INDUSTRY BIOSECURITY PLAN

FOR THE POTATO INDUSTRY

Threat Specific Contingency Plan

Zebra chip complex

Specific components detailed in this plan:

Psyllid vector – *Bactericera cockerelli*

Pathogen - *Candidatus* Liberibacter solanacearum

(syn. *Ca.* L. psyllaurous)

Plant Health Australia

The contents of this contingency plan is current as of November 2011

Disclaimer

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1 Purpose and background of this contingency plan

This contingency plan provides background information on the pest biology and available control measures to assist with preparedness for an incursion into Australia of the Zebra chip pathogen (*Candidatus* Liberibacter solanacearum; syn. *Ca.* L. solanacearum) and its psyllid vector (*Bactericera cockerelli)*, both of which collectively make up the zebra chip complex.

In this contingency plan factors that are considered of greatest economic impact and risk to the potato industry are outlined and information provided in this document is current as of November 2011. The contingency plan provides guidelines and options for steps to be undertaken or considered when developing a Response Plan to the psyllid and/or the pathogen.

The contingency plan was developed to provide an overview of Australia's potato industry preparedness for an incursion of the Zebra chip complex (psyllid and/or pathogens). The information for this plan has been primarily obtained from documents as cited in the reference section and the draft diagnostic protocols[1] developed for the Tomato-potato psyllid (*Bactericera cockerelli*) (Yen and Burckhardt 2010) and *Candidatus* Liberibacter solanacearum (syn. *Ca.* L. solanacearum) (Constable 2010).

For each component of the Zebra chip complex, information on background, life cycle, host range, distribution, symptoms, diagnostic and surveillance activities needed to respond to an incursion are provided, as well as possible control measures and management strategies. The emphasis of this document is the management and control of the psyllid vector as this was deemed the easiest component to which eradication or management options could be given.

The information contained within this document is designed to:

1. **Aid in an eradication or containment attempt** by providing guidelines for steps to be undertaken or considered when developing a Response Plan to the Zebra chip complex. Any Response Plan developed using information in whole or in part from this contingency plan must follow procedures as set out in PLANTPLAN (Plant Health Australia, 2010) and be endorsed by the National Management Group prior to implementation.
2. **Effectively manage** the pest and minimise the disruption to agricultural industries following entry and establishment, should eradication be deemed not feasible.

2 Australian potato industry

Potatoes are the largest vegetable industry in Australia in terms of production. In 2007/2008 the Australian Bureau of Statistics census indicated that there were 1280 growers producing 1,400,206 tonnes of potatoes from 38,190 hectares of crop.

Approximately 56% of the crop is processed (mainly French fries and crisps), 36% is sold on the fresh market (as potatoes) and 8% used as seed.

Potatoes are grown in all states and at times in the Northern Territory.

[1] To increase Australia's preparedness the Department of Agriculture, Fisheries and Forestry have funded specialised training scholarships for emergency plant pests/disease diagnosticians to gain knowledge and experience for a particular pest. Diagnostic protocols have been developed for the tomato- potato psyllid and *Ca*. Liberibacter solancearum under this scheme.

Table 1. *Potato production within the Australian vegetable sector*

Potatoes	2005/2006	2006/2007	2007/2008
Number of growers	1342	1270	1280
Area planted (hectares)	35,268	34,096	38,190
Production (tonnes)	1,249,605	1,211,988	1,400,206
Yield (tonnes/ha)	35.4	35.5	36.7
Gross value ($m)	463.5	514.4	689.0
Gross unit value ($/tonne)	371	424	492
Farm gate value ($m)	406.0	460.3	619.2

2.1 Notification process for the reporting of suspect pests

Early detection and reporting may prevent or minimise the long-term impact of an incursion into Australia of the Zebra chip pathogen (*Ca.* Liberibacter solanacearum) and its psyllid vector (*B. cockerelli*).

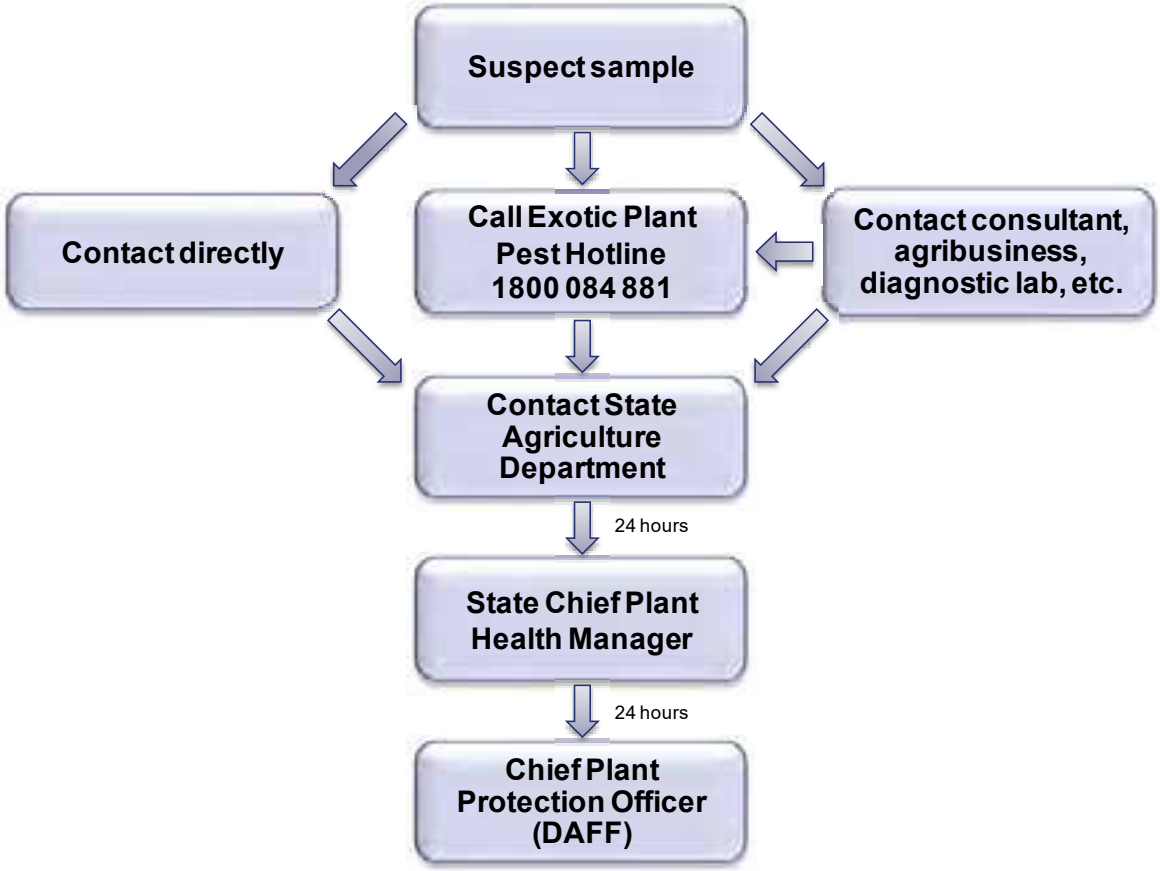

Figure 1. *Notification process for the reporting of suspect pests*

3 Eradication or containment decision matrix

The decision to eradicate should be based on the potential economic impact of host damage resulting from the Tomato-potato psyllid and/or Liberibacter pathogen infestation, the cost of eradication and on technical feasibility. Eradication costs must factor in long term surveys to prove the success of the eradication program.

A minimum of three years with no detections of the psyllid and/or the Liberibacter pathogen will be necessary to confirm that no Tomato-potato psyllid transmitted Liberibacter infestations remain before pest free status can be declared.

No specific eradication matrix has been determined for the psyllid transmitted Liberibacter, however, the Consultative Committee for Emergency Plant Pests and the National Management Groups will consider the factors outlined in Table 1 in determining whether to eradicate or contain the pest.

Table 2. *Factors considered in determining whether eradication or alternative action will be taken for an EPP Incident (taken from Appendix 12 of PLANTPLAN)*

Factors favouring eradication	Factors favouring alternative action
• Cost/benefit analysis shows significant economic loss to industry or the community if the organism establishes. • Physical barriers and/or discontinuity of hosts between production districts. • Cost effective control difficult to achieve (e.g. limited availability of protectant or curative treatments). • The generation time, population dynamics and dispersal of the organism favour more restricted spread and distribution. • Pest biocontrol agents not known or recorded in Australia. • Vectors discontinuous and can be effectively controlled. • Outbreak(s) few and confined. • Trace back information indicates few opportunities for secondary spread. • Weather records show unfavourable conditions for pest development. • Ease of access to outbreak site and location of alternate hosts.	• Cost/benefit analysis shows relatively low economic or environmental impact if the organism establishes. • Major areas of continuous production of host plants. • Cost effective control strategies available. • Short generation times, potential for rapid population growth and long distance dispersal lead to rapid establishment and spread. • Widespread populations of known pest biocontrol agents present in Australia. • Vectors unknown, continuous or difficult to control. • Outbreaks numerous and widely dispersed. • Trace back information indicates extensive opportunities for secondary spread. • Weather records show optimum conditions for pest development. • Terrain difficult and/or problems accessing and locating host plants.

4 Pest information/status – Zebra chip complex

4.1 Pest details

The potato disease zebra chip complex (spread by the tomato-potato psyllid) has caused widespread destruction in both New Zealand and the United States costing the international potato industry millions of dollars. It has been reported that the psyllid alone caused losses to New Zealand producers of $43 million in 2008/2009.

Historically, infestations of Tomato-potato psyllid (*Bactericera cockerelli)* in North America were associated with outbreaks of the physiological disorder Psyllid yellows caused in response to psyllid feeding (Wallis 1951).

More recently (since the mid-1990s to early 2000s) the psyllid has been associated with the Zebra chip disorder which has become a problem for potato growers in Central America (Secor and Rivera-Varas 2004) and the southern United States (Munyaneza *et al.,* 2007). The Zebra chip disorder reduces both potato yield and quality with some incursions so severe that entire potato paddocks have been abandoned (Munyaneza *et al.,* 2007).

The Tomato-potato psyllid is considered the main vector of Zebra chip but there is still some confusion in the literature over the identity of the newly discovered pathogen namely '*Candidatus* Liberibacter psyllaurous' (Hansen *et al.,* 2008) or '*Ca.* L. solanacearum' (Liefting *et al.,* 2008). In recent publications Hansen *et al.,* (2008) conclude "*Ca.* L. psyllaurous" causes the Psyllid yellows in solanaceous crops and Zebra chip in potato tubers whilst Sengoda *et al.,* (2009) report Zebra chip as being caused by "*Ca.* L. psyllaurous" but those Psyllid yellow symptoms on potatoes were caused by *B. cockerelli* not carrying the bacterium.

Within this contingency plan, the name "*Ca.* L. solanacearum" has been used to refer to the disease causing agent on the Zebra chip complex.

5 Pest information/status – Tomato-potato psyllid

5.1 Pest details

Common names:	Tomato-potato psyllid
Scientific name:	*Bactericera cockerelli* (Sulc, 1909)
Synonyms:	*Trioza cockerelli* (Sulc); *Paratrioza cockerelli* (Sulc)
Taxonomic position:	Kingdom, Animalia; Phylum, Arthropoda; Class, Insecta; Order, Hemiptera; Family, Triozidae

5.1.1 Background

The Tomato-potato psyllid *(Bactericera cockerelli*) was first recorded in New Zealand in 2006 (Gill 2006) and continues to spread throughout the country. It was initially believed to be a pest of solanaceous greenhouse crops but has more recently been shown to have major impacts on outdoor tomatoes and potatoes.

The psyllid is thought to have originated in North America where both a native and an invasive biotype are reported (Liu *et al.,* 2006). It is believed that the native species overwinters in Mexico and Texas, migrating in spring to northern regions (Wallis 1955). Historically psyllid infestations have been associated with outbreaks of Psyllid yellows (Davidson *et al.,* 2008) whilst since the mid 1990s potato psyllid has been associated with the Zebra chip disorder, a major problem for potato growers in Central America, Mexico and the United States (Munyaneza *et al.,* 2007) that severely reduces potato yield and quality.

The Tomato-potato psyllid is a small winged insect about 3 mm long that resembles a miniature cicada. It belongs to the family Triozidae (Burckhardt and Lauterer 1997).

Figure 2. *Bactericera cockerelli, adult image lateral view (source: Whitney Cranshaw, Colorado State University, Bugwood.org)*

Adults and nymphs feed on the foliage by sucking plant juices, with the nymphs causing more serious damage. The psyllid uses its piercing mouth parts to extract plant juices from foliage. Excess sugar ingested by the insect is excreted as small waxy beads of psyllid sugar (Lazaneo 2005). When the toxin is present it affects growth of the plant parts and causes a symptom called 'Psyllid yellows' (see section 6.1.1.2).

The symptoms of Psyllid yellows and Zebra chip are very similar. In potato plants the common symptoms include yellow, red or purple shoots and curled and leathery leaves. Over time, enlarged nodes produce clusters of abnormally shaped leaves or small aerial tubers. Potato purple top is another disease with similar symptoms (Munyaneza *et al.,* 2007).

Psyllids have been found on more than 160 plant species, with 46 species recorded as having all three life stages (eggs, nymphs and adults) present in the field, suggesting these plant species are potential breeding hosts (Pletsch 1947; Davidson *et al.,* 2008). Most (42) of the host species belong to the Solanaceae family, with 3 Convolvulaceae species and possibly 1 Labiatae (formally Menthaceae) species. It has also been shown that the psyllid may breed on a particular host in one country but not in another, due possibly to genetic inferences in either the host plant or the psyllid. Using *Solanum nigrum* as an example, *B. cockerelli* breeds on this host in the USA but not in New Zealand (Martin 2008). As well as hosts of economic importance including tomato, potato, capsicum, sweet potato and eggplant, some ornamentals and weeds have also been shown to be hosts (Davidson *et al.,* 2008).

5.1.2 Life cycle

All psyllid species have 6 immature life history stages (eggs and five nymphal instars) before the adult stage.

