A TARGET LIST OF HIGH RISK PATHOGENS OF CITRUS

Prepared by S. Dempsey, G. Evans and E. Szandala

Office of the Chief Plant Protection Officer
(Scientific Advisory Section)

Agriculture, Fisheries and Forestry – Australia
Canberra 2002

TABLE OF CONTENTS

LIST OF TABLES

1. EXOTIC HIGH RISK PATHOGENS OF CITRUS

Exotic pathogens of citrus may be introduced into Australia through human activities, natural spread of windborne propagules and dissemination by arthropod vectors. Human movement of citrus may be of either legal or illegal. Movement of pathogens of citrus by humans can be on fruit, leaves, trees, seeds, budwood, and nursery stock of Citrus and alternative hosts. Natural movement of exotic pathogens and vectors can be either by chance or by intentional migration of arthropod vectors and birds.

The exotic pathogens of citrus considered in this analysis are from the initial 'target list' (Table 1) prepared by citrus pathologists Pat Barkley and Nerida Donovan. Sources of data used to determine entry pathways of exotic pathogen of citrus included:

- import access proposals received by the Australian Quarantine and Inspection Service (AQIS);
- quarantine import conditions set out in AQIS's ICON (Import Conditions) database;
- draft import risk analyses undertaken by AQIS following applications from South Africa and Florida for access of fruit to the Australian market;
- imports of citrus nursery stock, budwood and seed;
- AQIS Pest and Disease Interception (PDI) database;
- citrus fruit import statistics from Australian Citrus Growers Incorporated;
- literature referenced in CABI abstracts, CABI Crop Compendium 2001 and AQIS reviews.

Table 1: Exotic High Risk Pathogens of Citrus

Disease	Causal organism	Known distribution	Comment
Greening (Huanglongbing)	*Liberibacter asiaticum* (phloem-limited, uncultured bacterium) **Vector:** *Diaphorina citri**	Asia, Indian subcontinent, Saudi Arabia, Reunion Island, Mauritius.	One of the most devastating citrus diseases. Vectors are not present in Australia.
	Liberibacter africanum (phloem-limited, uncultured bacterium) **Vector:** *Trioza erytreae*	Southern Africa, Yemen, Madagascar, Reunion, Mauritius.	
Citrus variegated chlorosis; 'pecosita' (in Argentina)	*Xylella fastidiosa* (xylem-limited bacterium) **Vectors:** Virtually all sucking insects that feed predominantly on xylem fluid are potential vectors. Leafhoppers in the subfamily Cicadellinae (sharpshooters) and spittle bugs or frog hoppers (Cercopidae)	Brazil, Argentina, Paraguay.	One of the most devastating citrus diseases. Potential vectors such as citrus jassid from the sub-family Cicadellidae, occur in Australia and feed on citrus.
Citrus canker	*Xanthomonas axonopodis* pv. c*itri* (bacterium)	Asia, South America, Central America, Caribbean, Florida, parts of Africa, Papua New Guinea, Cocos Islands, Fiji, Christmas Island.	Serious threat given the number of interceptions on fruit and leaves at airports.
Mal Secco	*Phoma tracheiphila* (fungus) **Vectors:** Possibly birds and animals, no known insect vectors.	Countries around the Mediterranean Basin, Black Sea and Asia Minor.	Ideally suited to climates where the majority of citrus is grown in Australia
Stubborn	*Spiroplasma citri* (mycoplasma like organism) **Vectors:** *Circulifer tenellus*, *Neoaliturus haematoceps,* *N. tenellus*, *Scaphytopius delongi,* *S. nitridus*	California, Mexico, eastern Mediterranean Basin, North Africa, Middle East.	Severe threat to young trees in hot inland areas if the vector and pathogen are introduced. Vectors have not been reported in Australia.
Leprosis (non-systemic)	Citrus leprosis rhabdovirus (title not definite) (mite vectored, naked bacilliform) **Vectors:** *Brevipalpus californicus,* *B. obovatus,* *B. phoenicis*	South America (particularly Brazil), Florida (rarely found).	Potential to cause extensive crop loss and tree debilitation. False spider mite vectors are not present in Australia.
Mandarin stem pitting	Certain strains of citrus tristeza closterovirus (virus) **Vectors:** *Toxoptera citricida*, *Aphis gossypii*, *A. spiraecola, T. aurantii*	Thailand, Malaysia.	Potentially serious threat to mandarin production. Aphid vectors are present in Australia.
Cercospora spot	*Phaeoramularia angolensis* (fungus)	Sub-Saharan Africa, Yemen.	Potentially serious disease.

