



Generic Pest Risk Assessment: Armoured scale insects (Hemiptera: Coccoidea: Diaspididae) on the fresh produce pathway



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Cover photo

Heavy infestation of *Pseudaulacaspis pentagona* on commercial *Actinidia chinensis* 'Hongyang' fruit,
Sichuan, China. Photo credit: Garry Hill, Plant & Food Research

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New Zealand is a member of the World Trade Organisation and a signatory to the Agreement on the Application of Sanitary and Phytosanitary Measures (“The Agreement”). Under the Agreement, countries must base their measures on an International Standard or an assessment of the biological risks to plant, animal or human health.

This document provides a scientific analysis of the risks associated with a family of scale insects (the armoured scales - Diaspididae) on the fresh produce pathway. It assesses the likelihood of entry, exposure, establishment and spread of diaspidids in relation to imported fresh produce and assesses the potential impacts of those organisms should they enter and establish in New Zealand. The document has been internally and externally peer reviewed and is now released publically. Any significant new science information received that may alter the level of assessed risk will be included in a review, and an updated version released.

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1.1 SUMMARY

1. Diaspidids (or armoured scale insects; Hemiptera: Coccoidea: Diaspididae) are some of the most common organisms identified at the New Zealand border. A range of exotic species are regularly identified, including live specimens from all lifestages. Species from the related coccoid families Pseudococcidae (mealybugs) and Coccidae (soft scales) are also very commonly detected.
2. The large majority of diaspidid identifications (over 80%) are associated with the commercial fresh produce pathway. The level of biosecurity risk posed by diaspidids on imported fresh produce is examined in this analysis.
3. **The likelihood of entry** of diaspidids on fresh produce is commodity-dependent and is considered to range from negligible to high.
4. **The likelihood of exposure**¹ of diaspidids on commercial fresh produce is considered to be a critical step limiting their ability to establish in New Zealand. This is due to their specialised biology: most lifestages are sessile, are attached to the host commodity and will die as the host decomposes. Only first instar “crawlers” and adult males are mobile. Both lifestages are unlikely to survive production and transit due to their small size and fragile nature. However, crawlers may emerge from eggs laid by mature, mated or parthenogenetic females once they have crossed the border. They must then escape the host commodity and survive to locate and successfully settle on a suitable host plant in New Zealand. The proportion of imported hosts that are both infested with mature reproducing females and are disposed of in a manner that allows this to occur is likely to be very low.

Therefore the likelihood of exposure on fresh produce is considered to range from negligible to low (at highest). Any practices which involve concentrating imported infested fresh produce within close proximity of suitable hosts (*e.g.* repacking of imported produce in packhouses, followed by disposal of rejects in orchards) may result in an increased likelihood of exposure.

5. **The likelihood of establishment**² **and spread** of diaspidids in New Zealand is species-specific and is considered to range from negligible to high³. For establishment to occur, crawlers released from imported females must survive to maturity and must successfully reproduce. Asexually reproducing species are considered to have a higher likelihood of establishment than sexually reproducing species, since only one individual is required to found a reproducing population. For sexually reproducing species, at least one crawler of each sex must survive to sexual maturity, following which a male must locate a female, mate, and the female must produce viable offspring. The low likelihood of this series of events occurring successfully within a small number of founding individuals is likely to be an important barrier to establishment.

Some factors influencing the likelihood of establishment also influence those of exposure and extent of spread. The rate of spread varies from low (by walking) to high (wind or vector-assisted or by movement of infested plant material). Species that have a largely tropical, subtropical or warm temperate

¹ the initial biological pathway from the imported commodity to a new host.

² defined as the the perpetuation of the species to which the organism belongs within an area for the foreseeable future.

³ considered here across all pathways

distribution may have limited to extremely limited distributions within New Zealand, or may be able to establish only in sheltered habitats or greenhouses.

However it is important to note that crawlers produced by imported females are less likely to be successfully exposed to plants in domestic or commercial greenhouses than to outdoor hosts. In order for successful exposure to take place in this situation, either crawlers must be transported into greenhouses by vectors or by wind; or imported infested fresh produce must be taken into these places and discarded in close proximity to suitable hosts. Both scenarios are considered to be extremely unlikely. After establishment, spread through domestic and commercial greenhouses throughout much of New Zealand may occur by the movement of infested plant material. The level of phytosanitary hygiene in commercial operations is generally higher than in domestic situations and colonisation may therefore be less likely.

6. **The economic, environmental, socio-cultural and human health impacts** of establishment of any particular diaspidid are species-specific and are independent of the commodity association/pathway. Only a relatively small proportion of known diaspidid species have been reported as agricultural or horticultural pests of consequence.
7. Seven exotic diaspidid species are known to have been accidentally introduced into New Zealand in the last fifty years, one of which was eradicated. Six of these introductions are very likely to have resulted from the legal or illegal movement of plant material for planting ('plants for planting' or 'nursery stock'). The last known exotic armoured scale species introduction that could reasonably be attributed to trade in fresh produce was that of *Hemiberlesia lataniae* in 1977, however this species could equally have been introduced along the cut flower/foilage or nursery stock pathways.
8. Other coccoids⁴ such as mealybugs (Pseudococcidae) and soft scales (Coccidae) differ from diaspidids in that all lifestages are able to move, albeit to a limited extent. Some evidence suggests that mealybugs and soft scale insects are very similar to diaspidids in terms of likelihood of exposure via the fresh produce pathway; that is, successful dispersal from the point of entry is most likely to take place at the crawler stage. The increased mobility of the nymphal stages is likely to result in a slightly increased likelihood of exposure for mealybugs and for soft scale (coccid) species that are similar to mealybugs; however an analysis of interception and establishment records would be needed to confirm this.
9. Pest risk assessments for five coccoid (Superfamily Coccoidea) species have been carried out (see Appendices 2 to 6). Three diaspidids or armoured scales are assessed: (*Chrysomphalus aonidum*, *C. dictyospermi* and *Pseudaulacaspis pentagona*). Two commonly intercepted non-diaspidid coccoids are also assessed for comparison: one coccid or soft scale (*Ceroplastes rubens*) and one pseudococcid or mealybug (*Maconellicoccus hirsutus*). These assessments are summarized in Table 1.

⁴ Coccoidea is the superfamily which contains, among many others, the families Diaspididae, Pseudococcidae and Coccidae.

**Table 1: Summary of Pest Risk Assessments:
Five coccoids on the imported fresh produce for consumption pathway**

Species	<i>Chrysomphalus aonidum</i> (Diaspididae)	<i>Chrysomphalus dictyospermi</i> (Diaspididae)	<i>Pseudaulacaspis pentagona</i> (Diaspididae)	<i>Ceroplastes rubens</i> (Coccidae)	<i>Maconellicoccus hirsutus</i> (Pseudococcidae)
Likelihoods					
Entry	Negligible to moderate	Negligible to moderate	Negligible to high	Negligible to low	Negligible to moderate
Exposure	Negligible to low	Negligible to low	Negligible to low	Negligible to low	Negligible to low
Establishment and spread	Low; very restricted distribution	Low to moderate (P) ¹ : very restricted distribution	Low; restricted distribution	Low to moderate (P); very restricted distribution	Low to moderate (P); very restricted distribution
Consequences					
Economic	Low	Low	Moderate	Low	Low
Environmental	Low	Low	Low	Low	Low
Socio-cultural	Negligible	Negligible	Negligible	Negligible	Negligible
Human Health	Negligible	Negligible	Negligible	Negligible	Negligible

¹(P); parthenogenetic populations

1.1.1 OVERALL CONCLUSION

Exotic diaspidid species are unlikely to be successfully introduced into New Zealand along the fresh produce for consumption pathway. This conclusion is supported by analysis of the biology and life history of these insects, the attributes of the fresh produce pathway and the invasion history of exotic diaspidids in New Zealand.

Key points:

1. The exposure step is limiting: the specialised biology of diaspidids suggests that the likelihood of successful introduction of these insects via the specific pathway of fresh produce commercially imported for human consumption will always be limited by the exposure step (that is, the initial biological pathway from the imported commodity to a new host).

The proportion of imported hosts that are both infested with mature reproducing females and are disposed of in a manner that allows exposure to occur is likely to be very low.

2. The establishment step is limiting: in addition, at least one crawler of each sex must survive to sexual maturity, following which a male must locate a female, mating must occur, and the female must produce viable offspring. The low likelihood of this series of events occurring successfully within a small number of founding individuals is likely to be a very important barrier to the introduction of new exotic diaspidid species via the fresh produce pathway.
3. A retrospective analysis of diaspidid invasions in New Zealand suggests that the most likely pathway for the introduction of these insects in recent times is via the legal or illegal movement of plant material for planting.

Uncertainty associated with this conclusion is based on the increasingly high volume of produce that moves along the commercial fresh produce pathway, the changing nature of international trade, data gaps relating to the disposal of imported fresh produce (especially by industry), and the inherent problems involved with using interception data.

1.2 PURPOSE AND SCOPE

This document examines the likelihood of exotic armoured scale insects (Family Diaspididae) being successfully introduced into New Zealand via importations of fresh produce (FP). Fresh produce is defined as commercially produced fruit and vegetables (including leafy vegetables such as island cabbage and curry leaves), imported for human consumption.

Diaspidids and other coccoids (particularly mealybugs and soft scale insects) commonly appear on the pest lists of Import Health Standards (IHSs) for fresh produce commodities. It is apparent there is some inconsistency in the way these organisms are managed on different fresh produce pathways. The reasons for this are unclear and may not be related to the level of risk they pose. Five species (three diaspidids, a soft scale and a mealybug) that appear on the pest lists of a number of IHSs and show such inconsistencies are assessed as examples in Appendices 2 to 6.

The purpose of this analysis is to assess the likelihood of exotic diaspidids being successfully introduced into New Zealand along the fresh produce pathway in order to:

- assist in determining whether current risk management is appropriate
- inform future risk management decisions to improve consistency across the pathway.

The scope of this analysis is limited to diaspidids on imported fresh produce. Two other high-profile coccoid families (mealybugs and soft scales) are also commonly intercepted on fresh produce. These families are closely related and biologically similar to diaspidids and are also referenced for comparative analytical purposes.

1.3 INTRODUCTION

Coccoidea are plant-sucking hemipterans (very roughly, scale insects and mealybugs). There are around 20 families and of these, the most common pests are from three families: the armoured scales (Diaspididae, referred to here as diaspidids), the mealybugs (Pseudococcidae) and the soft scales (Coccidae) (Hodges 2005). Most regulated coccoid taxa (species or genera) are in these three families (Diaspididae 291, Pseudococcidae 228 and Coccidae 145; BRAD 2014). Pseudococcids and diaspidids are the two families most commonly intercepted on fresh produce (see Section 1.5.1).

1.4 BIOLOGY OF ARMoured SCALE INSECTS

Diaspidids are extremely specialised insects. The number of immature instars has been reduced to two in the female, which has no pupal stage. In the male, there are 2 feeding nymphal instars followed by two non-feeding stages (pre-pupa and pupa) before a winged adult male emerges (Watson 2005). Other than the adult male, the only mobile stage is the first instar (or crawler) of both sexes, which has legs and can crawl. After hatching, crawlers disperse to locate a suitable feeding site, on which

they settle permanently. The length of this dispersing stage is very short, approximately 24 hours (Greathead 1972, 1990; Willard 1973). Settled crawlers then construct a cap from the moulted skin of the previous instar, incorporating waxy secretions. Females do not move again in their lifetime. **Diaspidids are thus unusual among insects in that they have only one brief opportunity to disperse during their life cycle.** Their mouthparts are highly adapted for piercing and sucking plant sap; these activities deplete the host plant's resources and may also distort plant tissues and/or transmit plant diseases. Adult males have degenerate mouthparts and do not feed; they are consequently short-lived and are seldom collected (Watson 2005).

Diaspidids are found in all ecozones except for Arctic and sub-Antarctic habitats, though most species are probably native to the tropics (Gill 1997).

Reproduction is usually sexual, but asexual reproduction by parthenogenesis is not uncommon. Brown (1965, cited by Watson 2005) found that, in 133 species examined, 17% were either entirely parthenogenetic or had some parthenogenetic populations; this may be an over-estimate (Nur 1990, cited by Watson 2005). There is some evidence that species that can reproduce parthenogenically are more likely to be invasive, for example Hoffmann *et al.* (2008) found that pest species in several insect orders displayed high incidences of parthenogenesis. However, although some of the most serious exotic pest species in New Zealand (including *Aspidiotus nerii*, *Diaspidiotus ostreaeformis*, *Lepidosaphes ulmi*, *Hemiberlesia rapax* and *H. lataniae*) may be, or are completely, uniparental, most of the exotic diaspidid species in New Zealand are biparental (Charles & Henderson 2002).

1.5 GENERIC PEST RISK ASSESSMENT: DIASPIDIDS ON THE FRESH PRODUCE PATHWAY

1.5.1 Likelihood of entry

Information from interception data:

Diaspidids are some of the most common organisms identified on imported fresh produce at the New Zealand border⁵. The MPI identification database⁶ contains records of identifications on all pathways⁷ from 1988. In February 2014, this database contained records of 138,933 identifications⁸ of organisms belonging to 1055 families of plants and animals (ranging from viruses to reptiles). An analysis of this data found that 7169 identifications⁹ of the total of 138,933 (5.1%) were diaspidids.

Pseudococcidae (mealybugs) was the most commonly identified family (all pathways; 10762/138,933 identifications or 7.7%), with diaspidids the second most commonly identified family and Coccidae (soft scales) the 21st most commonly identified (1107/138933 identifications or 0.8%). The relative importance of the diaspidids at the border does not appear to have changed in recent times; Keall (1980) stated that diaspidids were the most common family intercepted at the New Zealand border “over the last 20 years”.

⁵ Including post-border detections (e.g. in imported fruit in supermarkets or reported by consumers)

⁶ MPI (2014): Ministry for Primary Industries Identification database, downloaded 14 January 2014.

⁷ There are 4 broad categories of pathway that are managed by MPI: cargo, passengers, mail and craft. Each of these is subdivided into segments. The fresh produce pathway is a segment of the cargo category; other segments in this category that involve the importation of plant material are: nursery stock, cut flowers/foilage, seed-for-sowing, grain for consumption, feed or processing and processed plant material, including growing media.

⁸ The number of detections, organisms or interceptions may be different from the number of identifications

⁹ As of February 2014, this represents 85 species identified at the border. 1927 of 7169 detections (27%) were identified to family (Diaspididae) only, and 337 of 7169 detections (4.7%) were identified to genus level only.

When diaspidid identifications (MPI 2014) are analysed by pathway, the majority (about 5800 of 7169, ~81%) were detected on the commercial fresh produce pathway, 2.9% on “plant material”, 1.8% on nursery stock and 1.5% on cut flowers/foilage (see Appendix 1). The high detection rate on fresh produce is unsurprising, since fresh produce is one of the most carefully inspected pathways and also comprises the greatest volume of the biological pathways, and this data is uncorrected for volume. This means that although it is an important source of information about the kinds of organisms arriving at the border on any particular pathway, the data cannot be used quantitatively. Additionally, it cannot be assumed that if an organism is on a pathway there will be interception data to show this. Even rigorous quarantine inspections only detect a portion of contaminants (up to half, Work *et al.* 2005). Of the 31 species of exotic diaspidid established in New Zealand, almost 40% (12/31) have not been identified on any pathway (Appendix 1, Table 2). This is reasonably consistent with an analysis of exotic scolytine (bark and ambrosia) beetles established in New Zealand, which found that over 50% (6/11) had never been reported as interceptions at our border (Brockerhoff *et al.* 2006). Lack of identifications at the border does not however necessarily mean the species has not been detected: more than a quarter (26.7%; 1927 of 7169) of diaspidids detected at the New Zealand border were only identified to family level (MPI 2014 dataset). The most common reason that any intercepted specimen is not identified is that it is dead, because it then presents no immediate phytosanitary danger, although the presence of dead organisms on a pathway can be important in a risk context.

Viability: Although dead specimens do not present an immediate phytosanitary risk, determining viability for individual diaspidids can be difficult due to their morphology (the body is protected by a waxy cap) and their sessile habit¹⁰. Moreover, because there may be multiple specimens in each interception event, and viabilities may differ within an event, it is only possible to get a very rough indication of the proportion of diaspidids that were alive when intercepted at the border.

When viability information for diaspidids on fresh produce was analysed for an MPI data set comprising diaspidid identifications from 1988 to 2010, data for 3330 interception events was available. In 1504 (around 45%) of these events, some or all of the diaspidids were recorded as “alive” or “viable”. Where identification is not made to species or genus level the quarantine status of the organism may be unclear. In such cases, and when the specimens are considered to be viable, a precautionary stance may be taken by treating these organisms as if they are quarantine pests which require treatment.

Entry by lifestage: Crawlers and males are short-lived and fragile. The likelihood of their surviving harvesting of the export crop, various industry practices (that may include cleaning, pressure washing, bathing, brushing, and culling), packing and international transport is very low. However, eggs are likely to hatch en route or on arrival, and crawlers are often found protected by the scale cover with adult females post border (pers. comms., S. George 2010, J. Richmond 2014; IDC, MPI), although they are not often specifically recorded in interception data. An aggregated distribution is typical for many diaspidid species (Wright & Diez 2005) and females usually produce offspring continuously over several weeks (Kotega 1990, cited by Morse *et al.* 2009), so the occurrence of more than one lifestage together on one piece

¹⁰ However, the presence of live crawlers often allows viability to be confirmed and additionally an enzyme-based live/dead test has been developed by AgResearch. This test is available for use where a decision to treat based on viability is required (A. Flynn, pers. comm., September 2014).

of fruit is very likely. This is also supported by interception data; records show that aggregations and mixed lifestages are relatively common.

Factors influencing the likelihood of entry: the likelihood of entry for any particular live diaspidid species on any particular consignment of fresh produce is dependent on:

- the host status of the commodity with respect to the diaspidid species
- population levels in the country of origin
- in-field controls and production systems
- end-point treatments
- length of transit and transit conditions
- the architecture of the commodity: diaspidids will be easier to detect on architecturally simple, smooth-skinned commodities (*e.g.* citrus¹¹, nectarines) than on complex commodities such as grapes.
- the physical characteristics of the diaspidid species (*e.g.* size, colour) that influence visual detectability
- the volume of host imported.

1.5.1.1 Entry conclusion

Interception data indicate that viable exotic diaspidids (including species already established) arrive very regularly at the New Zealand border on the fresh produce pathway. The rate of arrival is country/commodity dependant. The lifestages that are detected most commonly are adult females, but detections of mixed lifestages, particularly adult females and eggs, appear to be relatively common. Diaspidids are frequently detected in aggregations *i.e.* they are not homogeneously distributed through the commodity.

The likelihood of entry of diaspidids on fresh produce is commodity-dependent¹² and is considered to range from negligible to high.

1.5.2 Likelihood of exposure

Exposure is defined here as the point at which a contaminating organism becomes associated with a host in New Zealand in a manner that allows it to complete a normal life cycle (*i.e.* the biological pathway from the commodity a hazard organism arrives on to another host). It is one of the critical steps for establishment (the perpetuation of the species to which the organism belongs within an area for the foreseeable future).

The likelihood of exposure is dependent on the species' biological factors, risk analysis area factors (*e.g.* climate conditions, host availability *etc.*) and commodity/pathway factors. Successful exposure depends on *i*) dispersal from the pathway (infested commodity) and *ii*) the location of suitable hosts. Due to their unique biology, the potential for dispersal from the pathway in diaspidids is highly dependent on the life stage and sex. The only mobile stages are crawlers (first instar nymphs) and adult males, the latter being the only winged stage and unlikely to remain associated with the infested commodity due to their fragility. All other immature stages and adult females are immobile, and would die once the imported fruit they were attached to was either consumed or decomposed to the point where it was no longer a suitable host. Crawlers may hatch in transit, or once past the border.

¹¹ scales on these fruit may be hidden under the calyx but this is a site that appears to be targeted by inspectors (J. Richmond, pers. comm. 2014).

¹²Including other factors intrinsic to the particular imported commodity, such as where it came from, how it was produced, how it was transported

Successful exposure is therefore highly likely to depend on the importation of lifestages which are able to produce crawlers either in transit or once past the border. This could be achieved by mated females, unmated parthenogenetic females or dead females with viable eggs remaining on fruit to the point of post-border disposal. Additionally, crawlers could be produced if fruit was infested with at least one immature of each sex (or females only for parthenogenetic species), if these stages were able to survive to maturity on fruit and to then mate.

