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BS1847: Review of White Peach Scale (*Pseudaulacaspis pentagona* (Targioni Tozzetti, 1886) MacGillivray, 1921) (Hemiptera: Diaspididae)

Morales-Rodriguez A, McKenna C

March 2019















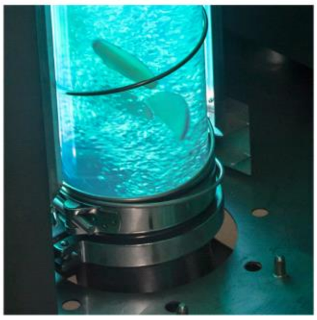


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EXECUTIVE SUMMARY

BS1847: Review of White Peach Scale (*Pseudaulacaspis pentagona* (Targioni Tozzetti, 1886) MacGillivray, 1921) (Hemiptera: Diaspididae)

Morales-Rodriguez A, McKenna C
Plant & Food Research: Te Puke

March 2019

The aim of this report was to review the biology and management of white peach scale (WPS) *Pseudaulacaspis pentagona* (Targioni -Tozzetti), and discuss options for its management in New Zealand kiwifruit orchards should it become established here.

Biology and ecology

WPS is native to Asia but is now widely distributed throughout the world. A highly polyphagous species, WPS feeds on several hundred plant species, many of which are fruit crops present in New Zealand. Heavy infestations detract from the appearance of the fruit and cause dieback or death of branches.

WPS is bi-parental. The number of generations per year is largely dependent on climate and varies from one to four in different parts of the world. WPS overwinters on the host plant as fertilised adult females. Eggs are laid in spring, which hatch soon after into tiny mobile crawlers. The crawlers emerge from under the protective cap of the mother and move to new sites to settle and feed. Soon after settling, crawlers begin secreting the protective scale cap. Females undergo two moults, and the males five moults, before reaching sexual maturity as adults. Females remain under the scale cap throughout their life, but the males develop wings when mature and are attracted to females by a sex pheromone. The adult males live for 1 d only whereas females may live for 40–100 d depending on temperature.

Over 60 species of parasitoids and hyperparasitoids and 80 species of predators have been associated with WPS worldwide, the most common and important of which is the parasitoid *Encarsia berlesei* (Howard) (Hymenoptera: Aphelinidae).

Pest management

In commercial settings pheromone traps or sticky bands are used to monitor WPS populations, with trap catches used to predict crawler emergence and time sprays against WPS**.**

Multiple insecticides have been determined as effective against WPS including spirotetramat, insect growth regulators and mineral oil sprays. In Europe these sprays are generally not permitted for use after bud break.

Biological control, in particular *E. berlesei*, can contribute a significant amount to the control of WPS. However in many commercial orchards outbreaks of WPS are common and are often a result of broad-spectrum insecticides killing the natural enemies.

Few cultural control practices targeting WPS are reported in the literature, but obtaining scale-free nursery plants, removal of alternative host plants in the vicinity of commercial plantings, and mechanical removal of adult scale from the bark of trees have been shown to assist in reducing WPS populations on the crop.

Host plant resistance to WPS has not been widely investigated. In Japan, a new cultivar of tea with resistance to WPS was released in 2012, but there have been no reports of fruit trees with resistance to WPS in the literature. *Actinidia* genotypes are currently being screened in China for susceptibility to WPS using assays adapted from New Zealand, but the programme is in its infancy.

Most of the fruit produced in Europe or Asia that may be infested with WPS is sold and consumed on the continent where it was produced so postharvest treatment of WPS-infested fruit is not common. In the USA an irradiation protocol for use against WPS on papaya is routinely used to disinfest fruit for export, and a second treatment, metabolic stress disinfection and disinfestation (MSDD) is under evaluation.

White peach scale as a pest of New Zealand kiwifruit

WPS has the potential to be a significant production and quarantine pest of kiwifruit in New Zealand. Many of the techniques currently used to manage the armoured scale pests in New Zealand kiwifruit orchards will also be important to achieve an acceptable degree of WPS control. Preventing the build-up of WPS populations on the vines will be important to any management programme.

Appropriately timed insecticide applications, as determined by monitoring using pheromone traps or sticky bands, will be central to the programme. To this end it would be useful to test spray forecasting models developed in Asia in additional kiwifruit growing locations such as Italy and France.

A number of products listed in the Zespri Crop Protection Standard have proven efficacy against WPS including spirotetramat and mineral oil. Spirotetramat can only be applied pre-blossom which is coincidentally the optimal time for sprays against the first generation of WPS after winter. After fruit set, sprays of mineral oil have the potential to reduce the size of the second (and third) generations of WPS. Dormant and pre-blossom oil sprays will also be important, but questions remain over the plant safety of winter applications and further investigations are warranted.

Cultural control techniques to reduce WPS populations on the vines or improve spray coverage will also be required. These include removal of alternative host plants (e.g. willow or poplar) or plant parts (woody crowns) that could harbour WPS, and in some instances mechanical removal of WPS from the wood of vines.

Fumigation of harvested fruit using methyl bromide is an effective treatment against WPS on kiwifruit that could be used in the short term to meet international phytosanitary standards. However, the proposed methyl bromide phase-out means alternatives such as irradiation would be required in the medium to long term.

It is possible that differential resistance may be expressed for WPS within *Actinidia* germplasm. Screening for tolerance could start immediately, however a long-term research effort would be required to phenotype for resistance and to understand the genetic basis of resistance for this polyphagous insect.

1 SECTION ONE: BIOLOGY AND ECOLOGY

1.1 Classification and nomenclature

Pseudaulacaspis pentagona (Targioni -Tozzetti, 1886) MacGillivray, 1921

Synonyms

Aspidiotus lanatus (Cockerell) Ferris, 1941

Aspidiotus vitiensis Maskell, 1895

Aulacaspis pentagona (Targioni Tozzetti) Cockerell, 1902

Aulacaspis pentagona auranticolor (Cockerell) Carnes, 1907

Aulacaspis pentagona rubra (Maskell) Fernald, 1903

Aulacaspis pentagona theae (Maskell) Fernald 1896

Chionaspis prunicola Maskell, 1895

Diaspis amygdali Tryon, 1889

Diaspis amygdali var. *rubra* Maskell, 1889

Diaspis auranticolor Cockerell, 1899

Diaspis geranii Maskell, 1897

Diaspis lanata (Cockerell) Green, 1896

Diaspis lanatus Cockerell, 1892

Diaspis patelliformis Sasaki, 1894

Diaspis pentagona Targioni Tozzetti, 1885

Diaspis rubra (Maskell) Scott, 1952

Epidiaspis vitiensis (Maskell) Lindinger, 1937

Howardia prunicola (Maskell) Kirkaldy, 1902

Pseudaulacaspis amygdali Tryon, 1889

Pseudaulacaspis prunicola

Sasakiaspis pentagona (Targioni-Tozzetti), Kuwana, 1926

Common names

White peach scale, mulberry scale

Other common names

English: peach scale; West Indian peach scale; white scale

French: cochenille du mûrier; kermès du mûrier

German: Mandel-Schildlaus; Maulbeer-Schildlaus

Italian: cocciniglia bianca del gelso e del pesco

Portuguese: cochonilha branca da amoreira

Russian: tutovaya schitovka

Spanish: cochinilla algodonosa; escama de flecos

Taxonomic classification

Domain: Eukaryota

Kingdom: Metazoa

Phylum: Arthropoda

Subphylum: Uniramia

Class: Insecta

Order: Hemiptera

Suborder: Sternorrhyncha

Superfamily: Coccoidea

Family: Diaspididae

Genus: *Pseudaulacaspis* MacGillivray 1921

Species: *Pseudaulacaspis pentagona* (Targioni Tozzetti 1886) MacGillivray 1921

There is some debate as to whether *Pseudaulacaspis pentagona* and *P*. *prunicola* should be treated as separate species. Borchsenius (1966) treated *P. prunicola* as a synonym of *P. pentagona*. Some other authors called attention to the variability of the characteristics of *P. prunicola* and *P. pentagona* and treated them separately (Davidson et al. 1983, Danzig 1993, Kosztarab 1996). For this review we have considered them as two different species.

1.2 Geographical distribution

White peach scale (WPS) is native to eastern Asia (China and Japan). It was accidentally introduced into Italy at the end of the nineteenth century where Targoni first described it in 1886. It has since been introduced to many other countries and is now widely distributed throughout the world (Kozar 1990) (Table 1, Figure 1). Infested fruit and/or plant material is the most common method of spread into new regions or countries.

Table 1. Global distribution of white peach scale (WPS), *Pseudaulacaspis pentagona.*

Continent	Country
America	Antigua and Bermuda, Argentina, Bahamas, Barbados, Bermuda, Bolivia, Brazil, Canada[1], Colombia, Costa Rica, Cuba, Dominica, Dominican Republican, Guadeloupe, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Panama, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, United States, Uruguay, Venezuela and Virgins Islands.
Africa	Cape Verde, Comoros, Egypt, Ghana, Madagascar, Malawi, Mauritius, Réunion, Saint Helena Sao Tome and Principe, Seychelles, South Africa, Tanzania and Zimbabwe.
Asia	Azerbaijan, Brunei Darussalam, China, Georgia, India, Indonesia, Iran, Iraq, Israel[2], Japan, Korean Peninsula, Malaysia, Maldives, Nepal, Philippines, Singapore, Siri Lanka, Syria, Taiwan, Turkey and Vietnam.
Europe	Bulgaria, Croatia, Cyprus, Czech Republic, France, Germany, Greece, Hungary, Italy, Macedonia, Malta, Montenegro, Netherlands, Portugal, Russia, Serbia, Slovakia, Slovenia, Spain, Switzerland, United Kingdom[3], Ukraine and Yugoslavia.
Australia/Oceania	Australia, Fiji, Guam, Micronesia, New Caledonia, Norfolk Islands, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu and Wallis and Fortuna Islands.

[1] Current pest situation evaluated by Secretariat of the European and Mediterranean Plant Protection Organization (EPPO) on the basis of information dated 1997: Absent, pest no longer present (https://gd.eppo.int/taxon/PSEAPE/distribution/CA) (21/09/2018). This record in fact corresponds to two finds in 1955 in the Niagara peninsula. There are no other records in Canada.

[2]The National Plant Protection Organization (NPPO) of Israel has been informed that the record by Nakahara (1982) was based on an erroneous quarantine report. An unknown passenger on an Israeli passenger plane carrying an infested fruit which was quarantined in the USA, but the fruit most likely came from another Mediterranean country (EPPO 2018). WPS has not been collected in Israel.