Disease	Causal organism	Known distribution	Comment
Bacterial spot	*Xanthomonas axonopodis pv. citrumelo* (bacterium)	Florida.	Serious nursery disease.
Powdery mildew	*Oidium tingitaninum* (fungus)	Asia, Central and South America and California.	Only likely to be a problem in very humid areas such as the tropical areas in the Northern Territory, Kununurra and North Queensland.
Post bloom fruit drop	*Colletotrichum acutatum* (fungus)	Florida, South America, Caribbean.	Can cause 100% fruit drop under certain climatic conditions.
Lime anthracnose	*Colletotrichum acutatum* (fungus)	North, South and Central America, Zanzibar.	Only affects Mexican limes.
Phymatotrichum root rot	*Phymatotrichopsis omnivora* (fungus)	South Western United States, northern Mexico.	Minor importance. Nursery problem.
Lime witches' broom	*Phytoplasma aurantifolia* **Vectors:** unknown. Suggested vector: *Hishimonus phycitis* (leafhopper)	Oman, United Arab Emirates, Iran, India.	Potentially devastating disease on limes. Suggested vector is not present in Australia, other possible vectors are unknown.
Mancha foliar	*Alternaria limicola* (fungus)	Mexico.	Epidemiology is similar to other *Alternaria* diseases of citrus and therefore a major threat in coastal areas and the Central Burnett. Disease severe during winter dry season followed by wet summer.
Greasy spot	*Mycosphaerella horii* (fungus)	Japan.	Minor importance.
Sweet orange scab	*Elsinoe australis* (fungus)	Southern America.	Epidemiology is similar to other scab diseases of citrus and therefore a major threat in coastal areas and the Central Burnett.
Scab	Biotypes of *Elsinoe fawcettii* with a wider host range (fungus)	Florida.	Wider host range and therefore potentially greater losses.
Chlorotic dwarf	(phloem limited isometric particle?) **Vector:** *Parabemesia myricae*	Turkey.	Potentially serious. The vector is not present in Australia, but other whitefly species in Australia may vector the pathogen.
Satsuma dwarf (Citrus mosaic, Natsudaidai dwarf, Navel orange infectious mottling)	Satsuma dwarf virus (virus)	Originated in Japan. Now present in China, Iran, Korea and Turkey.	Minor risk, importation of virus-free budwood is essential, being spread in Satsuma mandarin budwood.
Yellow mosaic	Citrus yellow mosaic virus (badnavirus) **Vector:** *Planococcus citri*	India.	Importation of virus-free budwood is essential.
Impietratura	Uncharacterised virus-like	Mediterranean, Venezuela, South Africa, Iran and Israel.	Spread only by budwood. Importation of virus-free budwood is essential.
Spreading decline	Citrus race of *Radopholus similis* (nematode)	Florida.	All commercial rootstocks susceptible, severe decline would occur on deep sandy soils.

* *Diaphorina citri* also occurs in Brazil, Bolivia, Honduras, Guadeloupe, Iran and Florida. Greening does not occur in these countries.

2. IDENTIFYING PATHWAYS FOR ENTRY

2.1 Fresh Fruit

Entry of fresh citrus fruit into Australia is closely regulated by AQIS. Approval is subject to AQIS assessing that applications for entry are acceptable, in terms of the risks posed, while taking account of pests and pathogens in the area from which imported fruit is to be sourced and opportunities to manage any identified risks. The formal process is known by quarantine agencies around the world as Pest Risk Analysis (PRA). Assessments made by Biosecurity Australia in response to applications to access the Australian market are referred to as Import Risk Assessments (IRAs).

In addressing applications to access Australia's markets, AQIS is bound by the Agreement on the Application of Sanitary and Phytosanitary (SPS) Measures that, among other things:

- removes the rights of members of the World Trade Organization (WTO) to arbitrarily restrict access to their markets on health and safety grounds;
- requires quarantine impediments on commodities in trade to be transparent and scientifically based; and
- requires importing countries to manage risk by the least trade restrictive measures.

Fresh fruit has been imported into Australia for some years from the South-western states of the United States of America (California, Arizona and Texas) and from Israel. Citrus from Israel are restricted to grapefruit, orange and mandarin. Other citrus are not permitted because of susceptibility to mal secco that is known to be present in Israel. Those approvals predate the establishment of the WTO and the formal PRA process developed in response to the requirements that bind members. AQIS's intention is to reassess these approvals, adopting the process that is applied to current and new applications for market access.

Importation of citrus from Spain was approved following a pest risk analysis undertaken by AQIS in 1994. The analysis concluded that none of the diseases of citrus in mainland Spain was of quarantine concern to Australia because fruit was not a potential pathway for entry of exotic diseases that might otherwise be of concern.

There are a number of IRAs for citrus imports currently being processed by AQIS. These are for citrus from Florida, Italy, South Africa, Japan, Mexico and New Caledonia. All are pending decision.

The Australian Bureau of Statistics records about 18 000 tonnes of citrus fruit (fresh and dried) imported into Australia in 1999/2000 (Table 2). About 14 800 tonnes was sourced from the United States of America, with lesser quantities from Spain (about 3 090 tonnes). Small quantities of citrus were imported from New Zealand, Thailand and Hong Kong as fresh or dried products. Fresh fruit from South East Asian countries is allowed entry in small quantities for the hospitality trade under quarantine supervision.

Table 2: Imports of Fresh/Dried Citrus Fruit (Tonnes) 1999/2000

Import origin country	Oranges	Lemon/ limes	Grapefruit	Mandarins	Other citrus	Total citrus
USA	11413	1544	703	637	472	14769
Spain	2976	74		39		3089
New Zealand	*	45			7	52
Hong Kong	*					<1
Thailand					1	1
Total	14389	1663	703	676	480	17911

*Less than 500kg.
[Source: Australian Citrus Growers Inc. (Sept 2000) ***Statistics: Citrus Fruits – Fresh or Dried Imports Cleared for Home Consumption*****]**

2.1.1 Exotic pathogens that might enter on legal consignments of citrus fruits

Exotic pathogens of concern associated with citrus fruits from exporting countries and those seeking access to Australia's markets are listed in Table 3. The risk of these pathogens entering on approved imports is judged, implicitly or explicitly, to be acceptable, based on risk management procedures imposed by AQIS (see annotations).