Eggs are oviposited on fresh plant tissues and are embedded by a fine filament. Eggs are oval shaped and yellow and attached to the leaf by a stalk. They are laid on both leaf surfaces and new shoots. Eggs are more prominent on leaf margins and will hatch in six to 10 days. Most (70-80%) eggs, nymphs and adults are found on the underside and middle of the leaf (Clayton-Green pers. comm.).

Figure 3. *Adult psyllids, eggs and nymphs on the underside of a leaf. Note the characteristic white band on the adults and also the position and shape of eggs. (source: Whitney Cranshaw, Colorado State University, Bugwood.org)*

Nymphs are wingless and develop into winged adults. Nymphs are the damaging form of the insect. The nymphs are 2 mm long and usually found on the undersides of leaves. The nymphs are either naked without a waxy or sugary covering or found inside galls. They look like a small scale insect and under magnification a fringe of spines are visible around the edge of the nymphs' bodies. Newly hatched nymphs are yellowish but become progressively greener as they develop. The immature nymphs go through five instars in as little as 13 days. The larger nymphs have wing buds, a feature distinguishing them from whitefly nymphs. Nymphs excrete a waxy sugar-like white granular substance that will cover leaves during heavy infestations. The nymph stage lasts between 14 and 22 days. Unlike whitefly nymphs that move readily with prodding, psyllid nymphs seldom move (Clayton-Green pers. comm.).

The adult is a small insect (3 mm long) and like most psyllids have white markings on its back in front of the clear wings (thorax). Lines on its abdomen (located beneath the wings) separate the abdominal segments. Adult psyllids change colour as they age from light yellow/brown (immediately after emergence) to grey/black after 5 days. Mature adults have white stripes across the abdomen. The adults are agile and "jump" easily when disturbed (see section 5.3 for key diagnostic features).

The development stage from eggs to adults for *B. cockerelli* is temperature related and may be affected by the host plant species. From the literature, the life cycle of the psyllid from egg to adult varies from 15 to 30 days with up to seven overlapping generations per year recorded in the United States on potato crops (Pletsch 1947). In the laboratory, life cycles can be completed after 29 days at 26^{o}C and 33 days at 18^{o}C (Davidson *et al.,* 2008). In greenhouses development and survival can occur from between 15.5°C and 32.2°C with optimum development occurring at 26.6°C.

Psyllid adults can also mate more than once, with the first mating usually occurring only 2-3 days after emergence. Over their lifetime females can lay up to 510 eggs over a period of about 21 days (Biosecurity Australia 2009; MAF NZ). The literature has also shown that adult longevity and female fecundity are dependent on the host plant (Pletsch 1947).

5.1.3 Dispersal

In New Zealand the psyllid was first detected in Auckland (North Island) in 2006 and has since spread more widely across New Zealand. As psyllid populations are present in high numbers and now widespread across New Zealand, it is believed that psyllids were present for a number of years prior to their initial detection in 2006. Adult psyllids mode of short distance dispersal is jumping hence they are (commonly referred to as "jumping plant lice" which they can mix with limited flight. Wind and thermal currents are their main mode of long distance dispersal (A. Yen pers. comm.).

Although the adults are highly mobile and jump readily when disturbed, they generally rely on wind for dispersal over large distances.

5.2 Affected hosts of *B. cockerelli*

5.2.1 Host range

The psyllid adult is reported to have a host range that encompasses 20 families, however many of these records appear to involve transient movement of psyllids on plants. A host plant species for *B. cockerelli* is therefore best defined as a plant species that the psyllid oviposts on and the nymphs develop through to adults. In New Zealand the complete psyllid lifecycle has only been found on three families, primarily in the Solanaceae family. Solanaceous species (capsicum,

eggplant, potatoes, tomatoes, tamarillos and black night shade) are the preferred hosts. It has also been found on species of Convolvulaceae, including kumara (sweet potato) when high psyllid populations are nearby, and on Lamiaceae under greenhouse conditions (Table 2). A list of the known hosts of tomato-potato psyllid (Biosecurity Australia 2009) is presented in Appendix 1. From a recent visit to New Zealand in September 2010, Trumble (University of California) reported the psyllid on solanaceous weeds and non-solanaceous spp in New Zealand including lettuce, peas, beans, radish, sunflower, violets and spruce. If *Solanum laciniatum* is included there are 64 known host plant species, 36 of which are known to occur in Australia. To further complicate the issue of host plants, it is been reported that the psyllid may breed on a particular plant species in one country but not in another country, presumably due to genetic differences in either the host plant or psyllid. *B. cockereilli* breeds on *Solanum nigrum* in the USA but not in New Zealand (Martin 2008).

Refer to Appendix 1 for a comprehensive list of all known hosts of the psyllid.

Table 3. *Psyllid preferred host list*

Major hosts	Potatoes, tomatoes
Minor hosts	Capsicums, eggplants, peppers and other solanaceous crops
Weed hosts	Pororo, thorn apple, apple of peru

5.2.2 Current geographic distribution

The distribution of Tomato-potato psyllid includes Arizona, California, Colorado, Idaho, Kansas, Minnesota, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah and Wyoming, in the USA (Blood *et al.,* 1933; Pletsch 1947; Carter 1954; Ferguson *et al.,* 2003). It has been reported in Canada in Alberta, British Columbia, Ontario, Quebec and Saskatchewan (Ferguson *et al.,* 2003), in Mexico in Durango, Tamaulipas, Michoacán, Mexico City and Rio Frio (Pletsch 1947; Cranshaw 1993) and an unconfirmed report that has found it in Guatemala and Honduras (Secor *et al.,* 2009). Two psyllid biotypes have been identified; a native biotype that overwinters in Mexico and Texas and migrates north to Colorado, Montana, Nebraska and southern Canada in spring and summer, and an invasive biotype that is active in California and Mexico (Liu *et al.,* 2006). The psyllid was detected in the Auckland region of New Zealand in 2006, with subsequent surveys finding it throughout the North island and South island (MAFBNZ 2008: Davidson *et al.,* 2008; EPPO RS 2009/089).

B. cockerelli is not known to occur in Australia.

5.2.3 Symptoms

Psyllids are found on the foliage of plants and are described as sap-sucking insects that feed through stylet mouthparts (like Hemiptera). They insert stylets into the plant, suck the sap and excrete the excess water and sugar as honey dew or as a solid waste of small white waxy beads (psyllid sugar). When searching for psyllids the first symptom that you are most likely to see on plant leaf is psyllid sugar. Nymphs and possibly adults inject a toxin into the plants when they feed.

The Psyllid yellow symptoms caused by injection of toxic saliva into the plants are generally similar on potato and tomato plants.

The first symptom is discoloration (yellowing or purpling) along the midribs and the edge of the leaves. The basal portions of the leaves tend to curl upwards. Over time the entire plant top

changes to yellowish-green or purple-red. The leaves are small and narrow tending to remain upright with a feathery appearance.

Figure 4. *Tomato foliage showing effects of psyllid feeding. Note the yellowing, cupping and narrowing of leaves and also the distinct purple hue in the tomato plants. (source: Dr Kevin Clayton-Greene)*

Figure 5. *A potato plant infected with Liberibacter. Note the erect stem 'flag' which is typical and often a distinguishing feature from other diseases such as blackleg or Verticillium where the stem lies on the ground. (source: Frank Mulcahy)*

In tomatoes, when the plants are young and psyllid attack is severe, little or no fruit is set. Late attack results in production of small fruit and poor quality fruit. In potatoes, if the attack occurs before tuber set numerous tubers on each stolon are often formed. An attack after tubers are partially developed results in greatly reduced growth and irregularly shaped potatoes. Potatoes from infested plants may also sprout prematurely and even underground before harvest.

5.3 Diagnostic information

A draft "Diagnostic protocol for the detection of the potato and tomato psyllid, *Bactericera cockerelli* (and *B. trigonica*)" has been prepared by Yen and Burckhardt (2010). In Australia, the current protocol for *B. cockerelli* can be found on the PaDIL website (Walker 2007).

Morphological identification of psyllids

From the literature there are numerous US and New Zealand information sheets that contain images of egg, selected nymphal stages, and adults, but none of these have adequate detail for accurate differentiation of this species from Australian species. Accurate identifications rely on adult morphology, generally of the male genitalia. Psyllid nymphs are not well characterised for most species. For further information on morphological identification of the *B. cockerelli* psyllid refer to the draft protocol of Yen and Burckhardt (2010).

Molecular diagnostic tests for adults and nymphs

Even though molecular diagnostic tests have been used to differentiate two biotypes of *B. cockerelli* (Liu *et al.,* 2006), adult morphological identification has been adequate when required. Outside of North and Central America, *B. cockerelli* has only been found in New Zealand, and as the only *Bactericera* found there it is also distinct from native psyllid species. This same uniqueness would apply to Australia.

A molecular diagnostic test would not be required for adults of *B. cockerelli* in Australia because adults can be differentiated from other Australian psyllid species on the basis of morphological characters. The nymphs of *Acizzia* and *Bactericera* are quite different and can be distinguished on morphological characters (Yen and Burckhardt 2010).

5.4 Psyllid transmission

Under natural conditions a number the following psyllids are known to be vectors of "*Candidatus* Liberibacter":

- *Bactericera cockerelli,* Sulc 1909 (Tomato-potato psyllid) vectors "*Candidatus* L. solanacearum" (Hansen *et al.,* 2008)
- *Diaphorina citri,* Kuwayama 1908 (Asian citrus psyllid) vectors "*Ca.* L. americanus" and "*Ca.* L. asiaticus" (Bove 2006; Yamamoto *et al.,* 2006)
- *Trioza erytreae,* Del Guercio, 1918 (African citrus psyllid) vectors "*Ca.* L. africanus" (Bove 2006)
- *Trioza apicales,* Forster vector association with "*Ca.* L. solanacearum" (Munyaneza *et al.,* 2010a)
- *Cacopsylla pyri* vectors "*Ca*. L. europaeus" (Raddadi *et al.,* 2010).

The reason for this vector specificity is not known but the literature does show that the Asian citrus psyllid and its pathogen, and the African citrus psyllid and its pathogen are present in a number of countries, with the *T. erytreae* vectors "*Ca.* L. africanus" at higher altitudes and *D. citri* vectors "*Ca.* L. asiaticus" at lower altitudes in these countries (Bove 2006).

Psyllids acquire "*Candidatus* Liberibacter" species by feeding on infected hosts and are then able to transmit the bacterium to other hosts as they feed and inject saliva (Bove 2006).

Hansen *et al.,* (2008) used PCR screening to study transmission of "*Ca.* L. solanacearum" infection showing that all life stages from eggs to adults were near 100% infected in potato-reared psyllids, though fewer eggs and early instar nymphs were infected on tomato-reared psyllids. Other studies have shown that *B. cockerelli* can readily transmit "*Ca.* L. solanacearum" (Jones *et al.,* 2008a, 2008b).

A more recent study has shown an association between the psyllid *Trioza apicalis,* and *Ca.* L. solanacearum (Munyaneza *et al.,* 2010b). *T. apicalis* is one of the most destructive pests of carrots in Europe causing curling and discolouration of carrot leaves and overall reduction of plant and root growths. *T. apicalis* and *B. cockerelli* are two geographically distinct psyllids with different host plants but both can harbour the same species of Liberibacter.

6 Pest information/status – Zebra chip

6.1 Pest details

Common names:	Zebra chip
Scientific name:	*"Candidatus* Liberibacter solanacearum"
Synonyms:	"*Candidatus* Liberibacter psyllaurous"
Taxonomic position:	Bacteria, Proteobacteria, Alphaproteobacteria, Rhizobiales, Rhizobiaceae,

6.1.1 Background

Information on Zebra chip has been thoroughly reviewed by Constable (2010) and summarised in the following sections.

There are a number of diseases associated with "*Candidatus* Liberibacter solanacearum" including Zebra chip in potatoes, Psyllid yellows in potatoes, Psyllid yellows in tomatoes and *Capsicum annuum*, dieback in tamarillo, and leaf curl and secondary root proliferation symptoms in carrots. The bacterium infects Cape gooseberry but an associated disease has not been reported. Symptomless infections may also occur in some other solanaceous hosts such as silverleaf nightshade and wolfberry (Wen *et al.,* 2009).

"*Ca*. L. solanacearum" and the associated diseases have been successfully transmitted to potatoes and tomatoes by grafting infected material onto unaffected plants (Crosslin and Munyaneza 2009; Secor *et al.,* 2009). The bacterium and disease has also been successfully transmitted to healthy plants by *B. cockerelli* (Hansen *et al.,* 2008; Secor *et al.,* 2009). These experiments provide further evidence for an association between the bacterium and the disease.

6.1.1.1 ZEBRA CHIP IN POTATOES`

Zebra chip disease in potato was first reported in Mexico in 1994 and since reported in the United States, Guatemala, Honduras and New Zealand. Zebra chip was first reported in the United States in 2000 causing widespread losses in 2004-2006 to both potato producers and processors (Munyaneza *et al.,* 2007). Because the association of the potato psyllid with Zebra chip was only made within the past few years limited information is available on factors affecting spread and occurrence.

Zebra chip is a significant problem for the processing potato industry in the United States causing serious economic damage in the regions where it is found. The characteristic symptoms of Zebra chip are a striped pattern of discolouration in cross-sections of potato tubers seen after frying. These dark streaks, flecks or spots in tubers are due to the presence of sugars in the tuber. When infected potatoes are fried the necrosis becomes more prominent, resulting in chips with a burnt appearance and taste, making them unsaleable (Munyaneza *et al.,* 2007). There may also be significant yield loss, with affected tubers having 13% less dry matter than unaffected potatoes (Munyaneza *et al.,* 2007; Liefting *et al.,* 2008a).

Figure 6. *Characteristic striped discolouration in potato tubers caused by Zebra chip (source: Constable 2010)*

Symptoms in the aerial parts of Zebra chip affected potato plants include; yellowing or purpling of potato leaves and shoots, interveinal chlorosis, vein-greening and downward curling of leaves. Other symptoms that may be evident are; stunted shoots and thickening of internodes, scorched potato tops, formation of aerial tubers or early senescence (Liefting *et al.,* 2008a&b; Hansen *et al.,* 2008; Li *et al.,* 2009; Rehman *et al.,* 2010).