[3] Current pest situation evaluated by EPPO on the basis of information dated 1988: Absent, pest no longer present. Malumphy et al. (2016) reported several outbreaks in England (Cornwall, Devon, Gloucestershire, Kent and Oxfordshire) on peach trees under protection and on Catalpa trees grown outdoors in Kent. Both trees species were imported from Italy. Control action was taken and the white peach scale was eradicated from all reported areas.

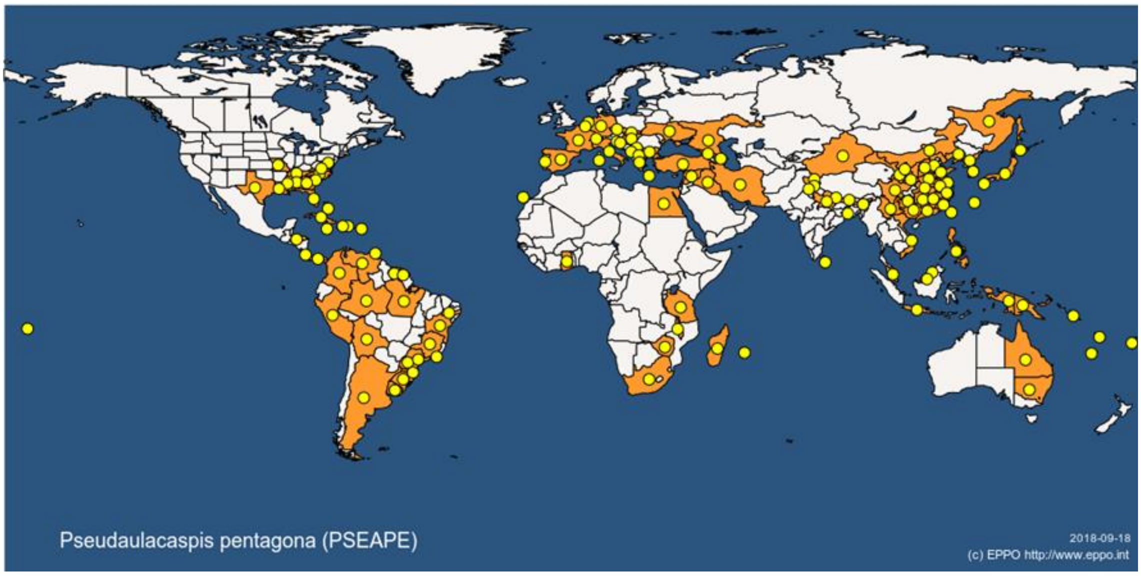

Figure 1. Global distribution of white peach scale (WPS), *Pseudaulacaspis pentagona*, according to EPPO (2018).

1.2.1 New Zealand

New Zealand is the only kiwifruit producing country where WPS is absent. Fernald (1903) erroneously listed WPS as present in New Zealand, misinterpreting reports of Maskell (1887, 1894). Contrary to Fernald's (1903) interpretation, Maskell (1894) clearly wrote "I have not yet heard of it on peaches in New Zealand" (Charles & Henderson 2002). Fernald's mistake was cited by several other authors including MacGillivray (1921), Borchsenius (1966), Wise (1977) and Nakahara 1982.

WPS is regularly intercepted on kiwifruit imported from Italy to New Zealand between December and March, and can commonly be found attached to fruit for sale in supermarkets (Hill 2018). Most Italian kiwifruit is now fumigated on arrival in New Zealand, but in spite of this some live WPS were still detected on fruit in 2017 and 2018 (C McKenna, pers. comm.). The establishment of WPS from infested, imported fruit is considered very unlikely (Anon. 2015), but the risk may increase with increasing volumes of imported produce and risky post-border behaviours associated with re-packing and disposal of waste fruit.

1.3 Description

WPS is an armoured scale insect. Unlike the three common armoured scale species on kiwifruit in New Zealand (*Aspidiotus nerii*, *Hemiberlesia lataniae*, and *H. rapax*) (Edwards et al. 2009), both males and females of WPS are known. Populations of WPS typically occur on the bark of trees as well as on the leaves and fruit of some host species.

1.3.1 Eggs and crawlers

Eggs are laid underneath the mother scale cap and are salmon (females) or white (males) in colour (Bennett & Brown 1958). Eggs of an intermediate colour may also be evident which can produce offspring of either sex (Hanks & Denno 1993). They are ovoid and approximately 0.2 mm long and 1.2 mm diameter (Waterhouse & Norris 1987) (Figure 2). The eggs hatch into first instar 'crawlers' that are oval shaped, flattened and have prominent antennae and three pairs of legs (Figures 2 and 3).

Figure 2. Eggs and crawlers of white peach scale (WPS), *Pseudaulacaspis pentagona* beside an adult scale insect with the cap removed. The salmon-coloured eggs are female, the white eggs are male. (Photo source Lyle J. Buss, University of Florida).

1.3.2 Female scale

After settling, the crawlers 'spin' a protective armour cap. The insect begins to feed, and after about a week it moults to become a second instar nymph. After this moult the female has no eyes, legs or antennae. Female scales undergo one more moult into a third and final 'mature' instar nymph. The adult female cap is convex, circular to oval (generally 2–2.5 mm in diameter) and is a dull white colour with a yellowish to reddish 'spot' towards one side (Waterhouse & Norris 1987) (Figure 4). This 'spot' is made up of the skins shed during moulting. Pieces of bark from the host plant may be incorporated into the cap which aids in camouflage (Kosztarab & Kozar 1988).

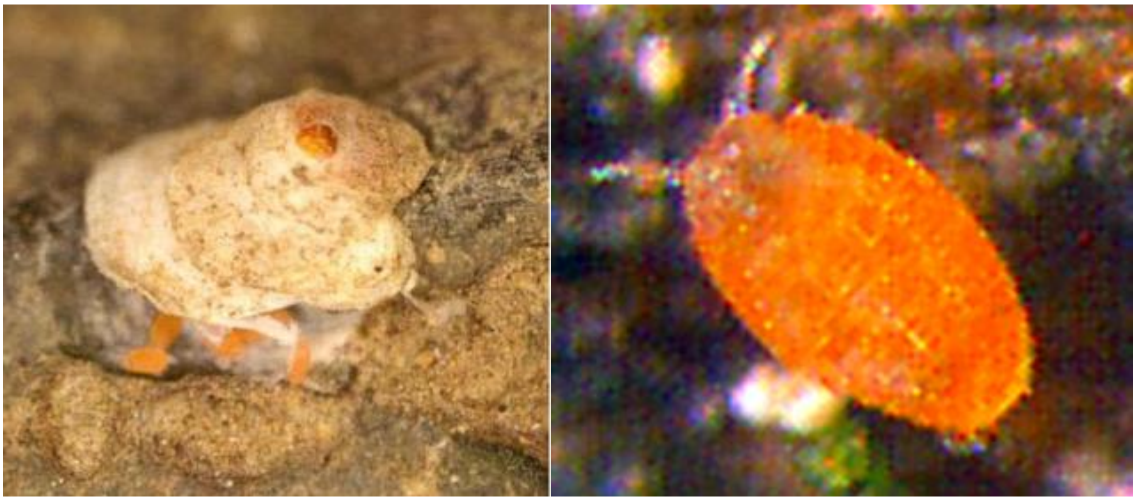

Figure 3. Crawler of white peach scale (WPS), *Pseudaulacaspis pentagona*, crawlers dispersing from the female (left) (Photo source Gordon Johnson University of Delaware), Male crawler (right) (Photo source Peter Shearer, Rutgers University).

Figure 4. Aggregation of female adult white peach scale (WPS), *Pseudaulacaspis pentagona* with crawlers (left) (Photo source A. Davidson, University of Maryland, College Park, Bugwood.org) and single adult scale with the cap removed (right) (Photo source Lyle J. Buss, University of Florida).

The body of the adult female insect is pear-shaped, 0.8–0.9 mm long and pink-yellow in colour, with a brown anal plate. A description of the key morphological features is provided by Lawrence et al. (1993). Dorsal macroducts are two-barred, and arranged in transverse rows. The pygidium has three pairs of well-developed lobes, notched on the outer margin. The large median lobes are joined at their bases (“zygotic”), the second pair of lobes are much smaller and bi-lobed, and the third lobes are very small and sclerotised. The perivulvar pores occur in four clusters of about 60–80 pores on either side of the anus. A fifth cluster of about 10–25 pores is situated above the anus, which is located between the anterior group of pores.
The prosoma is devoid of gland ducts.

1.3.3 Male scale

In contrast to the female scale, the male scale is elongated and white in colour, with a terminal yellow spot made up of the moult skins (shed skin) (Tippins & Howell 1983) (Figure 5). Moulting of the second instar nymphs results in a third instar pre-pupa with short backward antennae, and leg and wing buds. After another moult (fourth instar) the pupa has longer antennae, wing pads and rudimentary legs. The male adult emerges after a final moult (Waterhouse & Norris 1987) as a tiny (<1 mm long, 1.4 mm wingspan), yellow to orange, two-winged insect (Figure 5). It has no mouthparts and is unable to feed.

Figure 5. Male white peach scale (WPS), *Pseudaulacaspis pentagona* (left). Winged adult (right). (Photo source Lyle J. Buss, University of Florida).

1.4 Host plants

WPS is a highly polyphagous species that feeds on several hundred plant species, many of which are crops and present in New Zealand. Garcia Morales et al. (2016) report 85 families and 221 genera are hosts of WPS (Table 2), however the host plant range could be much wider. WPS is unable to complete development on many of the host plants listed, which indicates that they may not be true host plants (CABI 2018).