Table 3: Exotic Pathogens of Citrus in Countries Exporting or Proposing to Export Citrus to Australia

Pathogen	Vectors	Import origin countries where pathogens exist	Pathogen present in Countries yet to receive AQIS approval to export	Risk assessment
Citrus leprosis rhabdovirus	*Brevipalpus californicus, B. obovatus, B. phoenicis*	None	USA (Florida)	Infected mite vectors should be eliminated by risk management requirements.
Citrus tristeza closterovirus (mandarin stem-pitting strain)	*Toxoptera citricida, Aphis gossypii, A. spiraecola, T. aurantii*	Thailand – 1 t (1999/00)	Malaysia	Infected vectors carried on fruit should be eliminated by fumigation. Fruits free from peduncles and leaves, washed and waxed have a low risk of carrying the pathogen.
Colletotrichum acutatum (SGO strain)	None, though bees suspected.	None	USA (Florida)	Latent infections are not totally eliminated by washing, waxing and fungicide treatment of fruit. Will need to be addressed in risk management requirements before being approved by AQIS.
Elsinoe fawcettii	None	None	USA (Florida)	Spores not readily produced on fruit, but still a risk.

Pathogen	Vectors	Import origin countries where pathogens exist	Pathogen present in Countries yet to receive AQIS approval to export	Risk assessment
Liberibacter asiaticum	*Diaphorina citri*	China – 1 t (1998/99) Thailand – 1 t (1999/00) Vietnam – 1 t (1999/00)	Japan and Malaysia	Entry on fruit is extremely unlikely. The risk of introduction of vectors can be eliminated by fumigation.
Liberibacter africanum	*Trioza erytreae*	None	South Africa	Entry on fruit is considered extremely unlikely (CABI/EPPO, 1997). Pre-export inspection and treatment should eliminate infected psyllid vectors.
Phoma tracheiphila	No insect vectors	Israel – 579 t (1998/99)	Italy Syria	Could enter on fruit and peduncles but not considered to be seed transmissible.
Phymatotrich-opsis omnivora	None	USA – 14769 t (1999/00)	USA (currently being revised)	Fruit free from soil should eliminate the risk of pathogen entry.
Oidium tingitaninum	Potential risk on clothes.	South East Asia and California		Need for seed treatment as principally on Sevengle citrumelo.
Spiroplasma citri	It is generally transmitted by leafhoppers, including: *Circulifer tenellus* *Neoaliturus haemoceps* *N. tenellus* (sugar beet leafhopper) *Scaphytopius delongi* *S. nitridus*	Israel – 579 t (1998/99) New Zealand – 1 t (1999/00) USA – 14769 t (1999/00)	Egypt Spain USA (currently being revised)	Pre-export inspection and treatment should eliminate infected leafhopper vectors. Leafhoppers do not preferentially feed on citrus and therefore may not move with fruit.
Xanthomonas axonopodis pv. *citri*	None	Hong Kong – <1 t (1999/00) USA – 14769 t (1999/00) Thailand – 1 t (1999/00) Vietnam – 1 t (1998/99)	Japan Malaysia Korea USA (Florida eradication in progress but considered to be out of control; oranges currently being revised)	Potentially.
Xanthomonas axonopodis pv. *citrumelo*	None	None	USA (Florida)	Possible, however, the pathogen affects citrus plants in the nurseries and not mature plants, therefore risk of the bacterium contaminating is low.

Among the pathogens that might come from areas consigning citrus fruit to Australia, one is of concern. Infected citrus fruits are an important inoculum source for *Xanthomonas axonopodis* pv. c*itri* (citrus canker). The bacterium may also survive epiphytically on fruits produced in, or exposed to, areas where citrus canker occurs.

2.1.2 Pathogens that could enter on illegal fruit introductions

Illegal introductions of citrus fruit pose a greater risk of carrying exotic pathogens than legal introductions which are sourced from areas in which pathogens of concern are not present. Or, if present, AQIS judges that it is able to manage risk to an acceptable level by imposing risk management measures on fruit exported to Australia. In addition to pathogens of concern listed in Table 3 above, four other pathogens could enter on illegal fruit introductions. These are *Xylella fastidiosa*, *Phaeoramularia angolensis*, *Elsinoe australis, Phoma tracheiphila* and citrus chlorotic dwarf virus.

2.1.3 Illegal importations of citrus

Pathway analysis indicates that illegally imported citrus fruit, leaves and propagating material arriving in mail or carried by travellers entering Australia represents a high risk pathway for the entry of exotic pathogens of citrus.

Since 1999, AQIS has recorded over two hundred interceptions of citrus fruits from air passengers that were found to be carrying plant pathogens (Table 4). Leaves of citrus species and their relatives have also been intercepted on a number of occasions. The majority of interceptions were from passengers arriving on flights from South East Asia, with a small number originating from European countries. Fruits and leaves are most commonly intercepted but on a handful of occasions, budwood too has been confiscated from air passengers. The majority of these interceptions were made in New South Wales, followed by Victoria, Queensland and Western Australia. Relatively few interceptions of fruit have been recorded from the Northern Territory since 1999. Illegal imports of citrus fruits are most often carried for personal consumption.

An increasing incidence of fruit and leaf interceptions are being intercepted from mail items entering Australia with approximately 1600 interceptions recorded between January 1999 and September 2000.

Table 4: Countries of Origin of Passengers Carrying Citrus Fruit

Region	Country of origin	Interception number
Africa	Egypt	3
	Eritrea	1
	Kenya	1
	South Africa	5
	Subtotal	**10**
South Asia	Bangladesh	2
	India	9
	Sri Lanka	3
	Subtotal	**14**
South East Asia	Indonesia	18
	Malaysia	9
	Singapore (Malaysia)	22
	Philippines	7
	Thailand	14
	Vietnam	9
	Subtotal	**79**
East Asia	China	5
	Hong Kong (China)	13
	Japan	3
	North Korea	4
	South Korea	9
	Russia	3
	Subtotal	**37**
South Pacific	Fiji	1
	New Zealand	3
	Subtotal	**4**
Mediterranean	Italy	8
	Spain	5
	Turkey	6
	Subtotal	**19**
Middle East	Iran	4
	Israel	2
	Lebanon	1
	Subtotal	**7**
North America	USA	5
	Subtotal	**5**
South America	Brazil	1
	Subtotal	**1**
Europe	Belgium	1
	Denmark	1
	Europe	1
	France	1
	Germany	1
	Poland	1
	Yugoslavia	1
	United Kingdom	3
	Subtotal	**10**
	Unknown	**15**
	Total	**201**