Species which have aggregated distributions (such as diaspidids) have a higher probability of introduction into new areas via trade than do solitary species, due to the heightened likelihood of their locating a mate in the new environment (Yamamura & Katsumata 1999). From post border distribution of fruit, the likelihood of successful exposure depends on:

- longevity of the host (infested imported commodity)
- host disposal methods
- active and passive dispersal ability of crawlers, and
- mortality at the crawler stage.

These factors are discussed in the following sections.

(i) Longevity of the host

Diaspidids produce 1 to 10 eggs daily and females usually produce offspring continuously over several weeks until their death (Koteja 1990, cited in Morse *et al.* 2009). Therefore it is likely that crawlers will be produced by a mature female diaspidid for as long as the host fruit remains in good condition, which would vary depending on the type of fruit and the ambient conditions. While cool-stored fruit will remain in good condition longer, any associated poikilotherms¹³ will not develop unless their thermal threshold is reached.

There is little experimental evidence available regarding how long diaspidids can survive on picked fruit, but existing information suggests this may be highly variable.

- Schweig and Grunberg (1936) found that adult female *Chrysomphalus aonidum* survived for 3 to 4 weeks on picked citrus fruit, and from 6 to 17 days on peel.
- A laboratory study in New Zealand (Whyte *et al.* 1994) showed that whole apples remained viable hosts for successive generations of mealybugs (Pseudococcidae, a related coccoid family with a similar biology to diaspidids) for up to 5 months, despite withering. The adults themselves survived up to 43 days on apples and 49 days on oranges.
- Morse *et al.* (2009) suggested that diaspidids could survive on harvested avocados for 5 to 21 days.
- Hennessey *et al.* (2013) infested oranges, tangerines, avocado and squash with *Aonidiella orientalis* (Newstead) and placed them in orchard situations. They found that crawlers were produced for 7 to 14 days depending on the type of fruit and the level of infestation. Oranges, tangerines and avocados did not produce crawlers after 7 days in the field, while heavily infested squash (a much larger host, therefore able to be more heavily infested, and additionally with a longer shelf life) produced crawlers for up to 30 days.

On some hosts and under some conditions, therefore, it would seem likely that mated females or unmated parthenogenetic females could survive on imported fruit long

¹³ "cold-blooded" organisms whose body temperature varies with the temperature of their surroundings.

enough to produce crawlers past the border. In some circumstances, immature females may survive long enough to mature and produce crawlers, if the species or population is parthenogenetic or, for sexual forms, if males also survive to adulthood and mating takes place.

(ii) Fruit disposal methods

Culled and unsold fruit, uneaten fruit and fruit remains may be disposed of by wholesalers, retailers, food services (*e.g.* restaurants, hospitals) and consumers. The main domestic disposal pathways are disposal in bagged waste into landfill, disposal into sewage through a sink disposal unit, and disposal in garden compost (Ventour 2008, Hogg *et al.* 2010). Domestic disposal could also include public rubbish bins or random disposal in parks/roadsides. Industry (wholesale and retail) disposal pathways for culled and unsold fruit are likely to include distribution to rural areas for animal food and dumping near packhouses.

Some methods of disposal are higher risk than others. Crawlers on infested fruit/remains disposed of as bagged waste into landfill, or into sewage via sink disposal units would have a negligible likelihood of exposure. Those on fruit disposed of into domestic compost (particularly open compost), into gardens, into orchards near packhouses, into rural areas as food or randomly by the roadside would have a higher likelihood of exposure to a suitable host. Indeed, some diaspids develop and reproduce extremely well on the tubers and particularly on the sprouts of potatoes (Berry 1983, Abbasipour 2007), and may be capable of establishing on such hosts in domestic compost¹⁴. A further risk scenario is transfer from fruit bowls to house plants in households, offices or supermarkets. It should be noted that both these scenarios (establishment on tubers in compost and on house plants) are purely speculative. There is no evidence that successful exposure has occurred as a result of infested imported fruit in these situations, and the likelihood is considered to be very low.

Domestic waste: A survey in the United Kingdom found that about 12% of food waste is disposed of at home through either composting, as animal feed to pets or wild animals, or down the sink; the remaining 88% is collected by local authorities (Ventour 2008; 20,000 households). This survey also reported that between 15 and 25% of households home-compost. A similar survey in New Zealand found that (approximately) 13% of household organic waste is composted, 13% is disposed of in sink disposal units and 71% is landfilled (Hogg *et al.* 2010). In 1993, a small survey showed that about 30% of New Zealand households used composting as a primary disposal method (specifically of fruit waste) and another 5% disposed of it in the garden (Viggers 1993; 846 respondents). Viggers (1993) additionally estimated that in December 1992, in any week about 7.5% of the population over 12 years old was likely to drop fruit waste on roadsides or on the ground in New Zealand¹⁵. This was classified as a high risk disposal method.

Note: it is important to note that the proportions discussed above are for the total amount of food waste. The proportion of this waste that comprises imported produce,

¹⁴ No research appears to have been conducted on the potential of crawlers to move successfully from infested material in domestic compost to new hosts. However Gould and Maldonado (2006) conducted field trials to determine the likelihood of caterpillars of the noctuid lepidopteran *Copitarsia decolora* moving off imported infested asparagus. They found that only a small percentage (1.2%) of caterpillars crawled out of a dumpster filled with asparagus after one week.

¹⁵ even if accurate, this estimate is likely to have changed over 20 years due to shifts in the social acceptability of behaviours perceived as "littering", though this may apply less to organic matter.

and the proportion (of that proportion) that is infested with live regulated organisms is much lower, and is likely to be extremely small.

Industry (wholesale and retail) waste: A survey of commercial fruit waste (whole fruit and fruit remains/peels) and disposal in New Zealand found that approximately 20.3% of retail (supermarkets, dairies and groceries) and 6.9% of non domestic outlets (hospitals, rest-homes, restaurants etc.) used high risk methods (garden compost, other and unknown) to dispose of waste (Wigbout 1991; 894 respondents). Wholesale fruit disposal pathways and practices were not covered. Although normal commercial practice is to reduce waste, fruit waste in New Zealand may be collected from unpacking areas (*e.g.* supermarket preparation rooms) and taken to rural areas where it is placed on the ground for eventual consumption by pigs or other farmed animals (I. Wallace, Nashi NZ Inc., pers. comm. to MAFBNZ, September 2009). In California, disposal of large numbers of culled imported Mexican avocados at packhouses in close proximity to avocado trees has been identified as a potential introduction pathway for diaspidids (Morse *et al.* 2009), though a subsequent quantitative analysis (USDA 2012) concluded that the likelihood of a mating pair arising in the United States from crawlers originating on imported Mexican avocados was negligible.

Domestic surveys suggest that the majority of household organic waste is disposed of via landfill; that household organic waste is more commonly disposed of as compost in New Zealand than in the UK, and that the amount that is composted in New Zealand has decreased over the last two decades (Ventour 2008, Hogg *et al.* 2010). Although the majority of domestic disposal is via low risk methods, the amount of organic waste, particularly uneaten fruit and vegetables, is surprisingly high. Ventour (2008) calculated all fruit waste (avoidable and unavoidable, *i.e.* peelings, cores *etc.*) to be 1,100,300 tonnes p.a. in the UK. Roughly half of this (550,800 tonnes) was “avoidable” waste; individual items of fruit thrown away whole and untouched. Ventour (2008) calculated that 2.9 billion (=1000 million) whole items of fruit and 1.9 billion whole vegetables are thrown away each year. Twenty-six percent (by weight) of fruit and 19% of vegetables purchased for domestic consumption were thrown away whole and uneaten (avoidable waste). In New Zealand, Hogg (2010) estimated that each household throws away 248 kg of food waste per year (all food, plant and animal), a similar figure on a per capita basis to that estimated from the UK. The New Zealand study did not break food waste into categories but it is assumed that a similar proportion would be fruit waste.

Little is known about industry pathways and practices such as the disposal of culled and unsold fruit by wholesalers and retailers, or regarding the amount of waste produced by industry. One small study carried out in the early 1990s (Wigbout 1991) found that New Zealand retail outlets discarded between 0.86% and 13.3%¹⁶ of fruit, while non-domestic consumers discarded between 0.63% and 42% of fruit.

In summary:

- there is little information available regarding industry pathways and practices such as the disposal of culled and unsold fruit by wholesalers and retailers.
- current information suggests that **the majority of domestic disposal is by very low risk methods** – almost 85% of household organic waste is via landfill or in sink disposal into sewage. **The proportion of this material that**

¹⁶ the amount of waste is highly dependent on the type of fruit.

is both imported and infested with risk organisms is likely to be extremely low.

- however, the amount of household organic waste is relatively large. The amount disposed of by composting can be calculated (very approximately from currently available data) as being around 25 kg per household per year¹⁷.

(iii) Dispersal ability of crawlers

Crawlers can disperse by walking, by wind or via vectors such as animals. Mealybugs (Coccoidea: Pseudococcidae) are similar to diaspidids in their crawler life-stage, and given the limited evidence available, information on mealybug crawler dispersal is included in this review, on the assumption that their behaviour and physiology is very similar¹⁸.

- Walking: recent research on the significance of walking as a dispersal mechanism in mealybug crawlers has produced slightly different conclusions, though it is clear that the distance covered by walking is small. Lo *et al.* (2006) suggested that mealybug crawlers moved from plant to plant by walking, using vine trunks, strainer wires and posts. Grasswitz and James (2008) found a maximum active movement of 90 cm from the origin point, leading them to suggest that crawlers only very rarely reach adjacent plants by this means. Hennessey *et al.* (2013) found that *Aonidiella orientalis* crawlers produced from females on very heavily infested fruit were able to colonise trees 2m away in an orchard, however most infestations occurred when a fruit with crawlers was in contact with the tree. Branscome (2007) showed sexual differences in diaspidid crawlers: females moved about on plants for up to 12 hours before settling to feed, but males remained near their mother.
- Wind and vectors: long distance movement of crawlers by wind and vectors is certainly known to occur and some species are known to deliberately move to high points of their host plants in order to disperse (Brown 1958, Beardsley & Gonzalez 1975, Greathead 1990, Lo *et al.* 2006). Washburn and Washburn (1984) showed that crawlers of the coccid *Pulvinariella mesembryanthemi* (Vallot) deliberately entered the air, not only by moving up the plant but by orienting their bodies most favourably to the air current and standing on their hind legs. Lo *et al.* (2006) found mealybug crawlers on aerial traps placed 5m to 15m from source vines. Grasswitz and James (2008) showed that some *P. maritimus* crawlers dispersed as far as eight metres, but overall there was a rapid drop-off in dispersal with increasing distance from the source plants after three metres. Stouthamer and Morse (2011) found that crawlers hitchhike along with flying insects and could be transported long distances, although this work was based on laboratory studies, and the significance of such dispersal in the field is not known. The passive nature of wind dispersal means crawlers cannot actively choose to land on a suitable host plant but phoretic dispersal

¹⁷ Each household in New Zealand throws away 248 kg of food waste per year (Hogg 2010). Just over a quarter of household food waste (*i.e.* 25% of 248 kg = 62 kg) “may be being managed by means other than landfill at present (primarily through home composting and in sink food waste disposers)” (Hogg *et al.* 2010). These amounts are about equivalent: of household food waste that is disposed of in ways other than landfill (low risk), around 43% is composted (high risk) and about the same amount (44%) is disposed of in in sink disposal units (negligible risk) (Hogg *et al.* 2010, Table 3). Using these figures, roughly 40% of 62 kg (=25 kg) of household food waste may be composted per household per year.

¹⁸ Greathead (1997) reviewed literature on coccid crawlers and concluded that their behaviour was consistent with that of diaspidids.

by other insects would increase the likelihood of crawlers landing on a suitable plant host¹⁹.

Information about dispersal of crawlers from situations comparable to a piece of discarded fruit²⁰ is scarce, outdated and somewhat contradictory. Schweig and Grunberg (1936) heaped fruit infested with *Chrysomphalus aonidum* under clean trees and left it for several months. They found that the only infestation that took place was onto branches that were in direct contact with the fruit. Similarly Melis (1943, reported in APHIS 2007) found that infested fruit placed on the ground were not important in spreading *Diaspidiotus perniciosus* unless fruit was placed in direct contact with a susceptible host. However a study using mealybugs (Whyte *et al.* 1994) showed that when apples infested with crawlers and adults were caged outdoors close to but not touching a suitable host tree, 83% of the trees used ($n = 12$) had been infested with crawlers within 30 days (no adults moved successfully from fruit to trees). In a more recent study (Hennessey *et al.* 2013) placed fruit heavily infested with *Aonidiella orientalis* (Newstead) into orchard situations. They found that crawlers were able to settle on trees that were in contact with the infested fruit and also on trees 2m away from the infested fruit. Overall, they estimated that around 1.5% of the crawlers produced from infested fruit settled on new hosts (range 0.3 to 2.8%). Hosts that were in contact with the infested fruit were more heavily settled (range 0.3% to around 2.6% of all crawlers produced). Hosts that were 2m from the infested fruit were less heavily settled (from no detected settlement to 0.3% of all crawlers produced). The type of fruit used as an infestation source influenced the settlement rate, either due to different levels of infestation and/or longer shelf life²¹.

In summary, the available evidence suggests that for successful exposure the source of infestation must be contiguous with or close to the new host (unless crawlers are dispersed by phoresy). Situations of exposure consistent with this scenario include: infestation of sprouting potatoes in domestic compost, infestation of hosts such as weeds or overhanging trees that are very closely adjacent to backyard compost piles; transfer from fruit bowls to house plants in households, offices or supermarkets or infestation of hosts contiguous with infested fruit disposed of by wholesalers or retailers, particularly in growing areas.

(iv) Mortality at the crawler stage

Mortality in this lifestage is often extremely high. Crawlers are short-lived and fragile and are susceptible to extremes of temperature, desiccation, rain, predation and a lack of suitable settling sites (Beardsley & Gonzalez 1975). Mortality in *Pseudaulacaspis pentagona* crawlers (Diaspididae) in the field has been assessed at around 90%, compared to that of 30% for subsequent life stages (Oda 1963). Itioka and Inoue (1991) cited mortality in a citrus orchard of 67.4% and 90.2% for *Ceroplastes rubens* and *C. ceriferus* (Coccidae) crawlers respectively.

Desiccation in particular is an often-cited mortality factor. However Barrass *et al.* (1994) found that 75% of mealybug crawlers (three species of *Pseudococcus*) survived low humidity (32% RH) for 48 hours. Although this work was laboratory-

¹⁹ However USDA (2012) found that including phoretic dispersal into their quantitative model did not change the overall outcome, even when using laboratory-derived figures for phoresy that were obtained in a highly artificial environment and may have overestimated the true probability.

²⁰ where the source of the crawlers is small, is not a whole plant, where the crawler density is low and the source of the crawlers is low to or is on the ground.

²¹ It should be noted that the fruit used in these experiments was very heavily infested, to a degree that no commercially produced imported fruit would be affected; and that this experiment did not evaluate whether the settling of crawlers on the trees led to a reproducing population long-term that would indicate actual establishment.

based, it suggests that mealybug crawlers may be more likely to survive wind-dispersal than other literature suggests.

(v) Infestation of greenhouses and other protected environments

Temperature is also an important factor. If temperatures at the time of arrival in New Zealand are below their lower developmental threshold (LDT or T_{min}), crawler movement and development will be minimal. This is most important for species with high LDTs, which may have tropical, subtropical or warm temperate distributions. Some of these species may be able to establish only in protected environments such as greenhouses. However for crawlers arising from imported females to be exposed to plants in domestic or commercial glasshouses, either:

- crawlers must be transported into these places by vectors (*e.g.* by phoresy on other invertebrates; by humans working both outside and inside glasshouses, see Hennessey *et al.* 2013) or by wind. Commercial and domestic glasshouses are clearly able to be infested by outside pests, however this is likely to happen only when the propagule pressure is relatively high or when the event is happening very frequently. A relatively small number of crawlers originating from one or a few items of infested imported produce would be very unlikely to be moved by chance into a glasshouse and onto or near a suitable host plant.
- imported infested fresh produce must be taken into these places and discarded in close proximity to suitable hosts.

Both these scenarios are considered to be very unlikely.

1.5.2.1 Exposure conclusion

Due to their specialised biology, exposure for all diaspidids is dependent on the delicate crawler (first-instar, the only mobile lifestage excluding adult males) leaving the imported host commodity and successfully finding a suitable host. This restriction is common to all Coccoidea in which the post-settlement life stages are more or less immobile.

This likelihood of exposure of diaspidids on fresh produce is considered to vary from negligible to low, depending on the following factors:

- the method of host (imported fresh produce) disposal. Any practices which involve concentrating imported infested fresh produce within close proximity of suitable hosts (*e.g.* repacking of imported produce in packhouses, followed by disposal of rejects in orchards) may result in an increased likelihood of exposure.
- whether unavoidable waste is generated: host commodities which are entirely consumed, such as pele (island cabbage) or summerfruit present a lower exposure risk than those whose skin or other parts are discarded, such as kiwifruit, grapes, citrus or cucurbits.
- the robustness (shelf life) of the host commodity: most diaspidids produce eggs continuously over several weeks, until their death. Therefore crawlers are likely to be produced for as long as the host fruit remains in good condition. Soft fruit hosts such as berries or summerfruit are likely to deteriorate more quickly than more robust hosts such as cucurbits, avocado or citrus.
- the availability of suitable hosts for crawlers. Polyphagous diaspidid species will have an increased likelihood of encountering a suitable host for crawlers to settle on.
- temperature and time of year. If ambient temperatures at the time of arrival in New Zealand are below their lower developmental threshold, crawlers will be

unable to develop, except in protected environments such as greenhouses. However exposure²² to plants in domestic or commercial greenhouses is much less likely than exposure to outdoor hosts.

1.5.3 Likelihood of establishment

The likelihood of establishment of any particular diaspidid species is assessed assuming that successful exposure to a suitable host plant has already occurred. However there is some overlap between factors influencing exposure and establishment, for example temperature and host availability. There is also overlap between factors determining establishment and rate and extent of spread.

An aggregated distribution is typical for many diaspidid species (Wright & Diez 2005). These species are described as gregarious, and some authors (*e.g.* Yamamura & Katsumata 1999) consider that such species have a higher probability of introduction into new areas via trade than do solitary species, due to their heightened likelihood of locating a mate in the new environment.

The likelihood of establishment of diaspidids in New Zealand is species-specific and is considered to range from negligible to high.

Factors influencing the establishment of any particular diaspidid are similar to those for any invertebrate species and include:

- climatic suitability
- mode of reproduction: asexually reproducing species are considered to have a higher establishment likelihood than sexually reproducing species, since only one individual is required to found a reproducing population. For sexually reproducing species, at least one crawler of each sex must survive to sexual maturity, following which a male must locate a female, mate, and the female must produce viable offspring. The low likelihood of this series of events occurring successfully within a small number of founding individuals may be an important barrier to establishment.
- mate detection mechanisms: species that utilise pheromones or have similarly specialised mate detection strategies are considered to have a higher likelihood of establishment than species which do not
- host range: polyphagous species (or species with hosts that are very common and widely distributed) are considered to have a higher likelihood of establishment than oligophages or monophages, or species with hosts with very restricted distributions.

An analysis of diaspidid species that have been successfully introduced into New Zealand over the past 50 years (Appendix 3) suggests that the last diaspidid introduction that could reasonably be attributed to trade in commercial fresh produce was that of *Hemiberlesia lataniae* in 1977. However this species could equally have been introduced along the cut flower/foilage or nursery stock pathways.

1.5.4 Likelihood of spread

Natural short distance spread of diaspidids is achieved by crawlers walking, being blown or being vectored to suitable hosts (see Section 1.5.2). Long distance spread of crawlers is achieved by wind and vectoring. All lifestages can be spread short or long distances very effectively by the movement of host material.

²² of crawlers emerging from female/s infesting imported produce, not of crawlers from established populations.

The extent of potential spread for any particular species is dependent on factors such as climate and availability of host plants; the same factors which determine exposure and establishment likelihoods. Many diaspidids are polyphagous. The spread of polyphagous species is more likely to be restricted by climatic factors (see Section 1.5.3) than by the availability of host plants.

1.5.5 Impacts

Coccoids in general can be serious plant pests and as small, highly cryptic components of the plant ecosystem, they frequently are not detected until they have caused significant damage (ScaleNet 2014).