Figure 7. *Shoots of a "zebra chip" affected potato plant that was also infected with Candidatus Liberibacter solanacearum. Leaves are chlorotic, curled and rolled. Leaves on younger shoots display mild purpling. The shoots are stunted and swollen (arrows) and swelling is occurring at the nodes. (Image from Constable 2010 [courtesy of Dr L. Liefting, Ministry of Agriculture and Forestry, New Zealand]).*

Figure 8. *Aerial tuber formation on "zebra chip" affected potato plant that was also infected with Candidatus Liberibacter solanacearum. (Images from Constable 2010 [courtesy of Dr L. Liefting, Ministry of Agriculture and Forestry, New Zealand]).*

Studies in the United States have shown that the Tomato-potato psyllid can vector the Liberibacter solanacearum into potatoes and tomatoes causing Psyllid yellows type symptoms (Hansen *et al.,* 2008).

6.1.1.2 PSYLLID YELLOWS IN POTATOES

Psyllid yellows disorder was observed in the USA in 1927 (Richards, 1928) with the disorder first attributed to a physiological reaction to secretions injected by the psyllid during feeding (Richards and Blood 1933). Psyllid yellows were thought to be caused by the saliva of *B. cockerelli* (Hansen *et al.,* 2008). The factor in the saliva that cause the physiological disorder psyllid yellows was thought to be a toxin produced by the psyllid (Blood *et al.,* 1933, Richards and Blood 1933).

Psyllid yellows is associated with feeding of the tomato potato psyllid (Sengoda *et al.,* 2010). The first symptoms of Psyllid yellows have been observed within 3 days of feeding with complete symptoms not appearing until the nymphs have fed continuously for 36 days (Carter 1939). Psyllid yellows symptoms vary between solanaceous plants with symptoms on potatoes and tomatoes more apparent than with capsicum. Psyllid yellows have been found to develop on all early potato cultivars, however symptoms vary with cultivar (Pletsch 1947).

It was suggested that zebra chip and psyllid yellows diseases could be differentiated on the basis of symptomatology because psyllid yellows affected plants do not exhibit the tuber symptoms and survive longer than zebra chip affected plants (Sengoda *et al.,* 2010). However the bacterium is not necessarily evenly distributed throughout a plant and it is possible that not all tubers of infected plants are affected (Wen *et al.,* 2009; Pierson *et al.,* 2011). Timing of infection may also play an important role in the effect of the bacteria on tubers and some tubers may only display mild symptoms of disease. It is possible that there is a difference in symptom expression between varieties and some varieties may take longer to express some or all of the symptoms (Pierson *et al.,* 2011). Temperature also affects bacterial titre and symptom expression (Munyaneza *et al.,* 2011; Workneh *et al.,* 2011).

Psyllid yellows symptoms vary in severity and can be influenced by host, cultivar, temperature and growing conditions (glasshouse or field grown, soil moisture and nutrients) (Liefting *et al.,* 2009c) and reports in New Zealand suggest that "*Ca.* L. solanacearum" infected plants may be asymptomatic (MAFBNZ 2008).

6.1.1.3 POTATO PURPLE TOP AND PHYTOPLASMAS

To further complicate the Zebra chip story, researchers in the United States thought Psyllid yellows/ Zebra chip may be caused by phytoplasmas as symptoms appear similar to those of Potato purple top wilt syndrome which is caused by the Columbia Basin potato purple top phytoplasma (Secor *et al.,* 2006). *Ca*. Phytoplasma australiense has been found in potato plants with some of the aerial symptoms associated with purple top and Zebra chip (Leifting *et al.,* 2009c).

These other diseases include Haywire disease, Potato purple top, or Potato purple top wilt and Stolbur disease (Lee *et al.,* 2006; Lee *et al.,* 2009) with symptoms of stunting, leaf curl, chlorosis, purpling of the apical leaves, as well as scattered light brown discolouration of tubers which are enhanced when tuber tissue is fried (Munyaneza *et al.,* 2009). Phytoplasmas have previously been reported in Australia in potatoes with purple top symptoms (Harding and Teakle 1985) but tuber symptoms were not reported. Tomato big bud phytoplasma is most frequently detected (F. Constable pers. comm.).

6.1.1.4 PSYLLID YELLOWS IN TOMATOES AND CAPSICUM ANNUM

Psyllid yellows symptoms result from the feeding of psyllids. From the early literature, tomatoes and *Capsicum annuum* (peppers and chilli) were known to be affected by Psyllid yellows with no additional evidence supporting the presence of the pathogen.

More recently *Ca.* L. solanacearum was also reported in New Zealand on greenhouse tomatoes and capsicum with Psyllid yellows symptoms and confirmed in 14 commercial tomato and capsicum greenhouse sites in parts of New Zealand (Davidson *et al.,* 2008), Mexico and the United States (Wen *et al.,* 2009; French-Monar *et al.,* 2010) causing loss of quality and yield (Liefting *et al.,* 2009b).

On tomatoes these symptoms include stunted plants with apical spiky chlorotic growth, mottled or chlorotic leaves and for some varieties vein greening or purpling and a lack of fruit (Brown *et al.,* 2010; Liefting *et al.,* 2009c). For peppers and chilli the stems may be shortened, plants are stunted, leaves pale green or chlorotic. Leaves may also be cupped or spiky in appearance as a result of tapering of leaf apices. Severity of disease expression is dependent on cultivar (Liefting *et al.,* 2009c).

Figure 9. *Shoots of yellows affected tomato plants infected with Candidatus Liberibacter solanacearum showing chlorosis of the apical growth (Images from Constable 2010 [courtesy of Dr L. Liefting, Ministry of Agriculture and Forestry, New Zealand]).*

6.1.1.5 CA. L. SOLANACEARUM IN TAMARILLO AND AN ASSOCIATED DISEASE OF CARROTS

Ca. L. solanacearum in tamarillo was first reported in a home garden in plants in New Zealand (Liefting *et al.,* 2009a) with early symptoms showing pink colouration and cupping of new leaves progressing to leaves dropping, dieback of branches with eventual tree death. Disease progression and aerial symptoms are similar to phytophthora but without root rot (Watson 2009).

Figure 10. *Tamarillo tree infected with Candidatus Liberibacter solanacearum. The leaves have interveinal chlorosis, cupping and leaf scorching. Note the pink colouration of the new leaf in the centre of the image. (Image from Constable 2010 [courtesy of C Watson, Tamarillo Growers' Association, New Zealand]).*

The disease in carrots, thought to be caused by the feeding of the Carrot psyllid (*Trioza apicalis*), was first reported in Europe (Nissinen *et al.,* 2007) with *Ca.* L. solanacearum detected in both diseased and asymptomatic carrot plants infested with the psyllid (Munyaneza *et al.,* 2010b). Symptoms include curling and yellowing and/or purpling of leaves, stunted shoot and root growth and production of secondary roots along the primary root with yield losses of up to 100% in psyllid infested crops (Nissinen *et al.,* 2007).

Figure 11. *Purpling, yellowing and curling of carrot leaves associated with psyllid (Trioza apicalis) damage and Candidatus Liberibacter solanacearum. (Image from Constable 2010 [courtesy of Dr J. Munyaneza, USDA-ARS Yakima Agricultural Research Lab, USA, and Dr A. Nissinen, MTT Agrifood Research, Finland]).*

Figure 12. *Carrots with production of secondary roots along the primary root associated with psyllid (Trioza apicalis) damage and Candidatus Liberibacter solanacearum. (Image from Constable 2010 [courtesy of Dr J. Munyaneza, USDA-ARS Yakima Agricultural Research Lab, USA, and Dr A. Nissinen, MTT Agrifood Research, Finland]).*

6.2 Affected hosts of *Ca*. Liberibacter solanacearum

6.2.1 Host range

Table 4. *Zebra chip "Ca. Liberibacter solanacearum" plant hosts*

Known hosts	*Capsicum annuum* L. (pepper and chilli); *Capsicum frutescens* L.; *Physalis peruviana* L.; *Solanum betaceum* (tamarillo); *Solanum tuberosum L.* (potato); *Solanum lycopersicum (*syn *Lycopersicon esculentum*)(tomato)
Minor hosts	*Physalis peruviana* (cape gooseberry, may be a symptomless host)
Wild hosts	Solanaceous weeds include *Solanum ptychanthum* (black nightshade); *S. elaeagnifolium* (silver leaf nightshade) and *Lycium barbarum* (wolfberry)(Wen *et al.,* 2009)

6.2.2 Current geographic distribution

Psyllid yellows and Zebra chip can be found in many states of Northern American including Arizona, California, Colorado, Idaho, Kansas, Nebraska, Nevada, New Mexico, Montana, North Dakota, Texas, Utah and Wyoming, Alberta in Canada, parts of Mexico, Guatemala, Honduras and New Zealand (Munyaneza *et al.,* 2007; Abdullah 2008; MAFBNZ 2008). The bacterium is associated with a disease of carrots in Finland (Munyaneza *et al.,* 2010b).

Symptoms

Potatoes

Foliar symptoms include stunting, chlorosis, yellowing and purpling of potato leaves and shoots, curling or rolling of leaves, swollen nodes causing a zig-zag appearance of the upper growth, proliferated auxiliary buds, aerial tubers and leaf scorching leading to early dieback (Gudmestad and Secor 2007).

Below-ground symptoms include enlarged lenticels of the underground stem, collapsed stolons, brown discolouration of the vascular ring and necrotic flecking of internal tuber tissues (Gudmestad and Secor 2007). In conjunction with tubers being misshapen, smaller tubers and an increase in the number of tubers and shorter stolons may also be seen.

Figure 13. *Foliar scorching and premature tuber sprouting symptoms of psyllid yellows in potatoes (Biosecurity Australia 2009)*

Above ground symptoms of Zebra chip and Psyllid yellows are similar but there may be a difference in symptoms in potato tubers (see paper by Sengoda *et al.,* 2010).

The characteristic symptoms of Zebra chip are a striped pattern of discolouration in fried tuber cross sections (see Figure 5).

Tomato

Symptoms associated with diseased tomato plants include retarded growth, erectness of new growth, chlorosis and purpling of the leaves, stunting of growth for weeks to months, stimulated flower bloom and production of numerous small and poor quality fruit (Al-Jabar 1999). Liefting *et al.,* (2009c) reported greenhouse crops as spiky, with chlorotic apical growth, purpling of the midveins for some cultivars, mottling of leaves, curling of leaves and stunting of the plants with some fruit deformation.

Figure 14. *Symptoms of psyllid yellows in tomato plants (Biosecurity Australia 2009)*

Capsicum

The symptoms on capsicums include stunting, chlorotic pale green leaves, spiky leaf apex resulting in leaf cupping, short internodes and petioles and apical meristem necrosis and/or flower abortion and stunting (Biosecurity Australia 2009) that may vary between cultivars or when plants are grown under field or glasshouse conditions.

Figure 15. *Symptoms of psyllid yellows in capsicum plants (Biosecurity Australia 2009)*

Tamarillo trees and carrots

The symptoms on diseased tamarillo trees include poor bud-break, stunted shoot growth, shoot proliferation, small new leaf shoots, cupping and pink colouration of new leaves, leaf drop, shoot and branch dieback leading to tree death.

Symptoms on diseased carrots include curling and yellowing/purpling of leaves, stunted shoot and root growth, and production of secondary roots along the primary root.

6.3 Diagnostic information

In Australia DPI Knoxfield in Victoria offer services for testing potato material for *Ca.* L. solanacearum and phytoplasmas. In New Zealand three laboratories also offer services for testing potato material for Liberibacter and Phytoplasma. In New Zealand it is currently unclear whether Phytoplasma causes any damage to potato crops or tubers but research underway should clarify this. It has been confirmed that a positive Liberibacter test result indicates that potatoes will probably go on to develop Zebra chip as well as foliage yellowing and dying.

In Australia, a diagnostic protocol has been prepared by Dr Fiona Constable (Victorian Department of Primary Industries): "Diagnostic protocol for the identification and detection of *Candidatus* Liberibacter solanacearum" (syn. *Ca.* L. psyllaurous) as part of a DAFF funded training scholarship. This protocol was prepared in accordance with SPHDS Reference Standard 2.

Diseases associated with *Ca.* L. solanacearum can be identified by the presence of symptoms, however, due to the similarity of *Ca.* L. solanacearum symptoms with other organisms, diagnosis needs to be confirmed through PCR and sequencing of the amplified product.

6.3.1 Methodology

Refer to diagnostic protocol for detailed methodology (Constable 2010). The efficiency test is dependent on appropriate sampling of plant tissue, reliable nucleic acid extraction methods and species-specific primers used in the PCR test.

6.3.2 Sample selection

Ca. L. solanacearum is phloem-limited but may infect the phloem tissue of all parts of a plant including roots, tubers, stolons, trunk, branches, shoots, leaf petioles, leaf veins, fruit peduncles and fruit (Li *et al.,* 2009). Symptomatic tissue is best used in diagnostic tests. Symptomatic potato tubers are most reliable and the stems of symptomatic Zebra chip plants can also be used.

For tomato, tissue from symptomatic shoots should be used. Tissue may include stems, leaf petioles, the peduncles attached to fruit and the portions of affected fruit to which the peduncle is attached (Constable 2010).

If symptomless infections are suspected, thoroughly sample phloem tissue from different aerial and subterranean tissue.

7 Risk assessments for pathways and potential impacts

"*Candidatus* L. solanacearum" and its vector *B. cockerelli* are not present in Australia, but both pests have the potential for establishment of spread and economic consequences in Australia, and therefore they meet the criteria for a quarantine pest. Following a report of their presence in New Zealand Biosecurity Australia undertook a Pest Risk Analysis report for "*Candidatus* Liberibacter solanacearum" in fresh fruit, tubers, nursery stock and its vector the Potato-tomato psyllid (see report prepared by Biosecurity Australia (2009) for full details). Since then recent research in New Zealand has increased our understanding of "*Ca.* L. solanacearum" and its vector *B. cockerelli* which may change the ratings and separate pathways for entry of fruit, potato tubers and nursery stock described in the Pest Risk Analysis report prepared by Biosecurity Australia (2009).