Diagnosis of intercepted material suggests that a number of high-risk exotic pathogens of citrus could enter Australia with material concealed by air passengers. Twenty-seven interceptions were found to be carrying the citrus canker bacterium, *Xanthomonas axonopodis* pv. *citri*, predominantly on lime fruits (Table 5). The bacterium has also been intercepted from international mail and cargo on a handful of occasions. On at least eight occasions, confiscated fruits were found to be carrying *Elsinoe fawcettii.* However, it is uncertain whether these were the exotic or endemic biotypes. There have been no recorded interceptions of illegal budwood found contaminated with high-risk exotic pathogens.

Table 5: Interceptions of Pathogens of Quarantine Concern on Citrus Fruits, Leaves and Peel Since 1999

Pathogen	Quarantine status	Country of origin	Description	Method of import	Interception date & state
Elsinoe fawcettii	Quarantine	Philippines	Lime fruits (Fresh)	Air baggage	11 March 99 in QLD
Elsinoe fawcettii	Quarantine	Philippines	Unidentified citrus fruits (Fresh)	Air cargo	14 April 99 in QLD
Elsinoe fawcettii	Quarantine	Hong Kong	Citrus peel (Dried)	Air baggage	5 December 99 in NT
Elsinoe fawcettii	Quarantine	Malaysia	Orange fruits (Fresh)	Air baggage	1 June 00 in VIC
Elsinoe fawcettii	Quarantine	Singapore	Orange fruits (Fresh)	Air baggage	4 June 00 in VIC
Elsinoe fawcettii	Quarantine	New Zealand	Lemon fruits (Fresh)	Air baggage	2 December 00 in QLD
Elsinoe fawcettii	Quarantine	Thailand	Lime fruits (Fresh)	Air baggage	30 May 01 in VIC
Elsinoe fawcettii	Quarantine	Singapore	Lime fruits (Fresh)	Air baggage	11 June 01 in VIC
Xanthomonas axonopodis pv. *citri*	Quarantine	Indonesia	Lime fruits (Fresh)	Air baggage	17 August 99 in WA
Xanthomonas axonopodis pv. *citri*	Quarantine	Thailand	Kaffir lime leaves (Fresh)	Air baggage	10 November 99 in VIC
Xanthomonas axonopodis pv. *citri*	Quarantine	Indonesia	Lime fruits (Fresh)	Air baggage	5 January 00 in VIC
Xanthomonas axonopodis pv. *citri*	Quarantine	Indonesia	Lime fruits (Fresh)	Air baggage	13 January 00 in QLD
Xanthomonas axonopodis pv. *citri*	Quarantine	India	Lemon fruits (Fresh)	Air baggage	8 February 00 in QLD

Pathogen	Quarantine status	Country of origin	Description	Method of import	Interception date & state
Xanthomonas axonopodis pv. *citri*	Quarantine	Malaysia	Lime fruits & leaves (Fresh)	Air baggage	1 March 00 in QLD
Xanthomonas axonopodis pv. *citri*	Quarantine	Iran	Lime fruits (Fresh)	Air cargo	8 May 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	China	Citrus peel (Dried)	Air baggage	10 May 00 in QLD
Xanthomonas axonopodis pv. *citri*	Quarantine	Thailand	Lime fruits (Fresh)	Post	8 June 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Malaysia	Lemon fruits (Fresh)	Air baggage	6 July 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Thailand	Lime fruits (Fresh)	Post	6 July 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	India	Lime fruits (Fresh)	Air baggage	10 September 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Thailand	Lime leaves (Fresh)	Air baggage	13September 00 in VIC
Xanthomonas axonopodis pv. *citri*	Quarantine	Thailand	Lime fruits & leaves (Fresh)	Air baggage	18 September 00 in QLD
Xanthomonas axonopodis pv. *citri*	Quarantine	Indonesia	Lime fruits (Fresh)	Air baggage	21 September 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Indonesia	Lime fruits (Fresh)	Air baggage	22 September 00 in VIC
Xanthomonas axonopodis pv. *citri*	Quarantine	Thailand	Lime leaves & peel (Fresh & dried)	Air baggage	23 September 00 in QLD
Xanthomonas axonopodis pv. *citri*	Quarantine	Singapore	Lime fruits (Fresh)	Air baggage	3 October 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Vietnam	Lime fruits (Fresh)	Air baggage	8 October 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Malaysia	Lime fruits (Fresh)	Air baggage	19 October 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Sri Lanka	Lime fruits (Fresh)	Post	22 October 00 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Thailand	Lime fruits (Fresh)	Air baggage	19 November 00 in VIC
Xanthomonas axonopodis pv. *citri*	Quarantine	Singapore	Citrus leaves	Air baggage	4 December 00 in NT

Pathogen	Quarantine status	Country of origin	Description	Method of import	Interception date & state
Xanthomonas axonopodis pv. *citri*	Quarantine	East Timor	Unidentified citrus fruit (Fresh)	Air baggage	26 April 01 in NT
Xanthomonas axonopodis pv. *citri*	Quarantine	Unknown	Lime fruits (Fresh)	Other methods	14 May 01 in VIC
Xanthomonas axonopodis pv. *citri*	Quarantine	Vietnam	Lime fruits (Fresh)	Air baggage	30 October 01 in VIC
Xanthomonas axonopodis pv. *citri*	Quarantine	Indonesia	Lime fruits (Fresh)	Air baggage	2 November 01 in VIC

Although relatively few interceptions were made in the Northern Territory in the period since 1999, northern Australia is considered to be a risk zone for entry of illegally carried citrus fruits and leaves. This assessment is made on the basis that:

- Torres Strait Islanders regularly navigate between the southern coast of Papua New Guinea, the islands of the Torres Strait and the mainland. Citrus pests and pathogens on fruit carried by them could transfer to citrus or citrus relatives growing on the islands and eventually to the Australian mainland (Brown, 1998). In 1984 canker was found on Thursday Island in the Torres Strait and not declared eradicated until four years later.