Diaspidids in particular are mainly pests of perennial plants in managed systems. They may cause considerable damage and economic loss in environments such as nut and fruit trees, nurseries, greenhouses, landscapes and forests (Kosztarab 1990, Miller & Davidson 2005). Kosztarab (1990) reviewed the effects of scale insect feeding on plants and recognised 11 types of damage depending on the scale insect species involved and its preferred feeding site. Damage symptoms are usually most evident when feeding occurs on fruit or leaves. Heavy infestations of leaf-feeding species can cause leaves to die and fall from the host. Feeding damage by fruit feeders can reduce the value of fruit by making it unsaleable in fresh markets. Heavy infestations can become so dense they cover the bark of trees and branches and are associated with dieback. Diaspidids that feed on or under bark do not usually cause obvious damage symptoms, although some may cause pitting in wood or discolouration under the bark, possibly due to a reaction to salivary secretions (Miller & Davidson 2005). Charles & Henderson (2002) note that diaspidid populations can cause damage to fruit and trees which often appears out of proportion to their size. The reasons for this are not understood, but may be due to their unusual feeding and digestion system. Because they do not produce honeydew it is presumed that excess food is re-injected into the plant with salivary fluids, possibly with toxic effect.

Species which attack all plant parts (fruit, leaves, stem and bark) are probably the most damaging. *Aonidiella aurantii* infests citrus in this manner and is considered the most potentially injurious pest of Californian citrus (Miller & Davidson 2005).

As for any exotic invertebrates, incursions of new diaspidid species may trigger expensive eradication programmes. The decision to respond is made on a case-by-case basis. Globally, eradication attempts are not commonly attempted against coccoids (Kean *et al.* 2014). This may be for a number of reasons, including perceived cost/benefit ratio and the fact that natural biological control against these pests is often successful. Establishment may result in the disruption of current management practices, which could affect the cost of crop production. Chemical management of diaspidids can be difficult, due to the protection afforded by the waxy caps covering the insect body which makes insecticide penetration ineffective. Other impacts may include market access disruption or increased compliance costs for exports to sensitive markets. Diaspidid species with cosmopolitan distributions are less likely to cause market access problems than those which have restricted distributions.

However, despite their potential for causing economic impacts, only a relatively small proportion of known diaspidid species have been reported as agricultural or horticultural pests of consequence (Beardsley & Gonzalez 1976). Kondo *et al.* (2008) discuss the economic impacts of Coccoidea and use only mealybugs and allied forms

such as the monophlebids as examples, although two diaspidid species are mentioned as being common in greenhouses.

Miller and Davidson (2005) review the economic importance of diaspidids specifically, however where calculated economic impacts on particular crops are cited, it is from tropical or subtropical regions (Texas, Florida, Georgia and California). Tropical species may cause lower impacts in temperate New Zealand if their population size, distribution and/or the distribution of their host plants are restricted.

Diaspidid populations appear to be unusually susceptible to control by natural enemies (Miller & Davidson 1996), and are probably the most suitable group of pest insects for biological control programmes (Kosztarab 1996). Commercially available pheromones are available for some important species (*e.g. Pseudaulacaspis pentagona*). The availability of these tools increases opportunities for effective surveillance and/or monitoring, and can enhance IPM (Integrated Pest Management) by allowing sprays to be applied at the most effective life cycle stages (*e.g. to coincide with crawler release*) and by reducing impact on natural enemies.

Host plants are not often killed by infestations of diaspidids. *Pseudaulacaspis* species are unusual in that they are known to be able to kill some of their hosts (CSL 2007)²³. Heavy infestations of *P. prunicola*, for example, have been observed causing the death of *Prunus* species within 3 to 4 years (Miller & Davidson 2005).

The lack of honeydew production also means that diaspidids are not associated with sooty mould growth, so mould contamination of fruit and/or inhibition of photosynthesis are not consequent problems. Additionally, they do not support honeydew feeders such as ants, birds, geckos, bees, and wasps in natural ecosystems (Henderson 2011). Changes in population sizes of these organisms or associated knock-on effects are therefore not expected consequences of diaspidid invasion into native ecosystems.

Although mealybugs are known to vector plant viruses, for example grapevine leafroll-associated viruses, no reports have been found of disease transmission by diaspidids.

The establishment of exotic diaspidid species is likely to result in some damage to amenity plants and to home fruit crops. This may add to the pest control costs or result in loss of produce for home gardeners.

There are no known human health impacts associated with the establishment of diaspidids.

Impacts conclusion

The economic, environmental, socio-cultural and human health impacts of establishment of any particular diaspidid are independent of the commodity association/pathway. Impacts are species-specific and need to be assessed on a case-by-case basis, considering the following factors:

- host range
- whether favoured hosts include economically important crop species
- temperature/climate tolerances
- global distribution with respect to sensitive export markets

²³ host mortality is more likely in developing countries than in regions (such as New Zealand) which have high class agriculture and IPM programmes (M. Zlotina, USDA, pers. comm., 2014)

- whether an incursion is likely to trigger an expensive eradication response
- whether monitoring tools are available
- whether the species reproduces parthenogenetically
- whether specific natural enemies are already present in New Zealand

1.6 INTERNATIONAL POLICY

USA: A review carried out in the USA (APHIS 2007) examined the likelihood of introduction of diaspidids via the fresh produce pathway (that is: commercially produced fruit for consumption, shipped without leaves, stems, or contaminants). The conclusion of the review was that this likelihood is low because diaspidids have a very poor ability to disperse from fruit for consumption onto hosts. As a result of this assessment, California Department of Food and Agriculture (CDFA) altered its policy to allow shipments of scale-infested avocados from Mexico into California without treatment. As of 28 March 2008 USDA APHIS (United States Department of Agriculture's Animal and Plant Health Inspection Service) expanded no action policy to "all consumption commodities" (Stouthamer & Morse undated, 2011).

Morse *et al.* (2009) sampled avocados imported after this policy change and estimated that 47.6 million live, sessile diaspidids and an additional 20.1 million live eggs and crawlers entered California in an 8 month period. The samples comprised 8 species (7 exotic to California), and were heavily dominated by one exotic species. Their assessment of risk was that where imported fruit follow a path of gradual dispersion from the point of import to the consumer, the risk of establishment is generally low. However, taking into account the existence of other distribution pathways (*e.g.* re-concentration at packhouses for repackaging and disposal of culls), the sheer numbers of live diaspidids entering the US and their possible polyphagy, Morse *et al.* (2009) concluded "*we believe the threat of an invasive scale infestation originating from Mexican avocados on one of the many crops or plants found in California is real*". USDA-APHIS re-examined their 2007 pest risk assessment and published a quantitative risk analysis in 2012 (USDA 2012). This analysis upheld the finding of the original publication, specifically concluding that the likelihood of a potential mating pair of several species of avocado scale arising in the United States from crawlers originating on imported Mexican avocados was negligible.

Currently, commercially grown imported fruit for consumption infested with living diaspidids is permitted by PPQ to enter the USA following inspection and reporting of any species found, but is not subject to further mitigation measures (Hennessey *et al.* 2013).

Australia: an analysis of DAFF/Biosecurity Australia risk analyses and policy extension (dating back over ten years) showed that although diaspidids are relatively commonly identified as hazards on the fresh produce pathway, they are rarely assessed as risks *i.e.* the unrestricted risk estimate (URE) for assessments of diaspidids on fresh produce is most often found to be below Australia's ALOP (acceptable level of protection), and therefore no measures are deemed to be necessary²⁴.

²⁴ 78 species on 22 pathways were tabulated. For 59 species (75.6%), the unrestricted risk estimate (URE) was less than "low" *i.e.*, the risk posed by these species on these pathways was considered to meet Australia's ALOP without measures. For 8 species (10%) the URE was "low" *i.e.* the risk posed was considered to exceed Australia's ALOP and measures were required on the pathway (this comprised only two pathways, Philippines bananas and Fijian ginger; the ginger pathway assessment included elements more similar to NS or 'plants for planting' assessments than FP assessments). The remaining diaspidids were assessed as "quarantine pests" and no specific statement regarding measures was apparent.

1.7 OTHER COCCOID FAMILIES: PSEUDOCOCCIDAE AND COCCIDAE

Pseudococcids (mealybugs) and soft scales (coccids) have life histories that are very similar to those of diaspidids. Like diaspidids, all life stages except adult males are wingless and dispersal is mainly by the mobile first instar or crawler stage. All other female stages of diaspidids and most coccids (soft scales) are legless and non-mobile, settling on a plant and secreting a hard or soft wax cover respectively. Pseudococcid females however have functional legs and are mobile in all life stages (Hodges 2005, Howard *et al.* 2001).

Many analyses ascribe a higher likelihood of establishment to mealybugs than to diaspidids. This may be due in part to the ability of mealybug nymphs and adult females to move at least limited distances, unlike diaspidids and most coccids.

Pseudococcid movement: Geiger *et al.* (2001) recorded some female mealybugs²⁵ on grapevines in California vineyards moving from grape bunches to trunks to oviposit under bark, while others stayed and oviposited on the fruit. James (1937) reported that females moved intermittently during the production of young, sometimes ceasing to feed and leaving the host plant altogether. Additionally, some mealybugs may be carried to new host plants by ants (Beardsley *et al.* 1982). However, like diaspidids and coccids, the main dispersal stage for pseudococcids is the crawler stage, and it is uncertain how much other lifestages would contribute to dispersal. A study in New Zealand (Whyte *et al.* 1994) found trees in enclosures with mealybug-infested fruit were infested by crawlers produced by the mealybugs, but that no adult mealybugs moved successfully from fruit to trees. Vitullo (2009), in a series of experiments with sticky band traps on trees, found that the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green), dispersed mainly as crawlers searching for feeding sites. Once settled at a feeding site, nymphs tended to be non-dispersive. Adult females showed limited mobility seeking sheltered oviposition sites, but tended not to move if already in a protected site (Furness 1976, Vitullo 2009).

It is therefore likely that mealybugs are very similar to diaspidids and coccids in terms of likelihood of exposure via the fresh produce pathway; that is, that successful dispersal from the point of entry is most likely to take place at the crawler stage. However the increased mobility of the nymphal stages is likely to result in a slightly increased likelihood of exposure for mealybugs and coccid species that are similar to mealybugs.

²⁵ mostly *Pseudococcus maritimus* but four other species were also present.

1.8 APPENDIX 1: PATHWAY ANALYSIS FOR EXOTIC DIASPIDIDS

Interception data for all exotic diaspidids known to have established in New Zealand (31 species have been recorded) are presented in Table 2. The following sources of interception information were used:

- Databases: Quancargo (the MPI database of commercial consignments and interceptions of pests made by quarantine inspection at the New Zealand border) and the MPI Identification database (MPI 2014), a compilation of identifications made by MPI andASUREQuality since 1988 (downloaded February 2014).
- Historical print sources: compilations of interception information from the following sources: Jacks (1953), Richardson (1979), Keall (1981) and Townsend (1984).

Common synonyms for all species were also checked and probable misidentifications have been assessed:

- *Lepidosaphes pinnaeformis* has been identified at the border several times under the name *Lepidosaphes machili*. Consequently this species is counted as intercepted.
- *Carulaspis juniperi* has not been identified at the border but *C. visci* was recorded on juniper from Australia once (Keall 1981). It is likely that this was in fact *C. juniperi*, since *C. visci* has not been reported from Australia and additionally has only been reported from *Viscum album*, while juniper is a major host of *C. juniperi*. Consequently this species is considered to have been detected at the border.
- *Parlatoria desolator* has been reported once on apples from Australia. Since this species is not reported from Australia (ScaleNet 2010) this is regarded as a probable misidentification and the species is not considered to have been identified at the border.

Of the 31 known exotic diaspidids established in New Zealand, no records of detections at the border in MPI databases or historical print sources have been found on any pathway for 12 species (39%), and slightly over half have not been identified in the MPI Identification database (16/31).

Table 2: Established exotic diaspidid species and known pathway relationships (Source: MPI 2014)

Species	Date ^A	Hosts	Detected at border	Detections by pathway	FP: total detections†
<i>Neopinnaspis harperi</i>	2012	polyphagous	No records found	None	n/a
<i>Carulaspis minima</i>	2009	conifers	Y (MPI 2014)	PM	0:1 (0%)
<i>Chrysomphalus aonidum</i> (erad.)	2004	polyphagous	Y (MPI 2014)	FP>NS>PM>CFF	38:53 (72%)
<i>Furchadaspis zamiae</i>	2004	cycads, other ornamentals	Y (MPI 2014)	NS	0:5 (0%)
<i>Lepidosaphes pallida</i>	2001	conifers	No records found	None	n/a
<i>Hemiberlesia lataniae</i>	1979	polyphagous	Y (MPI 2014)	FP>NS>PM=CFF	92:118 (80%)
<i>Kuwanaspis pseudoleucaspis</i>	1976	oligophagous (Gramineae)	No records found	None	n/a
<i>Pseudoparlatoria parlatorioides</i>	1962	polyphagous	No records found	None	n/a
<i>Parlatoria fulleri</i>	1956	polyphagous	No records found	None	n/a
<i>Lepidosaphes pinnaeformis</i>	1952	orchids	Y (MPI 2014)	CFF (as <i>L. machili</i>)	0:1 (0%)
<i>Carulaspis juniperi</i>	1942	conifers	Probably (Keall 1981)	None	n/a
<i>Diaspidiotus ostreaeformis</i>	1939	polyphagous	Y (MPI 2014)	NS	0:1(0%)
<i>Pseudaulacaspis brimblecombei</i>	1938	oligophagous, Proteaceae	No records found	None	n/a
<i>Parlatoria desolator</i>	1936	Rosaceae	No records found	None	n/a
<i>Pinnaspis aspidistrae</i>	1935	polyphagous, ferns	Y (MPI 2014)	FP>CFF>PM>NS	33:62 (53.2%)
<i>Abgrallaspis cyanophylli</i>	1934	polyphagous	Y (MPI 2014)	FP	20:28 (71.4%)
<i>Pseudaulacaspis eugeniae</i>	1922	polyphagous	No records found	None	n/a
<i>Trulliflorinia acaciae</i>	1922	oligophagous, Fabaceae	No records found	None	n/a
<i>Parlatoria pittospori</i>	1921	polyphagous	Y (Townsend 1984)	None	n/a
<i>Diaspidiotus perniciosus</i>	1908	polyphagous	Y (MPI 2014)	FP>>CFF	288:309 (93.2%)
<i>Lepidosaphes multipora</i>	1904	polyphagous	No records found	None	n/a
<i>Lepidosaphes beckii</i>	1895	polyphagous, Citrus	Y (MPI 2014)	FP>>CFF	145:177 (81.9%)
<i>Lindingaspis rossi</i>	1895	polyphagous	Y (MPI 2014)	PM>NS=CFF=NS	2:10 (20%)
<i>Aulacaspis rosae</i>	1891	<i>Rosa</i> spp., <i>Rubus</i> spp.	Y (Townsend 1984)	None	n/a
<i>Anzaspis angusta</i>	1890	Myrtaceae	No records found	None	n/a
<i>Aspidiotus nerii</i>	1879	polyphagous	Y (MPI 2014)	PM>CFF=FP>NS	4:23 (17.4%)
<i>Diaspis boisduvalii</i>	1879	polyphagous, orchids, palms, cacti	Y (MPI 2014)	FP	129:134 (xxx%)
<i>Hemiberlesia rapax</i>	1879	polyphagous	Y (MPI 2014)	FP>>NS =PM	51:63 (80.9%)
<i>Lepidosaphes ulmi</i>	1879	polyphagous	Y (Richardson 1979, Keall 1981, Townsend 1984)	None	n/a
<i>Aonidiella aurantii</i>	1878	polyphagous, Citrus	Y (MPI 2014)	FP>>>NS	910:957 (95.1%)
<i>Aulacaspis rosarum</i>	1877	<i>Rosa</i> spp., <i>Rubus</i> spp.	No records found	None	n/a

FP= fresh produce; NS=nursery stock; SG= seeds and grain; PM=plant material; CFF=cut flowers and foliage; ^A Date of first detection in New Zealand; † (all pathways)

The exotic diaspidid species first reported from New Zealand in the last 50 years are assessed individually below (from the most recent report) in order to determine how likely it is that they could have been introduced successfully along the commercial fresh produce pathway. Fifty years is an arbitrarily selected timeframe; it is assumed that meaningful comparisons cannot be made over longer time frames.

EXOTIC ARMoured SCALE SPECIES REPORTED FROM NEW ZEALAND SINCE 1976

Neopinnaspis harperi: first recorded in 2012. This species has not been identified at the New Zealand border on any pathway. It is Nearctic (USA, Hawaii) and known from Japan and Taiwan. Although broadly polyphagous, *N. harperi* primarily occurs on the bark of twigs and branches; in cases of heavy infestations, it may be found on the trunk, occasionally on petioles, and rarely on leaf surfaces (ScaleNet 2014). Evans *et al.* (2009) report it as living “in cracks in bark or buried in bark tissue”²⁶. Therefore, *Neopinnaspis harperi* is unlikely to be associated with fresh produce (fruit or leaf material for consumption), or to have been introduced along the fresh produce pathway.

Carulaspis minima: first recorded in 2009. At the border it has only been detected on plant material. *C. minima* is typically a Mediterranean species and is found mostly in southern Europe, western Asia and South Africa (ScaleNet 2014). It is associated with conifers (Miller & Davidson 2005, Henderson 2011) and infests needles, leaves and sometimes cones (Watson 2005). Therefore, *Carulaspis minima* is unlikely to be associated with fresh produce (fruit or leaf material for consumption), or to have been introduced along the commercial fresh produce pathway.

Chrysomphalus aonidum: This species has been detected at the border relatively frequently²⁷, mainly on fresh produce but also on nursery stock, plant material and cut flowers/foilage. It is broadly polyphagous and prefers fruit, but is commonly found on leaves and rarely on branches (Miller & Davidson 2005). *C. aonidum* was detected in New Zealand in 2004; its distribution appeared to be limited to heated greenhouses at the Auckland Domain, and some indoor plants in Auckland City Council offices. It was not detected alive outside heated/protected environments and was confirmed eradicated in 2005 (Kean *et al.* 2014). The incursion appeared to be linked to imported *Dracaena* plants that are commonly used in the houseplant trade (Biosecurity New Zealand Response Close-out Report, 2010²⁸). Therefore, although *Chrysomphalus aonidum* has a preferential association with fruit, the commercial fresh produce pathway is very unlikely to have been responsible for its 2004 incursion in New Zealand.

Furchadaspis zamiae: first reported in 2004. This species has only been detected on nursery stock at the border. It occurs throughout the world in warm areas and in greenhouse in colder places. This species has a relatively restricted host range and prefers cycads such as *Cycas* and *Zamia* (Miller & Davidson 2005). Therefore *Furchadaspis zamiae* is unlikely to be associated with fresh produce (fruit or leaf material for consumption), or to have been introduced along the commercial fresh produce pathway.

Lepidosaphes pallida: first reported in 2001. This species has not been detected at the border on any pathway. It is a Holarctic species which is associated with the foliage of

²⁶ however one specimen was intercepted on Hawaiian avocado fruit in Seattle, Washington in 1963 (https://archive.org/stream/cooperativeecono1541unit/cooperativeecono1541unit_djvu.txt).

²⁷ see Appendix 4

²⁸ [/FCS_MAF/MONITORING, SURVEILLANCE and RESPONSE/Surveillance and Response - Biosecurity/Response/Pest Animals/Chrysomphalus aonidum 2004](#)

conifers (ScaleNet 2014) and is therefore unlikely to be associated with fresh produce (fruit or leaf material for consumption), or to have been introduced along the commercial fresh produce pathway.

Hemiberlesia lataniae: first reported in 1979. There are many border detections for this species, and the overwhelming majority are on fresh produce. Small numbers of detections have been reported on nursery stock, plant material and cut flowers/foilage. *H. lataniae* is found on all aerial plant parts, but especially young branches (Watson 2005); ScaleNet (2014) states “Occurring on any part of the host, but perhaps most commonly on the bark”. It is not known how *Hemiberlesia lataniae* was introduced into New Zealand but the commercial fresh produce pathway cannot be ruled out.