Table 2. Host plants of white peach scale (WPS), *Pseudaulacaspis pentagona.*

Family	Latin name (common name)
Primary hosts	
Acanthaceae	*Acantus* spp., *Asystasia* spp., *Crossandra* spp.
Actinidiaceae	*Actinidia* sp., *A. arguta*, *A. chinensis*, *A. deliciosa*, *A. polygama* (kiwifruit)
Apocynaceae	*Nerium oleander* (oleander)
Bignoniaceae	*Catalpa* spp., *Catalpa bignonioides* (catalpa or catawba)
Caricaceae	*Carica* spp., *Carica papaya* (pawpaw)
Crassulaceae	*Sedum* spp.(stonecrop)
Euphorbiaceae	*Ricinus communis* (castor bean)
Fabaceae	*Sophora* spp. (kōwhai)

Family	Latin name (common name)
Grossulariaceae	*Ribes* spp. (currants)
Hydrangeaceae	*Philadelphus coronarius* (mock orange)
Juglandaceae	*Juglans* spp. (walnuts)
Malvaceae	*Abelmoschus esculentus* (okra)
Moraceae	*Ficus* spp. (fig), *Morus rubra* (mulberry tree, mulberry)
Oleaceae	*Ligustrum sinense* (Chinese privet)
Rosaceae	*Malus* spp. (ornamental apple), *Prunus* spp. (stone fruit), *Prunus armeniaca* (apricot), *Prunus avium* (sweet cherry), *Prunus japonica* (Japanese bush cherry tree), *Prunus mume* (Japanese apricot tree), *Prunus persica* (peach), *Prunus salicina* (Japanese plum), *Prunus tomentosa* (nanking cherry tree), *Pyrus* spp. (pears), *Rubus* spp. (blackberry, raspberry) and *Sorbus* spp. (rowan)
Salacia	*Euonymus europaeus* (spindle trees)
Ulmaceae	*Celtis australis* (nettle tree)
Vitaceae	*Vitis* spp. (grape)
Secondary hosts	
Aceraceae	*Acer* spp. (maples)
Anacardiaceae	*Mangifera indica* (mango), *Rhus coriaria* (sumach), *Rhus typhina* (staghorn sumac) and *Schinus molle* (pepper tree)
Apocynaceae	*Allamanda* spp. (Allamanda), *Calotropis* spp. (milkweeds) and *Plumeria rubra* (frangipani)
Arecaceae	*Cocos nucifera* (coconut) and *Phoenix dactylifera* (date palm)
Asclepiadaceae	*Tylophora asthmatica* (Indian ipecac) and *Cynanchum vincetoxicum* (white swallowwort)
Asteraceae	*Mikania ternata*
Berberidaceae	*Berberis* spp.(barberry)
Betulaceae	*Ostrya* spp. (hophornbeam, ironwood)
Bignoniaceae	*Bignonia* spp (bigonias), *Campsis* sp. (American or Chinese trumpet vine), *Catalpa bignonioides* (Southern catalpa), *Tecoma* spp. (trumpet bush), *Ehretia* spp. and *Heliotropium arborescens* (cherry-pie)
Cannabaceae	*Trema lamarckiana* (Lamarck's trema or West Indian nettle tree) and *T. micrantha* (Jamaican nettle tree or guacimilla)
Calophyllaceae	*Mammea americana* (mammee, mamey)
Caprifoliaceae	*Symphoricarpos albus* (snowberry)
Casuarinaceae	*Casuarina* spp. (beefwood)
Clusiaceae	*Hypericum perforatum* (St John’s wort)
Convolvulaceae	*Argyreia* sp. (asia glory)
Cornaceae	Cornus (dogwood), *Cornus alba* (red-barked dogwood)
Crassulaceae	*Kalanchoe* spp, *K. pinnata* (cathedral bells), *K. bracteata* (silver teaspoons), *K. orgyalis* (copper spoons) and *Sedum* spp. (stonecrops)
Cycadaceae	*Cycas* spp. *C. media* (nut palm) and *C. revolute* (sago palm)
Ebenaceae	*Diospyros malabarica* (malabar ebony) and *Diospyros kaki* (persimmon)

Family	Latin name (common name)
Euphorbiaceae	*Aleurites* spp., *Euphorbia pulcherrima* (poinsettia), *Hevea brasiliensis* (rubber), *Mallotus japonicas*, Manihot, *Ricinus* spp.
Fabaceae	*Acacia* spp.(wattles), Bauhinia (camel's foot), *Cajanus*, *Cassia* (sennas), *Cytisus* (broom), *Erythrina* spp. *E. gauca*, *E. poeppigiana*, *Genista* (broom), *Gleditsia triacanthos* (honey locust), *Gymnocladus*, *Phaseolus* (beans), *Robinia* (locust), *Spartium* and *Styphnolobium japonicum* (pagoda tree)
Flacourtiaceae	*Flacourtia jangomas* (Indian plum), *F. rukam* (rukam)
Geraniaceae	*Geranium* spp. (cranesbill), *Pelargonium* spp. (pelargoniums)
Ginkgoaceae	*Ginkgo biloba* (ginkgo or gingko)
Hippocastanaceae	*Aesculus* spp. (buckeye and horse chestnut)
Juglandaceae	*Juglans regia* (walnut) and *Pterocarya* sp. (wing nut)
Lamiaceae	*Callicarpa* spp. (beautyberry) and *Cinnamomum* spp. (cinnamon)
Loganiaceae	*Buddleia* spp. (butterfly bush)
Lythraceae	*Punica granatum* (pomegranate)
Malvaceae	*Brachychiton acerifolius* (flame tree), *Firmiana* spp. (parasol tree), *Gossypium hirsutum* (cotton), *Guazuma* spp, *Hibiscus tiliaceus* (coastal hibiscus), *Hibiscus* spp. (rosemallows and amapola), *Thespesia grandiflora* (=*Montezuma speciosissima*) (maga), *Sida* spp. (sidas or fanpetals), *Sterculia urens* (kateera gum) and *Theobroma* spp. (cacao)
Meliaceae	*Azadirachta indica* (neem tree), *Cedrela odorata* (cedar) and *Melia azedarach* (chinaberry)
Moraceae	*Broussonetia papyrifera* (paper mulberry), *Morus alba* (mora) and *M. nigra* (black mulberry)
Myrtaceae	*Psidium guajava* (guava)
Oleaceae	*Forsythia intermedia* (golden bells), *Fraxinus* spp. (ashes), *Fraxinus americana* (white ash), *Fraxinus excelsior* (ash), *Jasminum* spp. (jasmine), *Ligustrum* spp. (privet) and *Olea europaea* subsp. *europaea* (European olive)
Onagraceae	*Fuchsia* spp. (fuchsia)
Paeoniaceae	*Paeonia* spp. (peonies)
Passifloraceae	*Passiflora* spp. (passionflower) and *P. edulis* (passionfruit)
Plantaginaceae	*Veronica* spp. (speedwell)
Platanaceae	*Platanus* spp.(planes)
Ranunculaceae	*Clematis* spp. (clematis, traveller's joy) and *Consolida ambigua* (rocket larkspur)
Rosaceae	*Cydonia oblonga* (quince) and *Prunus serotina* (black cherry)
Rubiaceae	*Bouvardia* spp. (bouvardias)
Rutaceae	*Citrus* spp. (orange, lemons, grapefruit, limes and pomelo), *Phellodendron* spp.(cork tree), *Ptelea trifoliate* (hoptree), *Tetradium ruticarpum* (wu zhu yu) and *Zanthoxylum americanum* (prickly ash)
Salicaceae	*Populus* spp. (poplars), *Salix* spp. (willows) and *S. babylonica* (weeping willow)
Sapindaceae	*Koelreuteria* spp. (China tree, pride of India, goldenrain tree) and *Nephelium lappaceum* (rambutan)
Scrophulariaceae	*Paulownia* spp. *P. tomentosa* (paulownia)
Solanaceae	*Capsicum* spp. (peppers) and *Solanum* spp. (nightshade)

Family	Latin name (common name)
Strelitziaceae	*Strelitzia* spp. (bird of paradise flower)
Theaceae	*Camellia sinensis* (tea)
Ulmaceae	*Ulmus* spp. (elms) and *Zelkova* spp. (zelkova)
Zamiaceae	*Zamia* spp. (zamia)

1.5 Damage

White peach scale use their long stylet to pierce plant cells and feed on the sap. Yasuda (1979) found that on mulberry every plant cell that is pierced by the stylet dies. Feeding mainly occurs on trunks, branches and stems of the host plant, and when present, the fruit. Leaves are occasionally infested.

On fruit, feeding damage by WPS is often apparent as a 'dimple' or dark mark. Heavy infestations detract from the appearance of the fruit (Figure 6) (USDA-APHIS 2011).

Host plants are not generally adversely affected when infestations of WPS are low, but heavy infestations can result in a reduction in plant vigour, stem dieback, distortion and discoloration of bark and fruit, low yields, premature fruit drop, and/or early senescence. If the infestation is severe, branches or the entire plant can die (e.g. Davidson & Miller 1990; Hanks & Denno 1993; Erkilic & Uygun 1997; Takeda 2006). Younger plants are more susceptible than older plants.

Figure 6. White peach scale (WPS), *Pseudaulacaspis pentagona* on peach fruit showing typical 'dimpling' at the site of feeding (left) (Photo source Peter Shearer, Rutgers University) (left). A heavily infested papaya (right) (Photo source Scot Nelson).

1.5.1 Damage to kiwifruit

WPS feeds on the trunks, stems, shoots, and fruit of *Actinidia*, and in very serious cases, the leaves (Paulokis et al. 1997, Brun 1992, Güncan 2015). Reported symptoms include dieback and yield loss (Hill et al. 2008), a lack of new shoot production and, in extreme cases, death of the vine (Zhuang et al. 2016).

1.6 Pest status

Listed as one of the 43 principal armoured scale pests of the world (Beardsley & González (1975), WPS is regarded as a serious pest capable of causing considerable economic damage to multiple fruit crops and important ornamental species. Significant losses have been reported in stonefruit, kiwifruit and mulberry orchards in Europe, US, Brazil and Asia (e.g. Bertels 1956; Hickel & Schuck 1996; Hill et al 2007). WPS is also considered a serious pest of flowering cherry trees and many other species of ornamental trees and shrubs in United States (Bobb et al. 1973; Johnson & Lyon 1988). In Hungary (Kosztarab & Kozar 1988) and Switzerland (Kozar et al. 1994; Mani et al. 1997) heavy outbreaks have been reported in ornamental plants.

WPS is also classified as a quarantine pest in many countries around the world. Infested fruit or plant material may be refused entry, or may be fumigated or destroyed on arrival.

1.6.1 Pest status in kiwifruit

WPS is considered a serious pest of kiwifruit in Iran (Abbasipour 2007), China (Zhuang et al. 2016), Northern Greece (Paloukis et el. 1997), Turkey (Güncan 2015; Mohammed et al. 2016), France (Marc 2009), and Italy (Ferrari et al. 2006; Hill et al. 2007). Hickel and Schuck (1996) also reported WPS as a pest of kiwifruit in Santa Catarina, Brazil.

WPS is an increasingly important pest of *Actinidia chinensis* var. *deliciosa* 'Hayward' and *Actinidia chinensis* var. *chinensis* 'Zesy002' Gold3 kiwifruit grown in France and Italy, and because of a lack of effective control measures, increasing fruit losses are being recorded (S Max, pers comm). Hill et al. (2007) found WPS infesting all above-ground plant parts of *A. chinensis* var. *chinensis* 'Hort16A' in Italy, with an estimated 10–20% fruit loss through loss of cosmetic quality. The presence of WPS on the fruit at harvest can also have implications for market access; infested fruit lines can trigger market access restrictions and/or fumigation.