- citrus fruit and leaves are carried on ships and international yachts. Ships are intercepted at recognised ports, but cruising ships could dump decaying fruit at remote or unauthorised localities;

- island hopping by people in light aircraft is known.

2.2 Leaves, Peel and Pomander

There are a number of citrus species that are edible and used for processing, for herbal teas and pot pourri. These include Kaffir lime (*C. hystrix*), daidai (*C. aurantifolia*) in teas and perfumes; and citrus relatives (*Murraya koenigii*) as curry leaves for culinary purposes. AQIS does not permit the importation of fresh citrus leaves, peel and pomander because these products can carry serious plant pathogens. If imported, these products are destroyed by incineration, disposed of by deep burial or re-exported. AQIS permits the entry of dried citrus leaves, peel and pomander. Frozen consignments are rarely permitted entry.

AQIS requires that consignments of unprocessed and processed citrus leaves, peels and pomander must be covered by a valid Import Permit, be inspected for live pests, treated with methyl bromide, if required, and be subjected to either heat treatment or ethylene oxide fumigation. Further, AQIS requires processed citrus leaves, peels and pomander as ingredients of herbal teas to be heat treated. Pot pourri mixture is subject to mandatory gamma irradiation.

Given the conditions for entry, legal imports of leaves, peel and pomander constitute a negligible risk of acting as a pathway for entry of exotic pathogens even though almost all imports of Kaffir lime have symptoms of canker.

2.2.1 Exotic pathogens on illegal imports of citrus leaf material

Illegal citrus leaf material may be fresh or dried, in processed goods or unprocessed ingredients. Illegal introductions of frozen citrus material have been intercepted, but only rarely, and seem an improbable pathway for entry of exotic pathogens. Fresh leaf material is likely to pose the greatest risk of carrying exotic pathogens.

Exotic pathogens associated with fresh citrus leaf material can be categorised into two groups: those pathogens which are transmissible by the leaf material alone (Table 6); and those pathogens which require vectors to move to living hosts (Table 7). The first group consists of fungi and (possibly) the bacterium responsible for citrus canker, the latter, viruses, virus-like organisms, mycoplasma-like organisms and (possibly) the bacterium responsible for canker. Within these two groups, pathogens can be further divided into those that come from Australia's neighbouring countries in the north and those from further afield.

Among the non-vectored pathogens assessed as being associated with illegal citrus leaf material (Table 6)**,** only four might be considered as potential threats based on assessed capacity to survive on moribund and drying citrus leaves. These are:

- *Xanthomonas axonopodis* pv. *citri*. The bacterium can live for up to six months in dead host material (Graham *et al*., 1987), but all dried samples of canker tested by the Elizabeth McCarthur Agricultural Institute have been negative for live bacteria (Pat Barkley pers. comm., 2001).

- *Oidium tingitaninum.* The fungus can over-winter as dormant mycelium in buds which allows it to disperse with planting stock, even when plants are defoliated.

- *Phaeoramularia angolensis*. Produces numerous conidiophores on the underside of leaves. Leaf lesions produce conidia and constitute the main source of infection for this disease (CAB INTERNATIONAL, 1999). Dormant lesions are able to survive until conditions are conducive for development.

- The slow-growing (SGO) strain and the Key lime anthracnose (KLA) strain of *Colletotrichum acutatum* have latent infections which are formed in vegetative tissue. Appressoria are capable of surviving for many months in that state on leaves (CAB INTERNATIONAL, 1999).

X. axonopodis pv. *citri* occurs in Indonesia, the Philippines, Malaysia and Papua New Guinea. *O. tingitaninum* occurs in tropical and subtropical Asia, including India, Sri Lanka, Vietnam, Indonesia (Java), Malaysia and the Philippines.

Table 6: Exotic, Non-vectored Pathogens that may be Associated with Fresh Citrus Leaf Material

Pathogen	Carried in fresh leaf material (phloem or surface)?	Dispersal by leaves?	Are there noticeable lesions or scabs?	Is the pathogen sapro-phytic?	Survival on drying leaf matter?	Found in NAQS region or north of Aus?
Alternaria limicola	Yes	Probably yes	Yes	Probably yes	Probably yes	No
Colletotrichum acutatum (KLA)	Yes	Yes	Yes	Yes, on twigs	Yes	No
Colletotrichum acutatum (SGO)	Yes	Yes	Yes	Yes, on twigs	Yes	No
Elsinoe australis	Yes	Yes	Yes	No	?	No
Elsinoe fawcettii (various biotypes)	Yes	Yes	Yes	No	?	Yes
Mycosphaerella horii	Yes	Yes	Possible	Yes	Possible	No
Oidium tingitaninum	Yes	Yes	Yes	No	Possible	Yes
Phaeoramu-laria angolensis	Yes	Yes	Yes	No	Yes	No
Phoma tracheiphila	Possible	Unlikely	?	Possibly	Unlikely, possible on peduncle	No
Xanthomonas axonopodis pv. *citri*	Yes	Yes	Yes	Yes, mulch, soil, & some grasses	Yes	Yes
Xanthomonas axonopodis pv. *citrumelo*	Yes	Yes?	Yes	Yes	Yes	No

Exotic pathogens associated with citrus leaves that require a vector for transmission are listed in Table 7.