Kuwanaspis pseudoleucaspis: first reported in 1976. This species has not been detected at the border on any pathway. *K. pseudoleucaspis* is oligophagous and occurs on bamboos and grasses. *K. pseudoleucaspis* is therefore unlikely to be associated with fresh produce (fruit or leaf material for consumption), or to have been introduced along the commercial fresh produce pathway.

PATHWAY ANALYSIS CONCLUSION

Seven diaspidid species are known to have been accidentally introduced into New Zealand since 1976 (38 years). This is a similar rate to the historic steady rate of establishment of around one species every 5–6 years (Charles & Henderson 2002). The last exotic armoured scale species whose introduction could reasonably be attributed to trade in commercial fresh produce is *Hemiberlesia lataniae* in 1977; however this species is equally likely to have been introduced along the cut flower/foilage or nursery stock pathways.

1.9 APPENDIX 2: PRA FOR *CHRYSOMPHALUS AONIDUM* ON FRESH PRODUCE

- Scientific name:** *Chrysomphalus aonidum* (Linnaeus, 1758) (Hemiptera: Diaspididae)
- Other names:** *Coccus aonidum* Linnaeus, 1758; *Chrysomphalus ficus* (Ashmead, 1880); *Aspidiotus (Chrysomphalus) ficus*, *Aspidiotus aonidum* (ScaleNet 2014).
- Common names:** Florida red scale (recommended) circular scale, black scale, circular black scale, citrus black scale.

Hazard identification

New Zealand status

Chrysomphalus aonidum is not known to be present in New Zealand. Not recorded in Charles and Henderson (2002), Gordon (2010) or PPIN (2014). Reported as “not known to occur in New Zealand” (MPI Country Freedom List²⁹).

C. aonidum was detected post-border in New Zealand in 2004. Its distribution appeared to be limited to heated greenhouses at the Auckland Domain, and some indoor plants in Auckland City Council offices. It was not found alive outside heated/protected environments and was confirmed eradicated in 2005 (Kean *et al.* 2014). The incursion appeared to be linked to imported *Dracaena* plants that are commonly used in the houseplant trade (Biosecurity New Zealand Response Close-out Report, 2010).

General geographical distribution

C. aonidum is apparently indigenous to Southeast Asia (Miller & Davidson 2005). It is widely distributed in many tropical and subtropical regions in North and South America, Africa, the Mediterranean Basin, the far East, Pacific Islands and Australia. In northern countries in its range, this species occurs in greenhouses (CPCI 2014).

In the US, this species occurs out-of-doors in the following states: California (eradicated), Florida, Georgia, Hawaii, Louisiana, Mississippi and Texas. Other records from the US are from greenhouses (Miller & Davidson 2005).

In the EPPO region, *C. aonidum* is known from the Mediterranean Basin on outdoor citrus but in other European countries (*e.g.* France, Hungary, Netherlands, Poland), it is only occasionally reported on ornamental plants grown in greenhouses. However establishment outside protected environments appears to be quite recent in some Mediterranean areas (see Establishment and spread assessment).

Plant associations

Chrysomphalus aonidum is a highly polyphagous species with a preference for citrus, particularly navel and Valencia oranges and grapefruits. It has been recorded from hosts in 77 plant families, including crops, ornamentals, palms and forestry trees; however, its host range is probably wider. In the laboratory, *C. aonidum* can be mass-reared on *Citrullus* (melons), potato tubers or pumpkins (Watson 2002).

Although citrus species are the main hosts, other hosts of economic or environmental importance in New Zealand include *Agathis*, *Asparagus officinalis*, *Cordyline*,

²⁹ <http://www.mpi.govt.nz/biosecurity-animal-welfare/pests-diseases/country-freedom-list>

Cucurbita, *Eucalyptus*, *Ipomoea*, *Malus domestica*, *Nothofagus*, *Persea americana*, *Phormium*, *Pinus*, *Podocarpus*, *Prunus*, *Pyrus*, *Solanum* and *Vitis vinifera*. *C. aonidum* also infests a range of ornamentals, including *Cycas*, *Dracaena* and *Ficus*, and a wide range of cut flower species (Watson 2002, CPCI 2014).

Hosts that New Zealand imports³⁰ as fresh produce include: avocado, banana, breadfruit, *Citrus* species, lychee, mango, mangosteen, watermelon and zucchini.

Association with fresh produce

According to Watson (2005), *Chrysomphalus aonidum* is a leaf-infesting species, but in high-density infestations it may spread to fruits, stems and trunks. However this may vary with host and season, for example Miller and Davidson (2005) report that on citrus (a favoured host) during warm parts of the year up to three times as many scale occur on fruit as on leaves.

C. aonidum is detected relatively frequently at the New Zealand border on fresh produce from various tropical and subtropical countries (MPI Identification database).

Biology

The scale cover of the live adult female is circular, flat to moderately convex, 1.5–2.5 mm in diameter, dark brown or bluish-black with reddish brown central exuviae (Watson 2005).

Reproduction is sexual; no evidence of parthenogenesis has been recorded. The sex ratio has been found to be biased in favour of females. Each adult female lays about 50 to 150 oval eggs under the scale over a period of one to 8 weeks, depending on the part of the plant infested; those on the leaves being less fecund than those infesting fruit (Watson 2005). Miller and Davidson (2005) also report that egg production varies with time of year. Eggs hatch within a few hours up to 10 days depending on weather conditions (Miller & Davidson 2005). The second-instar nymphs are the main feeding stage in both sexes (Watson 2005).

Development to adult takes 7 to 16 weeks, depending on temperature (Watson 2005); host plant and position on the host also influence developmental rate (Miller & Davidson 2005). Gill (1997) reported 5 or 6 annual generations (presumably from California). In countries with a cold winter, such as Taiwan, there may be three distinct generations per year, while in tropical conditions (and heated greenhouses) breeding is continuous and generations are asynchronous (Watson 2005). In Hunan (China), three to four generations are completed (Miller & Davidson 2005). Miller & Davidson (2005) reported that a generation requires approximately 875 degree-days.

Chrysomphalus aonidum has a preference for humid environments and cannot tolerate freezing temperatures. It tends to prefer the lower and central parts of mature citrus trees and rarely infests green wood. Males are more tolerant of lower humidity than females, so male scales are more often found on the upper surface of the leaf while females congregate on lower leaf surfaces. Like other diaspidids, *C. aonidum* suffers increased mortality in heavy rain and reaches high population levels during dry weather (Watson 2005).

³⁰ or has Import Health Standards for but may not currently import or may not ever have imported.

Potential for establishment and impact

Chrysomphalus aonidum is likely to be able to establish in at least some parts of New Zealand, or in sheltered habitats, or in greenhouses. It is capable of causing unwanted impacts within the horticultural, cut flower and nursery industries.

Hazard identification conclusion

Given that this species

- is associated with some fresh fruit and/or vegetables
- is not known to be present in New Zealand
- is potentially able to establish and cause unwanted impacts,

Chrysomphalus aonidum is therefore considered to be a hazard on the fresh produce pathway.

Risk assessment

Entry assessment

Chrysomphalus aonidum is often detected in international trade in fresh produce. Miller and Davidson (2005) and Gill (1997) both report frequent detections at US ports of entry. It has been intercepted in quarantine inspections in Oman and the Netherlands (CPCI 2014).

In New Zealand, *C. aonidum* has been detected alive at the border reasonably frequently (MPI Identification database). There are occasional detections on nursery stock, plant material and cut flowers/foilage but most are on fresh produce, in particular on bananas, coconuts, mango and mangosteen from various tropical and subtropical countries (e.g. Philippines, Mexico, Solomon's, Tonga, Taiwan, Thailand).

C. aonidum is therefore able to survive at least some transit conditions on fresh produce. The likelihood of entry on any particular consignment is dependent on:

- the host commodity. Although citrus is its favoured host, *C. aonidum* has only been detected on citrus once at the New Zealand border (MPI Identification database).
- the population levels in the country of origin. This species is widely distributed in tropical and subtropical regions, and may be present on commodities produced in temperate countries in greenhouses. In other places, area or country freedom or low pest prevalence is possible.
- the in-field controls and production systems
- any end-point treatments
- the architecture of the commodity that is imported. *C. aonidum* will be easier to detect during handling and inspection on architecturally simple, smooth-skinned commodities such as citrus than on more complex commodities such as coconuts.
- the volume of the host imported; some hosts are imported in very large volumes e.g. 129,548,152 kilograms of *Musa* spp. (bananas) were imported in 986 consignments in 2012 (Quancargo database)

Entry conclusion

The likelihood of *Chrysomphalus aonidum* entering New Zealand on the fresh produce pathway is commodity-dependent and is considered to range from negligible to moderate.

Exposure assessment

Due to their specialised biology, exposure for all diaspidids is dependent on the delicate crawler (first-instar, the only mobile lifestage excluding males) leaving the imported host commodity and successfully finding a suitable host. Crawlers are susceptible to extremes of temperature, desiccation, rain, predation and a lack of suitable settling sites. This restriction is common to all coccoids in which the post-settlement life stages are more or less immobile (see Section 1.5.2). Some specific aspects of the biology of *C. aonidum* and some attributes of the particular host commodity may also influence the exposure likelihood:

- unavoidable waste: host commodities which are entirely consumed present a lower exposure risk than those whose skin is discarded, such as citrus or avocados
- robustness of host commodity: diaspidid females produce eggs continuously over several weeks until their death (Koteja 1990, cited in Morse *et al.* 2009). Therefore crawlers are likely to be produced for as long as the host fruit remains in good condition. Soft fruit hosts are likely to deteriorate more quickly than more robust hosts such as citrus.
- availability of suitable hosts: *C. aonidum* is polyphagous and there would be no shortage of suitable host species throughout New Zealand. The presence of weedy hosts outside cultivation is likely to facilitate exposure.
- developmental thresholds: there appears to be little information available on development rates of this species. Based on the establishment of this species outdoors in some parts of the world similar to New Zealand (see Establishment and spread assessment) it is assumed that temperature thresholds for crawlers will be exceeded in at least some parts of New Zealand in at least some months.

Successful exposure of crawlers emerging from female/s infesting imported produce, to plants in domestic or commercial greenhouses is much less likely than exposure to outdoor hosts (see 1.5.2. (v) “Infestation of greenhouses and other protected environments”).

Exposure conclusion

The likelihood of *Chrysomphalus aonidum* on imported fresh produce being successfully exposed to new hosts in New Zealand is considered to vary from negligible to low, depending on the attributes of the host and the disposal conditions.

Establishment and spread assessment

Chrysomphalus aonidum reproduces sexually; there are no reports of parthenogenesis. Therefore a mated female or immatures of both sexes would be necessary to establish a reproductive population. Since exposure depends on successful crawler dispersal, for establishment to take place crawlers of both sexes need to find a suitable host, develop to adults, successfully locate each other, mate and produce viable offspring. *C. aonidum* is multivoltine at higher temperatures and females lay up to 150 eggs so the potential for rapid population increase in suitable conditions is high.

C. aonidum is polyphagous on a wide variety of plants many of which are present in New Zealand, including garden plants and weed species. Therefore suitable hosts are highly likely to be readily found. Populations which establish in home gardens and on weeds can also act as population reservoirs for re-infestation of commercial crops.

There appears to be little information available about developmental thresholds for this species. In the US, outdoor populations are only reported from regions much warmer than New Zealand (Florida, Georgia, Hawaii, Louisiana, Mississippi, Texas), while indoor (greenhouse) populations have been reported from many more temperate states (DC, IL, IN, KS, MA, MD, MI, MO, NC, NH, NJ, NY, OH, OK, OR, PA, RI, SC, WV; Miller & Davidson 2005).

Based on its US distribution³¹ it seems likely that *C. aonidum* would be limited to protected or indoor habitats in New Zealand³². However CPCI (2014) cites some evidence that the distribution of this species is extending into colder regions, perhaps as a result of global climate change. Some distribution records suggest that it may be able to establish outdoors in at least some warmer parts of New Zealand:

- it has been reported to complete three to four generations on oranges (presumably outside) in Hunan, China (Gan *et al.* 1993). Much of Hunan province has a 0.7 climate match with all of New Zealand (Phillips *et al.* in prep.). Climate matches over 0.7 are generally considered to be biologically meaningful.
- in Australia it is reported to occur as far south as Sydney, where it has 2 to 4 generations per year (Waterhouse & Sands 2001). However, despite being established in Australia for at least 100 years (Froggatt 1914), *C. aonidum* has apparently not established in Victoria or Tasmania, which are much more climatically similar to New Zealand.
- in the Mediterranean, it appears to have established outside protected environments quite recently in some areas *e.g.* it was detected outdoors in Italy on citrus for the first time in spring in 2006 in Calabria. Parts of Calabria have a 0.8 climate match with all of New Zealand (Phillips *et al.* in prep.). In Greece and Spain³³, its presence on outdoor citrus trees is also rather recent (2000 and 1999 respectively). In mainland Spain, *C. aonidum* was first detected on outdoor citrus near Valencia³⁴ (EPPO 2010/012). Valencia has a 0.7 climate match with all of New Zealand (Phillips *et al.* in prep.).

There is no specific data available on the dispersal rate of *C. aonidum*. Crawlers can actively crawl over short distances or be carried in air currents or on vectors. Long distance dispersal is likely to be in trade. Colonisation of domestic and commercial greenhouses throughout much of New Zealand may occur by the movement of infested plant material. The level of phytosanitary hygiene in commercial operations is likely to be higher than in domestic situations and colonisation may therefore be less likely, though it is still possible.

Establishment and spread conclusion

The likelihood of establishment of *Chrysomphalus aonidum* is considered to be low. Current distribution data suggest that the maximum extent of spread within New Zealand is likely to be limited to the warmer parts of the North Island.

Consequence assessment

Economic consequences

³¹ *C. aonidum* was first reported from Florida in 1879 (Mathis 1941)

³² however, the likelihood of imported crawlers being successfully exposed to hosts in greenhouses is low (see Exposure assessment).

³³ In mainland Spain, *C. aonidum* was first detected on outdoor citrus near Valencia in 1999, but the pest was successfully eradicated from this region. It is still recorded as present from Islas Canarias (EPPO 2010/012).

³⁴ it was subsequently eradicated (EPPO 2010/012).

Beardsley and González (1975) consider *Chrysomphalus aonidum* to be one of 43 serious armoured scale pests, and Miller and Davidson (1990) consider it to be a serious world pest (citations in Miller & Davidson 2005). This species has been recorded as a serious pest of citrus in Florida, Texas, Brazil, Mexico, Lebanon, Egypt and Israel and is damaging to bananas in Central America, and coconut palm in the Philippines (ScaleNet).

Citrus is the most important crop damaged by *C. aonidum*; damage has been recorded in the USA (Florida, Texas), Central and South America, the Caribbean, the Mediterranean, North Africa, South Africa, India, Pakistan, Australia, China, New Caledonia and Western Samoa.

In unsprayed citrus orchards in South Africa, *C. aonidum* caused almost complete defoliation and crop loss of individual trees. Heavy fruit infestation resulted in up to 100% culling at the packhouse. Control costs were high prior to the introduction of effective biological control, which reduced infestation by over half. Heavy infestation of citrus foliage in New Caledonia resulted in the death of trees. In 1976, it was estimated that *C. aonidum* caused an annual loss on citrus in Texas of US\$3.85 million.

Other crops from which impacts have been reported include: olives in Israel and Turkey; ornamental plants in greenhouses in Poland; pine seedlings in Papua New Guinea, several economically important hosts in Brazil; young tea in India; bananas in the Caribbean and Central America and coconuts in the Philippines and historically in the Seychelles. It is an occasional pest in France (Watson 2005).

C. aonidum is especially difficult to control with insecticides because it may occur on a wide range of weedy hosts including conifers and grasses. Once an infestation is under control reinfestation may be very rapid (Miller & Davidson 2005).

If *Chrysomphalus aonidum* became widespread in New Zealand it has the potential to cause losses to fruit production (e.g. citrus, avocado), and to have negative economic impacts on the nursery and cut flower industries. However its impact on outdoor crops is likely to be very much reduced by its limited potential geographic range in New Zealand. Although this scale has been reported causing severe damage to pine seedlings in Papua New Guinea, significant impacts on the *Pinus radiata* industry are very unlikely in temperate regions such as New Zealand.

Unlike other scale insect families, diaspidids do not excrete honeydew. They are therefore not associated with sooty mould growths (Watson 2005), so mould contamination of fruit and/or inhibition of photosynthesis are not consequent problems.

The establishment of *Chrysomphalus aonidum* in New Zealand could cause some limited disruption of access to some markets, e.g. Western Australia.

Noyes (2002) lists 49 known chalcidoid natural enemies of *C. aonidum*. Four of these species (*Aphytis chrysomphali*, *A. diaspidis*, *Encarsia citrina* and *Zaomma lambinus*) are known to be present in New Zealand (Gordon 2010). It is likely that these natural enemies³⁵ would exert some level of population control on *C. aonidum* in New Zealand that may reduce its impact, but it is not known how significant this would be. Biological control agents, especially *Aphytis holoxanthi* (not reported from New Zealand) have successfully controlled *C. aonidum* in most citrus-growing parts

³⁵ and others present in New Zealand and closely related to important parasitoids overseas.

of the world. In Hunan, *Aphytis chrysomphali* and *Comperiella bifasciata* provided parasitism rates of over 50% (Gan *et al.* 1993), and *A. chrysomphali* is the main parasitoid in Surinam (CPCI 2014). In Florida, armoured scale pests in citrus are under biological control by a large number of natural enemies and are no longer considered key pests in the development of IPM programmes³⁶.

Mitigating factors:

- The impact of this species is likely to be reduced by its limited potential geographic range in New Zealand.

Economic impacts conclusion

The potential economic consequences of *C. aonidum* establishing in New Zealand are independent of pathway and are considered to be low.

Environmental consequences

C. aonidum is a polyphagous species, with over 230 recorded hosts. Beever *et al.* (2007) suggested that in terms of risk to native flora, sap-sucking hemipterans such as armoured scale insects are a high risk group. However it must be noted that this study assessed exotic species in terms of risk, not solely impact (the risk ranking of a species included its likelihood of reaching New Zealand as well as its anticipated impact). This study also concluded that highly damaging polyphagous species appear to be exceptional and that the impact of relatively specialised organisms is likely to be greater.

Charles and Henderson (2002) recorded a number of exotic armoured scale insect species on native plant hosts, and noted that some polyphagous exotic species are now occasionally found on native plants in isolated patches of native bush, raising concerns of the threat they may pose to native plants. However no such impacts are known to have been reported from exotic diaspidids that have been established in New Zealand for many decades.

Diaspidids do not secrete honeydew, so they are not they are not associated with the growth of sooty mould fungi in their habitat, nor do they support honeydew feeders (see Section 1.5.5). Changes in population sizes of these organisms or associated knock-on effects are therefore not expected consequences of diaspidid invasion into native ecosystems.

Environmental impacts conclusion

The potential environmental consequences of *C. aonidum* establishing in New Zealand are independent of pathway and are considered to be low.

Socio-cultural and human health consequences

The establishment of *Chrysomphalus aonidum* is likely to result in some damage to amenity plants and to home fruit crops. This may add to the pest control costs or result in loss of produce for home gardeners. However costs are not expected to be significant and it is likely that over time some control will be exerted by the suite of parasitoids already known to be present.

There are no known human health impacts associated with the establishment of *C. aonidum*.

³⁶ http://www.crec.ifas.ufl.edu/academics/classes/PMA5205/PDF/Rogers_Lecture1_revised%204_10_13.pdf

Socio-cultural and human health impacts conclusion

The potential socio-cultural and human health consequences of *Chrysomphalus aonidum* establishing in New Zealand are independent of pathway and are considered to be negligible.

Overall risk estimation for *Chrysomphalus aonidum* on the fresh produce pathway:

- the likelihood of entry is commodity-dependent and is considered to range from negligible to moderate
- the likelihood of exposure is considered to range from negligible to low depending on the attributes of the host and the disposal conditions.
- the likelihood of establishment is considered to be low. The maximum extent of spread within New Zealand is likely to be limited.
- the potential economic, environmental, socio-cultural and human health consequences of establishment independent of pathway and are considered to be: low, low, negligible and negligible respectively.

1.10 APPENDIX 3: PRA FOR *CHRYSOMPHALUS DICTYOSPERMI* ON FRESH PRODUCE

- Scientific name:** *Chrysomphalus dictyospermi* (Morgan, 1889) (Hemiptera: Diaspididae)
- Other names:** *Aspidiotus dictyospermi* Morgan, 1889; *Aspidiotus mangiferae* Cockerell, 1893; *Chrysomphalus minor* Berlese in Berlese & Leonardi, 1896; *Chrysomphalus castigatus* Mamet, 1936; (ScaleNet 2014)
- Common names:** Dictyospermum scale, Spanish red scale, Morgan's scale, palm scale, western red scale.