In the Caspian Sea region of Iran, WPS is the most important insect pest of 'Hayward' kiwifruit (Maleki et al. 2018), with infestation levels ranging from 20% of vines in the mountain areas to 60% of vines at sea level (Abbasipour 2007). In China, WPS is a major pest of *A. chinensis* var. *chinensis* 'Hongyang' and is prevalent on vines and fruit of *A. chinensis* germplasm (Zhuang 2016). In Turkey, a survey of fruit in the markets determined that kiwifruit was the fruit most frequently infested with scale insects, with WPS identified as the species (Ulgenturk & Ayhan 2014). The authors noted that scale insects found on fruit in the markets implied a heavy infestation on the plants.

1.7 Biology and ecology

1.7.1 Life cycle and seasonality

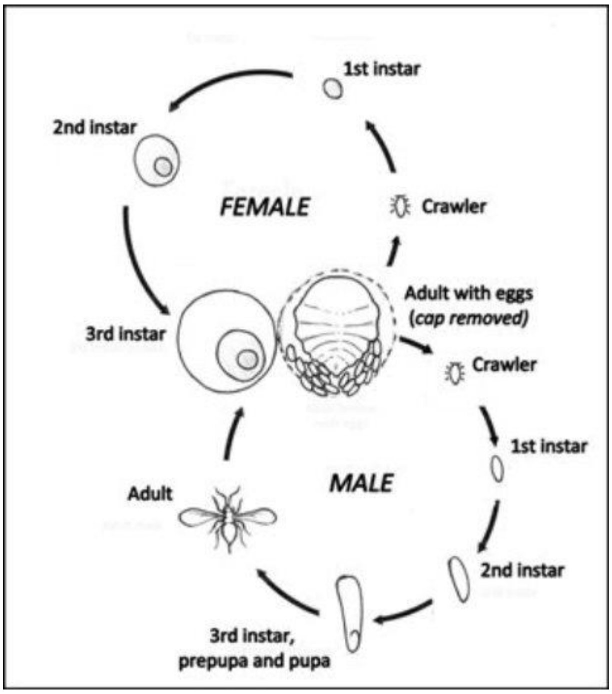

Figure 7. Life cycle of the white peach scale (WPS), *Pseudaulacaspis pentagona* (Source Hill 2018)

WPS overwinters on the host plant as fertilised adult females (Figure 7). In spring, the female lays eggs which hatch into tiny mobile crawlers. The crawlers emerge from under the protective cap of the mother and move to new sites to begin feeding on the bark, leaves or other plant parts. Male crawlers tend to settle relatively near the mother scale and it is common to see clusters of male scales adjacent to the mother scale. Female crawlers, by comparison, disperse more widely before settlement (Zhuang et al. 2016). They can also be dispersed on the wind and settle on new host plants (Van Duyn & Murphey 1971).

Soon after settling down to feed, crawlers begin secreting the protective scale cap. Females remain under the scale cap throughout their life, but the males develop wings when mature and emerge from the scale cap to seek out and mate with females. Females undergo two moults, and the males five moults, before reaching sexual maturity as adults. Once mature, the males live for 1 d only whereas females may live for 40–100 d depending on temperature (Table 3).

The number of generations per year is largely dependent on climate and varies from one to four in different parts of the world, although Bennett (1956) reported that WPS reproduces all year around in Trinidad. In the Emilia-Romagna region of Italy, WPS has two generations per year with the first generation starting in April and the second in July–September (Kreiter et al. 1997), while in the Lazio region Hill et al. (2007) recorded three generations with estimated 50% crawler emergence dates of 12 May, 11 July and 8 September respectively. Three generations have also been recorded in Northern Greece (Paloukis et al. 1997) and the coastal plains of Turkey, but only two in the cooler mountain regions (Erkilic & Uygan 1997). Three generations have been reported in Sichuan, China (Zhuang et al. 2016) and the tea-producing regions of Japan (Takeda 2004) (Figure 8).

New Zealand kiwifruit growing regions are likely to be climatically suitable for WPS; the whole of New Zealand has a 0.9 climate match with the inland areas of Lazio, Italy and a 0.8 climate match with the cooler north-western regions of Italy (Phillips et al. 2018). A composite match index of ≥ 0.7 is generally interpreted as indicating two climates are sufficiently similar for a species to persist in both.

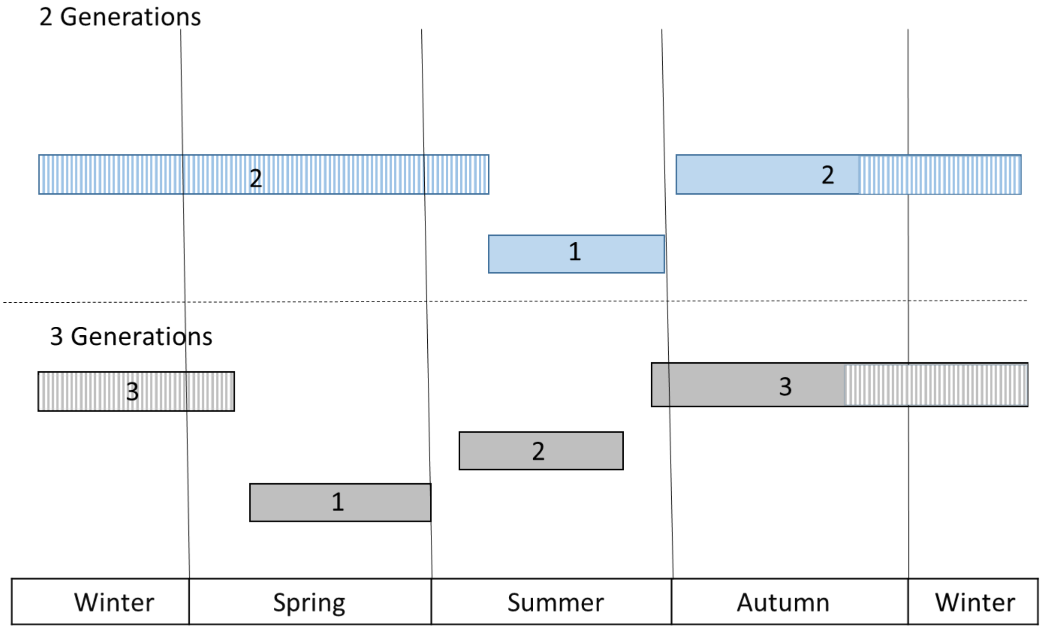

Figure 8. Estimated timing of two (top) or three (bottom) generations of white peach scale (WPS), *Pseudaulacaspis pentagona*. Each year the first generation starts with fertilised females and the last generation overwinters as fertilised females (vertical patron in the bars). The number of generations per year is largely dependent on temperatures.

1.7.2 Development biology

Each mated female lays about 100 eggs over a period of two to four weeks (Ball 1980, Van Duyn & Murphy 1971; Hanks & Denno 1993). The incubation period varies with temperature, for example, Ball (1980) reported egg development takes 14.2 days at 13.3°C but only 2.9 days at 26.4°C. Egg-laying commences in the spring when an average of 149 degree-days above a base temperature of 10.5°C has accumulated, with peak hatching after 288 degree-days (Takeda 2004). Bennett and Brown (1958) and Hughes (1960) reported that some females produce only male eggs under certain conditions, but failed to specify those conditions. Hanks and Denno (1993) found a positive relationship between the proportion of females laying only male eggs and density of female scales on the trees.

Eggs of both sexes hatch into tiny mobile crawlers within 3–5 d of oviposition (Hanks & Denno et al. 1993; Zhuang et al. 2016) and emerge from under the mother scale cap soon after. Hatching occurs over a period of one to three weeks, with ≥ 50% of crawlers hatching within the first 7–10 d (Zhuang et al. 2016). Crawler hatching by the first generation is more synchronised than that of later generations (Kreiter et al 1997; Nalepa & Meyer 1990).

The developmental time of WPS life stages varies according to temperature with the female adults the longest-lived stage (Table 3). Erkilic and Uygun (1997) reported developmental times at four constant temperatures, with development fastest at 30°C (50 d) and slowest at 15°C

(118 d) (Table 3, Figure 9). Ball (1980) reported slightly shorter generational times; 40 d at 26.4°C and 110 d at 13.3°C.

Table 3. Mean development time of various stages of white peach scale (WPS), *Pseudaulacaspis pentagona* on potato tubers at four constant temperatures (adapted from Erkilic and Uygun (1997))

Temp. (°C)	Mean development time (days)					Duration of oviposition periods (days)		
	Male			Female				
	1st instar	2nd instar	Pupae	1st instar	2nd instar	Pre-ovi-position	Ovi-position	Post-ovi-position
15	20.9	32.3	23.2	21.5	33.4	36.1	26.5	39.4
20	11.3	17.9	11.5	11.8	18.3	27.0	22.7	29.7
25	9.4	13.7	10.2	9.5	13.6	20.8	13.3	10.1
30	7.4	12.5	13.9	7.3	13.1	16.5	13.5	9.1

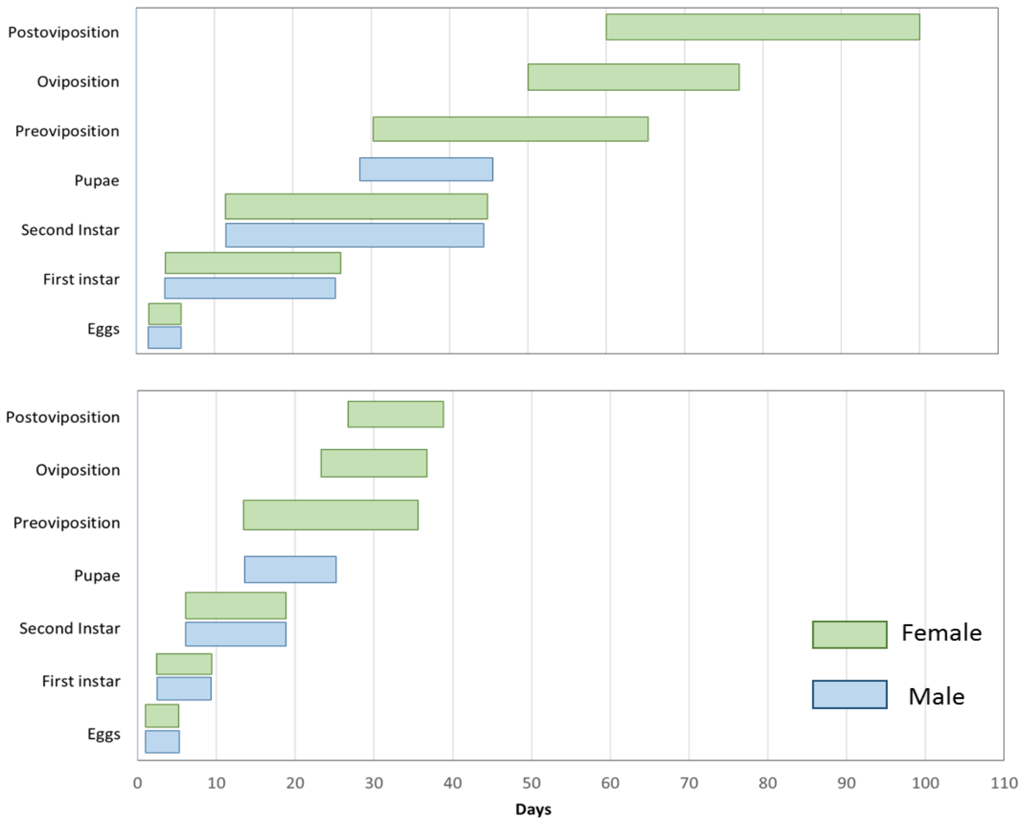

Figure 9. Mean development time for each life stage of white peach scale (WPS), *Pseudaulacaspis pentagona* at 15°C (top) and 20°C (bottom) (adapted from Erkilic and Uygun (1997)).