Table 7: Vector Transmitted Exotic Pathogens of Citrus

Pathogen	Vector(s)	Carried in fresh leaf material (phloem or surface)?	Dispersal by leaves?	Are there noticeable lesions or scabs?	Transmitted by vector?	If vector, is feeding preference on citrus species?	How long does the pathogen stay virulent on vector?	Found in NAQS region or north of Aus?
Citrus chlorotic dwarf virus	*Parabemisia myricae* (Japanese bayberry whitefly)	No	N/a	N/a	Yes	Yes	Persistent?	Yes
Citrus leprosis rhabdovirus	False spider mites -*Brevipalpus californicus, B. obovatus, B. phoenicis*	Yes	No	Yes	Yes	Yes	Persistent?	No
Citrus tristeza closterovirus (mandarin stem-pitting strain)	*Toxoptera citricida* (brown citris aphid), *Aphis gossypii* (melon aphid) *A. spiraecola* (spiraea aphid) *T. aurantii* (black citrus aphid)	Yes	No	No	Yes	Yes	24–48 hrs after feeding	Yes
Liberibacter africanum	*Trioza erytreae* (psyllid)	Yes	No (symptoms on fruit)	No	Yes	Yes	Semi-persistent	No
Liberibacter asiaticum	*Diaphorina citri* (psyllid)	Yes	No (symptoms on fruit)	No	Yes	Yes	Persistent	Yes
Spiroplasma citri	*Circulifer tenellus, Neoaliturus haemoceps, N. tenellus* (sugar beet leafhopper), *Scaphytopius delongi, S. nitridus*	Yes	No (symptoms on fruit)	No	Yes	Yes	Vectors become infective 10–20 days after feeding	No
Witches' broom disease of lime	Unknown. Suggested vector: *Hishimonus phycitis* (leafhopper)	Yes	No	No	Possibly, but unknown	?	?	No
Xylella fastidiosa	Virtually all xylem feeding, sucking insects are potential vectors. Leafhoppers subamily Cicadellinae (sharpshooters) and spittle bugs or frog hoppers (Cercopidae)	Yes	No	No	Yes	Yes	Persistent	No

While some exotic pathogens and vectors may be carried with citrus leaf material brought into Australia illegally, the pathway for entry and establishment of most is not convincing.

2.2.2 Illegal importation of citrus leaf material

While there are few records of illegal importation of citrus leaf material into Australia, attempts to smuggle such material are known. For example, leaf material was intercepted in refrigerated commercial consignments of medicinal/culinary 'herbs' arriving in Perth by air (Mark Stuart, pers. comm., in Brown, 1998) and untreated shipments into the Northern Territory a few years ago (Pat Barkley, pers. comm. 2000).

Citrus leaf material is known to be carried for personal consumption by Torres Strait Islanders, Indonesian fisherman, 'boat people', yacht and ship crews on international sea vessels entering Australia (Brown, 1998; Brown, 1989; Broadbent, 1995; and Philemon 1993, 1994). Air passengers on international flights and passengers on inter-Torres Strait Island flights are also known to carry citrus leaves for culinary purposes (Brown, 1998). In 1999, a Rapiscan X-ray examination at Melbourne airport revealed fresh lime leaves concealed in a passenger's baggage. Pathologists confirmed that the causal agent of citrus canker, *Xanthomonas axonopodis* pv. *citri*, was detected in leaf tissue (AQIS Bulletin, 1999). On approximately four other occasions, leaf material concealed by air passengers was found to be carrying the citrus canker pathogen (Table 5).

2.3 Seed

For many years, the Australia citrus industry was denied access to new genetic material as bud wood because of concern about the reliability of diagnostic methods available at the time to detect some exotic pathogens. Access to new genetic material was via nucellar seed - that is seed produced from somatic cells of the nucellus.

AQIS regards seed as comparatively low risk and allows direct entry after treatment in a fresh solution of 1% (1g/100 ml) 8-hydroxyquinoline sulphate for 3 minutes on arrival (Source: ICON). No post entry quarantine is required because AQIS does not consider the one recognised seed borne virus of citrus as being of quarantine concern, notwithstanding the seed borne nature of psorosis and suggestions that yellow shoot disease and citrus vein phloem degeneration virus, though largely discounted, may be transmitted through seed (Barkley, 1989).

2.4 Nursery Stock

2.4.1 Legal introductions

Plant quarantine policy excluding entry of citrus bud-wood was overturned in the 1980s following advances in technology using a combination of heat therapy and shoot tip grafting in vitro that allowed scientist to eliminate graft transmissible diseases. With the support of the citrus industry, AQIS thereafter adopted a very cautious approach to introductions of clonal material that:

- restricted access to bud-wood from countries with citrus canker (in practise, this requirement has been waived to allow access to citrus from Florida and California);
- restricted access to bud-wood from countries with greening;
- limited industry to accessing bud-wood from recognised improvement programs that adopt heat therapy and shoot tip grafting in vitro with indexing and protect high health status clones against infection by pathogens;
- required clonal material entering Australia, other than micro-propagated plants in culture, to be fumigated and disinfected with sodium hypochlorite followed by shoot tip grafting and indexing in post entry quarantine.

AQIS requires micro-propagated plants to be accompanied by a phytosanitary certificate attesting to health status and should state: when the material was indexed, by whom, what methods and controls; and the conditions under which the parental stock was maintained since last indexed; with indexing post arrival for diseases not certified on the phytosanitary certificate. In practice, all such material is fully indexed in post entry quarantine, thus ensuring only healthy bud-wood enters the propagation chain.