Hazard identification

New Zealand status

Chrysomphalus dictyospermi is not known to be present in New Zealand: not recorded in Charles and Henderson (2002) or Gordon (2010); recorded as absent from New Zealand in PPIN (2014).

General geographical distribution

Chrysomphalus dictyospermi is probably native to southern China. It is widespread in tropical and subtropical regions, and occurs in greenhouses in temperate areas (Watson 2005). Miller & Davidson (2005) state it occurs outdoors in most tropical areas of the world.

C. dictyospermi is widespread in the Mediterranean, the Middle East and the South Pacific, where plant quarantine interceptions suggest it has an even wider distribution than has been documented (CPCI 2014). It is present in central and South America, and in over 30 states of the USA, predominantly southern but also in more northern states and in the mid-west in greenhouses (Miller & Davidson 2005). It is regarded as absent from the UK (Watson 2005). It has been reported from Queensland in Australia (ScaleNet 2014).

C. dictyospermi is also widely distributed in Africa, South Asia and southern Europe (Watson 2005; CPCI, 2014; ScaleNet 2014) and is present in many provinces in China (Watson 2005).

Plant associations

C. dictyospermi is highly polyphagous. Watson (2005) cites a reference recording it from hosts belonging to 73 plant families, but notes the host range is probably wider than this. A combined host list from Watson (2005), CPCI (2007) and ScaleNet (2009) includes 234 species, 226 genera and at least 95 families. Hosts include woody trees, shrubs and monocotyledons such as irises. Favoured hosts are palms, *Dracaena* and *Citrus* species (Watson 2005).

The hosts most significantly damaged by *C. dictyospermi* vary from place to place. It is known mainly as a serious pest of *Citrus* (Watson 2005) and is recorded as such in the Western Mediterranean Basin, Greece and Iran (ScaleNet 2014); in Florida and in a number of countries in the South Pacific Region (Watson 2005) and in Chile and the Republic of Georgia (CPCI 2014). In Turkey, *C. dictyospermi* has in the past been most active in citrus plantations in the Aegean region. Damage is generally caused by immature instars and is not economically serious (CPCI 2014).

C. dictyospermi is a pest of olive in Italy, Spain and Turkey (Watson 2005). In Russia, it is a pest of tea (CPCI 2014). It is economically important in France (Watson 2005). It is also important on several hosts in Brazil, and is regarded as a pest in Argentina, where it occurs on both cultivated and native plants (CPCI 2014). It is regarded as a “dangerous pest” in the Palearctic region (Watson 2005). In Egypt, it attacks ornamental plants in greenhouses. It has also been recorded attacking *Pinus caribaea* and *P. caribaea* var. *hondurensis* in Fiji (CPCI 2014).

Hosts that New Zealand imports³⁷ as fresh produce include: avocado, banana, *Citrus* species, eggplant, grapes, lychee, mango, papaya and pears.

Association with fresh produce

C. dictyospermi generally prefers leaves (usually the upper leaf surface; Salama 1970), but is sometimes found on fruit and occasionally on branches (Watson 2005). This preference may differ among host plants; Miller and Davidson (2005) reported that the fruit of citrus seemed to be the most preferred feeding site, although individuals are commonly encountered on leaves and rarely on branches.

C. dictyospermi has been detected on fresh produce from various tropical areas at the New Zealand border.

Biology

The scale cover of the adult female is flat and thin, 1.5–2.0 mm in diameter and greyish or reddish-brown (Salama 1970, Watson 2005).

C. dictyospermi has bisexual and parthenogenetic forms. Parthenogenetic populations are reported outdoors in California, Florida and Mexico, and in greenhouses in Connecticut and Germany. Obligate sexual populations are known outdoors in Louisiana (Miller & Davidson 2005). Females produce from 80 to 200 eggs each over one or several months (Cabido-Garcia 1949, Chkhaidze & Yasnosh 2001).

Eggs may hatch within one to 24 hours of being laid, or crawlers may be laid directly (Miller & Davidson 2005). Crawlers develop for 10–15 days before the first moult, with total development lasting 91 days at 18°C and 71 days at 25 °C (Cabido-Garcia 1949).

In California, *C. dictyospermi* has three or four overlapping generations each year; in Egypt, only two; in the Republic of Georgia there are two or three generations per year and no winter diapause; in Turkey three to six generations were reported and overwintering was usually as first- or second-instar nymphs; in Italy, the species overwintered mainly as young adult females. In tropical conditions, reproduction is continuous (CPCI 2014). Salama (1970) reported that *C. dictyospermi* preferred “conditions of both moderate temperature and relative humidity”. In this study, peak populations were reached in Giza, Egypt in October, when the mean temperature ranged between 22 and 25°C and mean relative humidity 50 to 58%.

Mortality due to abiotic factors is high; in winter, in the Republic of Georgia it may reach 78% (Chkhaidze & Yasnosh 2001).

Potential for establishment and impact

³⁷ or has Import Health Standards for but may not currently import or may not ever have imported.

Chrysomphalus dictyospermi is likely to be able to establish in at least some parts of New Zealand, or in sheltered habitats or in greenhouses. It is capable of causing unwanted impacts within the horticultural, cut flower and nursery industries.

Hazard identification conclusion

Given that this species:

- is associated with some fresh fruit and/or vegetables
- is not known to be present in New Zealand
- is potentially able to establish and cause unwanted impacts,

Chrysomphalus dictyospermi is therefore considered to be a hazard on the fresh produce pathway.

Risk assessment

Entry assessment

Chrysomphalus dictyospermi does not preferentially infest the fruit of most hosts. EPPO non-compliance reports only appear to have reports of this species on *Areca* plants for planting³⁸. Miller and Davidson (2005) report it is most often intercepted in US quarantine from Mexico and Central and Southern America, but do not specify the pathway(s).

In New Zealand *C. dictyospermi* has been detected at the border reasonably frequently. Most detections (live or dead) are on fresh produce, but most are pre-2000 (MPI Interception database download February 2014). Fresh produce detections include coconuts from the Solomon Islands and Fiji; bananas from Tonga, lemons from Australia and Indonesia; lime from the USA, mangos from the Philippines and Mexico and nectarines from the USA. However, this species has been identified only rarely on fresh produce since 2000 and on only one of these occasions was it reported to be alive (lime from the USA, 2006, C2006/266527).

C. dictyospermi is able to survive at least some transit conditions on fresh produce.

The likelihood of entry on any particular consignment is dependent on:

- the host commodity. Fresh produce commodities imported into New Zealand which are also favoured (“main” as defined by CPCI 2014) hosts include citrus, mango, bananas, coconuts, olives, avocado and aubergine. Most of these are tropical or subtropical.
- population levels in the country of origin. This species is widely distributed in tropical and subtropical regions, and may be present on commodities produced in temperate countries in greenhouses. In other places, area or country freedom or low pest prevalence is possible.
- the in-field controls and production systems
- any end-point treatments
- the architecture of the imported commodity. *C. dictyospermi* will be easier to detect during handling and inspection on architecturally simple, smooth-skinned commodities such as aubergines than on more complex commodities such as coconuts.
- the volume of the host imported; some favoured hosts are imported in very large volumes *e.g.* 129,548,152 kilograms of *Musa* spp. (bananas) were

³⁸ EPPO reports on notifications of non-compliance: EPPO Reporting Service – Pests and Diseases. EPPO reports available online at: http://archives.eppo.org/EPPOReporting/Reporting_Archives.htm.

imported in 986 consignments in 2012 (Quancargo database). However, although bananas are “main” hosts according to CABI, identifications on bananas are not common.

Entry conclusion

The likelihood of *Chrysomphalus dictyospermi* entering New Zealand on the fresh produce pathway is commodity-dependent and is considered to range from negligible to moderate.

Exposure assessment

Due to their specialised biology, exposure for all diaspidids is dependent on the delicate crawler (first-instar, the only mobile lifestage excluding males) leaving the imported host commodity and successfully finding a suitable host. Crawlers are susceptible to extremes of temperature, desiccation, rain, predation and a lack of suitable settling sites. This restriction is common to all sternorrhynchs in which the post-settlement life stages are more or less immobile (see Section 1.5.2). Some specific aspects of the biology of *C. dictyospermi* and some attributes of the particular host commodity may also influence the exposure likelihood:

- unavoidable waste: host commodities which are entirely consumed, such as stonefruit, present a lower exposure risk than those whose skin is discarded, such as citrus or avocados.
- robustness of host commodity: diaspidid females produce eggs continuously over several weeks until their death (Koteja 1990, cited in Morse *et al.* 2009). Therefore crawlers are likely to be produced for as long as the host fruit remains in good condition. Soft fruit hosts such as grapes and pears are likely to deteriorate more quickly than more robust hosts such as citrus.
- availability of suitable hosts: *C. dictyospermi* is highly polyphagous and there would be no shortage of suitable host species throughout New Zealand.
- developmental thresholds: there appears to be little information available on development rates of this species. Developmental data cited by Cabido-Garcia (1949) suggests that temperature thresholds for crawlers will be exceeded in at least some parts of New Zealand in at least some months.

Successful exposure of crawlers emerging from female/s infesting imported produce, to plants in domestic or commercial greenhouses is much less likely than exposure to outdoor hosts (see 1.5.2. (v) “Infestation of greenhouses and other protected environments”).

Exposure conclusion

The likelihood of *Chrysomphalus dictyospermi* on imported fresh produce being successfully exposed to new hosts in New Zealand is considered to vary from negligible to low, depending on the attributes of the host and the disposal conditions.

Establishment and spread assessment

Chrysomphalus dictyospermi has obligate bisexual and parthenogenetic forms. For obligate bisexual forms, a mated female or immatures of both sexes would be necessary to establish a reproductive population. Since exposure depends on successful crawler dispersal, for establishment to take place crawlers of both sexes need to find a suitable host, develop to adults, successfully locate each other, mate and produce viable offspring. The introduction of parthenogenetic females is assumed to increase the likelihood of establishment.

C. dictyospermi is multivoltine at higher temperatures and females lay up to 200 eggs so the potential for rapid population increase in suitable conditions is high.

C. dictyospermi is polyphagous on a wide variety of plants many of which are present in New Zealand, including garden plants. Therefore suitable hosts are highly likely to be readily available. Populations which establish in home gardens can also act as population reservoirs for re-infestation of commercial crops.

In southern Portugal, four generations a year were recorded, however the species was said to be virtually absent from northern Portugal in the late 1940s (Cabido-Garcia 1949). Field work for these studies was carried out in Lisbon, which has an overall climate match of 0.8 with the whole of New Zealand (Phillips *et al.* in prep.).

This information suggests that *C. dictyospermi* may be able to establish outdoors in warmer parts of New Zealand. In addition, populations of *C. dictyospermi* could establish in greenhouses, which can be considered as tropical ecological islands in a temperate climate (Kaas 2002). This likelihood is higher if the source population is parthenogenetic, in which case a single individual could found a reproducing population. However, the likelihood of imported crawlers being successfully exposed to hosts in greenhouses is low (see Section 1.5.2).

There is no specific data available on the dispersal rate of *C. dictyospermi*. Crawlers can actively crawl over short distances or be carried in air currents or on vectors. Long distance dispersal is likely to be through the plant trade, particularly live plants. After establishment, spread through domestic and commercial greenhouses throughout much of New Zealand may occur by the movement of infested plant material. The level of phytosanitary hygiene in commercial operations is generally higher than in domestic situations and colonisation may therefore be less likely.

Establishment and spread conclusion

The likelihood of establishment of *Chrysomphalus dictyospermi* is considered to be low; if founder populations are parthenogenetic the likelihood of establishment is assumed to increase. The maximum extent of spread within New Zealand is likely to be limited to the northern North Island.

Consequence assessment

Economic consequences

Chrysomphalus dictyospermi is a serious pest of avocado and a range of tropical and subtropical plants (Miller & Davidson 2005) and is capable of infesting many commercial crops including all *Citrus* species, *Prunus* species and grapevine. Infestation disfigures the fruit reducing market value. Additionally, infested leaves and branches cause the plant to gradually lose vigour with individual portions of the infested plant dying (Beardsley and Gonzalez 1975, McClure 1990, Charles & Henderson 2002, CPCI 2014). As for all armoured scale insects, management is difficult due to the protection afforded by the waxy caps covering the insect body.

If *C. dictyospermi* became widespread in New Zealand the losses to horticultural commodities could be considerable. In the year ending March 2014, New Zealand's combined fresh fruit export value was \$2030 million (2.03 billion; SOPI 2104). In addition to damaging fruit production, *C. dictyospermi* has the potential to have negative economic impacts on the nursery and cut flower industries. However its impact on outdoor crops is likely to be very much reduced by its limited potential geographic range in New Zealand.

Although *C. dictyospermi* has been reported infesting several pine species, significant impacts on the *Pinus radiata* industry are unlikely.

Unlike other scale insect families, diaspidids do not excrete honeydew. They are therefore not associated with sooty mould growths (Watson 2005), so mould contamination of fruit and/or inhibition of photosynthesis are not consequent problems.

The establishment of *Chrysomphalus dictyospermi* in New Zealand could cause disruption of access to some markets, including Western Australia.

Mitigating factors:

- The impact of this pest is likely to be reduced by its limited potential geographic range in New Zealand.
- Noyes (2002) lists 48 known chalcidoid natural enemies of *C. dictyospermi*. Eight of these species (*Aphytis chilensis*, *A. chrysomphali*, *A. diaspidis*, *A. mytilaspidis*, *Encarsia citrina*, *Arrhenophagus chionaspidis*, *Signiphora flavopalliata* and *S. merceti*) are known to be present in New Zealand (Gordon 2010). It is likely that these parasitoids³⁹ would exert some level of population control on *C. dictyospermi* in New Zealand that may reduce its impact, but it is not known how significant this would be.

Economic impacts conclusion

The potential economic consequences of *C. dictyospermi* establishing in New Zealand are independent of pathway and are considered to be low.

Environmental consequences

C. dictyospermi is a polyphagous species, with over 230 recorded hosts. Beever *et al.* (2007) suggested that in terms of risk to native flora, sap-sucking hemipterans such as armoured scale insects are a high risk group. However it must be noted that this study assessed exotic species in terms of risk, not solely impact (the risk ranking of a species included its likelihood of reaching New Zealand as well as its anticipated impact). This study also concluded that highly damaging polyphagous species appear to be exceptional and that the impact of relatively specialised organisms is likely to be greater.

Charles and Henderson (2002) recorded a number of exotic armoured scale insect species on native plant hosts, and noted that some polyphagous exotic species are now occasionally found on native plants in isolated patches of native bush, raising concerns of the threat they may pose to native plants. However no such impacts are known to have been reported from exotic diaspidids that have been established in New Zealand for many decades.

Diaspidids do not secrete honeydew, so they are not they are not associated with the growth of sooty mould fungi in their habitat, nor do they support honeydew feeders (see Section 1.5.5). Changes in population sizes of these organisms or associated knock-on effects are therefore not expected consequences of diaspidid invasion into native ecosystems.

Environmental impacts conclusion

The potential environmental consequences of *C. dictyospermi* establishing in New Zealand are independent of pathway and are considered to be low.

³⁹ and others present in New Zealand and closely related to important parasitoids overseas.

Socio-cultural and human health consequences

The establishment of *Chrysomphalus dictyospermi* is likely to result in some damage to amenity plants and to home fruit crops. This may add to the pest control costs or result in loss of produce for home gardeners. However costs are not expected to be significant and it is likely that over time some control will be exerted by the suite of parasitoids already known to be present.

There are no known human health impacts associated with the establishment of *C. dictyospermi*.

Socio-cultural and human health impacts conclusion

The potential socio-cultural and human health consequences of *Chrysomphalus dictyospermi* establishing in New Zealand are independent of pathway and are considered to be negligible.

Overall risk estimation for *Chrysomphalus dictyospermi* on the fresh produce pathway:

- the likelihood of entry is commodity-dependent and is considered to range from negligible to moderate
- the likelihood of exposure is considered to range from negligible to low depending on the attributes of the host and the disposal conditions.
- The likelihood of establishment is considered to be low; moderate if founder populations are parthenogenetic. The maximum extent of spread within New Zealand is likely to be very limited.
- the potential economic, environmental, socio-cultural and human health consequences of establishment independent of pathway and are considered to be: low, low, negligible and negligible respectively.

1.11 APPENDIX 4: PRA FOR PSEUDAULACASPIS PENTAGONA ON FRESH PRODUCE

Scientific name: *Pseudaulacaspis pentagona* (Targioni-Tozzetti, 1886)

(Hemiptera: Diaspididae)

Common name/s: White peach scale

Common synonyms and combinations: *Aspidiotus lanatus*, *Aspidiotus vitiensis*, *Aulacaspis (Diaspis) pentagona*, *Diaspis (Aulacaspis) pentagona*, *Diaspis amygdali*, *Diaspis geranii*, *Diaspis lanata*, *Diaspis lanatum*, *Diaspis patelliformis*, *Diaspis pentagona*, *Diaspis rosae geranii*, *Epidiaspis vitiensis*, *Sasakiaspis pentagona*

Taxonomy

The status of *Pseudaulacaspis pentagona* with respect to *Pseudaulacaspis prunicola* (Maskell) is uncertain.

Watson (2005) states: “Borchsenius, 1966 treated *Pseudaulacaspis prunicola* (Maskell) as a synonym of *P. pentagona*. However, Davidson and Miller, 1990; Davidson *et al.*, 1983; Danzig, 1993; and Kosztarab, 1996, treated these species separately and they are treated as separate species here.” Subsequent to these publications, Kreiter *et al.* (1999) examined specimens reared from potato for more than 100 generations and found specimens that fit both *P. pentagona* and *P. prunicola*. They concluded that the two are variants of the same species. However Miller and Davidson (2005) treat the two species as separate and state (p. 364) “[*P. prunicola*] long has been confused with ... *Pseudaulacaspis pentagona*. Most published biologies probably deal with [*P. pentagona*] since they usually report work done in warm areas of the world on hosts other than *Prunus*”.

New Zealand status

Neither *Pseudaulacaspis pentagona* nor *P. prunicola* is known to be present in New Zealand. Not recorded by: Charles and Henderson (2002), ScaleNet (2014). *P. pentagona* is reported absent by PPIN (2014).

General geographical distribution; summarised from ScaleNet (2014) unless otherwise stated: Africa, Australia, Polynesia, Micronesia, Hawaiian Islands, Canada, USA, Mexico, South America, China, Hong Kong, India, Indonesia, Malaysia, Mongolia, Tibet, the Mediterranean, North Africa, the former USSR, the Middle East and Japan.

Within Europe it now occurs in Azerbaijan, Bulgaria, France, Georgia, Germany, Greece, Hungary, Italy, Macedonia, Malta, Netherlands, Portugal, Russia, Serbia and Montenegro, Spain, Sweden, Switzerland, Turkey and Ukraine (probably in greenhouses in colder areas). In the past 20 years it has spread northwards in Europe, possibly as a result of climate change (Malumphy *et al.* 2009).

P. pentagona was collected from California prior to 1920, but never collected again (Gill 1997, CPCI 2014).

Balachowsky (1954) states that *P. pentagona* is probably native to Japan.

Plant associations

P. pentagona is a broadly polyphagous species.

ScaleNet (2014) lists over 300 hosts in 78 plant families. CPCI (2014) lists the main hosts as: *Abelmoschus esculentus*, *Actinidia* spp., *Carica* spp., *Catalpa* spp., *Celtis*

spp., *Euonymus* spp., *Ficus* spp., *Juglans* spp., *Malus* (ornamental species), *Morus* spp., *Nerium* spp., *Philadelphus coronarius*, *Prunus* spp., *Pyrus* spp., *Ribes* spp., *Ricinus communis*, *Rubus* spp., *Sedum* spp., *Sophora* spp., *Sorbus* spp. and *Vitis* spp.

P. pentagona can be reared very successfully in the laboratory on potatoes (Abbasipour 2007). The host plant range could be much wider than is listed but the life cycle cannot be completed on some of the attributed hosts, indicating they may not be true hosts (CPCI 2014).