1.8 Natural enemies

WPS is attacked by a large number of natural enemies (Waterhouse & Norris 1987) (Table 4). Hanks and Denno (1993) reported 60 species of parasitoids and hyperparasitoids and 80 species of predators associated with WPS worldwide**.** Comprehensive lists of the natural enemies of WPS have also been provided by Berlese (1910) for Italy, Ogilvie (1928) and Simmonds (1958) for Bermuda, Bennett (1956) for Trinidad, Clausen (1956) for Florida, Yasuda (1981) for Japan and Lawrence et al. (1993) for Maryland.

Of the reported natural enemies, *Encarsia berlesei* (Howard) (Hymenoptera: Aphelinidae) is the most common and important species in many parts of the world. Unfortunately *E. berlesei* is attacked by several species of hyperparasitoids that may be accidentally introduced at the time of the initial *E. berlesei* introductions.

Table 4. Natural enemies of white peach scale (WPS), *Pseudaulacaspis pentagona.*

Type	Species
Entomopathogens	*Cosmospora* (= *Nectaria*) *flammea* (Tul. & C. Tul.) (anamorph *Fusarium coccophilum* (Desm.), *Cosmospora (= Nectaria) aurantiicola* (anamorph *F. larvarum* (Fuckel)), *Verticillium lecanii* (Zimmerman), *Myriangium duriaei* (Mont. & Berk (1845).
Parasitoids	*Aphytis chilensis, A. chrysomphali, A. diaspidis, A. lingnanensis, A. proclia, Aprostocetus purpureus, Arrhenophagus albitibiae, A. chionaspidis, A. orientalis, Azotus atomon, A. lepidus, A. pentagona, A. perspeciosus*, A. platensis, Aspidiotiphagus citrinus, A. lounsburyi, Coccophagoides kuwanai, Comperiella bifasciata, Encarsia amicula, E. berlesei, E. citrina, E. diaspidicola, E. fasciata, E. lounsburyi, E. perniciosi, Marietta leopardine, Epitetracnemus comis, E. zetterstedtii, Prospaltella berlesei, Pteroptrix orientalis, Signiphora aspidioti* and *Zaomma lambinus**
Predators	*Adalia bipunctata, Chilocorus cacti, C. circumdatus, C. hupehanus, C. kuwanae, C. nigrita, C. politus, C. renipustulatus, C. similis, C. stigma, Chrysopa rufilabris, Coccidophilus cariba, C. citricola, Cryptognatha simillima, Cybocephalus fodori minor, C. gibbulus, C. nipponicus, C.* nr. *nigritulus, Decadiomus hughesi, Dentifibula viburni, Exochomus quadripustulatus, Hemisarcoptes malus, Heteroconis picticornis, Lindorus lophanthae, Microweisea coccidivora, Orius minutus, Pentilia insidiosa, Pharoscymnus horni, P. pharoides, P. tomeensis, Prodilis* sp. nr. *gorhami, Rhyzobius lophanthae, R. pulchellus, Sticholotis quadrisignata, Sukunahikona prapawan.*

*Also listed as hyperparasitoids of *E. berlesei* (Kreiter et al. 1997, Garonna & Viggiani 1997, Pedata et al. 1995, Waterhouse & Norris 1987)

2 SECTION TWO: PEST MANAGEMENT

2.1 Monitoring techniques

Pheromone traps

In bi-parental armoured scale populations, the female scale insects release a sex pheromone to attract males. The pheromone for WPS was identified by Heath et al. (1979) as (Z)-3,9-dimethyl-6-isopropeniyl-3, 9-decadient -1-ol propionate. Trap catches using a synthetic blend of the pheromone have been widely used in research programmes to understand aspects of WPS biology and ecology.

In commercial settings the pheromone has been used as a tool to forecast the timing of sprays against crawlers. The adult male emergence period lasts 5–7 d only (Zhuang et al. 2016), so pheromone trap catches provide an indication of when the next crawler generation may occur. Trap catches have been used to predict crawler emergence and time sprays against WPS in peach and plum crops in Italy (Cravedi & Mazzoni 1993), on tea crops in Japan (Kaneko et al. 2006) and in peach crops in Northern Greece (Kyparissoudas 1992). The pheromone traps appear to be extremely effective, with so many males caught on the sticky surface of the trap that sticky parts need to be replaced every 2–3 d (Cravedi & Mazzoni 1993).

The pheromone has also been considered for mating disruption of WPS on peaches and plums in Italy (Cravedi & Mazzoni 1993), but this does not appear to be an active area of research.

Sticky boards and bands

Sticky boards or bands have also been used as a tool to monitor WPS. In Japan, sticky boards set inside tea bushes to capture WPS crawlers are used as a simple and accurate monitoring method for predicting optimal spraying time. According to Tatara (1999), this is 2–5 d after the peak capture of crawlers. The same boards were also used by Kaneko et al. (2006) to investigate the relationship between WPS crawlers and adults, and the coccinellid predator, *Pseudoscymnus hareja*, in Japanese tea fields. Sticky boards have also been deployed to detect crawlers blown by the wind from adjacent host plants onto the crop (Dreistadt et al. 1994 cited by Miller & Davidson 2005).

WPS crawlers have been monitored using sticky bands applied sticky side down to the trunks and leaders of kiwifruit vines. For example, bands wrapped around the trunk and leader of ‘Hort16A’ vines were successfully used to determine the phenology of crawler activity in the Latina region of Italy, with three generations recorded (Hill et al. 2007). Zhuang et al. (2016) similarly used bands to measure the phenology of first generation WPS crawlers on kiwifruit in Sichuan, China and determined that the degree-day models calculated by Takeda (2004) and Erklilic and Uygun (1997) gave acceptable predictions of crawler emergence that could potentially be used to forecast spray timing.

The same banding technique has been used in multiple studies to monitor armoured scale insects abundance on kiwifruit wood in New Zealand (e.g. Hill et al. 2008; McKenna et al. 2013). However, this technique is largely a research tool and is likely to be too labour intensive to be used on a commercial scale in New Zealand.

2.2 Management options

2.2.1 Biological control

Of the natural enemies of WPS, the parasitic wasp, *E. berlesei*, is generally considered to be the most important (DeBach & Rosen 1976) (Figure 10). Thought to be native to Asia, *E. berlesei* is an endoparasitoid that attacks young female scale, although the larger life stages are also parasitised (Pedata & Garonna 2001). This parasitoid has been the subject of multiple successful classical biocontrol introductions against WPS in different parts of the world (Table 5), including one of the most successful classical biocontrol projects known; WPS was a serious pest of mulberry at the beginning of the 20th century in Italy but following the introduction of the *E. berlesei*, WPS lost its economic significance (Waterhouse & Norris 1987*).*

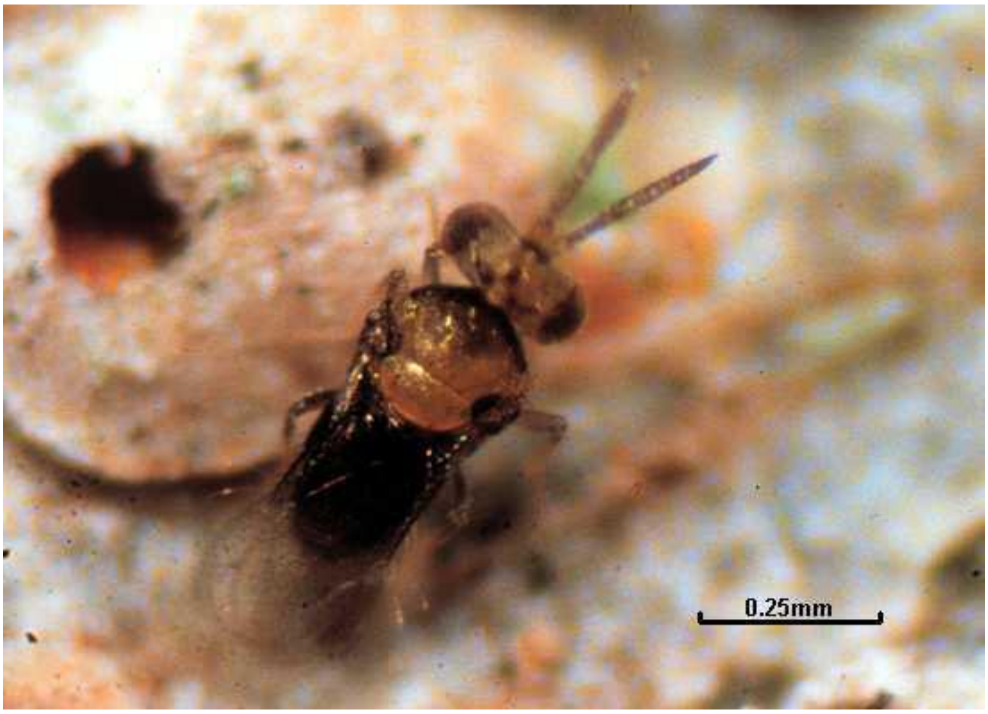

Figure 10. Adult *Encarsia berlesei* (Hymenoptera: Aphelinidae), an important parasitoid of adult white peach scale (WPS), *Pseudaulacaspis pentagona*. (Photo source Natural History Museum, UK, © Walter Klerks)

Table 5. Successful classical biological control introductions of the parasitoid *Encarsia berlesei* against white peach scale (WPS), *Pseudaulacaspis pentagona*.