In recent years, Australia has imported citrus bud wood and scion varieties from Vietnam, United States of America (Florida and California), Argentina, Japan, France (Corsica), South Africa and Spain (Pat Barkley, pers. comm. 2000). Graft transmissible pathogens of concern in these countries are listed here in Table 8.

Table 8: Countries from which Industry has Sourced Clonal Citrus and Pathogens of Concern

Import origin countries	Pathogen of concern
Argentina	*Elsinoe australis*
	Citrus leprosis rhabdovirus
	Xanthomonas axonopodis pv. *citri*
	Xylella fastidiosa
California, Arizona	*Spiroplasma citri*
	Oidium tingitaninum (rare)
Florida	*Xanthomonas axonopodis* pv. *citrumelo*
	Radopholus similis (citrus race)
	Elsinoe fawcettii
	Citrus leprosis rhabdovirus
France, Corsica	*Spiroplasma citri*
	Phoma tracheiphila
Japan	Satsuma dwarf virus
	Liberibacter asiaticum (only island off coast)
	Xanthomonas axonopodis pv. *citri*

Import origin countries	Pathogen of concern
South Africa	*Liberibacter africanum*
	Virus-like Impietratura ??
	Xanthomonas axonopodis pv. *citri* (eradicated)
Spain	*Spiroplasma citri* (not a problem)
Vietnam	*Xanthomonas axonopodis* pv. *citri*
	Oidium tingitaninum
	Liberibacter asiaticum

Precautions taken by AQIS to prevent the unwitting entry of exotic pathogens of citrus leave little to chance and legal introductions of citrus bud wood and other genetic material do not appear to provide a pathway for entry.

2.4.2 Illegal importation of citrus nursery stock

Illegal introduction of bud-wood of horticultural crops has been known to occur as growers sought to circumvent quarantine requirements that made access to new genetic material difficult. Based on recent experience with interceptions of other citrus material, the authors suggest that the greatest risk of exotic diseases and their vectors entering Australia on clonal material is likely to come from passengers boarding planes in the Mediterranean/Middle East and in some parts of Asia. Since 1997 AQIS has recorded approximately ten cases were passengers have attempted to smuggle citrus bud-wood into Australia. None of these interceptions were found to be carrying pathogens of quarantine concern to Australia.

While South East Asia represents an area of particular concern to AQIS, Brown (1998) suggests that it is unlikely that whole citrus plants or bud-wood would enter mainland Australia from PNG or Indonesia, since there would appear to be no rational demand for planting material from these sources. If this assumption is right, illegal entry of clonal material through our northern borders may not be a major pathway for entry of exotic pathogens of citrus. On the other hand, there are no readily available sources of 'native' limes in Australia and this may account for many illegal interceptions of limes (see Table 5). The very nature of northern Australia, its sparse population and the difficulty of regulating the movement of traditional peoples in the region indicate a possible pathway for entry of graft transmissible diseases of citrus. Exotic pathogens of concern associated with citrus nursery stock from South East Asia and their vectors are presented in Table 9.

Table 9: Exotic Graft Transmissible Pathogens of Citrus in South East Asia

Pathogen	Transmission	Vectors	Distribution
Citrus tristeza closterovirus (mandarin stem-pitting strain)	The virus is transmitted by vectors and by grafting.	*Toxoptera citricida, T. aurantii, Aphis gossypii* and *A. spiraecola*.	Thailand and Malaysia.
Liberibacter asiaticum	The bacterium could enter Australia through bud-wood, grafted trees, rootstock seedlings.	*Diaphorina citri*	Bangladesh, China, India, Indonesia, Japan, Malaysia, Mauritius, Nepal, Pakistan, Philippines, Reunion, Saudi Arabia, Thailand and Vietnam.
Oidium tingitaninum	The fungus over-winters as dormant mycelium in buds which allows it to be dispersed with planting stock even when this is defoliated.	None.	Tropical and subtropical Asia, Vietnam, India, Florida, Sri Lanka, Uganda, Brazil, Cuba, India, Indonesia, Nepal, Poland, Philippines, Israel, Taiwan, California, Guatemala, Honduras and Mexico.
Satsuma dwarf virus	The virus is transmitted by mechanical inoculation and grafting with infected bud-wood.	Possibly, but unknown.	China, Iran, Japan, Korea, New Zealand and Turkey.
Xanthomonas axonopodis pv. *citri*	Infected propagating material such as bud-wood, rootstock seedlings or budded trees from nurseries.	None.	Asia: Cambodia, China, Indonesia, PNG, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, Japan; South America, Central America, Caribbean, Florida, parts of Africa, Cocos Island, Fiji, Christmas Island.

Exotic graft transmissible diseases of citrus and their vectors in the Mediterranean and Middle East are presented in Table 10.

Table 10: Exotic Graft Transmissible Pathogens of Citrus in the Mediterranean and Middle East.

Pathogen	Transmission	Vectors	Distribution
Citrus chlorotic dwarf virus	Transmissible by grafting and stem-slash inoculation.	*Parabemisia myricae* (Japanese bayberry whitefly)	The eastern Mediterranean region of Turkey.
Phoma tracheiphila	In budwood.	Birds and animals are suspected of being vectors.	Algeria, Tunisia, Cyprus, Georgia, Iraq, Israel, Lebanon, Syria, Turkey, Yemen, Albania, France, Greece, Italy, Mediterranean countries, Russian Federation.
Satsuma dwarf virus	The virus is transmitted by mechanical inoculation and grafting with infected budwood.	Possibly, but unknown.	China, Iran, Japan, Korea, New Zealand and Turkey.
Spiroplasma citri	The pathogen can be graft-transmitted from infected trees.	*Circulifer tenellus* (USA), *Neoaliturus haemoceps* and *N. opacipennis* (Mediterranean area), *N. tenellus*, *Scaphytopius delongi* and *S. nitridus* (leafhoppers).	North Africa, Middle East, Turkey, France, Italy, Spain, New Zealand, Mexico and the USA.
Virus-like Impietratura	The virus-like disease is graft or bud-transmitted.	None.	India, Iran, Italy, South Africa, Tanzania, Turkey, USA and Venezuela.