The risk assessments in this section focus on the major pathways identified for the potential introduction "*Ca.* L. solanacearum" associated with Solanaceae crops. Unlike most other pests, the risk of establishment and spread will depend both on the commodity on which it enters Australia and also whether or not the vector is present.

7.1 Tomato-potato psyllid pathway

B. cockerelli is the vector for "*Ca*. L. solanacearum" which causes the diseases Psyllid yellows in solanaceous crops (cape gooseberry, capsicum, chilli, tamarillo, potato and tomato) and Zebra chip in potato chips (Horticulture New Zealand 2008b). There is potential to introduce infected psyllids with importation of fruit or nursery stock.

In summary, the likelihood that "*Ca*. L. solanacearum" could enter on infected Tomato-potato psyllids, be distributed in a viable state to suitable hosts, establish in the pest risk analysis area and then spread throughout Australia is considered **HIGH.**

A summary of these ratings are shown Table 5. Based on this information, Tomato-potato psyllid *Bactericera cockerelli* is considered a **HIGH o**verall risk to Australia.

Further information on each of these ratings is provided in the following sections.

Table 5. *Pest risk ratings for the Tomato-potato psyllid*

Potential or impact	Rating
Entry potential	High
Establishment potential	High
Spread potential	High
Economic impact	High
Overall risk	**High**

7.1.1 Entry potential

Rating: HIGH

The likelihood that Tomato-potato psyllids infected with "*Ca.* L. solanacearum" will arrive in Australia with trade in fresh fruit or nursery stock of host species of the Solanaceae family is **HIGH**.

There are a number of factors contributing to this rating including the psyllids ability to complete its life cycle on all known hosts of "*Ca.* L. solanacearum" (Horticulture New Zealand 2008b) and the risk of propagative material from pathogen affected areas harbouring infected psyllid eggs, nymphs and/or adults. The optimum temperatures for shipping and storing fresh fruit and nursery stock would unlikely affect survival and development of the psyllid (Ferguson *et al.,* 2003) or survival of the pathogen within the eggs, nymphs or adults during post-harvest transport and storage.

The probability that the bacterium having entered Australia in an infected psyllid will be transferred in a viable state to a host plant is **HIGH**. This is based on the potential distribution of imported fruit and nursery stock of host plants within Australia through wholesale and retail sale for consumption or growth in commercial production areas and the wide host range, feeding and breeding of the psyllid on plants in the Solanaceae, Convolulaceae and Lamiaceae families.

It is also highly possible that appropriate wind conditions could transport the psyllid from New Zealand as this is believed to be the source of introduction of Lettuce currant aphid. If infected fruit were to enter Australia without its *B. cockerelli* vector, it is unknown if the two *Acizzia* species that have colonised plants in Australia would be a vector (Kent and Taylor 2010).

The association of the pathogen with its psyllid vector, the ability for infected psyllids to disperse both independently and through the movement of fruit and nursery stock, and the presence of multiple hosts within the pest risk area support the rating of **HIGH** for distribution of "*Ca.* L. solanacearum" in *B. cockerelli.*

7.1.2 Establishment potential

Rating: HIGH

The likelihood that the "*Ca*. L. solanacearum" having entered on infected Tomato-potato psyllids, will establish within Australia, together with the ability of "*Ca*. L. solanacearum" to multiply in infected hosts, especially in perennial species imported as nursery stock supports the rating as **HIGH** for the establishment of "*Ca*. L. solanacearum".

The initial mode of entry (and establishment) of "*Ca*. L. solanacearum" in New Zealand is unknown but the presence of the tomato-potato psyllid only two years prior to the confirmation of the pathogen suggests that it was introduced with the psyllid and able to establish as an undetected founding population (MAFBNZ 2008).

7.1.3 Spread potential

Rating: HIGH

The likelihood that "*Ca*. L. solanacearum" having entered on infected Tomato-potato psyllids will spread within Australia is **HIGH**. The bacterium could spread to new areas through the movement of infected potato tubers, nursery stock or the psyllid. The widespread distribution of hosts of "*Ca*. L. solanacearum" and *B. cockerelli* in many parts of Australia would assist the spread of the pathogen if the pathogen and its vector were established in Australia.

B. cockerelli has spread rapidly across New Zealand and in four years it has colonised most of the North Island and a significant part of the South Island (Teulon *et al.,* 2009). It is not known how much of this dispersal is natural or mediated by human activity.

7.1.4 Economic impact

Rating: HIGH

Historically *Bactericera cockerelli* has been linked to incursions of Psyllid yellows in North America, (Wallis 1955). This was considered to be a physiological response to psyllid secretions released while feeding (Eyer and Crawford 1933; Eyer 1937). Since the mid-1990s, *B. cockerelli* has been associated with the Zebra chip disorder in potatoes in Central America, Mexico (Secor and Rivera-Varas 2004), and the southern states of the United States (Munyaneza *et al.,* 2007).

7.2 Other pathways

New Zealand and Australian scientists are working together to research and understand the Zebra chip complex in laboratory, glasshouse and field based studies in New Zealand. Information gained by this collaboration can assist Australia in its preparedness should either the psyllid and/or the Liberibacter enter Australia.

7.2.1 Fresh fruit

The likelihood of importation into Australia of "*Ca.* L. solanacearum" with the trade in fresh fruits of known hosts including their seeds is **HIGH**. The factors contributing to this rating are the pathway of the pathogen at its origin, presence of asymptomatic fruit and the ability of the pathogen to survive storage. Plant hosts that "*Ca.* L. solanacearum" are known to infect include capsicum, tomato, cape gooseberry, chilli, tamarillo and potato (Liefting *et al.,* 2009c) with the bacterium detected in tomato and capsicum fruit (MAFBNZ 2008).

Symptomatic fruit would be small and likely to be removed during grading. Asymptomatic fruit can contain the bacterium but is unlikely to be culled at harvest or during grading. Standard post-harvest treatments such as washing and brushing the fruit would not remove the bacterium. Laboratory testing has confirmed that the bacterium can be found in the seed (Liefting et al 2008a).

Normal storage conditions are unlikely to have any significant impact on the level of bacteria in tomato or any other imported fruits and with storage conditions kept to a minimum it is unlikely that there will be changes in bacterial viability post harvest and during storage.

Before establishment in Australia the "*Ca*. L. solanacearum" entering on imported fruit would need to find a suitable vector to establish. In addition to the lack of seed and mechanical transmission it is not known if any of the endemic species of psyllid in Australia would be able to vector the bacterium as the only species of Australian Psyllidae or Triozidae known to feed on a solanaceous host is a species of *Acizzia* (Kent 2008).

7.2.2 Potato tubers

Potato tubers for human consumption are also a potential pathway for the introduction of the pathogen. While intentionally imported for human consumption, tubers may be planted or disposed of in the environment leading to the growth of other plants infected by the pathogen. While import

of potato tubers is not currently permitted in Australia, it is understood that New Zealand is seeking access for potato tubers for processing in Australia (Biosecurity Australia 2009).

The likelihood that "*Ca.* L. solanacearum" will arrive in Australia with trade in potato tubers is **HIGH** (Biosecurity Australia 2009). The factors contributing to this rating include the presence of the pathogen in tubers, infected hosts may be asymptomatic and the characteristic Zebra chip symptom is not apparent until after the potato tuber is cooked.

"*Candidatus* L. solanacearum" is known to infect all parts of potato plants (Secor *et al.,* 2009) and may be transmitted through infected seed potato (Henne *et al.,* 2010). Zebra chip, the characteristic symptom, is a striped pattern of discolouration that becomes apparent after the potato tuber is cooked (Secor *et al.,* 2009) and would not be obvious at the time of import. Infected hosts may also be asymptomatic; hence infection may not be obvious at the time of import.

Standard post-harvest treatments would not remove the bacterium and it is unknown what effect storage conditions would have on the bacterium.

The only known vector of "*Ca.* L. solanacearum" is *B. cockerelli* which is not known to be present in Australia. For "*Ca.* L. solanacearum" to be distributed through infected tubers, tubers must be able to grow and produce infected plants. While germination of zebra chip affected tubers may be poor (Lin *et al.,* 2009), there is still a possibility this could occur i.e. for the bacterium to be distributed with the planting or disposal of infected tubers into locations where they could grow, without the aid of its psyllid vector. Hence "*Ca.* L. solanacearum" could also be spread by potato tubers.

7.2.3 Nursery stock

As nursery stock of known hosts can support all life stages of the pest and "*Ca.* L. solanacearum" can be associated with all vegetative parts of plant hosts, nursery stock can provide a pathway for the importation of the bacterium. Importation into Australia of "*Ca.* L. solanacearum" with nursery stock is based on the pathogens association with nursery stock, the ability of infected plants to remain asymptomatic and the bacterium remaining viable during transport and storage.

Of those known hosts of "*Ca.* L. solanacearum", nursery stock of cape gooseberry, potato and tamarillo are permitted into Australia (Biosecurity Australia 2009) and as the bacterium is a newly described pathogen (Hansen *et al.,* 2008) it is likely that additional hosts (including members of the Solanaceae, Convolvulaceae or Lamiaceae) will continue to be identified.

Symptomatic nursery stock will be detected on arrival in Australia but it is likely that infected asymptomatic plants would pass visual inspection and could be released from quarantine into Australia. Nursery stock imported into Australia for propagation can be widely distributed and planted directly into suitable habitats.

7.2.4 Natural wind pathway (from New Zealand)

In the event of an unlikely wind event, it is possible that *B. cockerelli* could be transported from New Zealand.

While adult psyllids do fly, they can be dispersed considerable distances by wind currents. *B. cockerelli* has a migration phase in North America, but it is not known if this is occurring in New Zealand. In New Zealand, the presence of this species was confirmed in 2006, but as it was found at more than one location, it is uncertain when or how it entered the country (Davidson *et al.,* 2008).

8 Pest management

8.1 Response checklist

The following checklist (Table 6) provides a summary of generic requirements to be identified and implemented within a Response Plan.

Table 6. *Checklist of requirements to be identified in a Response Plan*

Checklist item	Further information
Destruction methods for plant material, soil and disposable items	Section 9.1.1, 9.1.2
Disposal procedures	Section 9.1.5
Quarantine restrictions and movement controls	Section 9.3
Decontamination and property cleanup procedures	Section 9.5
Diagnostic protocols and laboratories	Section 5.3
Trace back and trace forward procedures	Section 9.6
Protocols for delimiting, intensive and ongoing surveillance	Section 8.2
Zoning	Section 9.4
Reporting and communication strategy	Section 12.4

A range of specifically designed procedures for the emergency response to a pest incursion and a general communication strategy refer to PLANTPLAN (Plant Health Australia, 2010). Additional information is provided by Merriman and McKirdy (2005)[2] in the Technical Guidelines for Development of Pest Specific Response Plans.

8.2 Surveys and epidemiology studies

Information provided in Section 8.2.1 to 8.2.3 provides a framework for the development of early detection and delimiting surveys for the Zebra chip pathogen (*Ca.* L. solanacearum) and its psyllid vector (*B. cockerelli).*

To minimise the impact of the Liberibacter on production and market access regular monitoring for the Tomato-potato psyllid is needed. Horticulture New Zealand (2008b) has produced a code of practice for the management of the psyllid in greenhouse tomato and capsicum crops. Baseline information from this document together with surveillance information sourced from the diagnostic protocol of Yen and Burckhardt (2010) have been used as a guide in development of the Pest Management section.

When any survey and epidemiology studies are undertaken personnel should avoid moving infested plant material between production areas. Shoes, tools and vehicle tyres should be thoroughly washed of soil and then sanitised with a registered disinfectant. Extra precaution should

[2] Available on the PHA website (**www.planthealthaustralia.com.au/go/phau/biosecurity/general-biosecurity-information**)

be taken when working in areas known to be infested, including disposable overboots that may be used and disposed of on-site.

8.2.1 Technical information for planning surveys

When developing surveys for presence and/or distribution of the psyllid (and its potential as a vector for the Zebra chip pathogen ("*Ca.* L. solanacearum")), the following characteristics of the pest provide the basic biological knowledge that informs the survey strategy:

- Tomato-potato psyllid (*B. cockerelli*) has a wide host range and as a virus vector share many of the same hosts with the Zebra chip pathogen.
- Endemic host species in Australia are likely to be numerous and widely dispersed.
- The risk of Tomato-potato psyllid movement on machinery, equipment and personal effects is high.
- Vegetable production areas (outdoor and greenhouses) and significant proportions of Australia have favourable climatic conditions for the Tomato-potato psyllid spread and establishment.

8.2.2 Surveys for early detection of an incursion in a nursery and outdoors

The survey protocol described to monitor the Tomato-potato psyllid is based on the protocol developed by Horticulture New Zealand (2008b) as part the 'New Zealand Code of Practice for the management of the Tomato-potato psyllid in greenhouse tomato and capsicum crops', diagnostic protocols (Yen and Burckhardt 2010), discussions held with Dr Alan Yen, psyllid entomologist with Victorian Department of Primary Industries and a summary of recent results from the United States. The research is a report on the sampling and Integrated Pest Management (IPM) of psyllids undertaken by John Tumble from the University of California and presented in New Zealand (September 2010).

Points to consider in effectively monitoring Tomato-potato psyllids in both outdoor and greenhouse production areas are:

- Tomato-potato psyllid adults and nymphs are small (2 - 3 mm approx.) and can be difficult to see. Detection is therefore dependent on careful visual inspection, preferably supplemented by use of a hand lens magnifier.
- If Tomato-potato psyllids are detected, leaves infested with Tomato-potato psyllids (nymphs and adults if possible) should be collected for identification of the species.
- Surveillance for the tomato-potato psyllid after winter may provide greater opportunities to control them before late spring-summer population build ups. Adults are easier to collect, but the presence of eggs and/or nymphs is an indication that the species is using the plant as a host. Surveillance methods can be either active (direct sampling) or indirect (trapping).
- Yellow sticky traps have limited use, as whilst they have a role in monitoring psyllid numbers in a greenhouse environment they are more difficult to use in outdoor areas because of wind and dust issues (pers. comm. A Yen). In addition, yellow sticky traps may give some indication of psyllid activity but currently little information is available relating trap catches with psyllid activity (Horticulture New Zealand 2008b). Yellow sticky traps have been used successfully in California to monitor the annual arrival of psyllids via winds from the south and thereafter they are used in-field monitoring to gauge the level of

infection. US researchers have found no correlation between sticky trap numbers and the level of infestation (Clayton-Green and Trumble pers. comm.).