Crop	Country	Date(s) of introduction	Origin of Agent	Source
Mulberry, peach	Argentina	1909, 1915	Japan	Clausen 1978
Mulberry, peach	Brazil	1921	Japan	Altieri et al 1989
Peach	Peru	1909-10	Japan	Altieri et al 1989
Mulberry, peach	Uruguay	1912-14	Japan	Delucchi 1976
Woody plants	W Samoa	1986	Japan	Sands et al 1990
Mulberry	WP Austria	1910-11	Japan	Clausen 1978
Mulberry	Italy	1906	Japan	Greathead 1976
Mulberry	Spain	1914	Japan	Clausen 1978
Mulberry	Switzerland	1910	Japan	Clausen 1978
Mulberry	USSR	1947	Japan	Delucchi 1976 Izhevskii 1988
Woody plants	W Samoa	1986	Italy	Sand et al 1990

Encarsia berlesei is usually the most abundant parasitoid of WPS in European orchards (e.g. Bianchi et al. 1995; Paloukis et al. 1997; Pedata & Garonna 2001). A study in Lazio, Italy found that parasitism of WPS on kiwifruit by *E. berlesei* ranged between 17–35% from April to late June, but tended to decrease from July to August when the second generation of WPS was present (Bianchi et al. 1995). This reduction in parasitism was attributed to high temperatures and low humidities, and it was suggested that improved control could be obtained through augmentive releases of *E. berlesei* at this time. In Northern Greece, Paloukis et al. (1997) reported that *E. berlesei* had four overlapping generations per year in kiwifruit orchards, and there was up to 45% parasitism of WPS. Most parasitism was during the fourth generation. Graora and Spasis (2008) similarly recorded significant parasitism of WPS in Serbia of up to 64% with *E. berlesei* and *Aphytis proclia* the most common species.

A number of other natural enemies have been recorded as important in maintaining low populations of WPS including *Archenomus orientalis*, *Encarsia citrina*, *Azotus perspeciosus*, and *Pteroptrix orientalis*. The latter species is also very common in the Campania region (Garonna & Viggiani 1997), but has reduced competitiveness in colder regions (Pedata & Garrona 2001).

In Europe predators of WPS are also thought to play a significant role in reducing populations of WPS including *Lindorus lophanthae*, *Cybocephalus rufifrons*, *Chilocorus bipustulatus*, *Exochomus quadripustulatus*, and *Rhizobius satellus* (Garonna & Viggiani 1988; Bianchi et al. 1995; Pedata et al. 1995; Paloukis et al. 1997; Graora & Spasic 2008).

Although natural enemies of WPS can contribute a significant amount to the control of the pest, in many commercial orchards outbreaks of WPS are common and often a result of broad-spectrum insecticides killing the natural enemies (e.g. Collins & Whitcomb 1975; Paloukis et al. 1997; Tatara 1999). For example *E berlesei* is highly susceptible to many of the pesticides used to control WPS or other pests in fruit crops. In a study targeting first generation WPS crawlers on kiwifruit vines, Paloukis et al. (1997) reported that the insect growth regulators buprofezin and fenoxycarb reduced parasitism of WPS by about 50%, and the organophosphorus pesticide methidathion by about 90%.

Several fungal species are specialist entomopathogens of armoured scale insects and can cause localised epizootics (Evans & Prior 1990). Fungi found in association with WPS in Japan, Taiwan, Sri Lanka and USA include *Cosmospora* (= *Nectria*) *flammea* (Tul. & C. Tul.) (anamorph *Fusarium coccophilum* (Desm.), *Cosmospora aurantiicola* (anamorph *F. larvarum* (Fuckel)), *Verticillium lecanii* (Zimmerman) and *Myriangium duriaei* (Mont. & Berk (1845)) (Evans & Prior 1990). Terada and Imanishi (1974) frequently found *C. flammea* infesting WPS on tea twigs in Nara prefecture Japan, and a new record of *C. aurantiicola* parasitising WPS was found in Bulgaria in 2004 (Draganova 2004). In New Zealand, *C. flammea* and *C. aurantiicola* have been found on several diaspidid species (*A. nerii, H. lataniae, Hemiberlesia* sp., *Leucaspis brittini*, *Leucaspis* sp., *Pinnaspis dysoxyli*) (Tyson et al. 2005), and found parasitising armoured scale insects residing on kiwifruit vines (N Mauchline, pers. comm.). The infection process of armoured scale insects by *F. coccophiulum* has been identified (Mauchline et al. 2012) and this species is currently being developed as biopesticide for use against armoured scale insects (N Mauchline, pers. comm.).

2.2.2 Chemical control

Whilst biocontrol can play an important role in limiting WPS populations, control of WPS in commercial orchards is largely reliant on insecticide applications. Chemical control measures are most effective against immature life stages (crawlers or the first instar white caps), and most sprays are timed to correspond to about 50% crawler emergence as determined by monitoring or forecasting (see Section 2.1) (Takeda 2006; Zhuang et al. 2016). First generation crawler emergence in spring is well synchronised and takes place over 5 to 10 d (Zhuang et al. 2016), and sprays targeting this generation are generally more effective than those applied against subsequent generations. This is because crawler emergence occurs over a longer period in summer (Tatara 1999), and adult scale are present which are harder to kill because of their protective waxy cap (Blank & Olsen 1987).

Multiple insecticides have been determined as effective against WPS. However, many of these are older chemistries that are no longer available or acceptable for use in commercial cropping situations because of their high mammalian and environmental toxicity, broad-spectrum activity, and/or persistence. These insecticides include organophosphates such as chlorpyrifos, diazinon and azinphos methyl (Bazrafshan et al. 2010), carbamates such as carbaryl and sevin (Gorsuch et al. 2018) and synthetic pyrethroids such as cyfluthrin (Halcomb & Hale 2012). These products have largely been replaced with those that have reduced mammalian toxicity and improved selectivity, albeit in some instances, reduced efficacy.

Spirotetramat

Spirotetramat, the first two-way systemic insecticide, is highly effective against multiple species of armoured scale insects. In the US spirotetramat has been used successfully against WPS on peaches. A single application in late spring resulted in 91% clean fruit compared with 44% in the untreated control (Shearer & Rucker 2004). It is also highly effective against the armoured scale insects, greedy scale (*H. rapax*) and latania scale (*H. lataniae*) on kiwifruit in New Zealand when applied pre or post-blossom (McKenna et al. 2013; 2017). However, there are no records of its use or effectiveness against WPS on kiwifruit in the literature. Research to test the efficacy of spirotetramat against WPS on *Actinidia* in China is underway and it is being used off-label by commercial kiwifruit growers there. Kiwifruit is considered a minor crop in China and few insecticides are registered for use on the crop (QG Zhuang pers. comm.). In Italy, spirotetramat is registered for use on a number of crops in Italy, but kiwifruit is not included (Bayer CropScience 2019).

Neonicotinoids

Neonicotinoids are banned in Europe (Butler 2018) but are still permitted for use in many other countries including North and South America, China and New Zealand. In Brazil, neonicotinoid insecticides are used for winter treatments in peach orchards to reduce overwintering WPS populations (Botton et al. 2002), but no details are provided regarding the type of neonicotinoid or treatment efficacy. In New Zealand, thiacloprid can be applied to kiwifruit vines pre-blossom. This product is effective against greedy and latania scale (McKenna & Dobson 2006), but most growers choose to apply spirotetramat pre-blossom, so thiacloprid is not widely used. As a neonicotinoid, thiacloprid may also be subject to phase-out in New Zealand.

Insect growth regulators

Insect growth regulators (IGRs) inhibit cuticle formation (e.g. buprofezin, diofenolan) or affect the hormonal regulation of development by binding to the insect’s natural hormone receptors (e.g. fenoxycarb, kinoprene, pyriproxyfen). They are effective against immature insect stages but do not normally affect adult stages.

Hill et al. (2007) reported that one or two applications of buprofezin applied against first and second generation crawlers on ‘Hort16A’ kiwifruit vines in Italy significantly reduced the percentage of WPS-infested fruit at harvest by about two-thirds relative to untreated vines. Diofenolan is also effective in controlling first generation WPS on kiwifruit vines and was less harmful to *E. berlesei* when compared to buprofezin (Paloukis et al. 1997). In Hungary, Darvas and Zseller (1985) found an application of kinoprene or fenoxycarcb at a 0.1% concentration to Japanese pagoda (*Sophora japonica*) trees resulted in high mortality of WPS after the first moult and a reduction in the number of eggs deposited by surviving insects. Kinoprene did not affect parasitism by *E. berlesei* but fenoxycarb caused slightly adverse effects. Pyriproxyfen was also found to be highly effective against WPS on peaches in the US, and provided 90% clean fruit versus 44% in the untreated control (Shearer & Rucker 2004).

Although IGRs are effective against armoured scale insects and generally cause less harm to natural enemies, they are highly persistent, thereby limiting their use to the pre-blossom period on kiwifruit orchards (Hill 2002).

Mineral oil

Mineral oil sprays play an important role in the control of armoured scale in many crops (Kozar 1990). Meyer and Nalepa (1991) reported significant reductions in WPS scale populations on peaches in North Carolina following a dormant season oil spray, while Zhuang et al. (2015) reported that mineral oil had good efficacy against first instar WPS on kiwifruit in China. In France, mineral oil is effective against WPS on kiwifruit vines, but the spray cannot be applied past bud break (C. Cazy, pers. comm). In Italy mineral oils are not registered for use on kiwifruit crops, however, some studies are underway to investigate efficacy against WPS (R. Spinelli pers. comm.).

In New Zealand mineral oil sprays are an integral part of the pest management programmes used on kiwifruit crops, and are the only product that can be applied post-fruit set to control scale insects (Zespri Crop Protection Standard, 2018). The products provide adequate control providing good spray coverage is achieved, but they can be phytotoxic and should only be applied when conditions give fast spray drying, and during periods when the crop is not susceptible to oil-induced damage (McKenna & Steven 1993; McKenna et al. 2007).

Other products

A number of other insecticides tested against WPS have been reported as having little or no effect. These include spinosad and methoxyfenoxide (Bazrafshan et al. 2010), insecticidal soaps (Williamson 2019), and neem (Kwaiz et al. 2009).

2.2.3 Cultural control

Few cultural control practices targeting WPS are recorded in the literature. Obtaining scale-free nursery plants when establishing an orchard is important as young plants infested with WPS fail to thrive, and if the infestation is heavy, the plants may die.

Removal of alternative host plants in the vicinity of commercial plantings may assist in reducing WPS populations on the crop, especially if the alternative host plants are providing a source of new infestations through wind dispersal. However, this practice could have a negative impact on natural enemy populations. A common practice in peach orchards in China is the removal of branches that are heavily infested with WPS in late autumn to reduce populations of overwintering females (Zhou & Zhou 1999). A similar practice of removing large crowns on the leaders of kiwifruit vines is recommended in New Zealand to reduce armoured scale populations (Hill & McKenna 2008).