Hosts that New Zealand imports⁴⁰ as fresh produce include: capsicum, cherries, *Citrus* species, eggplant, kiwifruit, lychee, okra, papaya, peaches, pears, nectarines, squash and zucchini.

Association with fresh produce

According to CPCI (2014) “Heavy infestations [of *P. pentagona*] are often found as thick crusts on tree trunks and older branches in temperate regions, and rarely on the roots. The leaves and fruits are not usually infested”. However Hill (1987) records this species as encrusting twigs, with some on leaves; Hely *et al.* (1982) state that “scale attacks wood, leaves and fruit”; Hetherington (2005) reports it as able to “infest bark, fruit and leaves” and Watson (2005) states that fruit infestations can occur.

Hill *et al.* (2007) reported that up to 23% (average 10.3%) of unsprayed “Hort 16A” *Actinidia chinensis* fruit were infested with *P. pentagona* in Italian orchard samples in 2004. Australian risk analyses (Poole *et al.* 2001, 2003) have categorised *P.*

pentagona as being present on the cherry and stonefruit pathways (defined as fresh, mature fruit) for commercial Australian produce.

P. pentagona has been detected on the fresh produce pathway in international trade including:

- on Hawaiian papaya in California and
- on Italian kiwifruit and cucurbits from the Pacific in New Zealand (see Entry assessment).

Biology (after Watson 2005, unless otherwise stated)

In common with other diaspidids, the number of immature instars has been reduced to two in female *Pseudaulacaspis pentagona*, and there is no pupal stage. In the male, there are 2 feeding larval instars followed by two non-feeding stages (pre-pupa and pupa) before a winged adult emerges.

The adult female is sedentary and is covered by a pale scale or test which measures from 1.5 to 3 mm in diameter. Reproduction is sexual, no reports of asexual reproduction have been found. Males respond to a pheromone released by adult females; a pheromone trap is commercially available for monitoring. It has been estimated that *P. pentagona* would be detected in a pheromone trap ten years before symptoms became clearly visible on hosts (CSL 2007).

This species overwinters as mated females in cold climates and can survive temperatures as low as -20°C although there is high mortality at such temperatures (CSL 2007). Eggs may also overwinter in warmer climates. Within its existing geographic range there are one to four generations per year, depending on climate.

At 11–15°C, a minimum of 110 days is taken to complete a generation, but at 26°C, generation time is 40 days and females begin to oviposit around 16 days after

⁴⁰ or has Import Health Standards for but may not currently import or may not ever have imported.

maturing (Ball 1980). Abbasipour (2007) calculated a lower developmental threshold of 9.8 °C for the first and second instars. CSL (2007) used various developmental data to calculate the threshold temperature for development from egg to adult females capable of oviposition as approximately 9.7°C, with 714 degree days required to complete such development. Takeda (2006) found that temperature was the most important factor in diapause termination, and that even when females were collected in mid-winter, exposure to temperatures of 25°C caused some to start egg-laying. Overwintering females continued feeding in the laboratory (Takeda 2006). Adult females lay about 100 eggs, which hatch around 3–14 days after laying, depending on temperature.

Noyes (2002) lists 75 known chalcidoid natural enemies (parasitoid microwasps) of *P. pentagona* in the families Aphelinidae, Encyrtidae, Eulophidae and Signiphoridae. In Italy the aphelinids *Aphytis proclia*, *Encarsia berlesei* (as *Prospalta berlesei*) and *Pteroptrix orientalis* are reported to be important mortality factors in *P. pentagona* populations, capable of combined rates of mortality of 20–90% (references in Hill *et al.* 2007).

Potential for establishment and impact

Pseudaulacaspis pentagona is likely to be able to establish in at least some parts of New Zealand, or in sheltered habitats or in greenhouses. It is likely to cause unwanted impacts within horticultural industries.

Hazard identification conclusion

Given that this species

- is associated with some fresh fruit and/or vegetables
- is not known to be present in New Zealand
- is potentially able to establish and cause unwanted impacts,

Pseudaulacaspis pentagona is therefore considered to be a hazard on the fresh produce pathway.

Risk assessment

Entry assessment

Although *P. pentagona* does not preferentially infest fruit and leaves and is more often found on woody material, fruit can be heavily infested (see cover photo). EPPO non-compliances only appear to have reports of this species on *Prunus* plants for planting⁴¹ and these are also very rare. However CPCI (2014) states that it is probably intercepted in most countries, but the interceptions go largely unreported, and there is ample evidence of its presence on the fresh produce pathway in international trade:

- CSL (2007) reports interceptions on peach and kiwifruit fruit in the United Kingdom from 1998 through 2006
- it is frequently intercepted in California on shipments of papaya from Hawaii (Follett 2006)
- *P. pentagona* is relatively frequently detected at the New Zealand border on fresh produce (1.4% of all diaspidid identifications on fresh produce were *Pseudaulacaspis pentagona*)⁴². Roughly half (42/83) of the identifications of *P. pentagona* reported some live specimens, including females and eggs. Most

⁴¹ EPPO reports on notifications of non-compliance: EPPO Reporting Service – Pests and Diseases. EPPO reports available online at http://archives.eppo.org/EPPOReporting/Reporting_Archives.htm.

⁴² 83/5763, MPI Identification database, downloaded January 2014.

(75/83) identifications of *P. pentagona* on fresh produce were on Italian kiwifruit. Italian kiwifruit is cold treated for medfly, *Ceratitis capitata* (Wiedemann), at 0.00°C or below for 10 days (MPI Standard 152.02; other schedules are given but 0.00°C is used, J. Wilson, MPI, pers. comm.). Since 2009 live specimens have been detected at the border on Italian kiwifruit in 11 instances, with the most recent being in December 2013 (MPI 2014)

- *P. pentagona* has also been identified at the New Zealand border alive on squash from Tonga (2013) and on pumpkin from Fiji (unknown status, 1993).

P. pentagona is a long-lived species (at 11–15°C a minimum of 110 days is taken to complete a generation). It is known to survive transit conditions including cold storage and treatment, and thus it is very likely to survive air or sea transit.

The likelihood of entry on any particular consignment of fresh produce is dependent on:

- the host commodity. Fresh produce commodities imported into New Zealand which are also favoured (“main” as defined by CPCI 2014) hosts include: *Abelmoschus* (okra and island cabbage), kiwifruit, papaya, stonefruit and *Vitis*.
- the population levels in the country of origin. This species is widely distributed globally, but area or country freedom (*e.g.* Western Australia; Biosecurity Australia 2008) or low pest prevalence (*e.g.* Pacific Northwest) is possible.
- the in-field controls and production systems
- any end-point treatments
- the architecture of the commodity. *P. pentagona* will be easier to detect during handling and inspection on architecturally simple, smooth-skinned commodities such as nectarines than on complex commodities such as grapes.
- the volume of the host imported; some favoured hosts are imported in very large volumes *e.g.* 14,558,508 kilograms of grapes and 935,666 kg of kiwifruit were imported in the 2013-2104 financial year⁴³ (Cath Kingston, MPI).

Entry conclusion

The likelihood of *Pseudaulacaspis pentagona* entering New Zealand on fresh produce pathways is commodity-dependent and is considered to range from negligible to high.

Exposure assessment

Due to their specialised biology, exposure for all diaspidids is dependent on the delicate crawler (first-instar, the only mobile lifestage⁴⁴) leaving the imported host commodity and successfully finding a suitable host. Crawlers are susceptible to extremes of temperature, desiccation, rain, predation and a lack of suitable settling sites. Oda (1963) assessed mortality of *P. pentagona* crawlers in the field at ~90%, compared to that of 30% for subsequent life stages. Some specific aspects of the biology of *P. pentagona* and some attributes of the particular host commodity may also influence the exposure likelihood:

- unavoidable waste: host commodities which are entirely consumed, such as pele (island cabbage) and summerfruit present a lower exposure risk than those whose skin is discarded, such as kiwifruit or cucurbits.

⁴³ from all places

⁴⁴ excluding males

- robustness of host commodity: *P. pentagona* females produce eggs continuously over several weeks (or longer depending on temperature) until their death (Takeda 2004, 2006). Therefore crawlers are likely to be produced for as long as the host fruit remains in good condition. Soft fruit hosts such as summerfruit are likely to deteriorate more quickly than more robust hosts such as cucurbits, avocado or citrus.
- the availability of suitable plants and plant parts: *P. pentagona* is extremely polyphagous and there would be no shortage of suitable host species throughout New Zealand. Additionally, this scale insect is able to exploit most plant parts including bark, leaves and fruit (hence the reference to a “triple threat”; Branscome 2012) so it is not dependent on crawlers coming into contact with a specific part of a host plant.
- developmental thresholds: the lower developmental threshold of *P. pentagona* was calculated by CSL (2007) as 9.7°C. Takeda (2004) calculated that 50% of females began laying eggs at 10.5°C, and peak egg-hatch was reached at 10.9°C. If the commodity is shipped in cool-storage, insects are unlikely to continue developing and eggs are unlikely to hatch in transit. However development may continue after arrival, even if insects are coming from northern hemisphere winter, since temperature has been found to be the most important factor in diapause termination (Takeda 2006). Temperatures above 10.5°C could be met outdoors all year round from Auckland north, and over the whole of the North Island and the Nelson region from October to April (NIWA 2014)⁴⁵, allowing eggs to hatch and the release of crawlers to the environment.

Successful exposure of crawlers emerging from female/s infesting imported produce, to plants in domestic or commercial greenhouses is much less likely than exposure to outdoor hosts (see 1.5.2. (v) “Infestation of greenhouses and other protected environments”).

Exposure conclusion

The likelihood of *Pseudaulacaspis pentagona* on imported fresh produce being successfully exposed to new hosts in New Zealand is considered to vary from negligible to low, depending on the attributes of the host and the disposal conditions.

Establishment and spread assessment

A mated female or immatures of both sexes would be necessary to establish a reproductive population, since no reports of parthenogenesis in this species have been found. Since exposure depends on successful crawler dispersal, for establishment to take place, crawlers of both sexes need to find a suitable host, successfully develop to sexual maturity, the male must locate the female, mate and produce viable offspring. This is likely to be an important limiting step.

P. pentagona is multivoltine at higher temperatures and females each lay around 100 eggs, so the potential for rapid population increase in suitable conditions is high.

P. pentagona has a wide range of hosts including many that are widely grown in New Zealand commercially as well as in domestic gardens. Availability of hosts is not likely to be a barrier to establishment. Populations which establish in home gardens can also act as population reservoirs for re-infestation of commercial crops.

⁴⁵ and also in certain microclimates

P. pentagona is widely considered to be tropical/subtropical species, however this species is frequently intercepted at the border on kiwifruit from Italy, which occupies a similar latitudinal range to New Zealand, and much of which has a climate match of 0.9 with all of New Zealand (Phillips *et al.* in prep.). There is also regional information from Italy which supports an argument that New Zealand kiwifruit growing regions may be climatically suitable for *P. pentagona*:

- the neotype of *P. pentagona* is recorded from Como, northwestern Italy (Davidson *et al.* 1983). Como is an area with cold, wet winters at latitude 45°; the general Como region has a climate match of 0.8 with New Zealand.
- *P. pentagona* is a serious pest in commercial kiwifruit orchards around Cisterna di Latina, Lazio, Italy (Hill *et al.* 2007). Inland areas in this region have a 0.9 climate match with the whole of New Zealand (Phillips *et al.* in prep.).

In the United States, *P. pentagona* is recorded from the Washington D.C. area and from Indiana by Davidson *et al.* (1983), who state only that it “tends” to be a tropical or subtropical species (though it is unclear whether these are greenhouse records). It is similarly reported from Canada. In Australia, *P. pentagona* has been reported from Queensland and northern New South Wales (ScaleNet 2014, Donaldson & Tsang 2002, Hetherington 2005). Although it has been present for over a century (recorded by Maskell 1885 and 1887, according to Donaldson & Tsang 2002), its distribution does not appear to have extended to more temperate regions such as Victoria and Tasmania.

CSL (2007) used various developmental data to calculate that one generation would be possible each year outdoors in the UK, with development occurring between mid-May and the end of September. This analysis concluded that *P. pentagona* was “likely” to establish outdoors in the UK; that mild UK winters would not be likely to be a barrier inhibiting establishment, and that establishment success would depend upon whether sufficient thermal energy accumulates during the UK spring and summer. Empirical support for these calculations was provided by the observation that a population of *P. pentagona* discovered on *Catalpa bignonioides* trees in Kent (originating in Italy) had been present for 4 or 5 years. This was the first known occurrence of *P. pentagona* breeding and over-wintering outdoors in the UK. Action was taken to control/eradicate the pest (Malumphy *et al.* 2009), so it is not known how long the populations could have persisted or how far they would have spread. Northwards spread in Europe is occurring at present, possibly due to the effects of climate change (Malumphy *et al.* 2009).

These data suggest that *P. pentagona* may be able to establish in many of the warmer regions of New Zealand. In addition, populations may establish in greenhouses in colder regions. However, the likelihood of imported crawlers being successfully exposed to hosts in greenhouses is low (see Section 1.5.2).

There is no specific data available on the dispersal rate of *P. pentagona*. Crawlers can actively crawl over short distances or be carried in air currents or on vectors. Long distance dispersal is likely to be in trade. After establishment, spread through domestic and commercial greenhouses throughout much of New Zealand may occur by the movement of infested plant material. The level of phytosanitary hygiene in commercial operations is generally higher than in domestic situations and colonisation may therefore be less likely.

Establishment and spread conclusion

The likelihood of establishment of *Pseudaulacaspis pentagona* is considered to be low. The maximum extent of spread within New Zealand is likely to be moderate, *i.e.* it is likely to be limited to the warmer parts of New Zealand, but may include many important horticultural regions.

Consequence assessment

Economic consequences

Pseudaulacaspis pentagona is unusual as a scale insect in that it is known to be able to kill some of its hosts (CSL 2007). Severe infestations can form heavy crusts, causing branches or trees to die some years after the onset of infestation (CPCI 2014), and feeding activities can result in early leaf drop. This species was described as a very destructive pest by Kosztarab (1996, cited in Watson 2005), especially on flowering cherry, mulberry, peach and other deciduous fruit trees. Williams and Watson (1988) and Danzig and Pellizzari (1998, cited in Watson 2005) also describe it as a destructive species.

In warmer parts of its existing range, for example in the south-eastern USA, *P. pentagona* infestations can become significant. In Florida it has been reported from over 120 hosts and can cause major economic damage (Branscome 2012). It is a pest of tea and fruit crops (including kiwifruit) in China, tea in Japan, and fruit crops in the Pacific (references in Hill *et al.* 2007). Australian orchardists regard it as a serious problem on stonefruit, particularly for the emerging low-chill stone fruit industry in warmer coastal production regions (Hetherington 2007). Bazrafshan *et al.* (2010) reported it as the most important pest of peach in Iran, and it is economically important in France and Greece (citations in CSL 2007). A DEFRA analysis estimated the potential of this scale to cause economic and/or environmental damage in the United Kingdom as “medium” (CSL 2007). As for all armoured scale insects, management of *P. pentagona* is difficult due to the protection afforded by the waxy caps covering the insect body. Hetherington (2007) cites anecdotal reports that this species is more difficult to control than other scale insects in Australia.

Kiwifruit (*Actinidia* spp.) and *Vitis* spp. are among the main hosts listed by CPCI (2014). Kiwifruit and wine are New Zealand’s biggest horticultural export earners (Fresh Facts 2012, SOPI 2014).

Wine revenues for the year ended March 2014 were NZ\$ 1317 million (SOPI 2014). While grapes are not exported in large volumes, any additional production costs have the potential to impact negatively on the wine industry.

Kiwifruit export earnings were worth over \$1000 million in 2012 (Fresh Facts 2012), but the incursion of the bacterial disease *Pseudomonas syringae* pv. *actinidiae* (Psa, or bacterial canker) in 2010 resulted in a drop to \$817 million for the year ending March 2014. However, export volumes are expected to recover as the kiwifruit industry replaces the Psa-susceptible Hort 16A vines with the new tolerant Gold3 vines. Volumes and value of green kiwifruit are forecast to remain steady (SOPI 2014)⁴⁶. The European Union and Japan are the two main export markets (SOPI 2014). Most (around 80%) kiwifruit is grown in the Bay of Plenty region (Market Access Solutionz 2012).

In Italy *P. pentagona* has been recognised as a pest of *Actinidia deliciosa* ‘Hayward’ kiwifruit since the 1970s and in 2004 it was responsible for an estimated 10–20% loss

⁴⁶ in 2013 production was split between 80% green (*Actinidia deliciosa*) and 20% gold (*A. chinensis*); <http://www.mpi.govt.nz/agriculture/horticulture/fruits>.

of marketable *A. chinensis* 'Hort16A' fruit in commercial orchards around Cisterna di Latina, Lazio, Italy (Hill *et al.* 2007). It is not known whether the impact in New Zealand orchards would be of a similar magnitude. Although some parts of this region of Italy have a close climate match (to the whole of New Zealand), there may be important differences. There may also be important differences in management practices in Italian kiwifruit orchards. Two other armoured scale species (*Hemiberlesia lataniae* and *H. rapax*) are managed by Integrated Pest Management or IPM systems in New Zealand kiwifruit orchards. Although effective insecticide treatments have been trialled against *P. pentagona* in Italy (Hill *et al.* 2007), it is not known what effect these would have on established IPM systems that are based on phenological models (*e.g.* Hill *et al.* 2008). In addition these treatments would not be available to organic growers. Organic kiwifruit production was \$50 million in 2012/2013 (M.G. Hill, pers. comm.).

It is unclear whether commercial pipfruit crops are reproductive hosts of this species, although CSL (2007) and CPCI (2014) list ornamental apple species as major hosts.

Noyes (2002) lists 75 known chalcidoid natural enemies of *P. pentagona*. Ten of these species (*Aphytis chilensis*, *A. chrysomphali*, *A. diaspidis*, *A. mytilaspidis*, *Encarsia citrina*, *E. perniciosi*, *Arrhenophagus chionaspidis*, *Epitetracnemus intersectus*, *Zaomma lambinus* and *Signiphora flavopalliata*) are known to be present in New Zealand (Gordon 2010). *Encarsia citrina* is reported to be the most common scale parasitoid in New Zealand kiwifruit orchards (Beattie 2002), however its effectiveness against *P. pentagona* is unknown. It is likely that some or all of these parasitoids⁴⁷ would exert some level of population control on *P. pentagona* in New Zealand that may reduce its impact, but it is not known how significant this would be. In some parts of its invasive range (*e.g.* South America and Europe), *P. pentagona* has been reduced to subeconomic levels principally as a result of the introduced parasitoid *Encarsia berlese* (ScaleNet 2014).

Unlike other scale insect families, diaspidids do not excrete honeydew. They are therefore not associated with sooty mould growths (Watson 2005), so mould contamination of fruit and/or inhibition of photosynthesis are not consequent problems.

Although *P. pentagona* is widely distributed globally, it is absent from some New Zealand markets (*e.g.* Western Australia) and so establishment has the potential to cause very limited market access disruption.

Economic impacts conclusion

Given that *Pseudaulacaspis pentagona*:

- is a pest of a wide range of crops grown in New Zealand
- is reported to cause economic impacts on kiwifruit, one of New Zealand's biggest horticultural export earners, in other parts of the world and
- can be difficult to control and may interfere with existing IPM systems;

but considering:

- *P. pentagona* is already present in many important markets (*e.g.* Japan and much of the European Union for kiwifruit)
- effective control systems have been identified overseas
- a pheromone is available for surveillance and monitoring
- some range restriction is likely due to climatic factors

⁴⁷ and others present in New Zealand and closely related to important parasitoids overseas.

- there is an existing suite of known natural enemies present in New Zealand;

The potential economic consequences of *Pseudaulacaspis pentagona* establishing in New Zealand are considered to be moderate. They are independent of pathway.

Environmental consequences

P. pentagona is a polyphagous species, with over 300 recorded hosts in 78 plant species (ScaleNet 2014). Beever *et al.* (2007) suggested that in terms of risk to native flora, sap-sucking hemipterans such as armoured scale insects are a high risk group. However it must be noted that this study assessed exotic species in terms of risk, not solely impact (the risk ranking of a species included its likelihood of reaching New Zealand as well as its anticipated impact). This study also concluded that highly damaging polyphagous species appear to be exceptional and that the impact of relatively specialised organisms is likely to be greater.

