cocos (Keeling) Islands. Although spread of *Pu. urbicola* by birds (if it occurs at this large spatial scale – see above) cannot be controlled, human movements can be modified to minimize risk of spread. This should focus attention on inter-island quarantine and movement controls. At present, human-assisted transport of *Pu. urbicola* is unlikely given that *Pu. urbicola* infestations are at remote locations on Christmas Island. However, with a re-vegetation project underway on Cocos(Keeling) Islands, access to the re-vegetation nursery, which primarily uses *Pi. grandis,* in the Cocos Islands should be restricted. Further, it is advisable that seedlings and saplings in the nursery, and "plant outs" in re-vegetated areas undergo regular inspections for *Pu. urbicola*. Personnel in contact with *Pi. grandis* on the southern islands should not travel to Pulu Keeling within 24 hours of contact. No clothing or equipment in contact with the nursery should be transferred to Pulu Keeling.

3. *Chemical control.* At present, there are no feasible chemical options available for direct control of *Pu. urbicola* at the landscape scale. In situations where *Pu. urbicola* is tended by high densities of ants, indirect control may be achieved through the use of toxic baits against tending ants (Abbott and Green 2007). Further, chemical suppression of tending ants has been used on the Coral Cay islands (Smith et al. 2004) for the release of a biocontrol agent against *Pu. urbicola*, because of concerns that foraging ants may protect scales from attack. So far there are few ants tending *Pu. urbicola* outbreaks on Christmas Island, but should the need arise for their chemical control, careful consideration would have to be given to access issues to remote stands of *Pi. grandis*, and depending on the species of ant(s) acting as mutualist(s), and the most appropriate bait formulation and permitting regulations for its use.

4. Biological control. The redistribution or introduction of natural enemies to suppress populations of *Pu. urbicola* could provide a sustainable mechanism to suppress populations of *Pu. urbicola* and minimize impacts. Below we outline two possible approaches based on the manipulation of existing natural enemies on Christmas Island and the introduction of new control agents.

Redistribution of a control agent already present on Christmas Island. As discussed above, the parasitoid *Coccophagus* sp. attacks *Pu. urbicola* under laboratory conditions (G. Neumann, unpublished results). Since this parasitoid already occurs on the island, inoculative releases could be made at infested *Pi. grandis* stands. Although a quick knockdown of *Pu. urbicola* populations is unlikely, assisted dispersal of the parasitoid to infested sites could decrease the time needed for effect. The resources required to implement such a program should be relatively modest, including staff and nursery space for rearing *Coccophagus* sp. on *Pu. urbicola*, release, and monitoring establishment and impact.

Introduction of a new control agent. The addition of a generalist predator with the potential for quick knockdown of outbreaks of *Pu. urbicola* could facilitate any biological control effort made with parasitoids. The predator *Cryptolaemus montrouzieri* (Coccinellidae) is an obvious candidate. *C. montrouizeri* is known to attack mealybugs and young soft scale (http://www.biocontrol.entomology.cornell.edu/predators/Cryptolaemus.html; accessed 27 July 2011) and is often referred to as a mealybug/soft scale insect specialist. *C. montrouizeri* prefers to lay eggs on or near the waxy filaments of its prey (Merlin et al. 1996) and it is attracted to the waxy, cottony ovisacs of *Pu. urbicola*. It has been imported from its native Australia into over 40 countries and proved a very effective control agent in many cases, including suppressing populations of *Pu. urbicola* on oceanic islands (Booth and Pope 1986 and references therein; Smith and Papacek 2001a,b,c; Smith et al. 2004).

C. montrouizeri would appear to be the most promising available agent to combat an existing *Pu. urbicola* outbreak, but as a generalist predator, a detailed risk assessment of non-target impacts and food web effects would be essential prior to any decision on its release. On Christmas Island, intensive searches over one year has not yielded any evidence for the presence of any endemic, non-target mealybugs or scale insects that could be attacked by *C. montrouizeri* (G. Neumann, unpublished results). Non-target impacts of *C. montrouizeri* in the field have not been reported elsewhere; however, *C. montrouizeri* has been successfully reared in the laboratory on the eggs of a small moth, *Sitotroga cerealella* Olivier (Gelechioidae) but only when empty ovisacs of scale insects are available for oviposition (Mineo 1967). Thus, establishment and persistence of beetle populations in areas without wax-secreting Hemiptera appears unlikely.

Pu. urbicola is usually tended by ants which can interfere with the natural enemies of honeydew-secreting Hemiptera (e.g Bach 1991). Interestingly, *C. montrouizeri* larvae are generally not attacked by ants tending mealybugs. Although there are some reports of tending ants attacking adult *C. montrouizeri* (Way 1963), other studies show that this predator can forage effectively in patches of ant-tended mealybugs (Daane et al. 2007). Long-term establishment of beetle populations could require local chemical suppression of tending ants as has been done in the successful establishment of *C. montrouizeri* elsewhere (Smith et al. 2004).