Mechanical removal using high-pressure water spraying to dislodge adult scale from the crowns of peach trees has been demonstrated as an efficient control method for WPS in France (Kreiter & Dijoux 1998). In New Zealand some organic kiwifruit growers have also attempted to reduce armoured scale populations on kiwifruit vines by hand-gunning the trunk and leaders with water during winter. The technique was considered to be effective, but time-consuming (C McKenna, pers comm). Use of a stiff-bristled brush to remove WPS from the bark of trees has been reported as useful on peach trees when infestations are heavy and few trees are attacked, but the labour costs can be prohibitive (Malinconico 1992).

Bags applied to individual fruit have been reported as effective barriers against insects on multiple fruit crops for example, in tomatoes (Leite et al. 2014) or dates (Perring & Nay 2015). McKenna and Maher (2000) evaluated the effectiveness of specially designed nylon bags as a barrier to armoured scale and other insects on kiwifruit. The bags significantly reduced fruit contamination by armoured scale insects from 12% to 1.8%, but an economic analysis showed the use of nylon bags was not cost-effective because of the high labour component.
The method was not pursued.

2.2.4 Host plant resistance

Few studies have investigated host plant resistance to WPS. In Japan, a new cultivar of tea (*Camelia sinensis* (L) O. Kuntze) 'Nanmei' with resistance to WPS was released in 2012 by the National Agriculture and Food Research Organization (Taniguchi et al. 2018), but there have been no reports of fruit trees with resistance to WPS in the literature. Genotypes of *Actinidia* are currently being screened in China for susceptibility to WPS using assays adapted from New Zealand, but the programme is in its infancy (K. Stannard pers comm).

Differential resistance to armoured scale insects has been identified within kiwifruit germplasm in New Zealand (Hill et al. 2010, 2011), where *A. chinensis* var. *chinensis* 'Hort16A' was found to express greater resistance to *H. lataniae* (latania scale) than *A. chinensis* var. *deliciosa* 'Hayward' (Cheng et al. 2013). The segregation of resistance among progeny of 'Hort16A', suggested that resistance to latania scale is likely to be based upon a major gene (R-gene) response (Hill et al. 2015). The screening of *Actinidia* genotypes for resistance to latania scale has led to the discovery of a single large-effect QTL for latania scale resistance (Flay et al. 2019), and an understanding of the effector-triggered immune response, utilising salicylic acid-mediated defence pathways (Hill et al. 2015).

It is possible that differential resistance may be expressed for WPS within *Actinidia* germplasm. A long-term research effort would be required to phenotype for resistance and to understand the genetic basis of resistance for this polyphagous insect.

2.2.5 Postharvest

Most of the fruit produced in Europe or Asia that may be infested with WPS is sold and consumed on the continent where it was produced. For this reason, postharvest treatment of WPS-infested fruit is not common practice in Europe or Asia. One exception is Italian-grown kiwifruit exported to New Zealand which, because of the risk of WPS contamination, is subject to inspection and treatment with methyl bromide (https://www.mpi.govt.nz/dmsdocument/1865/loggedIn). However methyl bromide is being phased out and alternative disinfestation methods will be required.

Follett (2006) recommended the used of X-rays for disinfesting WPS-infested papaya exported from Hawaii. The USDA-APHIS approved a generic radiation treatment of 160 and 400 Gy for the disinfestation of different insect pests, including WPS, on papaya, and this protocol is now routinely used for the disinfestation of Hawaiian papayas for export (Follett 2006). In dose-response tests, the gravid adult female was found to be the most tolerant stage. In a large-scale validation test WPS females, with and without eggs, irradiated with an absorbed dose of 150 Gy, did not produce an F1 generation capable of reproducing (Follett 2006).

Metabolic stress disinfection and disinfestation (MSDD) was also evaluated against WPS on papaya in Hawaii. The treatment combined low pressure (125 mmHg), high CO_2 (>99%) and ethanol vapor (75 mg/ L) (Arevalo-Galarza et al. 2010). The authors reported 98% mortality of WPS and suggested that this combination could be used to disinfest surface insect pests from fresh fruit.

A number of other postharvest disinfestation treatments have also been tested against armoured scale insects (including WPS) on kiwifruit, but these have been largely unsuccessful.

Stannard et al. (in press), investigated cold storage disinfestation against overwintering WPS on ‘Hayward’ kiwifruit. In a study completed in Italy, it was determined that the time required to kill 99% of the WPS was 203 days of coolstorage at 0–2ºC. The authors also reported mortality did not rise above background levels until after 80 days in coolstorage, and WPS removed from coolstorage after 128 days were able to mature and hatch eggs.

Whiting et al (1998) tested the potential of high-pressure water jets to kill or remove armoured scale insects from kiwifruit, but ≤ 17% of fruit were free of scale insects post-treatment. Postharvest brushing of kiwifruit in a commercial setting was also unsuccessful in removing armoured scale insects from kiwifruit (Stevens & McKenna 1997).

Table 6. Current and potential methods for pre- and postharvest management of white peach scale (WPS), *Pseudaulacaspis pentagona*.

	Life stage	Method	Expected outcomes(s)	Likely impact on WPS populations	Used elsewhere	Key limitation(s)	Ease of on-orchard implementation	Technical difficulty of research	Relative development costs	Developmental time
Monitoring	Crawlers	Sticky bands	Population predictions. Forecast spray timing	Low	Europe, Asia, USA	Labour intensive. Scale species differentiation	Easy	Low to moderate	low	<3yrs
	Adult males	Pheromone traps	Population predictions. Forecast spray timing	Low	Europe, Asia, USA	Pheromone lures need to be imported	Easy	Low to moderate	low	<3yrs
Chemical	Crawlers Nymphs Adults	Trunk and foliar sprays (contact and systemic)	Population suppression	Medium to high	Used worldwide in many crops	Contact sprays require good coverage. Not compatible with beneficial insects. Few products meet BioGro standards	Easy	Easy	moderate	<3yrs
	Crawlers Nymphs Adults	New insecticides	Population suppression	Medium to high	No	Few new products being developed	Easy	Moderate	medium	4-6yrs
Cultural	Nymphs Adults	Resistant or tolerant plants	Change in pest status	High	Tea in Japan?	Little or no prior knowledge	Easy	Difficult	High	>7yrs
	Adults	High-pressure water spraying or brushing of vine wood	Reduction in overwintering populations	Medium	Europe	Labour intensive	Easy	Easy	Low	<3yrs

	Life stage	Method	Expected outcomes(s)	Likely impact on WPS populations	Used elsewhere	Key limitation(s)	Ease of on-orchard implementation	Technical difficulty of research	Relative development costs	Developmental time
	Adults	Removal of heavy infested branches or crowns in winter	Reduction of overwintering populations	Medium	China, Brazil	Labour intensive	Easy	Easy	Low	<3yrs
	Crawlers Nymphs Adults	Removal of alternative primary hosts combined with herbicide application	Reduced pest pressure. Reduced dispersal of wind-blown crawlers	Medium	China, Europe and USA	Unknown host range in New Zealand	Easy	Easy	Low	<3yrs
Biological	Nymphs Adults	Entomopathogens	Medium-term population suppression	Medium	No	Production and product stability. Field persistence	Easy	Moderate	Moderate to high	>7yrs
Biological	Nymphs Adults	Classical biocontrol – introduction of new natural enemies	Ongoing population suppression	Medium	Italy, Brazil, Japan, China USA, Russia, Latin America and Caribbean, Western Samoa	Regulatory approvals	Easy, once research is complete	Difficult	High	>7yrs
Post-harvest	Nymphs Adults	X-Rays at 150 Gy	Adult and nymph mortality. Adult sterility	High	USA (Hawaii)	Possible fruit damage. Availability of technology. Consumer acceptability	Moderate	Moderate	Moderate to high	4-6yrs

Life stage	Method	Expected outcomes(s)	Likely impact on WPS populations	Used elsewhere	Key limitation(s)	Ease of on-orchard implementation	Technical difficulty of research	Relative development costs	Developmental time
Nymphs Adults	Fumigation with methyl bromide	Adult and nymph mortality	High	New Zealand, Japan	Methyl bromide subject to phase-out. Consumer acceptability	Already available	Easy	Low	<3yrs
Nymphs Adults	Metabolic stress disinfection and disinfestation	Adult and nymph mortality	Medium	Experimental	Possible fruit damage. Availability of technology	Moderate for packing houses	Moderate	High	4-6yrs

3 SECTION THREE: PEST MANAGEMENT IN KIWIFRUIT

WPS has the potential to be a significant production and quarantine pest of kiwifruit in New Zealand. Many of the techniques currently used to manage the armoured scale pests in kiwifruit will also be important to achieve an acceptable degree of WPS control. Armoured scale insect populations build up relatively slowly, but once high, they can be difficult to reduce. Key to any management programme will be keeping the numbers of WPS on the vine low and preventing their build-up to pest proportions.

3.1.1 Monitoring

Severe infestations of WPS can occur on kiwifruit wood and fruit long before infestation of the leaves occurs. For this reason the current KiwiGreen monitoring system for scale insects will not be suitable for monitoring WPS populations. Instead, a monitoring system based on pheromone trap catches or sticky band catches will need to be implemented, either at the orchard block level or area-wide. Some research is likely to be necessary to optimise the use of pheromone traps and sticky bands in New Zealand orchards, including clarification on whether WPS crawlers can be differentiated from greedy or latania scale crawlers.

Monitoring to predict the timing of first generation crawler emergence in spring will be important, as sprays targeting the first generation have the greatest effect on WPS populations. Models for spray forecasting have been developed in Japan and China, and it would be worthwhile testing these in additional locations where kiwifruit is grown commercially, such as Italy.

After fruit set, the timing of sprays (mineral oil only) is largely governed by the need to avoid phytotoxicity. However, monitoring during summer and autumn with pheromone traps or sticky bands would provide valuable information regarding the relative abundance of WPS, and inform decisions around the need for summer oil sprays, as well as postharvest and/or dormant season sprays.

3.1.2 Chemical control

A number of products listed in the current Zespri Crop Protection Standard have proven efficacy against WPS (Table 7).

Unlike other kiwifruit-growing countries in the world, New Zealand has the advantage of being able to use the highly effective scalicide, spirotetramat (Movento® 100SC). This product can only be applied pre-blossom (October–November), which is coincidentally the optimal timing for sprays against first generation WPS (Figure 11). Targeting scale insects with a postharvest Movento spray is currently being investigated for use in orchards with heavily infested kiwifruit vines; this practice may also contribute to control of WPS.