- Yellow sticky traps can be used to trap adults (Goolsby *et al.* 2007). They are more effective in covered environments such as greenhouses, and while they can be effective in the field, they are subject to disruption by wind, rain and can trap windblown soil. Al-Jabr and Cranshaw (2007) tested sticky traps (7.5 x 12.5 cm) of 18 different colours; they found that neon green, neon orange and standard yellow are best for adult psyllids in greenhouses. They also found that traps placed near the tops of plants (150 cm) collected more psyllids than those at 30 cm; that traps partially shaded caught more psyllids than those in full sun; and that traps facing north caught more than south and there was no difference between east and west. These studies were undertaken in North America (Yen and Burckhardt 2010).
- Yellow pan water traps can be used to attract adults (Cranshaw 1993). The containers are generally painted bright yellow on the inside (although orange may also be effective) and partially filled with a solution of 1:10 70% ethanol:water and with a few drops of liquid detergent. Flying insects are attracted to the yellow and land in the water; the detergent breaks the surface tension and the insects do not escape. Water traps can be run continuously but need frequent checking to ensure that the liquid has not evaporated. They should be emptied regularly because even with ethanol, the specimens will begin to deteriorate after a week (Yen and Burckhardt 2010).
- Suction traps operated by mains electricity are very effective in collecting adult psyllids. However they collect a lot of material and considerable time is required to sort through the samples.
- Indicator trap plants can be used to detect the establishment of the psyllids as the presence of adult psyllids may not indicate local establishment (Cranshaw & Hein 2004). Local establishment can be determined by examining indicator plants that psyllids colonize early in the season and on which they are most easily detected. Green peppers are often the plants on which psyllids can first be found. Previously, matrimony vine was used for this purpose in North America, but this is now rarely planted (Yen and Burckhardt 2010). Chinese boxthorn is the common name in Australia for matrimony vine.
- Sampling in a greenhouse would include searching for psyllid sugars as an indicator of psyllid infestation. Recommendations within a 4 m section would be sampling a minimum of 15 tomato stems or 40 capsicum stems (Horticulture New Zealand 2008b).
- Scouting is an effective way of detecting psyllids in greenhouses but it is much more difficult to detect eggs and nymphs in outdoor conditions. Sampling for nymphs in potatoes requires extensive leaf sampling because nymphs can be difficult to detect; young nymphs are small, pale, and do not move. Psyllids can be highly aggregated in their distribution and may only be on a leaf or two within a plant. This requires that a large number of leaves be sampled to detect the presence of psyllids in a field. Sampling a minimum of 100 leaves is needed to have any confidence whether potato psyllid is present in a potato field (Cranshaw & Hein 2004).
- Crops should be monitored at least weekly and more frequent monitoring is recommended during times of high psyllid pressure. Horticulture New Zealand (2008b) recommends glasshouse monitoring be conducted weekly with each row sampled alternately over a 5 week period. If no sugars are seen, a plant at random should be monitored within the sampling 4 m section concentrating on monitoring the top section of capsicum plants and middle section of tomato plants. Plants showing Liberibacter disease symptoms should be recorded and representative samples removed for diagnosis.

- Sampling should be systematic in design. Trumble (pers. comm. 2010) reported that 70% of psyllids were found on the edges of paddocks declining to 8% when sampled 80 m from the paddock edge. Sampling was undertaken at the plant pre-flowering stage of development. He also reported on the spatial distribution of the psyllid with nearly all psyllids found on the underside of leaves towards the middle of the plant.

If the Tomato-potato psyllid transmitted Liberibacter pathogen is to be eradicated following an incursion, it must be detected early, before the vector has had the opportunity to disperse very far. It is therefore necessary to consider pathways and plan surveys and/or sentinel plantings accordingly. Important points to consider when developing early detection surveys are:

- Awareness information should be targeted at people who are in regular close contact with potential hosts in high risk areas.
- Systematic and careful inspection of crops and propagative plant material is essential to prevent introduction of a Tomato-potato psyllid transmitted Liberibacter pathogen and limit its spread within and from contaminated outdoor and greenhouse production areas. Early detection of the vector, while at low levels, will provide the best chance of eradication.
- An inspector must be trained to recognise Tomato-potato psyllid transmitted Liberibacter pathogen symptoms and other similar disorders for comparison (see Section 5.2.3). A layout map of the outdoor and greenhouse production area that includes approximate locations of target species will be required to develop a strategy for surveys. A survey map should include species and cultivar names, locations, approximate quantity and sources of targeted plants within the area. During the survey walkthrough, record the date, observations, and sampling information directly onto the survey map. The recorded information should be reviewed and used to develop an efficient survey strategy each time the production area is inspected.

8.2.3 Delimiting surveys in the event of an incursion

- In the event of an incursion, delimiting surveys are essential to inform the decision-making process
- The size of the survey area will depend on the size of the infected area and the severity of the infection, as well as prevailing winds and movement of plant material during the period prior to detection
- Tomato-potato psyllids can fly and can readily spread long distances by floating with the wind or being transported on infested plants. New introductions can pose serious threats and complicate identification of naturalised populations
- All potential host species (refer to Section 5.2) should be surveyed, with particular attention paid to the species in which the pest was initially detected
- In addition to inspection of possible host plants, material should be collected for diagnostic purposes (refer to Section 0)
- If the incursion is in a populated area, publication and distribution of information sheets and appeals for public assistance will be required

8.2.4 Collection and treatment of Tomato-potato psyllid samples

Protocols for the collection, transport and diagnosis of suspect Emergency Plant Pests (EPPs) must follow PLANTPLAN (Plant Health Australia, 2010). Any personnel collecting samples for assessment should notify the diagnostic laboratory prior to submitting samples to ensure expertise is available to undertake the diagnosis and that sampling and transport of specimens occurs correctly.

All sample containers should be clearly labelled with the name, address and contact phone number of both the sending and receiving officers. In addition containers should be clearly labelled in accordance with the requirements of PLANTPLAN (Plant Health Australia, 2010). Containers should be carefully sealed to prevent loss, contamination or tampering of samples. The Chief Plant Health Manager will select the preferred laboratory. Additional labelling includes the identification of plant species/parts affected, location of nursery and affected plant within the nursery (preferably with a GPS reading) as well as symptoms and an image if available.

Refer to PLANTPLAN for packing instructions under IATA 650.

8.2.4.1 COLLECTION OF SPECIMENS

Sampling procedures

Samples can be collected on leaf samples or on yellow sticky traps. The leaves should contain most Tomato-potato psyllid developmental stages. Yellow sticky traps have limited uses and should only be used as an indicator tool (see section 8.2.2).

Sampling a minimum of 100 leaves is needed to have any confidence whether potato psyllid is present in a potato field (Cranshaw & Hein 2004). When sampling it may be important to note that edge effects can be found in the region between green plants and bare ground. Previous studies have shown that 70% of psyllids were found on the edge of paddocks declining to 8% when sampled 80 m from the paddock edge (see section 8.2.2). Also consider the boundaries between infected plants showing symptoms and plants showing no visible symptoms.

Adult psyllids can be hand collected into glass vials or vacuum collected either with vacuum sampler, or swept from foliage with a hand net. Adult psyllids are normally found on the leaves and young shoots. A practical and reliable method for associating nymphs with adults as well as with host plants is the collection of infested leaves and shoots containing nymphs and rearing them in a constant temperature room/laboratory to obtain adults.

Sweeping may be the most effective method to detect adults, but is not effective for detecting nymphs. Weekly sweeping during the period when adults are expected to arrive in potato plants is recommended (Cranshaw & Hein 2004).

Vacuum sampling may be an alternative to sweeping. This involves using a hand held vacuum blower that is operated to suck up samples.

Adult psyllids are easily collected by sticky traps and water traps. However host plant information can only be inferred if these traps are adjacent to known host species.

Record the identity of the host plant where the psyllids were collected. Record the location, preferably as GPS co-ordinates, or alternatively, a map reference or distance and direction from a suitable landmark. If the land is privately owned, record the owner's details including contact telephone numbers.

Number of specimens to be collected

A large number of samples should be collected. Where possible, collect multiple specimens representative of all life stages of the population available. Adult psyllids are preferred, as the adult life stage is the easiest with which to confirm identification. Adult females are usually difficult to identify to species level. Males are needed to examine genitalia details to confirm species identification. As *Bactericera* sp are not known to occur in Australia, any identification to this genus of either males or females will most likely be *B. cockerelli* (Yen and Burckhardt 2010).

Of the three life stages only adults are identifiable to the species level using morphological features.

How to collect and send plant samples with eggs, larvae or pupae

Leaves and young shoots with suspect feeding damage can be stored between sheets of dry newspaper to permit slow drying. For laboratory rearing of psyllids, infested plant material containing mature nymphs can be collected in a large jar and kept in a constant temperature room for regular checking. It is recommended that a plant sample be collected for plant identification if there is either any question about the identity of the host plant or if the host plant is suspected of being a new record. It is important to record if only adult psyllids are found on the plant or if immature stages (eggs and nymphs) are present, to distinguish between chance visitation by adult psyllids or actual use of the plant for breeding.

All sample containers should be clearly labelled with the name, address and contact phone number of both the sending and receiving officers. In addition containers should be clearly labelled in accordance with the requirements of PLANTPLAN (Plant Health Australia, 2010; Appendix 3). Containers should then be carefully sealed to prevent loss, contamination or tampering of samples. The Chief Plant Health Manager will select the preferred laboratory. Additional labelling includes the identification of plant species/parts affected, location of affected plant (where available include GPS reading) as well as symptoms and an image if available.

Refer to PLANTPLAN for packing instructions under IATA 650.

How to preserve psyllids

Adults and nymphs can be placed in 70% ethanol and stored short term, although their colour fades gradually with time and when stored this way the specimen is not suited for molecular work. Adults can be dry mounted; these should be collected, killed by freezing and stored frozen until they are dry mounted. Specimens required for molecular diagnostic work should be kept cool before and during postage, and then stored in the freezer with no liquid at -20° to -80° C as soon as possible after arrival at the diagnostic laboratory.

How to transport psyllids

This will depend upon where the psyllids are to be transported to and the time it will take. Vials of ethanol should be sealed to avoid leakage and packed with cushioning material in a strong box. Be aware of regulations governing shipment of ethanol through the postal system.

Receipt

On receipt of the samples the diagnostic laboratory should follow strict quarantine and processing guidelines. In keeping with ISO 17025 refer to PLANTPLAN (Plant Health Australia, 2010).

8.2.5 Epidemiological study

The extent of infestation in a production greenhouse, on a property or within a region will depend on the initial population size and whether conditions have been favourable for the pest to spread from the initial location. Sampling should be based upon the origins of the initial suspect sample(s). Factors to consider will be:

- The proximity of other susceptible plants to the initial infestation source, including both current and previous crops. This will include crops in the production greenhouse or on the property with the initial detection and those on neighbouring properties.
- Machinery or vehicles that have been into the infested area or in close proximity to the infestation source.
- The extent of human movements into and around the infested area. A possible link to the recent importation of plant material from other regions should also be considered.
- The source of any production stock propagation material.
- If any other crops have been propagated from the same source and/or distributed from the affected production greenhouse or property.
- Depending on the temperature and environmental conditions, the psyllids can have multiple generations per year.

8.2.6 Models of spread potential

No models of spread potential have been developed yet for tomato and potato psyllids but work (PhD project) is in progress in New Zealand.

8.2.7 Pest Free Area guidelines

Determination of Pest Free Areas (PFAs) should be completed in accordance with the International Standards for Phytosanitary Measures (ISPMs) 8 and 10 (IPPC 1998a, 1999).

General points to consider are:

- Design of a statistical delimiting survey for symptoms on host plants (see Section 8.2 for points to consider in the design)
- It is proposed that plant sampling in a greenhouse could be completed as described in the BioSecure *HACCP* manual (Nursery and Garden Industry Australia, 2008), including monitoring processes (summarised in Table 7 and Table 8), indicator plants and weed monitoring. For additional information on the collection of psyllid samples see section 8.2.4
- Surveys should also consider alternative hosts (see Section 5.2.1) and not be limited to the primary infected host
- Information (including absence of the pest) should be recorded

Table 7. *Summary of monitoring processes for protected production areas as described in BioSecure HACCP Guidelines. (To ensure there is no evidence of the psyllid, monitoring would need to continue for at least 3 years).*

Wear protective clothing when handling suspect samples
Walk at random through the area in a zigzag pattern
Take at least 10 minutes to inspect 10-20 plants or plug trays per 100 m^2 of production area
Inspect the tops and bottoms or leaves, looking for any direct evidence of insects
Inspect the entire plant if it has less than 6 leaves, or from larger plants select six leaves from all parts of the plant (upper, lower, middle) and examine them individually
Inspect the length of all stems and branches for insects and symptoms
During individual plant inspection, examine the foliage for the presence of psyllids
If any plants show suspect symptoms or evidence of eggs or larvae (refer to Section 5.2.3) take a sample (refer to Section 8.2.4) to be formally diagnosed (refer to Section 5.3)
Check for a problem that have occurred regularly in the past, until you are certain it is not present
Record on the 'Crop Monitoring Record' sheet the presence or absence of the pest
Routinely inspect growing areas and remove alternate hosts and reservoirs of the pest, including weeds, crop residues and old plants that will not be marketed

Additional information is provided by the IPPC (1995) in Requirements for the Establishment of Pest Free Areas. This standard describes the requirements for the establishment and use of pest free areas as a risk management option for phytosanitary certification of plants and plant products. Establishment and maintenance of a PFA can vary according to the biology of the pest, pest survival potential, means of dispersal, availability of host plants, restrictions on movement of produce, as well as PFA characteristics (size, degree of isolation and ecological conditions).