Development and implementation of survey and monitoring of *Pu. urbicola*, as well as movement and sanitary protocols could be implemented immediately at modest cost to CINP.

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Table 1. Reported direct effects of outbreaks of *Pulvinaria urbicola* on *Pisonia grandis* forests across the Indo-Pacific region. These damaging direct effects subsequently alter habitat structure, nutrient cycling and understorey conditions and also can affect nest availability of seabirds. All of the listed ant associates also occur on Christmas Island (Frameneau and Thomas 2008).

Location	**Ant associates**	***Pulvinaria* impacts**	**References**
Capricornia-Bunker Cays (Australia)	*Pheidole megacephala*	Tree death, 87% forest loss	Olds et al. 1996; Keys et al. 2003
Coral Sea Cays (Australia)	*Tetramorium lanuginosum, T. bicarinatum*	Tree death, 100% forest loss	Smith & Papacek 2001a,b,c; Smith et al. 2004
Palmyra Atoll (USA)	*P. megacephala*	Tree death, 30% forest loss	Handler et al. 2007
Cousine Island (Seychelles)	*P. megacephala*	Increased *Pisonia* leaf damage	Gaigher et al. 2011
Bird Island (Seychelles)	*Anoplolepis gracilipes*	Increased leaf damage, tree death; reduced foliage cover	Hill et al. 2003 ; Gerlach 2004

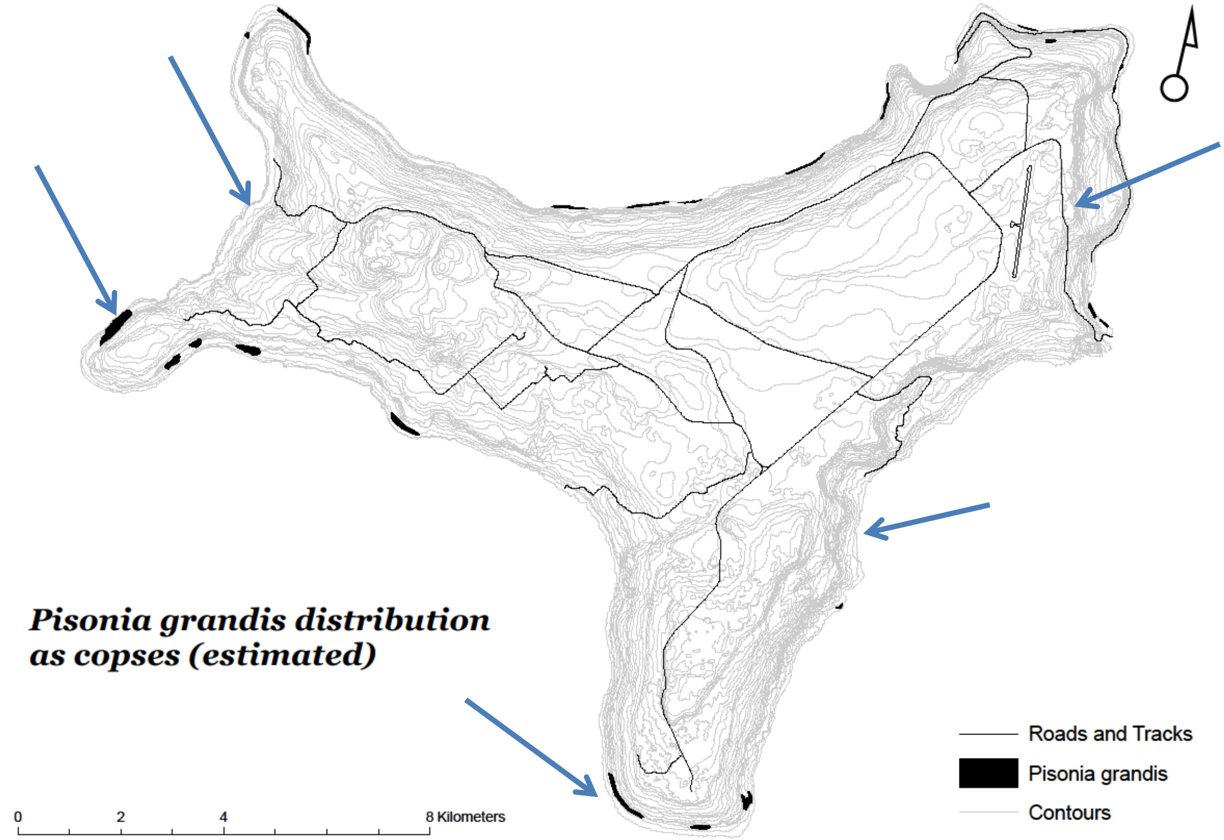

Figure 1. Estimated locations of major, known *Pisonia grandis* stands on Christmas Island. The arrows indicate locations where *Pulvinaria urbicola* was discovered between 1 June and 3 July 2011.