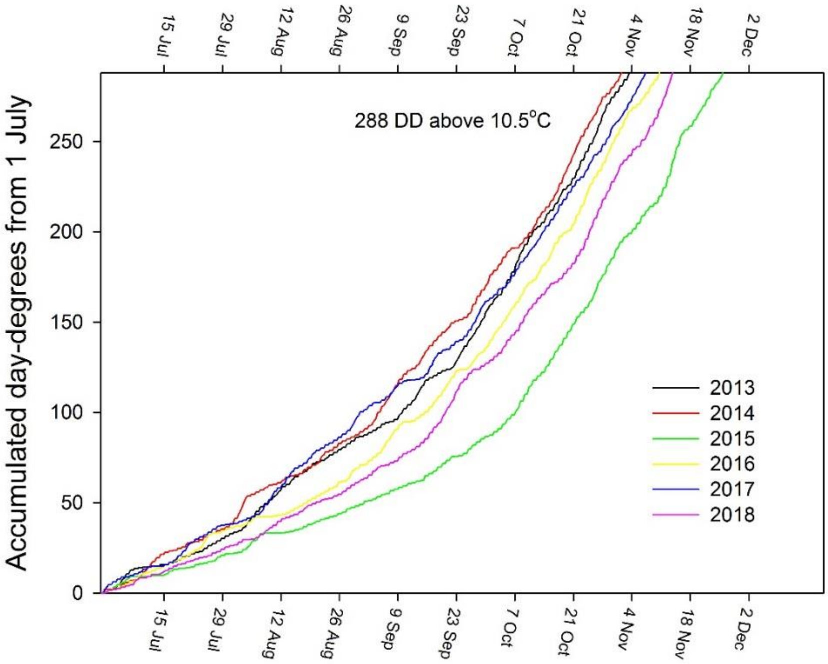

Figure 11. Accumulation of day-degrees above a threshold of 10.5°C from 1 July until the time of peak white peach scale crawler emergence at 288 day-degrees according to the model of Takeda (2004). Temperature data are from the Te Puke Research Orchard weather station. Dates of expected peak crawler emergence vary from as early as 29 October (2014) to as late as 21 November (2015).

After fruit set, mineral oil sprays can be applied against scale insects on kiwifruit vines in New Zealand. These sprays have the potential to reduce the size of the second (and third) generations of WPS, but to what is extent is largely unknown as oil sprays are generally restricted to the dormant or pre-blossom period in other kiwifruit-producing countries. In recent years, organic growers have been using dormant and pre-blossom oil sprays to help manage scale insects on both ‘Hayward’ and ‘Zesy002’ Gold3 vines, but questions remain over the optimal timing of these sprays in terms of plant safety. Further investigations are warranted as these winter/spring oil sprays may be of great importance should European countries enforce maximum residue limits.

Mineral oil is a contact insecticide and maximising spray coverage is of high importance. Current recommendations on sprayer calibration including nozzle choice, water volumes, and changing the direction of travel between applications will be relevant to achieving control of WPS. Many growers are using under-vine shelter cloths. These cloths often serve as a barrier to prevent sprays reaching the trunk or leader. To prevent the build-up of scale on the bark, cloths should be dropped before spraying to fully expose the vine trunk and leaders.

In the long term, entomopathogens may offer an additional tool for use against WPS. The infection process of armoured scale insects by *F. coccophiulum* has been identified and this species is currently being developed as biopesticide for use against armoured scale insects.

3.1.3 Cultural control

While chemical control is likely to be central to the management of WPS in New Zealand kiwifruit orchards, a number of cultural control techniques will be important in preventing the build-up of WPS populations on the vines.

Management of scale insects on young vines is often ignored until the vines start cropping. Allowing populations of scale insects to build up on young vines can cause ongoing issues. Both the spray guards used to protect young vines, and the tape used to help train young vines both create an environment conducive to scale-insect survival. Spray guards should be lifted at once or twice a year to allow treatment of the trunk with insecticides. Similarly, as soon as the leaders have been established, tapes should be removed to ensure good spray coverage of the bark.

On occasion only a few vines may have heavy scale infestations. In these circumstances mechanical removal by hand-gunning the trunks and leaders with water in winter, or brushing the wood may provide long-term benefits that outweigh the additional short-term costs.

Large, woody crowns have developed on many older vines in New Zealand. These crowns are often a significant source of scale insects as the insects are largely protected from spray applications, and ongoing crown removal will continue to be important.

The most important alternative hosts of scale insects in kiwifruit orchards are the trees used in shelter belts. The most common shelter species used are *Casuarina*, *Cryptomeria* and *Leylandii cypress*, none of which has been reported as hosts of WPS. *Poplar* spp. and *Salix* spp. shelters are (fortunately) less common; both species are hosts of WPS. Neighbouring crops such as avocado and citrus are not likely to be of major concern as reservoirs, however Chinese privet (*Ligustrum sinense*), a widespread weedy species present near orchard blocks, is a preferred host and could be removed**.**

3.1.4 Biological control

Whilst biocontrol of WPS is considered important in many European countries, its role in New Zealand is likely to be of less significance, at least in the short to medium term. There is no evidence to suggest biocontrol could provide the degree of control required to meet the phytosanitary and/or quality standards of importing countries. Augmentative biocontrol of WPS may have a role, especially in summer when few sprays are available, but because key parasitoids of WPS are not present in New Zealand, this would require a long-term research effort to identify the best candidate for a classical control programme.

3.1.5 Host plant resistance

It is possible that differential resistance may be expressed for WPS within *Actinidia* germplasm. A long-term research effort would be required to phenotype for resistance and to understand the genetic basis of resistance for this polyphagous insect.

3.1.6 Summary

Table 7 summarises the potential tools and techniques that could be included in a management programme for WPS in New Zealand kiwifruit orchards.

Appropriately timed insecticide applications, as determined by monitoring, will be central to the programme but cultural control techniques to improve spray coverage will also be important. To this end it would be useful to test spray forecasting models developed in Asia in additional kiwifruit-growing locations. The optimal timing of dormant season and pre-blossom oil sprays in terms of plant safety also needs to be confirmed.

Fumigation of harvested fruit with methyl bromide is an effective treatment against WPS on kiwifruit that could be used in the short term to meet the phytosanitary standards of importing countries. However, the proposed methyl bromide phase-out means alternatives such as irradiation would be required in the medium to long-term.

Table 7. A potential management plan for white peach scale WPS, (*Pseudaulacaspis pentagona*) in kiwifruit (based on methods currently available). Techniques marked with an asterisk (*) would be not be suitable for use in organic orchards.

Period	Method	Active Ingredient	Product name (available in New Zealand)	Allowed in CPP	Adverse impact risk	Comments
Dormancy	Mineral oil applied to vines	Mineral oil	Excel® Organic Oil D-C Tron® Plus Oil EnSpray 99® Organic JMS Stylet-Oil® Sinclairs Summer Spray Oil	Yes	Potential phytotoxicity	Apply at 1%, water volume 1000 L/ha. Hand gun heavily infested vines Optimal timing requires clarification
	Insecticides applied to vines*	Bifenthrin	Talstar®100 EC + plus Engulf® Venom®	Yes	Moderate	May require specialised nozzles. Target vine trunk and leader
	Primary host plant removal followed by *herbicide application	Herbicide	See Zespri Crop Protection Standard	Yes	Low	Willow, poplar and privet are preferred hosts of WPS
	Removal of large crowns on vines	NA	NA	Yes	None	Remove one large crown per vine each winter
	Mechanical removal of WPS from the bark of heavily infested vines	NA	NA	NA	None	Hand-gunning with water or brushing, can be useful if a few vines only are infested
	Remove spray guards and vine tape if no longer required	NA	NA	Yes	None	Scales insects congregate behind spray guards and tape on young vines
Bud Phase	Monitoring with pherotraps or sticky bands	(Z)-3, 9-dimethyl-6-isopropenyil-3, 9-decadient -1-ol propionate	NA	Yes (sticky bands)	Low	Use monitoring results to optimise spray timing Pherotrap lures will need to be imported
	Mineral oil applied to vines	Mineral oil	Excel Organic Oil D-C Tron Plus Oil Enspray 99 Organic JMS Stylet-Oil Sinclairs Summer Spray Oil	Yes	Potential phytotoxicity	Apply at 1%, water volume 1000 L/ha Lift spray guards on young vines before spraying

Period	Method	Active Ingredient	Product name (available in New Zealand)	Allowed in CPP	Adverse impact risk	Comments
	Insecticides applied to vines*	Bifenthrin Spirotetramat Thiacloprid	Talstar 100 EC Venom Movento® 100 SC Alpasso®, Calypso®, Commend®, Topstar®	Yes	Moderate to high	Lift spray guards on young vines before spraying
	Shelter management with insecticides*	Spirotetramat	Movento 100 SC	JA may be required	Moderate	Poplar or willow only, consider replacing with artificial or a non-host shelter species
Fruit-set to monitoring	Mineral oil applied to vines	Mineral oil	Excel Organic Oil D-C Tron Plus Oil Enspray 99 Organic JMS Stylet-Oil Sinclairs Summer Spray Oil	Yes	Potential phytotoxicity	Apply at 1%, water volume 2000 L/ha within 14 days fruit set. Possible phase out
	Male pruning	NA	NA	Yes	None	Maintain open canopy, to aid air movement and reduce humidity
Monitoring	Monitoring with pherotraps or sticky bands	(Z)-3, 9-dimethyl-6-isopropeniyl-3, 9-decadient -1-ol propionate	NA	Yes (sticky bands)	None	Use monitoring results to determine need for, and timing of sprays Pherotrap lures will need to be imported
	Mineral oil applied to vines	Mineral oil	Excel Organic Oil D-C Tron Plus Oil Enspray 99 Organic JMS Stylet-Oil Sinclairs Summer Spray Oil	Yes	Potential phytotoxicity	Apply at 1%, water volume 2000 L/ha. Possible phase out.
Postharvest	Mineral oil applied to vines	Mineral oil	Excel Organic Oil D-C Tron Plus Oil Enspray 99 Organic JMS Stylet-Oil Sinclairs Summer Spray Oil	JA may be required	Potential phytotoxicity	Apply at 1%, water volume 2000 L/ha. Optimal timing and potential impact requires clarification.

Period	Method	Active Ingredient	Product name (available in New Zealand)	Allowed in CPP	Adverse impact risk	Comments
	Insecticides applied to the vine*	Spirotetramat	Movento 100 SC	JA may be required	Moderate	Apply with Du-Wett. Water volume 2000 L/ha
	Fumigation of packed fruit*	Methyl bromide	NA	No	High	Possible phase-out Consumer acceptability Possible fruit damage

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