Table 8. *Summary of monitoring processes for field production areas as described in BioSecure HACCP Guidelines[3]. (To ensure there is no evidence of the psyllid, monitoring would need to continue for at least 3 years).*

Wear protective clothing when handling suspect samples
Pay particular attention to areas on the windward side, the sides bordering ditches, canals or other uncultivated areas and growing block centres
Place a flag or other marker at the entrance to the block or sampling area at the beginning of each inspection
Vary the entrance point in the sampling area (1 m to 3 m) for each subsequent sampling so that the same plants are not inspected each time
Walk at random through the area in a zigzag pattern
The scout should follow the same general pattern at each sampling
Make an effort to select those plants that appear less healthy for visual inspection
Take at least 10 minutes to inspect 10-20 plants or plug trays per 100 m^2 of production area
Inspect leaves, looking for any direct evidence of insects
Inspect the entire plant if it has less than 6 leaves, or from larger plants select six leaves from all parts of the plant (upper, lower, middle) and examine them individually
Inspect the length of all stems and branches for insects and symptoms
If any plants show suspect symptoms or evidence of eggs or larvae (refer to Section 5.2.3) take a sample (refer to Section 8.2.4) to be formally diagnosed (refer to Section 5.3)
Check for a problem that have occurred regularly in the past, until you are certain it is not present
Record on the 'Crop Monitoring Record' sheet the presence or absence of the pest
Routinely inspect growing areas and remove alternate hosts and reservoirs of the pest, including weeds, crop residues and old plants that will not be marketed

8.3 Availability of control methods

8.3.1 General procedures for control

- Keep traffic out of affected areas and minimise movement in adjacent areas.
- Adopt best-practice property hygiene procedures to retard the spread of the pest between fields, greenhouses and adjacent properties.
- After surveys are completed, and permission has been obtained from the Chief Plant Health Manager or OCPPO, destruction of the infested plant material is an effective control.
- On-going surveillance of infected areas to ensure the pest is eradicated.
- Do not use any material from infected or infested plants for propagation.

Controlling psyllid populations before they reach large numbers in crops is very important for successful management. If the adults are present in large numbers it becomes difficult to control

[3] See section 8.2.2 Surveys for early detection of an incursion in a nursery and outdoors for further information on sampling in the field as the number of samples to examine can vary between crops

the nymphal stages. Adults move between successive crops, so management approaches must be employed in all crops within the area.

Early observation is the key to successful control. Determine when the crop is at risk from adult psyllid infestation through weekly monitoring. At the first sign of adult psyllid presence in the crop, undertake physical methods to disturb the adults and prevent them from laying eggs (New Zealand Code of Practice 2008).

Some of the New Zealand literature on the opportunities for control can be found in the report on the 'Growers guide to the management of the tomato/potato psyllid in greenhouse tomato and capsicum crops' and the 'New Zealand code of practice for the management of the tomato/potato psyllid in greenhouse tomato and capsicum crops'.

8.3.2 Pest free (clean) seedlings

Seedlings are potentially a major means of spreading psyllids into new plantings. Ensure seedlings are free from psyllids. Clean seedlings can be the first line of protection against the development of damaging populations.

8.3.3 Cultural practices

Cultural control involves considering all of the basic growing best practice concepts to ensure optimum growing conditions for maintaining a healthy crop that has maximum resistance to pests and diseases.

8.3.4 Weed management

The availability of a continuous source of hosts, whether they are crops, weeds or abandoned crops, is a major contributing factor to the control of a pest problem. All crop debris should be removed from the greenhouse and immediate environments. Weed and volunteer plant material should also be removed to ensure no green bridge remains for hosting pests.

8.3.5 Insect Pest Management (IPM) strategy

If eradication is deemed not feasible, management of the psyllid should involve IPM. Information from this section has been mainly sourced from research led by Paul Horne from IPM Technologies Pty Ltd through funding from Horticulture Australia (project code PT09004) to undertake a project on the 'Control of potato psyllid within an IPM strategy' collaborating with Plant and Food Research and independent entomologists in New Zealand.

Research on a number of new natural enemies of the psyllid is underway. If agrichemicals were carefully managed, predatory mites, lacewings, ladybirds, parasitic wasps and other beneficial arthropods and entomopathogenic fungi will contribute to controlling pests. Consideration also needs to be given to the role pollinators' play in a crop and the importance of maintaining populations of natural enemies like parasitic wasps and predators.

It is has been reported in New Zealand that the occurrence of potato psyllid has affected IPM in many crops where minimal insecticide historically has been practiced and these findings include glasshouse crops where IPM practices had been implemented for many years. As IPM in New

Zealand has not been generally adopted in potato crops the impact of insecticide has been minimal to this practice.

In contrast Australia has been a world leader in the adoption of IPM and the consequent minimal use of insecticides during potato production. Horne reports that the use of broad spectrum insecticides on the potato psyllid will destroy the IPM control of other pests such as aphids and potato moth which are currently dealt with using IPM strategies (HAL proposal PT09004).

If IPM practices are to be maintained in Australia, IPM practices need to be developed to control the psyllid. The HAL project (PT09004) investigates natural enemies of potato psyllid. These laboratory feeding trials are being undertaken in New Zealand using a range of predatory insects that are found in both Australian and New Zealand potato crops and belong to groups known to prey on potato psyllid overseas. The species includes damsel bugs (*Nabis kinbergii*), brown lacewings (*Micromus tasmaniae)* and ladybird beetles (*Harmonia conformis* and *Coccinella transversalis*).

Work in New Zealand has commenced on the establishment of laboratory colonies for the natural enemies. The initial study was the “no-choice” where psyllids were offered as the only prey with the results showing the predatory insects accepting the psyllid as prey. The next test will be more complex experiments where the predators are offered a choice of different prey including psyllids. Biological control options are restricted in New Zealand due to the heavy use and reliance on insecticides to control the psyllid. Field trials will be conducted once information has been obtained from both biological and cultural control options (extract from HAL PT09004 milestone report September 2010).

8.3.6 Chemical options

The information contained within this document is designed to:

1. Aid in an eradication or containment attempt by providing guidelines for steps to be undertaken or considered when developing a Response Plan to the Zebra chip complex.
2. Effectively manage the pest and to minimise the disruption following entry and establishment, should eradication be deemed not feasible (see section 1 for details).

A chemical eradication program has not been suggested as feedback suggests that any program would depend strongly on the extent of the incursion. In a Response plan the eradication or containment would be dependent on a number of factors including location and size of the incursion. If a decision is made to eradicate the pest it is likely that the crop will be destroyed.

From the literature it would seem that there is no known agrochemical available for the control of the Liberibacter, therefore overall management must depend on control of the vector, Tomato-potato psyllid. There are a number of factors that need to be considered when developing a control regime and in this case with the high mobility of the psyllid and extremely rapid infection time required for uptake of the Liberibacter, repeated chemical applications are required. Factors to be considered when developing a control regime include the:

- Psyllid biology and infection process as affected by temperature, crop status and humidity
- Preservation and use of natural enemies
- Adherence to registration, residue and health requirement.

Chemical control regimes used in New Zealand and US are designed to manage rather than eradicate the psyllid and they therefore recommend that they must also consider Integrated Pest Management (IPM) practices currently used by the potato, tomato and greenhouse crop industries. In the United States a warning has been attached to the chemical control list for Tomato-potato

psyllids as follows; 'When choosing a pesticide, consider relating to the impact of natural enemies and honey bees and environmental impact....'(**www.ipm.ucdavis.edu** IPM University of California, Davis).

The greatest experience with insecticide control can be found in the United States with for example, Bayer CropScience recommending a program for both heavy and light psyllid infestation with more than 10 chemical applications of 5 classes of insecticides in block fashion. This is a substantially higher level of insecticide application than currently used in Australian potato production systems.

8.3.6.1 CHEMICAL OPTIONS USED IN NEW ZEALAND

The Tomato-potato psyllid is a relatively new pest in tomato and capsicum crops in New Zealand, with many chemicals not currently covered by any New Zealand agrochemical registrations (New Zealand code of practice (2008b)). A variety of chemical products are listed but only two are registered for control of the psyllid (Movento® and Oberon ® both from Bayer CropScience).

Based on the lower temperatures and longer growing season in New Zealand the recommended Bayer CropScience program recommends up to 15 applications from a range of insecticide classes.

A range of products registered for control of insect pests including Tomato-potato psyllid in New Zealand are shown in Table 9 (sourced from the Potatoes New Zealand website at **http://www.potatoesnz.co.nz/psyllid.htm**). Additional spray options can also be found in the "New Zealand code of practice for the management of tomato/potato psyllid in greenhouse tomato and capsicum crops" (2008b).

Table 9. Products with label claims for control of a range of insect pests including potato psyllid on potatoes in New Zealand (revised November 2009). Note: the information presented on overseas label claims for psyllid control is not a recommendation for use of the product. Growers must comply with label directions and withholding periods when using these compounds to ensure residues in the treated potatoes comply with the maximum residue limits. Products may not be registered for use in Australia.

IRAC mode of action group number, insecticide group	Notes on resistance management recommendations for each mode of action (MoA) group	Active ingredient (plus trade name, if label claim for potato psyllid control in New Zealand)	Application rates (check and follow label instructions)	With-holding period	Aphids	Potato tuber moth	Other cater-pillars	Tomato-potato psyllid
Methamidophos	Green peach aphid, Melon aphid, Tomato fruitworm. Rotate these insecticides with those in other MoA groups	Carbaryl	2.4 - 4.8 litres / ha or 240 ml / 100 litres	1 day		Yes	Yes	Note 1
		Pirimicarb	500 g in 200 – 400 litres / Ha	Nil	Yes			
1B Organophosphate	Green peach aphid, Melon aphid, Tomato fruitworm. Rotate these insecticides with those in other MoA groups	Acephate	See label	7 days	Yes	Yes		Note 2
		Azinphos-methyl	2.8 litres / ha	14 days		Yes		
		Methamidophos	See label	7 days	Yes	Yes	T	Note 1
		Phorate (granule)	11 kg / ha in furrow at planting	13 weeks	Yes			Note 1
3A Pyrethroids	Green peach aphid, Melon aphid, Tomato fruitworm. Rotate these insecticides with those in other MoA groups	Deltamethrin	See label	14 days		Yes	T	
		Lambda-cyhalothrin	40 ml / ha in at least 500 litres	14 days		Yes		Note 1

IRAC mode of action group number, insecticide group	Notes on resistance management recommendations for each mode of action (MoA) group	Active ingredient (plus trade name, if label claim for potato psyllid control in New Zealand)	Application rates (check and follow label instructions)	With-holding period	Aphids	Potato tuber moth	Other cater-pillars	Tomato-potato psyllid
			water					
		Esfenvalerate	See label	Not given			T & CW	Note 1
4A Neonicotinoids	Green peach aphid, Melon aphid, Tomato fruitworm. Rotate these insecticides with those in other MoA groups	Imidacloprid (seed treatments)	See label	Not given	Yes			Note 1
		Thiamethoxam (in furrow application)	See label	90 days	Yes			Note 1
5 Spinosyns	Tomato fruitworm. Rotate these insecticides with those in other MoA groups	Spinosad	See label	7 days		Yes	T	Note 1
6 Avermectins		Abamectin						Note 1
9B Pyridine azomethine	Green peach aphid, Melon aphid. Rotate these insecticides with those in other MoA groups	Pymetrozine	200 g / ha	7 days	Yes			
16 Buprofezin		Buprofezin						Note 2
23 Lipid biosynthesis inhibitors	May be applied up to a maximum of 2 times in total per crop cycle. At other times use an insecticide from a different chemical class and consider biological control.	Spiromesifen (Oberon®)	600 ml / ha	7 days				Yes Note 3
		Spirotetramat (Movento®)	350 ml / ha, plus 1L / ha Partner	35 days				Yes

“CW” Label claim for control of cutworm

“T” label claim for control of these pests on tomatoes

“V” Label claim for control of these pests on vegetables

“Note 1” Overseas label claim for control of Tomato-potato psyllid

“Note 2” Overseas label claim for control of psyllid (note: no specific claim for Tomato-potato psyllid)

“Note 3” Only approved for field use on potatoes in accordance with the special emergency approval controls and emergency management plan

8.3.6.2 CHEMICAL ERADICATION OPTION FOR AUSTRALIAN CONDITIONS

Four major chemical companies (Bayer CropScience, Dow, NuFarm, Syngenta Crop Protection) have been approached regarding chemical options for the eradication or management of the Tomato-potato psyllid under Australian conditions.

A chemical eradication program has not been suggested as feedback suggests that any program would depend strongly on the extent of the incursion. In a Response Plan the eradication or containment attempt would be dependent on a number of factors including location and size of the incursion. Chemical options for eradication would be more complex if the proposed destruction zone is either widespread, surrounding other crops or hosts, contains native bushlands or communities or could be damaging to natural fauna and food production.

All chemicals used for the eradication or control of the Tomato-potato psyllid must be registered for use through the Australian Pesticides & Veterinary Medicines Authority (APVMA). For information regarding chemical registrations visit the APVMA website at **www.apvma.gov.au.** Registrations may also be prepared under the emergency permit system.

8.3.6.3 CHEMICAL MANAGEMENT REGIME FOR AUSTRALIAN CONDITIONS

Each chemical company contacted has one or more products available for the management of the psyllid. NuFarm (Jeff Raymond pers comm. November 2010) advised that they have an Imidacloprid product that could be used in the management of Tomato-potato psyllid. Syngenta (Sean Richardson pers comm. November 2010) indicated that Syngenta has expertise on the Zebra chip complex management in New Zealand and as a company have a range of products that may be useful for eradication and/or management should the psyllid be found in Australia. Dow (Paul Downard pers. comm. December 2010) advised that a new product is under development in New Zealand for psyllid control.

The following is a management strategy proposed by Bayer CropScience. Bayer CropScience has experience in Tomato-potato psyllid control in the United States and more recently in New Zealand. A strategy has been proposed by Bayer CropScience (September 2010) which is based on management of the psyllid and not eradication, as there have been no examples of successful eradication of the psyllid in other countries.

The control program uses products already registered in Australia for other pests on host crops, an IPM approach, a gradation of usage of products and a 'window' approach to minimise resistance development. (Note: Tomato-potato psyllids have been shown to develop resistance quickly and, with very few classes of insecticides available for psyllid control the development of resistance to the existing classes is possible).