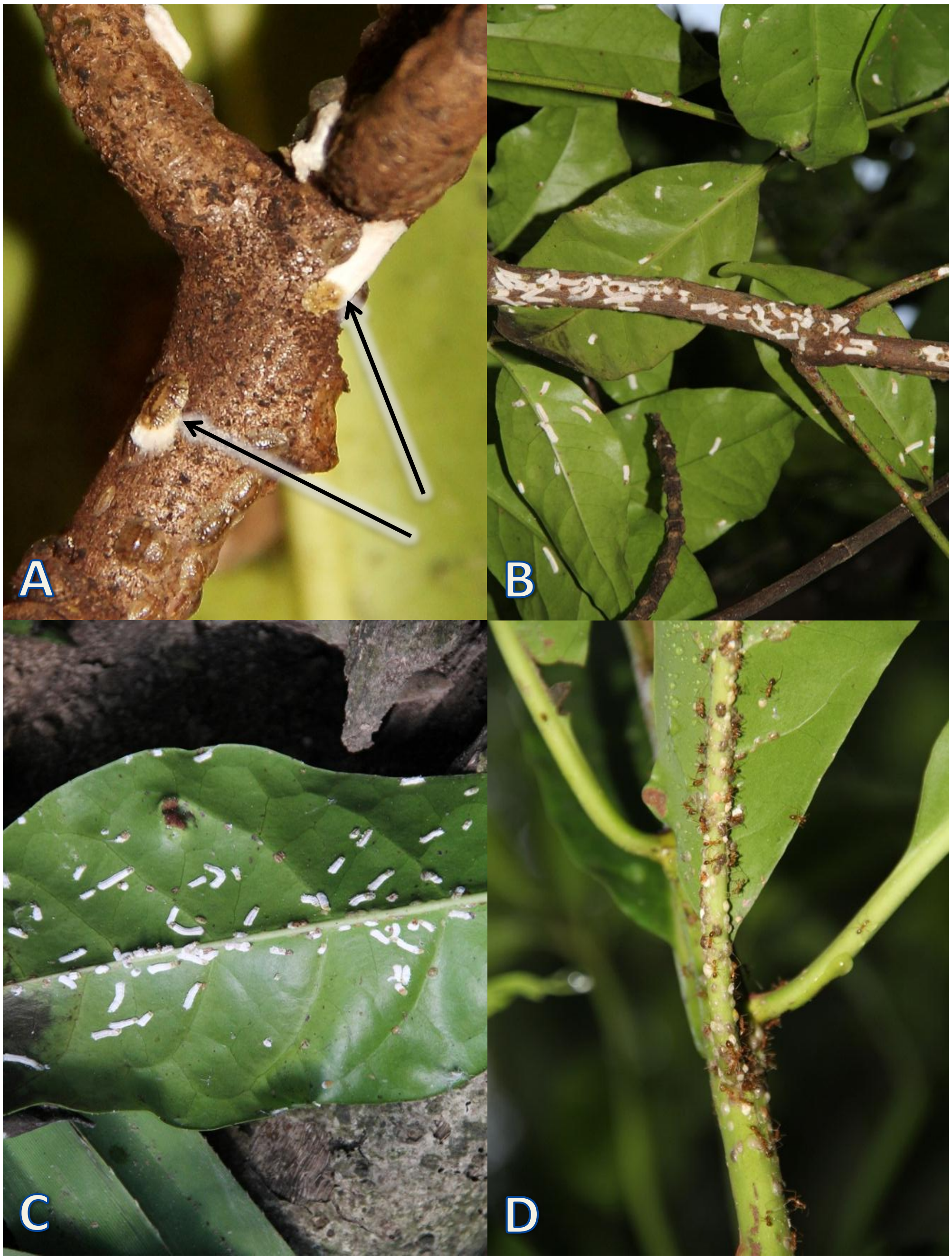

Figure 2. *Pulvinaria urbicola*. (A) *Pu. urbicola* on *Pisonia umbellifera.* Arrows indicate females with and without developing ovisac.(B) *Pu. urbicola* on *Pi. grandis* twigs and leaves. (C) *Pu. urbicola*, many with ovisacs, on a *Pi. grandis* leaf. (D) Yellow crazy ants tending *Pu. urbicola* on *Pi.umbellifera*.

Figure 3. A comparison of laboratory-maintained seedlings of *Pisonia umbellifera*, a dominant forest tree on Christmas Island, seven weeks after inoculation with *Pulvinaria urbicola* (A, uninoculated; B, inoculated). Mature females of *Pu. urbicola* are indicated by the white egg-containing sacs on the stems, and petioles and midribs of leaves. Note decreased stature, leaf yellowing and leaf fall of seedlings inoculated with *Pu. urbicola*.

A A B B