Charles and Henderson (2002) recorded a number of exotic armoured scale insect species on native plant hosts, and noted that some polyphagous exotic species are now occasionally found on native plants in isolated patches of native bush, raising concerns of the threat they may pose to native plants. However no such impacts are known to have been reported from exotic diaspidids that have been established in New Zealand for many decades.

Diaspidids do not secrete honeydew, so they are not they are not associated with the growth of sooty mould fungi in their habitat, nor do they support honeydew feeders (see Section 1.5.5). Changes in population sizes of these organisms or associated knock-on effects are therefore not expected consequences of diaspidid invasion into native ecosystems.

Environmental impacts conclusion

The potential environmental consequences of *Pseudaulacaspis pentagona* establishing in New Zealand are independent of pathway and are considered to be low.

Socio-cultural and human health consequences

The establishment of *Pseudaulacaspis pentagona* is likely to result in some damage to amenity plants and to home fruit and vegetable crops. This may add to the pest control costs or result in loss of produce for home gardeners. However costs are not expected to be significant and it is likely that over time some control will be exerted by the suite of parasitoids already known to be present.

There are no known human health impacts associated with the establishment of *P. pentagona*.

Socio-cultural and human health impacts conclusion

The potential socio-cultural and human health consequences of *Pseudaulacaspis pentagona* establishing in New Zealand are independent of pathway and are considered to be negligible.

Overall risk estimation for *Pseudaulacaspis pentagona* on the fresh produce pathway:

- the likelihood of entry is commodity-dependent and is considered to range from negligible to high
- the likelihood of successful exposure is considered to vary from negligible to low, depending on the attributes of the host and the disposal conditions.

- The likelihood of establishment is considered to be low. The maximum extent of spread within New Zealand is likely to be limited.
- the potential economic, environmental, socio-cultural and human health consequences of establishment are considered to be: moderate, low, negligible and negligible respectively.

1.12 APPENDIX 5: PRA FOR *CEROPLASTES RUBENS* ON FRESH PRODUCE

Scientific name: *Ceroplastes rubens* Maskell, 1893 (Hemiptera: Coccidae)
Other names: *Ceroplastes rubens minor* Maskell, 1897 (ScaleNet 2014).
Common names: red wax scale, pink wax scale

Hazard identification

New Zealand status

Ceroplastes rubens is not known to be present in New Zealand. Not recorded in Gordon (2010) or PPIN (2014).

General geographical distribution

C. rubens was first described from Australia, but is thought to have originated in Africa (Waterhouse & Sands 2001). In Australia it has been reported from every state and territory except Tasmania (Qin & Gullan 1994). It is currently widely distributed around the Orient, southern Asia, Australia, India, the South Pacific, East Africa and the West Indies. It occurs in some temperate regions, and is also found in greenhouses in temperate regions (CPCI 2014).

There is no conclusive evidence that *C. rubens* has become established in Europe or the Mediterranean region (Malumphy 2011).

Malumphy (2011) gives the following distribution summary:

North America: United States of America (Florida); Central America: (strongly suspected to be present despite the lack of official records); South America: Colombia; Venezuela; Caribbean: Dominica; Guadeloupe; Haiti; Jamaica; Martinique; Puerto Rico & Vieques Island; St Lucia; Trinidad & Tobago; US Virgin Islands (St John); Europe: absent; Africa: Ethiopia; Kenya; Seychelles; South Africa; Tanzania; Zanzibar; Middle East: absent; Asia: China; Hong Kong; India; Indonesia; Japan; Malaysia; Maldives; North Korea; Pakistan; Philippines; Ryukyu Islands; South Korea; Sri Lanka; Taiwan; Thailand; Vietnam; Oceania: Australia; Cocos Islands; Cook Islands; Fiji; French Polynesia (Tahiti); Guam; Hawaiian Islands; Kiribati; New Caledonia; Niue; Norfolk Island; Northern Mariana Islands (Rota Island, Saipan Island); Palau; Papua New Guinea; Samoa; Solomon Islands; Vanuatu.

Plant associations

C. rubens is a highly polyphagous species occurring on hundreds of plant species assigned to more than 80 families (Malumphy 2011). CPCI (2014) reports only *Citrus* species and mango as main hosts, while Gimpel *et al.* (1974) cite citrus, avocado, palm and gardenia as preferred hosts. It is primarily a pest of tropical and sub-tropical crops (Malumphy 2011).

Other hosts of economic importance to New Zealand include avocado (*Persea americana*), *Malus*, *Pinus*, *Prunus* and *Pyrus* species.

Hosts that New Zealand imports⁴⁸ as fresh produce include: avocado, breadfruit (*Artocarpus altilis*), *Citrus* species, lychee (*Litchi chinensis*), mango (*Mangifera indica*) and mangosteen (*Garcinia mangostana*).

⁴⁸ or has Import Health Standards for but may not currently import or may not ever have imported.

C. rubens also infests a range of ornamentals and amenity species, including *Acacia*, *Acer*, *Aglaonema*, *Anthurium*, *Aralia*, *Buxus*, *Camellia*, *Chrysanthemum*, *Cycas*, *Cydonia*, *Dieffenbachia*, *Euonymus*, *Euphorbia*, *Fatsia*, *Ficus*, *Hedera*, *Hibiscus*, *Ilex*, *Laurus*, *Ligustrum*, *Magnolia*, *Metrosideros*, *Monstera*, *Morus*, *Nerium*, *Olea*, *Pittosporum*, *Rhododendron*, *Rosa*, *Schefflera*, *Spiraea*, *Viburnum*, *Wisteria* and many others (CPCI 2014, ScaleNet 2014).

Association with fresh produce

The literature suggests that *Ceroplastes rubens* does not preferentially infest the fruit of most hosts, but association with fruit may vary with host plant and possibly season.

Gimpel *et al.* (1974) and Itioka and Inoue (1991) did not report association with fruit, instead, respectively reported that “specimens are found on the stems, branches, and leaves of its host” and that most crawlers settled on twigs of *Citrus unshui* in Japan, and very few on leaves. However Hill (2008) reported *C. rubens* may cover “shoots, fruit stalks and parts of the fruit” (without reference to host species), and CPCI (2014) states “On Citrus it feeds mainly on leaves, but also on twigs and fruit”.

Border detections on fruit of any host appear to be uncommon.

Biology (after CPCI unless otherwise stated)

In common with other wax scales (subfamily Ceroplastinae), adult *C. rubens* females have a characteristic thick wax covering, which is secreted by dorsal pores present in the cuticle. The secretion contains a water-in-wax emulsion, with honeydew being a major component of the water phase. It has been suggested that the thick wax protects the scale from attack by predators and from injury and desiccation. This group of insects produces honeydew, which leads to sooty mould production and attendance by ants.

In Australia *C. rubens* is univoltine in central and southern New South Wales, whereas it is bivoltine in Queensland and northern NSW. Univoltine populations oviposit in October and crawlers emerge from November to December, whereas bivoltine adults oviposit in early September and crawlers emerge from mid-September until early December. The second generation emerges from February to April (Waterhouse & Sands 2001). The mean fecundity of females in a study in Queensland was 292 eggs per adult female, with a range of 5–1178. In Japan, *C. rubens* is reported to be univoltine (Itioka & Inoue 1991).

Ceroplastes species seem to reproduce primarily by parthenogenesis, although males may be present in small numbers (Gimpel *et al.* 1974). *C. rubens* males have been reported from Japan but not from Australia (Qin & Gullan 1994) or the USA (Gimpel *et al.* 1974).

According to Waterhouse and Sands (2001), crawlers usually settle at or near the leaf veins, particularly on the midrib, where they penetrate the tissues with their stylets. The four instars are normally completed without migration from the original feeding site on the leaves. Occasionally crawlers settle and develop to adults on young stems or fruit of host plants. However in a study of *Citrus unshiu* in Japan *C. rubens* showed a preference for settling on new season twigs. The highest mortality in this study was due to cessation of growth, probably due to host plant quality, rather than to natural enemies or other factors (Itioka & Inoue 1991). In an Australian field study, mortality of *C. rubens* was greatest during the first 24 hours after hatching when approximately 50% were lost.

Potential for establishment and impact

Ceroplastes rubens is likely to be able to establish in at least some parts of New Zealand, or in sheltered habitats, or in greenhouses. It is capable of causing unwanted impacts within the horticultural, cut flower and nursery industries.

Hazard identification conclusion

Given that this species

- is associated with some fresh fruit and/or vegetables
- is not known to be present in New Zealand
- is potentially able to establish and cause unwanted impacts,

Ceroplastes rubens is therefore considered to be a hazard on the fresh produce pathway.

Risk assessment

Entry assessment

Ceroplastes rubens is detected in international trade relatively commonly. For example, between 1995 and 2005, it was intercepted at U.S. ports of entry 664 times⁴⁹ (USDA 2007), and has not established despite the fact it clearly entering the country. This scale does not preferentially infest the fruit of most hosts and (when plant parts are specified) border detections on fruit appear to be very uncommon. In Britain it has been intercepted on eight occasions, all either on foliage or plants for planting (Malumphy 2011); it has also been detected in the Netherlands on *Aglaonema* and *Podocarpus* (Jansen 1995).

At the New Zealand border, it has been identified alive at least 10 times, but all identifications have been from leaf material, most carried by air passengers (MPI Identification database)⁵⁰. It has not been identified at the New Zealand border on citrus. CPCI reports it having been detected in New Zealand on *Dieffenbachia* sp. from Fiji.

The likelihood of entry on any particular fresh produce consignment is dependent on:

- the host commodity. Hosts that New Zealand imports as fresh produce include: avocado, breadfruit, *Citrus* species, lychee, mango and mangosteen. However, infestation of fruit of these species by *Ceroplastes rubens* in international trade is not commonly reported.
- population levels in the country of origin. This species is widely distributed in tropical and subtropical regions, and may be present on commodities produced in temperate countries in greenhouses. In other places, area or country freedom or low pest prevalence is possible.
- the in-field controls and production systems
- any end-point treatments
- the architecture of the imported commodity. *C. rubens* will be easier to detect during handling and inspection on architecturally simple, smooth-skinned commodities than on more complex commodities.
- the volume of the host imported.

Entry conclusion

⁴⁹http://www.sel.barc.usda.gov/scalekeys/softscales/key/soft_scales/media/html/Species/05Cero_rubens/1Cero_rubensDesc.html

⁵⁰ There have been historic detections on cut flowers (1993) and zucchini (1992) however the identifications were tentative and it is not known if either was a commercial consignment (MPI Identification database).

The likelihood of *Ceroplastes rubens* entering New Zealand on the fresh produce pathway is commodity-dependent and is considered to range from negligible to low.

Exposure assessment

Most, but not all, coccids (soft scales) are legless and non-mobile apart from the crawler and adult male stages (Hodges 2005, Howard *et al.* 2001). Although *C. rubens* does possess legs, they are reduced and distorted (Gimpel *et al.* 1974, Williams & Watson 1990). Gimpel *et al.* (1974) and Itioka and Inoue (1991) both state that crawlers are unable to move again after settling. Therefore the only mobile lifestages are crawlers and males and factors affecting exposure are likely to be similar to those for diaspidids, where exposure is dependent on the delicate crawler leaving the imported host commodity and successfully finding a suitable host. Crawlers are susceptible to extremes of temperature, desiccation, rain, predation and a lack of suitable settling sites. This restriction is common to all sternorrhynchans in which the post-settlement life stages are more or less immobile (see Section 1.5.2). Some specific aspects of the biology of *C. rubens* and some attributes of the particular host commodity may also influence the exposure likelihood:

- unavoidable waste: host commodities which are entirely consumed present a lower exposure risk than those whose skin is discarded, such as citrus or avocados.
- robustness of host commodity: females produce eggs continuously, so crawlers are likely to be produced for as long as the host fruit remains in good condition. Soft fruit hosts are likely to deteriorate more quickly than more robust hosts such as citrus.
- availability of suitable hosts: *C. rubens* is polyphagous and there would be no shortage of suitable host species throughout New Zealand.
- developmental thresholds: there appears to be little information available on development rates of this species. Based on its global distribution, it is likely that temperature conditions in many parts of New Zealand and during the colder months would be below the lower threshold for crawler development.

Successful exposure of crawlers emerging from female/s infesting imported produce, to plants in domestic or commercial greenhouses is much less likely than exposure to outdoor hosts (see 1.5.2. (v) “Infestation of greenhouses and other protected environments”).

Exposure conclusion

The likelihood of *Ceroplastes rubens* on imported fresh produce being successfully exposed to new hosts in New Zealand is considered to vary from negligible to low, depending on the attributes of the host and the disposal conditions.

Establishment and spread assessment

Ceroplastes rubens usually reproduces parthenogenetically, although males have been reported from some countries (see Biology section). Since exposure depends on successful crawler dispersal, for establishment to take place in sexual species, crawlers of both sexes must find a suitable host, develop to adults, successfully locate each other, mate and produce viable offspring. In parthenogenetic species, the likelihood of establishment is increased, since this additional barrier (crawlers of both sexes surviving to maturity and mating) does not need to be overcome in order for perpetuation to occur.

C. rubens is a tropicopolitan species that, according to Williams & Watson (1990) “occurs in some temperate regions”, though it is not clear under what circumstances. Malumphy (2011) stated that it occurs in “warm temperate” areas.

There appears to be little information available about developmental thresholds for this species. Malumphy (2011) considered that *C. rubens* is “very unlikely to be able to overwinter outdoors in the UK and therefore establishment will be restricted to protected ornamental plants”.

Its congener *C. destructor* (also of African origin) is established in New Zealand. *C. destructor* was first reported from New Zealand in 1940 and is an important pest of citrus in Northland and Gisborne (Hodgson & Henderson 2000). *C. destructor* and *C. rubens* were both accidentally introduced into Australia around the late 1800s (Waterhouse & Sands 2001). Since their introductions into Australia, *C. rubens* has spread more widely than *C. destructor*, and has now been reported from every state and territory in Australia except Tasmania (Qin & Gullan 1994). Much of Victoria has a very high climate match with New Zealand (however no further details are available about the records of *C. rubens* from Victoria; Qin & Gullan 1994). ALA (2014) records *C. rubens* from Canberra (ACT) and as far south as Kioloa on the NSW coast. Kioloa is south of Sydney and Canberra and has a high (0.9) climate match with both all of New Zealand with the northern North Island (Phillips *et al.* in prep). In addition, *C. rubens* is reported from Shimotsu, Wakayama, Japan (34°06'04"N, 135° 12'27"E, 300m ASL), where it is reported to be univoltine in *Citrus unshui* crops (Itioka & Inoue 1991). Much of Wakayama Prefecture has a 0.7 climate match with all of New Zealand (Phillips *et al.* in prep.).

There is no specific data available on the dispersal rate of *C. rubens*. Crawlers can actively crawl over short distances or be carried in air currents or on vectors. Long distance dispersal is likely to be in trade. Colonisation of domestic and commercial greenhouses throughout much of New Zealand may occur by the movement of infested plant material. The level of phytosanitary hygiene in commercial operations is likely to be higher than in domestic situations and colonisation may therefore be less likely, though it is still possible.

Establishment and spread conclusion

The likelihood of establishment of *Ceroplastes rubens* is considered to be low; if founder populations are parthenogenetic the likelihood of establishment is assumed to be moderate. The maximum extent of spread within New Zealand is likely to be limited to the warmer parts of the North Island.

Consequence assessment

Economic consequences

Gill and Kosztarab (1997) regard *Ceroplastes rubens* as one of the major coccid pests of the world. It attacks many crop plants but is a particularly serious pest of citrus in Australia, Hawaii, Korea, China and Japan. It is also a widespread pest of tropical and sub-tropical crops such as coffee, tea, *Cinnamomum*, mango, avocado, litchi and ornamentals. Economic damage is caused directly through phloem feeding and indirectly through the promotion of sooty mould growth, which lowers the market value of fresh fruit and can reduce photosynthetic efficiency, causing reduced growth, disfiguring fruit and requiring removal before marketing (Gimpel *et al.* 1974, Gill & Kosztarab 1997, Williams & Watson 1990, Waterhouse & Sands 2001, Malumphy 2011).

If *Ceroplastes rubens* became widespread in New Zealand, it could cause losses to citrus production. The closely related species *C. destructor* is a serious pest of citrus in both of the major citrus orchard areas of Kerikeri (Northland) and Gisborne (Henderson & Hodgson 2001). Other hosts of economic importance to New Zealand include avocado, *Malus*, *Prunus* and *Pyrus* species. However, none of these are favoured hosts. In Australia, *C. destructor* and *C. rubens* are both minor avocado pests which rarely warrant spraying (Waite & Pinese 1991). *C. rubens* also has the potential to have negative economic impacts on the nursery and cut flower industries. In addition, it has been reported as a nursery pest on seedlings of *Pinus taeda* and *P. caribaea* in Papua New Guinea (Waterhouse & Sands 2001), but significant impacts on the *Pinus radiata* industry are unlikely in temperate regions such as New Zealand.

Noyes (2002) lists over 50 known chalcidoid natural enemies of *C. rubens*. Eight of these species (*Encarsia perniciosi*, *Coccidoctonus dubius*, *Epitetracnemus intersectus*, *Eusemion cornigerum*, *Microterys nietneri*, *Zaomma lambinus*, *Moranila californica* and *Scutellista caerulea*) are known to be present in New Zealand (Gordon 2010; S. Thorpe, pers. comm.). It is likely that these natural enemies would exert some level of population control on *C. rubens* in New Zealand that may reduce its impact, but it is not known how significant this would be⁵¹.

In summary, there is the potential for this species to have economic impacts in New Zealand, particularly on citrus and possibly on avocado. However, these impacts are likely to be mitigated by:

- any existing control practices for *C. destructor* in New Zealand,
- an existing suite of natural enemies, and
- its limited potential geographic distribution in New Zealand.

Economic impacts conclusion

The potential economic consequences of *Ceroplastes rubens* establishing in New Zealand are independent of pathway and are considered to be low.

Environmental consequences

Ceroplastes rubens is a polyphagous species with hosts in plant genera with important native New Zealand species (e.g. *Metrosideros*, *Pittosporum*). It is therefore likely that some native plant species will be suitable hosts. Beever *et al.* (2007) suggested that in terms of risk to native flora, sap-sucking hemipterans such as armoured scale insects are a high risk group. However it must be noted that this study assessed exotic species in terms of risk, not solely impact (the risk ranking of a species included its likelihood of reaching New Zealand as well as its anticipated impact). This study also concluded that highly damaging polyphagous species appear to be exceptional and that the impact of relatively specialised organisms is likely to be greater.

Like other soft scale insects, *C. rubens* secretes honeydew. This may result in sooty mould growth and/or ecosystem changes due to changes in population sizes of honeydew feeders (see Section 1.5.5) in natural ecosystems and associated knock-on effects. Another consequence of honeydew secretion is attendance by ants, and this in turn may reduce the effectiveness of natural enemies. However these impacts are likely to be limited by the presumed restricted distribution of *C. rubens* due to climatic factors.

⁵¹ additionally, many important parasitoids of *C. rubens* are not present in New Zealand, however they may have close relatives that are already present and that may be expected to exert some control on *C. rubens*.

Environmental impacts conclusion

The potential environmental consequences of *Ceroplastes rubens* establishing in New Zealand are independent of pathway and are considered to be low.

Socio-cultural and human health consequences

The establishment of *Ceroplastes rubens* is likely to result in some damage to amenity plants and to home fruit crops. This may add to the pest control costs or result in loss of produce for home gardeners. However costs are not expected to be significant and it is likely that over time some control will be exerted by the suite of parasitoids already known to be present.

There are no known human health impacts associated with the establishment of *C. rubens*.

Socio-cultural and human health impacts conclusion

The potential socio-cultural and human health consequences of *Ceroplastes rubens* establishing in New Zealand are independent of pathway and are considered to be negligible.

Overall risk estimation for *Ceroplastes rubens* on the fresh produce pathway:

- the likelihood of entry is commodity-dependent and is considered to range from negligible to low.
- the likelihood of exposure is considered to range from negligible to low, depending on the attributes of the host and the disposal conditions.
- the likelihood of establishment is considered to be low; if founder populations are parthenogenetic the likelihood of establishment is assumed to be moderate. The maximum extent of spread within New Zealand is likely to be limited.
- the potential economic, environmental, socio-cultural and human health consequences of establishment independent of pathway and are considered to be: low, low, negligible and negligible respectively.