The proposed program is summarised in Table 10 and is based on Bayer and non Bayer chemical products already registered on potatoes in Australia. ***Note: these recommendations are subject to the APVMA issuing permits for the use of the mentioned products on the Tomato-potato psyllid in Australia.***

Confidor Guard® (CNI group) applied in the planting furrow. This chemical is a targeted soil active product compatible with IPM strategies to allow control supplemented by natural biological control. It may control for up to 42 days but efficacy declines from 28 days. Confidor Guard is registered for use in potatoes in Australia.

Movento® (Ketoenol group) applied as spray application. Three applications are needed. The proposed rate has been shown to be effective against psyllids overseas. Product is long lasting and highly compatible with IPM allowing control to be supplemented by natural enemies. 1st spray is to be undertaken at 28 days after sowing coinciding with decline in Confidor® control. (Assume 7-10 day intervals for subsequent sprays and adjust with experience to possibly 7-14 days).

Control period of 28 days for Movento® with an overall timeline from planting of 56 days. Movento is registered for use in potatoes in Australia.

Spinosad applied as spray application. Spinosad (Conserve®, Dow AgroSciences) was used as two applications in New Zealand against psyllids and is registered for use on potatoes in Australia. Two sprays 7-10 days apart and control period of 14 days with an overall timeline from planting of 70 days. (note, Abamectin is used in New Zealand but is not registered for potatoes in Australia).

Remaining sprays to be either Organophosphates, Carbamate or Synthetic pyrethroids applied weekly providing control for 30 days. Timeline of 100 days (note, these products are not considered IPM compatible, but used when effectiveness of natural enemies is likely to be poor). Bayer CropScience will seek a permit for Bulldock® (beta-cyfluthrin) which is currently registered on tomato in Australia. Effective knockdown control of the psyllid has been demonstrated in the United States and Mexico.

Table 10. Summary of proposed seasonal program for Tomato-potato psyllid / Zebra chip management for Australia (summarised from the Bayer CropScience proposed management strategy - September 2010)

Days from planting	0	10	20	30	40	50	60	70	80	90-100
Stage of growth	Planting	Emergence	Stem formation	Main stem elongation	Tuber formation	Flower emergence	Flowering	Tuber development	Maturation bulking up	Senescence
Confidor® Guard[4]										
			Presumed, primary Zebra chip "infection" window							
Movento®[5]				1st spray	2nd spray	3rd spray				
Spinosad®[6]							1st spray	2nd spray		
Organophosphates, carbamate or synthetic pyrethroids sprays[7]								4 sprays applied over 4 weeks		

[4] In-furrow application + biological control, product is registered in potatoes at 14 ml/100m row, highly compatible with IPM, timeline 28 days.

[5] Up to 3 applications + biological control, registered in potatoes at 400ml/ha, highly compatible with IPM, timeline 56 days.

[6] 2 applications, Spinosad used in New Zealand and registered in potatoes in Australia, IPM compatible, timeline 70 days.

[7] 4 sprays weekly applications, not IPM compatible, timeline 100 days.

9 Course of action

Additional information is provided by the IPPC (1998b) in Guidelines for Pest Eradication Programmes. This standard describes the components of a pest eradication programme which can lead to the establishment or re-establishment of pest absence in an area. A pest eradication programme may be developed as an emergency measure to prevent establishment and/or spread of a pest following its recent entry (re-establish a pest free area) or as a measure to eliminate an established pest (establish a pest free area). The eradication process involves three main activities: surveillance, containment, and treatment and/or control measures.

9.1 Destruction strategy

9.1.1 Destruction protocols

- General protocols:
    - No plant material should be removed from the infested area unless part of the disposal procedure.
    - Disposable equipment, infested plant material or growing media/soil should be disposed of by autoclaving, high temperature incineration or deep burial.
    - Any equipment removed from the site for disposal should be double-bagged.
    - Machinery used in destruction processes need to be thoroughly washed, preferably using a detergent or farm degreaser.

9.1.2 Decontamination protocols

Machinery, equipment and vehicles in contact with infested plant material or growing media/soil, or present within the Quarantine Area, should be washed to remove plant material and growing media/soil using high pressure water or scrubbing with products such as a degreaser or a bleach solution (1% available chlorine) in a designated wash down area. When using high pressure water, care should be taken not to spread plant material. High pressure water should be used in wash down areas which meet the following guidelines:

- Located away from crops or sensitive vegetation.
- Readily accessible with clear signage.
- Access to fresh water and power.
- Mud free, including entry and exit points (e.g. gravel, concrete or rubber matting).
- Gently sloped to drain effluent away.
- Effluent must not enter water courses or water bodies.
- Allow adequate space to move larger vehicles.
- Away from hazards such as power lines.
- Waste water, growing media/soil or plant residues should be contained (see Appendix 18 of PLANTPLAN [Plant Health Australia, 2010]).

- Disposable overalls and rubber boots should be worn when handling infested plant material or growing media/soil in the field. Boots, clothes and shoes in contact with infested plant material or growing media/soil should be disinfected at the site or double-bagged to remove for cleaning.
- Skin and hair in contact with infested plant material or growing media/soil should be washed.

9.1.3 Priorities

- Confirm the presence and diagnosis of the pest and/or complex.
- Limit movement or people and prevent movement of vehicles and equipment through affected areas.
- Stop the movement of any plant material that may be infested with the pest.
- Determine the strategy for the eradication/decontamination of the pest and infested host material.
- Determine the extent of infestation through survey and plant material trace back and trace forward.

9.1.4 Plants, by-products and waste processing

As the adult psyllids can fly they have the ability to complete their life cycle on all known hosts of "*Ca.* L. solanacearum" and can reproduce easily it will be difficult to eradicate or even contain psyllid populations in production areas.

In the greenhouse, there are a range of actions that can be undertaken to control the psyllids including (refer to Biosecurity New Zealand website for details):

- As psyllids are easily spread, plant debris from the destruction zone must be carefully handled and transported.
- Remove and destroy affected leaves from actively growing and old crops. Plant material should be kept in a covered container until removed from property.
- Remove and destroy alternative host plants from outside greenhouses (especially prior to crop removal and replanting).
- Any growing media/soil or infected plant material removed from the infected site should be destroyed by (enclosed) high temperature incineration, autoclaving or deep burial.
- Infested areas or nursery yards should remain free of susceptible host plants until the area has been shown to be free from the pathogen.

9.1.5 Disposal issues

- Particular care must be taken to minimise the transfer of infected plant material from the area.
- Host material including leaf litter should be collected and incinerated or double bagged and deep buried in an approved site.

9.2 Containment strategies

For some exotic pest incursions where eradication is considered impractical, containment of the pest may be attempted to prevent or slow its spread and to limit its impact on other parts of the state or country. Containment is currently not covered under the Emergency Plant Pest Response Deed (EPPRD). The decision on whether to eradicate or contain the pest will be made by the National Management Group, based on scientific and economic advice. Emergency interim containment measures are possible under EPPRD arrangements to gather information to determine if eradication is technically feasible.

9.3 Quarantine and movement controls

Consult PLANTPLAN (Plant Health Australia, 2010) for administrative details and procedures.

9.3.1 Quarantine priorities

- Plant material and growing media/soil at the site of infestation to be subject to movement restrictions.
- Machinery, equipment, vehicles and disposable equipment in contact with infested plant material or growing media/soil, or present in close proximity to the site of infestation to be subject to movement restrictions.

9.3.2 Movement controls

Movement controls need to be put in place to minimise the potential for transport of the pest, and this will apply to all plant material, growing media and other items within the quarantined area.

Movement of people, vehicles, equipment and plant material, from and to affected properties or areas, must be controlled to ensure that the pest is not moved off-property. Movement controls can be achieved through the following, however specific measures must be endorsed in the Response Plan:

- Signage to indicate quarantine area and restricted movement into and within these zones.
- Fenced, barricaded or locked entry to quarantine areas.
- Movement of equipment, machinery, plant material or growing media/soil by permit only. Therefore, all non-essential operations in the area or on the property should cease.
- Where no dwellings are located within these areas, strong movement controls should be enforced.
- Where dwellings and places of business are included within the Restricted and Control Areas movement restrictions are more difficult to enforce, however limitation of contact with infested plants should be enforced.
- If a production greenhouse is situated within the Restricted Area, all production trading must cease and no material may be removed without permission, due to the high likelihood of pest spread. Movement restrictions would be imposed on both host and non-host material.
- Residents should be advised on measures to minimise the inadvertent transport of the psyllid or "*Ca.* L. solanacearum" from the infested area to unaffected areas.

- Clothing and footwear worn at the infested site should either be double-bagged prior to removal for decontamination or should not leave the site until thoroughly disinfected, washed and cleaned.
- Plant material or plant products must not be removed from the site unless part of an approved disposal procedure.
- All machinery and equipment should be thoroughly cleaned down with a high pressure cleaner (see Section 9.1.2) or scrubbing with products such as a farm degreaser or a 1% bleach (available chlorine) solution, prior to leaving the affected area. Machinery should be inspected for the presence of insects and if found, treatment with insecticide may be required. The clean down procedure should be carried out on a hard surface, preferably a designated wash-down area, to avoid mud being re-collected from the affected site onto the machine. When using high pressure water, care should be taken to contain all plant material and mud dislodged during the cleaning process

9.4 Zoning

The size of each quarantine area will be determined by a number of factors, including the location of the incursion, biology of the pest, climatic conditions and the proximity of the infested property to other infested properties. This will be determined by the National Management Group during the production of the Response Plan. Further information on quarantine zones in an Emergency Plant Pest (EPP) incursion can be found in Appendix 10 of PLANTPLAN (Plant Health Australia, 2010). These zones are outlined below and in Figure 16.

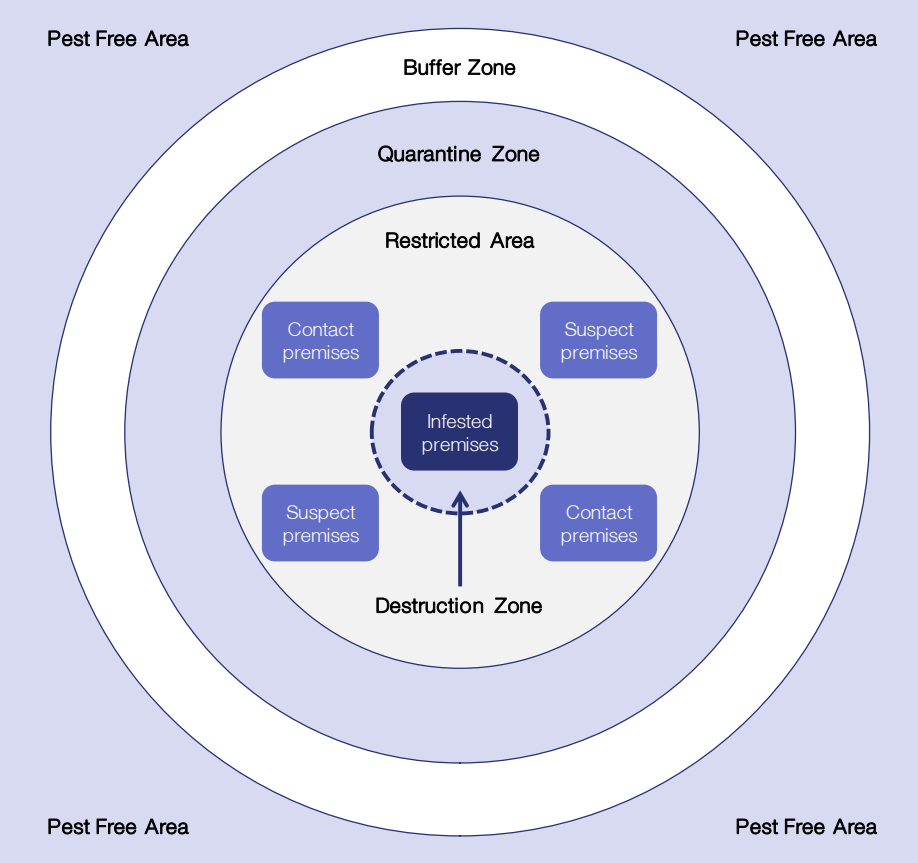

Figure 16. *Schematic diagram of quarantine zones used during an EPP incursion (not drawn to scale)*

9.4.1 Destruction Zone

The size of the destruction zone (i.e. zone in which the pest and all host material is destroyed) will depend on the ability of the pest to spread, distribution of the pest (as determined by delimiting surveys), time of season (and part of the pest life cycle being targeted) and factors which may contribute to the pest spreading.

All host plants should be destroyed after the level of infestation has been established. The delimiting survey will determine whether or not neighbouring plants are infested and need to be destroyed. Non-host plant material within this zone may be destroyed, based on recommendations in the Response Plan. The Destruction Zone may be defined as contiguous areas associated with the same management practices as, or in contact with, the infested area (i.e. the entire production nursery, property or area if spread could have occurred prior to the infection being identified).

Particular care needs to be taken to ensure that plant material (including non-hosts) is not moved into surrounding areas.

9.4.2 Quarantine Zone

The Quarantine Zone is defined as the area where voluntary or compulsory restraints are in place for the affected property or properties. These restraints may include restrictions or movement control for removal of plants, people, growing media/soil or contaminated equipment from an infected property.

9.4.3 Buffer Zone

A Buffer Zone may or may not be required depending on the incident. It is defined as the area in which the pest does not occur but where movement controls or restrictions for removal of plants, people, soil or equipment from this area are still deemed necessary. The Buffer Zone may enclose an infested area (and is therefore part of the Control Area) or may be adjacent to an infested area.

9.4.4 Restricted Area

The Restricted Area is defined as the zone immediately around the infected premises and suspected infected premises. The Restricted Area is established following initial surveys that confirm the presence of the pest. The Restricted Area will be subject to intense surveillance and movement control with movement out of the Restricted Area to be prohibited and movement into the Restricted Area to occur by permit only. Multiple Restricted Areas may be required within a Control Area.

9.4.5 Control Area

The Control Area is defined as all areas affected within the incursion. The Control Area comprises the Restricted Area, all infected premises and all suspected infected premises and will be defined as the minimum area necessary to prevent spread of the pest from the Quarantine Zone. The Control Area will also be used to regulate movement of all susceptible plant species to allow trace back, trace forward and epidemiological studies to be completed.