1.13 APPENDIX 6: PRA FOR *MACONELlicoccus hirsutus* ON FRESH PRODUCE

Scientific name:	<i>Maconellicoccus hirsutus</i> (Green, 1908) (Hemiptera: Pseudococcidae)
Other names:	<i>Phenacoccus hirsutus</i> ; <i>Phenacoccus quaternus</i> ; <i>Pseudococcus hibisci</i> ; <i>Phenacoccus glomeratus</i> ; <i>Pseudococcus crotolariae</i> ; <i>Spilococcus perforatus</i> ; <i>Paracoccus pasaniae</i> ; <i>Maconellicoccus perforatus</i> ; <i>Maconellicoccus pasaniae</i>
Common names:	pink hibiscus mealybug, hibiscus mealybug, pink mealybug, hirsutus mealybug, grape mealybug, mulberry mealybug, cochenille de l'Hibiscus

Hazard identification

New Zealand status

M. hirsutus is not known to be present in New Zealand. Not recorded in Gordon (2010) or PPIN (2014).

Geographic distribution

Maconellicoccus hirsutus has a virtually cosmopolitan distribution in tropical areas of the world (Meyerdirk *et al.* 2001); it also occurs in many subtropical parts of the Old World and extends into some temperate areas (Williams 1996). *M. hirsutus* is likely to be native to southern Asia, based on its current Asian distribution and that of its congeners (Meyerdirk *et al.* 2001); though some authors consider it may be native to Australia (Goolsby *et al.* 2002). Its Australian distribution includes South Australia, Western Australia, the NT and Queensland (OEPP/EPPO 2005).

M. hirsutus is now an introduced pest in many parts of the world including Africa, South and Central America and more recently the Caribbean Islands and North America. In North America, its range has greatly expanded to include California in 1999, Florida in 2002, Louisiana in 2006, Texas in 2007, Georgia in 2008, and South Carolina in 2009 (Aristizábal *et al.* 2012). It is also found through much of Asia including China, and in many Pacific Islands, but is absent from the EPPO region (OEPP/EPPO 2005).

Almost all the serious damage by *M. hirsutus* is in areas between 7° and 30°N (CPCI 2014). However in 1996, Williams suggested that outbreaks in the West Indies could pose a threat to cotton and grapes in more temperate areas of the USA (it was not reported from mainland USA at the time). This prediction was based on the known distribution of *M. hirsutus* (as far north as Lebanon in the Middle East), and a comparison with the tropical polyphagous mealybug *Phenacoccus madeirensis* (Green). *P. madeirensis* occurs throughout Central and Southern America and in Africa, and is known from many parts of Mexico and USA; it was first reported from Sicily in 1990, and by 1994 was reported infesting many plants there. Williams (1996) therefore suggested that *M. hirsutus* could similarly survive in southern Europe and southern USA. *M. hirsutus* has indeed been detected in the mainland USA subsequent to this prediction; its current distribution includes six southern US states (Aristizábal *et al.* 2012). It has apparently not yet been detected in the EPPO region.

Plant associations

M. hirsutus is highly polyphagous. OEPP/EPPO (2005) report host records from 76 families and over 200 genera, with some preference for Fabaceae, Malvaceae and Moraceae. It is a well-known pest of cotton, hibiscus and many ornamentals (Ben-Dov 1994); *Hibiscus rosa-sinensis* in particular is a favoured host (CPCI 2014, Aristizábal *et al.* 2012). When it established in Grenada, it rapidly became a pest of food plants, ornamentals, weeds, fruit and forest trees (Persad & Khan 2002). Some hosts enable the mealybug to complete its entire life cycle while others are only suitable for feeding.

Main hosts (as listed by CPCI 2104) include *Abelmoschus esculentus* (okra), *Allamanda*, *Alpinia purpurata* (red ginger), *Annona* spp., *Artocarpus* spp. (breadfruit trees), *Averrhoa carambola*, *Boehmeria nivea* (ramie), *Bougainvillea*, *Cajanus cajan* (pigeon pea), *Citrus*, *Glycine max* (soyabean), *Gossypium* spp. (cotton), *Hibiscus* spp., *Malpighia glabra* (acerola), *Manilkara zapota* (sapodilla), *Morus* (mulberrytree), *Morus alba* (mora), *Musa x paradisiaca* (plantain), *Passiflora edulis* (passionfruit), *Persea americana* (avocado), *Samanea saman* (rain tree), *Sida acuta* (sida), *Spondias* spp., *Tectona grandis* (teak), *Theobroma cacao* (cocoa) and *Vitis vinifera* (grapevine).

Hosts that New Zealand imports⁵² as fresh produce include: banana, *Citrus* species, grapes, mango, mangosteen, peaches, nectarines and squash.

Association with fresh produce

M. hirsutus infests the leaves, shoots and fruit of host plants (Meyerdirk *et al.* 2001, CPCI 2014).

Potential for establishment and impact

M. hirsutus may be able to establish at least temporarily in some parts of New Zealand, or in sheltered habitats or in greenhouses. It is likely to cause unwanted impacts within some horticultural and nursery industries.

Hazard identification conclusion

Given that this species

- is associated with some fresh fruit and/or vegetables
- is not known to be present in New Zealand
- is potentially able to establish and cause unwanted impacts,

Maconellicoccus hirsutus is therefore considered to be a hazard on the fresh produce pathway.

Risk assessment

Biology

M. hirsutus, like all mealybugs, feeds on phloem and secretes honeydew. Eggs are laid in a loose cottony ovisac that is attached to the plant surface, usually on twigs, branches and bark of the host plant, and also on the leaves and terminal ends. Females lay eggs on the terminal areas of the host, but as the weather gets colder females search for shelter in which to oviposit such as crevices in bark (Meyerdirk *et al.* 2001). The mobile crawlers settle in densely packed colonies in cracks and crevices of the host plant, with a preference for soft tender young tissues, and start to feed and

⁵² or has Import Health Standards for but may not currently import or may not ever have imported.

develop. New plant growth becomes severely stunted and distorted as a result of their feeding.

The male has four nymphal instars; the female has three. Males pupate at the end of the second instar; on emerging as adults they are winged and capable of flight whereas the female is wingless. The lifecycle can be completed in about five weeks under favourable conditions and there may be up to ten generations per year in the subtropics. *M. hirsutus* can overwinter at all life stages and this can occur in protected parts of the host such as bark crevices.

Both sexual and parthenogenetic reproduction has been reported. Reproduction is reported as mostly parthenogenetic in Egypt and Bihar, India. In West Bengal, India, *M. hirsutus* is recorded as being biparental and it seems likely that populations in the West Indies are also biparental. Females can lay 150–600 eggs over the period of a week (total ranges from 84 to 654). Infestations of *M. hirsutus* can be associated with attendant ants, which collect the honeydew they secrete (CPCI 2007; Meyerdirk *et al.* 2001; Mani 1989).

M. hirsutus forms colonies preferentially in apical and tender regions of the host plant, but older plant parts may also harbour large populations. As it feeds, *M. hirsutus* injects toxic saliva into the plant. Both this and direct feeding can cause various symptoms on the host, including malformed leaf and shoot growth, stunting, bushy shoot tips, and occasional death. Sooty mould may develop on leaves and stems due to heavy honeydew secretions. If undisturbed, colonies will grow into masses of waxy whitish coverings over most plant structures or even entire plants. Dieback of young shoots and limbs may occur and whole trees may eventually die (Meyerdirk *et al.* 2001). In cool climates, eggs or adults overwinter in the soil or on the host plant. In warm climates, the insects stay active and reproduce year round. Females only mate once and can live up to 28 days after eclosion at 20°C (Vitullo 2009 and references within).

Synthesized female sex pheromone is available for detection of males; the pheromone is very effective (Griffiths *et al.* 2005).

M. hirsutus is highly invasive if introduced in the absence of its natural enemies, as demonstrated by its rapid spread through the Caribbean Islands (CPCI 2014). However, in the presence of natural enemies, its field host range is much reduced and noticeable damage may be restricted to the preferred host, hibiscus (Goolsby *et al.* 2002). Noyes (2002) lists 34 known chalcidoid natural enemies of *M. hirsutus*. In subtropical eastern Australia the predatory ladybird *Cryptolaemus montrouzieri* Mulsant (the mealybug ladybird) appears to be the key natural enemy of *M. hirsutus* on ornamental stands of hibiscus (Goolsby *et al.* 2002).

Entry assessment

M. hirsutus has not been identified at the New Zealand border in commercial fresh produce shipments; the only identification has been on the passenger pathway (on rambutan from the Philippines in 1996)⁵³. It is occasionally intercepted entering the European Union, mainly on consignments of *Annona*, from Egypt, India and Thailand⁵⁴. Meyerdirk (undated) cites 813 interceptions in the USDA PIN database (2003). Almost all detections from the Caribbean into the USA were “baggage” rather

⁵³ MPI Identification database, download February 2014.

⁵⁴ EPPO reports on notifications of non-compliance: EPPO Reporting Service – Pests and Diseases. EPPO reports available online at http://archives.eppo.org/EPPOReporting/Reporting_Archives.htm.

than on commercial consignments. Williams (1996) states “*M. hirsutus* ...[is] sometimes intercepted at quarantine inspection of plants and plant produce in the USA and Europe”.

Most life stages are readily detectable. Eggs are laid in ovisacs which contain white waxy filaments, male puparia are up to 1.5 mm long and 0.45mm wide and adult females are approximately 2 to 3mm long, with a white waxy covering (Meyerdirk *et al.* 2001). Additionally *M. hirsutus* usually forms dense colonies (CPCI 2014), suggesting that it would probably be detected during harvest or packaging. OEPP/EPPO (2005) states it is “relatively easy to detect by inspection”. However, low level infestations may be missed, particularly since crawlers tend to settle in cracks and crevices of the host plant.

M. hirsutus does not appear to have been detected on commercial fresh produce imported into New Zealand, nor particularly often in international trade of fresh produce. The likelihood of entry on any particular consignment is dependent on:

- the host commodity. Fresh produce commodities imported into New Zealand which are also favoured (“main” as defined by CPCI 2014) hosts include Citrus, avocado, grape and *Spondias* species.
- the population levels in the country of origin. This species is widely distributed in tropical and subtropical regions, and may be present on commodities produced in temperate countries in greenhouses. In other places area or country freedom or low pest prevalence is possible.
- the in-field controls and production systems
- any end-point treatments
- the architecture of the commodity. *M. hirsutus* will be easier to detect during handling and inspection on architecturally simple, smooth-skinned commodities. This species is known to favour cracks and crevices on the host surface.
- the volume of the host imported.

Entry conclusion

The likelihood of *Maconellicoccus hirsutus* entering New Zealand on the fresh produce pathway is commodity-dependent and is considered to range from negligible to moderate.

Exposure assessment

Mealybug nymphs and adult females are able to move limited distances, unlike diaspidids and most coccids (see Section 1.7). However, laboratory and field work (*e.g.* Whyte *et al.* 1994, Vitullo 2009) suggests that most dispersal takes place in the crawler stage and it is uncertain how much other lifestages contribute to movement between hosts. It is therefore likely that mealybugs are very similar to diaspidids and coccids in terms of likelihood of exposure via the fresh produce pathway; that is that successful dispersal from the point of entry is most likely to take place at the crawler stage.

Some specific aspects of the biology of *M. hirsutus* and some attributes of the particular host commodity may also influence the exposure likelihood:

- unavoidable waste: host commodities which are entirely consumed present a lower exposure risk than those whose skin is discarded, such as citrus or avocados.

- robustness of host commodity: mated females lived for 28 days at 20°C, with each mated female producing 260-300 eggs between 20 and 27°C (Chong *et al.* 2008). Therefore crawlers are likely to be produced for as long as the host fruit remains in good condition. Soft fruit hosts such as grapes are likely to deteriorate more quickly than more robust hosts such as citrus.
- availability of suitable hosts: *M. hirsutus* is extremely polyphagous, and suitable host species are widely distributed throughout New Zealand, and likely to be available to dispersing crawlers
- developmental thresholds: Chong *et al.* (2008) calculated the T_{min} for *M. hirsutus* as 14.5°C. Temperatures above 14.5°C could be met outdoors in most of the North Island between November and March (NIWA 2014), allowing crawlers to continue development during these months.

Successful exposure of crawlers emerging from female/s infesting imported produce, to plants in domestic or commercial greenhouses is much less likely than exposure to outdoor hosts (see 1.5.2. (v) “Infestation of greenhouses and other protected environments”).

Exposure conclusion

The likelihood of *Maconellicoccus hirsutus* on imported fresh produce being successfully exposed to new hosts in New Zealand is considered to vary from negligible to low, depending on the attributes of the host and the disposal conditions.

Establishment and spread assessment

Reproduction is usually sexual with a male to female ratio of around 1:1 (Meyerdirk *et al.* 2001), although solely parthenogenetic populations have been reported, for example in India and Egypt. The introduction of parthenogenetic females is assumed to increase the likelihood of establishment. *M. hirsutus* females release a sex pheromone (Meyerdirk *et al.* 2001), which would likewise facilitate establishment and spread. Crawlers, ovisacs and males may migrate by means of air currents; females and crawlers are flightless but can walk, or may be carried from host to host (Meyerdirk *et al.* 2001).

M. hirsutus is polyphagous on a huge variety of plants including plants of commercial interest, garden plants and weeds in New Zealand, therefore suitable hosts are highly likely to be readily available. Populations which establish on weeds or in home gardens can also act as population reservoirs for re-infestation of commercial crops.

M. hirsutus is found predominantly in tropical and subtropical zones. A MAF assessment of climate suitability (Anonymous 2002) concluded that populations are unlikely to persist in New Zealand in most years because temperatures are not warm enough to supply sufficient day degrees (DD) to complete one generation in a year, with the exception of a very warm year in the Hawkes Bay region. However the lower developmental threshold (T_{min}) used for this analysis was that of the tropical mealybug *Phenacoccus manihoti* (20°C). Subsequent reports of the T_{min} for *M. hirsutus* are considerably lower. Chong *et al.* (2008) calculated the T_{min} as 14.5°C, and the thermal constant (K, the number of DDs) for females as 347 DD, and also reported a difference in developmental rates depending on host plants. A 2005 analysis (Borchert *et al.* 2005) suggested that *M. hirsutus* could complete at least one generation in all of the continental United States, while the Chong *et al.* (2008) analysis suggested that this may be somewhat more restricted.

These data indicate that a more widespread New Zealand distribution is possible than that suggested by the 2002 MAF analysis. In addition, populations of *M. hirsutus* could establish in greenhouses, particularly if the source population is parthenogenetic, in which case a single individual could found a reproducing population. However, the likelihood of imported crawlers being successfully exposed to hosts in greenhouses is low (see Section 1.5.2).

There is no specific data available on the dispersal rate of *M. hirsutus*. Crawlers can actively crawl over short distances or be carried in air currents or on vectors. Long distance dispersal is likely to be in trade. Colonisation of domestic and commercial greenhouses throughout much of New Zealand may occur by the movement of infested plant material. The level of phytosanitary hygiene in commercial operations is likely to be higher than in domestic situations and colonisation may therefore be less likely, though it is still possible.

Establishment and spread conclusion

The likelihood of establishment of *Maconellicoccus hirsutus* is considered to be low; if founder populations are parthenogenetic the likelihood of establishment is assumed to be increased. The maximum extent of spread within New Zealand is likely to be limited to the most northern North Island.

Consequence assessment

Economic consequences

M. hirsutus is a serious threat to over 250 species of agricultural, ornamental, and horticultural plants (Griffiths *et al.* 2005). In Grenada, it had a devastating impact on the agriculture, natural forests and tourism, damaging foreign exchange, trade in agricultural products, and the local ecology and water economy (CPCI 2014). However almost all the serious damage by *M. hirsutus* is in areas between 7° and 30°N (CPCI 2014) and many of the important hosts are tropical plants that are not widely cultivated in New Zealand. Hosts which could be of significance in New Zealand include fruit (for example grapes, passionfruit, *Citrus* spp., guava) and vegetable crops (for example asparagus, beetroot, sweet pepper, cucurbits, carrots, kumara, avocado). When fruits are infested, they can be covered with the white waxy coating and sooty mould resultant from honeydew secretion. Infestation can lead to fruit drop, or fruit may remain on the host in dried and shrivelled condition. If flower blossom is attacked, the fruit sets poorly. Thus fruit production and marketability is reduced.

An incursion could result in the need for expensive eradication programmes. If these fail, establishment may result in the disruption of current management practices, which could affect the cost of production. Other impacts may include disruption of market access or increased compliance costs for exports to sensitive markets *e.g.* the European Union or the Pacific Northwest of the USA.

Although some subsequently published data indicates that the potential distribution of *M. hirsutus* in New Zealand may not be as limited as that suggested by a previous analysis (Anonymous 2002), it is still unlikely to establish widely. Therefore, economic impacts are very likely to be limited by this presumed restricted distribution.

Some important control agents are already known to be present in New Zealand. The predatory ladybird *Cryptolaemus montrouzieri* Mulsant (the mealybug ladybird) is established in New Zealand, having been introduced as early as 1897 for the

biological control of *Eriococcus coriaceus* Maskell, the gum tree scale; Ferguson *et al.* 2007). Additionally, the encyrtid microwasp *Anagyrus fusciventris* (Girault) is a reported parasitoid of *M. hirsutus* (Noyes 2002) and is also known to be present in New Zealand (Gordon 2010). It is likely that these natural enemies would exert some level of population control on *M. hirsutus* in New Zealand that may reduce its impact, but it is not known how significant this would be.

Economic impacts conclusion

The potential economic consequences of *Maconellicoccus hirsutus* establishing in New Zealand are independent of pathway and are considered to be low.

Environmental consequences

M. hirsutus is a polyphagous species with hosts in plant genera with native New Zealand species (*e.g. Passiflora, Hibiscus*). It is therefore likely that some native plant species will be suitable hosts. *Hibiscus* species in particular are favoured hosts. Production of *Hibiscus rosa-sinensis*, an important production and landscape plant, has decreased in southern Florida due to widespread and severe damage by *M. hirsutus* in managed urban landscapes (Aristizábal *et al.* 2012). In Grenada, *M. hirsutus* caused severe devastation of natural habitats, destroying large areas of blue mahoe (*Hibiscus elatus*); a dominant species in natural rainforest (CPCI 2014). In New Zealand the native hibiscus, *Hibiscus diversifolius* subsp. *diversifolius* (conservation status: Threatened - Nationally Critical; NZPCN 2014) is restricted to the northernmost extremity of the North Island. *M. hirsutus* is a potential threat to native hibiscus, although almost all the serious damage by this mealybug occurs in more tropical regions of the world than northern New Zealand.

Like other mealybugs, *M. hirsutus* secretes honeydew. This may result in sooty mould growth and/or ecosystem changes due to changes in population sizes of honeydew feeders (see Section 1.5.5) in natural ecosystems and associated knock-on effects. Another consequence of honeydew secretion is mealybug attendance by ants and this in turn may reduce the effectiveness of natural enemies. However these impacts are likely to be limited by the presumed restricted distribution of *M. hirsutus* due to climatic factors.

Environmental impacts conclusion

The potential environmental consequences of *Maconellicoccus hirsutus* establishing in New Zealand are independent of pathway and are considered to be low.

Socio-cultural and human health consequences

The establishment of *Maconellicoccus hirsutus* is likely to result in some damage to amenity plants and to home fruit crops by feeding on and weakening plants, transmitting viruses, secreting honeydew and attracting ants. This may add to pest control costs for home gardeners. However:

- these costs are not expected to be significant,
- the area that *M. hirsutus* is able to establish in is likely to be very limited, and
- over time, some control will probably be exerted by natural enemies already known to be present in New Zealand.

There are no known human health impacts associated with the establishment of *M. hirsutus*.

Socio-cultural and human health impacts conclusion

The potential socio-cultural and human health consequences of *Maconellicoccus hirsutus* establishing in New Zealand are independent of pathway and are considered to be negligible and negligible respectively.

Overall risk estimation for *Maconellicoccus hirsutus* on the fresh produce pathway:

- the likelihood of entry is commodity-dependent and is considered to range from negligible to moderate
- the likelihood of successful exposure is considered to vary from negligible to low, depending on the attributes of the host and the disposal conditions.
- the likelihood of establishment is considered to be low; if founder populations are parthenogenetic it is likely to be increased to moderate. The maximum extent of spread within New Zealand is likely to be very limited.
- the potential economic, environmental, socio-cultural and human health consequences of establishment are considered to be: low, low to moderate, negligible and negligible respectively.

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