9.5 Decontamination and farm clean up

Decontaminant practices are aimed at eliminating the pathogen thus preventing its spread to other areas.

9.5.1 Decontamination procedures

General guidelines for decontamination and clean up:

- Refer to PLANTPLAN (Plant Health Australia, 2010) for further information.
- Keep traffic out of affected area and minimise it in adjacent areas.
- Adopt best-practice property hygiene procedures to retard the spread of the pest between growing areas/fields and adjacent properties.
- Machinery, equipment, vehicles in contact with infested plant material or growing media/soil present within the Quarantine Zone, should be washed to remove growing media/soil and

plant material using high pressure water or scrubbing with products such as a degreaser or a bleach solution in a designated wash down area as described in Section 9.1.2.

- Only recommended materials are to be used when conducting decontamination procedures, and should be applied according to the product label.
- Infested plant material should be disposed of by autoclaving, high temperature (enclosed) incineration or deep burial.

9.5.2 General safety precautions

For any chemicals used in the decontamination, follow all safety procedures listed within each MSDS.

9.6 Surveillance and tracing

9.6.1 Surveillance

Detection and delimiting surveys are required to delimit the extent of the outbreak, ensuring areas free of the pest retain market access and appropriate quarantine zones are established.

Initial surveillance priorities include the following:

- Surveying all host growing properties and businesses in the pest quarantine area
- Surveying all properties and businesses identified in trace-forward or trace-back analysis as being at risk
- Surveying all host growing properties and businesses that are reliant on trade with interstate or international markets which may be sensitive to pathogen presence
- Surveying production nurseries selling at risk host plants
- Surveying other host growing properties and backyards

9.6.2 Survey regions

Establish survey regions around the surveillance priorities identified above. These regions will be generated based on the zoning requirements (see Section 9.4), and prioritised based on their potential likelihood to currently have or receive an incursion of this pest. Surveillance activities within these regions will either allow for the area to be declared pest free and maintain market access requirements or establish the impact and spread of the incursion to allow for effective control and containment measures to be carried out. Detailed information regarding surveys for psyllids have been outlined elsewhere in this plan (refer to Section 8.2).

Steps outlined in Table 11 form a basis for a survey plan. Although categorised in stages, some stages may be undertaken concurrently based on available skill sets, resources and priorities.

Table 11. *Phases to be covered in a survey plan*

Phase 1	Identify properties that fall within the buffer zone around the infested premise Complete preliminary surveillance to determine ownership, property details, production dynamics and tracings information (this may be an ongoing action)
Phase 2	Preliminary survey of host crops in properties in buffer zone establishing points of pest detection
Phase 3	Surveillance of an intensive nature, to support control and containment activities around points of pest detection
Phase 4	Surveillance of contact premises. A contact premise is a property containing susceptible host plants, which are known to have been in direct or indirect contact with an infested premises or infected plants. Contact premises may be determined through tracking movement of materials from the property that may provide a viable pathway for spread of the disease. Pathways to be considered are: • Movement of plant material and growing media/soil from controlled and restricted areas • Items of equipment and machinery which have been shared between properties including bins, containers, irrigation lines, vehicles and equipment • The producer and retailer of infected material if this is suspected to be the source of the outbreak • Labour and other personnel that have moved from infected, contact and suspect premises to unaffected properties (other growers, tradesmen, visitors, salesmen, crop scouts, harvesters and possibly beekeepers) • Storm and rain events and the direction of prevailing winds that result in air-borne dispersal of the pathogen during these weather events
Phase 5	Surveillance of production and greenhouses, gardens and public land where plants known to be hosts of pathogen are being grown
Phase 6	Agreed area freedom maintenance, post control and containment

9.6.3 Post-eradication surveillance

The period of pest freedom sufficient to indicate that eradication of the pest has been achieved will be determined by a number of factors, including growth conditions, the previous level of infection, the control measures applied and the pest biology.

Specific methods to confirm eradication of the tomato/potato may include:

- Monitoring of sentinel plants
- Sentinel plants are to be grown in pots or small plots at the affected site. Plants are to be grown *in situ* under quarantine conditions and monitored for symptoms of infection
- If symptoms are detected, samples are to be collected and stored and plants destroyed
- Surveys comprising host plant sampling for *the vector* and the virus should be undertaken for a minimum of three years after eradication has been achieved
- Alternate non-host crops should be grown on the site and any self-sown plants sprayed out with a selective herbicide

10 Technical debrief and analysis for stand down

Refer to PLANTPLAN (Plant Health Australia, 2010) for further details

The emergency response is considered to be ended when either:

- Eradication has been deemed successful by the lead agency, with agreement by the Consultative Committee on Emergency Plant Pests [and the Domestic Quarantine and Market Access Working Group].
- Eradication has been deemed impractical and procedures for long-term management of the disease risk have been implemented.

A final report should be completed by the lead agency and the handling of the incident reviewed.

Eradication will be deemed impractical if, at any stage, the results of the delimiting surveys lead to a decision to move to containment/control.

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11.1 Related Websites

CABI 2007 **www.cabicompendium.org/cpc/home.asp**

IPPC website **www.ippc.int**

http://www.crop.cri.nz/home/insect-watch/psyllid_crop_symptoms.php

12 Appendices

12.1 Appendix 1: Known hosts of the tomato–potato psyllid (*Bactericera cockerelli*)

Host	Common name	Host association	Present in Australia	ICON conditions for Nursery stock
Datura meteloides Dunal		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Haegi 1976)	No (C7172)
Datura stramonium L.	Jimsonweed, Thornapple	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Haegi 1976)	No (C7172)
Hyoscyamus albus L.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Randall 2007)	Yes (C7301, C7302, C7300)
Hyoscyamus niger L.	Henbane	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Randall 2007)	Yes (C7301, C7302, C7300)
Lycium andersonii A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA

Host	Common name	Host association	Present in Australia	ICON conditions for Nursery stock
Lycium exsertum A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA
Lycium fremontii A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA
Lycium halimifolium Mill.	Matrimony vine	Breeding host (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA
Lycium macrodon A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA
Lycium pallidum Miers		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA
Lycium parishii A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA
Lycium quadrifidum Moc. & Sessé ex Dunal		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA
Lycium torreyi A. Gray		Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Fukuda *et al.,* 2001)	NA
Lycopersicon esculentum Mill [synonyms: *Solanum lycopersicum* L., *Lycopersicon lycopersicum* (L.) H. Karst.]	Tomato	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (APNI 2008)	No
Lycopersicon pimpinellifolium (L.) Mill	Currant tomato	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (AVH 2008)	No
Nicandra physalodes (L.) Gaertn.	Apple of Peru	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Hawton 1976)	Yes (C7301, C7302, C7300)
Nicotiana affinis Moore	Flowering tobacco	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	No	No (C6066)
Nicotiana glutinosa L.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (APNI 2008)	No (C6066)

Host	Common name	Host association	Present in Australia	ICON conditions for Nursery stock
Nicotiana tabacum L.	Tobacco	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Panchamuk hi 2000)	No (C6066)
Nicotiana texana Maxim.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	No	No (C6066)
Nierembergia hippomanica Miers	Cup flower	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Richardson *et al.,*. 2006)	Yes (C7301, C7302, C7300)
Physalis angulata L.	Cut leaf ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Bean 2006)	Yes (C7427, C7300, C18152)
Physalis comata Rydb.	Wild ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult(Wallis 1955)	No (Bean 2006)	NA
Physalis franchetti Mast.	Chinese lantern	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (APNI 2008)	Yes (C7427, C7300, C18152)
Physalis heterophylla Nees	Clammy ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	No (Bean 2006)	No
Physalis ixocarpa Brot. ex Hornem. [synonym: *Physalis philadelphica* Lam.]	Tomatillo	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Bean 2006)	Yes (C7427, C7300, C18152)
Physalis lanceolata Michx.		Breeding host (Wallis 1955)	No (Bean 2006)	No
Physalis lobata Torr.	Purple ground-berry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	No	Yes (C7427, C7300, C18152)
Physalis longifolia Nutt.	Longleaf ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Bean 2006)	NA
Physalis mollis Nutt.	Longleaf ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	No (Bean 2006)	NA
Physalis peruviana L.	Cape gooseberry	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Samuel *et al.,*. 1930)	Yes (C7427, C7300, C18152)
Physalis pruinosa L.	Husk tomato	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Randall 2007)	Yes (C7427, C7300, C18152)

Host	Common name	Host association	Present in Australia	ICON conditions for Nursery stock
Physalis rotundata Rydb.	Longleaf ground-cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	No (Bean 2006)	NA
Solanum aviculare G. Forst.	Bullibulli	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Subroto and Dolan 1994)	Yes (C7436,) C18152
Solanum baylisii Geras.		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Randall 2007)	Yes (C7436, C18152)
Solanum betaceum Cav. [synonym: *Cyphomandra betacea* (Cav.) Sendtn.]	Tamarillo	Breeding host (NZCOP 2008)	Yes (Randall 2007)	Yes (C7436, C18152)
Solanum capsicastrum Link ex Schauer	Jerusalem cherry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Radford *et al.,* 1994)	Yes (C7436, C18152)
Solanum carolinense L.	Ball nightshade, Bull nettle, Horse nettle, Devil's tomato	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Parsons and Cuthbertson 1992)	Yes (C7436, C18152)
Solanum citrullifolium A. Braun		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (Randall 2007)	Yes (C7436, C18152)
Solanum elaeagnifolium Cav.	White horse-nettle, Silver- leaf nightshade	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (Kidston *et al.,* 2007)	Yes (C7436, C18152)
Solanum gracile Sendtn.	Velvety nightshade	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	No	No
Solanum jamesii Torr.	Wild potato	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	No	Yes (C7436, C18152)
Solanum melongena L.	Eggplants, Aubergine	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (AVH 2008)	Yes (C7436, C18152)
Solanum mexicanum Moc. & Sessé ex Dunal		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	No	Yes (C7436, C18152)

Host	Common name	Host association	Present in Australia	ICON conditions for Nursery stock
Solanum nigrum	Wonderberry, Black nightshade, Blackberry nightshade, Garden huckleberry	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (AVH 2008)	Yes (C7436, C18152)
Solanum pyracanthum Jacq.	Porcupine tomato	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	No	Yes (C7436, C18152)
Solanum racemigerum Zodda		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	No	Yes (C7436, C18152)
Solanum sanitwongsei Craib		Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	No	Yes (C7436, C18152)
Solanum sisymbriifolium Lam.	Viscid nightshade, Sticky nightshade	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (AVH 2008)	Yes (C7436, C18152)
Solanum triflorum Nutt.	Wild tomato	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (AVH 2008)	Yes (C7436, C18152)
Solanum tuberosum L.	Potato	Oviposit, complete its nymphal development and emerge as normal adult (Wallis 1955)	Yes (AVH 2008)	Yes (C7322, C7323, C7300)
Solanum villosum Mill.	Hair nightshade	Oviposit, complete its nymphal development and emerge as normal adult (Knowlton and Thomas 1934)	Yes (AVH 2008)	Yes (C7436, C18152)

NA These species are prohibited entry into Australia by legislation pending an assessment.

12.2 Appendix 1: Standard diagnostic protocols

For a range of specifically designed procedures for the emergency response to a pest incursion refer to Plant Health Australia's PLANTPLAN (**www.planthealthaustralia.com.au/plantplan**).

12.3 Appendix 2: Resources and facilities

Table 12 provides a list of diagnostic facilities for use in professional diagnosis and advisory services in the case of an incursion.

Table 12. *Diagnostic service facilities in Australia*

Facility	State	Details
DPI Victoria – Knoxfield Centre	Vic	621 Burwood Highway Knoxfield VIC 3684 Ph: (03) 9210 9222; Fax: (03) 9800 3521
DPI Victoria – Horsham Centre	Vic	Natimuk Rd Horsham VIC 3400 Ph: (03) 5362 2111; Fax: (03) 5362 2187
DPI New South Wales – Elizabeth Macarthur Agricultural Institute	NSW	Woodbridge Road Menangle NSW 2568 PMB 8 Camden NSW 2570 Ph: (02) 4640 6327; Fax: (02) 4640 6428
DPI New South Wales – Tamworth Agricultural Institute	NSW	4 Marsden Park Road Calala NSW 2340 Ph: (02) 6763 1100; Fax: (02) 6763 1222
DPI New South Wales – Wagga Wagga Agricultural Institute	NSW	PMB Wagga Wagga NSW 2650 Ph: (02) 6938 1999; Fax: (02) 6938 1809
SARDI Plant Research Centre – Waite Main Building, Waite Research Precinct	SA	Hartley Grove Urrbrae SA 5064 Ph: (08) 8303 9400; Fax: (08) 8303 9403
Grow Help Australia	QLD	Entomology Building 80 Meiers Road Indooroopilly QLD 4068 Ph: (07) 3896 9668; Fax: (07) 3896 9446
Department of Agriculture and Food, Western Australia (AGWEST) Plant Laboratories	WA	3 Baron-Hay Court South Perth WA 6151 Ph: (08) 9368 3721; Fax: (08) 9474 2658

Table 9. *Experts in diagnosis of the Zebra chip complex*

Expert	State	Details
Dr Alan Yen (psyllid)	Vic	DPI Knoxfield 621 Burwood Highway Knoxfield VIC 3684 Ph: (03) 9210 9222; Fax: (03) 9800 3521DPI Victoria
Dr Fiona Constable (pathogen)	Vic	DPI Knoxfield 621 Burwood Highway Knoxfield VIC 3684 Ph: (03) 9210 9222; Fax: (03) 9800 3521DPI Victoria

12.4 Appendix 3: Communications strategy

A general Communications Strategy is provided in Appendix 6 of PLANTPLAN (Plant Health Australia, 2010).

12.5 Appendix 4: Market access impacts

Within the AQIS PHYTO database (**www.aqis.gov.au/phyto**) export of some material may require an additional declaration regarding freedom from the virus. Should the psyllid (*Bactericerea cockerelli)* and/or Zebra chip ("*Ca.* L. psyllaurous") be detected or become established in Australia, some countries may require specific declaration. Latest information can be found within PHYTO, using an Advanced search "Search all text" for the particular virus.