2.5 Alternative Hosts

AQIS recognises that there are alternative hosts of citrus pathogens, particularly in the Rutaceae (Table 11), and seeks to regulate importation of these to eliminate the entry and establishment of exotic pathogens. There has been no report of pathogens of citrus species entering Australia through movement of these alternative hosts.

Although the Satsuma dwarf virus has been reported to be transmitted by *Phaseolus vulgaris* (Brunt *et al*., 1996), seed transmission has not been reported in other hosts (Garnsey and Koizumi, 1988), including citrus species.

Table 11: Alternative Hosts of Exotic Pathogens of Citrus

Pathogen	Alternative hosts	Import conditions	Transmission along citrus pathways
Citrus tristeza closterovirus	*Aeglopsis chevalieri*	No import conditions	Nursery stock possible, fruit not probable.
	Afraegle paniculata, Fortunella margarita, Pamburus missiones	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	
	Passiflora gracilis	Weed – prohibited by legislation	
	Atalantia *Aegle* *Murraya* *Pamburus*	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	Nursery stock and possibly fruits
	Clymenia	Conditions as per *Citrus* sp.	
	Esemoatus *Clausera* *Menillia* *Hesserethusa* *Citropois*	No import conditions	
Elsinoe fawcettii	*Poncirus trifoliata* *Clausena* *Microcitrus* *Toddalia*	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	By fruit and leaves, possibly by nursery stock.
Liberibacter africanum and *L. asiaticum*	*Fortunella* spp.	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	By fruit, possibly by nursery stock.
Mycosphaerella horii	*Citrofortunella* sp.	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	By leaves.
Oidium similis	*Poncirus* *Aegle marmelos*	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	By leaves, nursery stock and possibly by natural movement.
Phoma tracheiphila	*Poncirus* and *Fortunella* spp.	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	By leaves and nursery stock.
Radopholus citrophilus	Wide host range, including ornamentals, cultivated crops, and many weeds	N/A	Nursery stock.
	Calathea spp. *Musa* spp., *Philodendron* spp., *Anthurium* spp.	Tissue cultures	
	Piper nigrum	Weed – prohibited by legislation	

Pathogen	Alternative hosts	Import conditions	Transmission along citrus pathways
Satsuma dwarf virus	*Chenopodium quinoa*	Tissue cultures	Nursery stock.
	Phaseolus vulgaris	Seed – prohibited except by permit	
	Sesamum indicum, Vigna unguiculata Vigna odoraissimus	Seed. No import conditions	
	Physalis floridana	Prohibited as a host of Moko disease	
Spiroplasma citri	Many non-Rutaceous hosts		By nursery stock.
	Fortunella spp.	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	
Xanthomonas axonopodis pv. *citri*	*Poncirus trifoliata, Fortunella spp., Aegle marmelos, Casimiroa edulis, Eremocitrus glauca, Limonia acidissima.*	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	By fruit, leaves and nursery stock.
	Severinia buxifolia, Swinglea glutinosa	No import conditions	
Xanthomonas pv. *citrumelo*	*Poncirus trifoliata* and its hybrids	Prohibited as alternative hosts of citrus canker, citrus greening and Tristeza	By fruit and leaves.
Xylella fastidiosa	Numerous hosts, peach and Prunus are of concern[1].	N/A	By fruit and nursery stock
	Prunus Coffea Vitis	Approved sources. Restricted access from unapproved sources.	

2.6 Natural Movement of Exotic Pathogens of Citrus

Some exotic pathogens of citrus have the potential to be dispersed over large distances by vectors assisted by air currents; by animal and bird vectors and by wind blown spores. This raises the possibility that exotic pathogens could be introduced into Australia having moved great distances (Thresh, 1983).

2.6.1 Arthropod vectors

While some arthropod vectors may migrate long distances, others are only short fliers. However, with the assistance of wind currents, the latter can also travel great distances (Thresh, 1983). Migration is almost always actively initiated and sustained,

[1] Citrus variegated chlorosis is caused by a strain of *X. fastidiosa* different to those causing Pierce's disease of grapes and phony disease of peaches.

although its termination, and the direction and distance of displacement are often controlled by environmental factors (Farrow and Drake, 1991). Weather has a major influence on migration partly because insects fly relatively slowly and the direction and speed of their migration is strongly influenced by the wind (Farrow and Drake, 1991). Long-distance migration is controlled by large-scale airflows and by weather phenomena associated with major disturbances to these flows. In the tropics and subtropics, migration occurs primarily on the opposing trade-wind and monsoon airflows, and is influenced by seasonal and short-term movements of the boundary between these flows and by disturbances such as tropical troughs and cyclones (Farrow and Drake, 1991).

There has been no recorded case of an exotic pathogen of citrus entering Australia by natural movement. There is, however abundant evidence that migrating aphids, whiteflies, leafhoppers and mites can disperse far, although evidence of long-range dispersal is still based on evidence that is anecdotal or circumstantial (Thresh, 1983). An incursion database maintained by the Office of the Chief Plant Protection Officer indicates that a very small proportion of incursions are the result of windblown introduction. Thus it remains unclear whether long-range dispersal is likely to be a very occasional phenomenon or whether it is a regular feature in the epidemiology of many pathogens with arthropod vectors (Thresh, 1983). In 1986, *Heteropsylla cubana*, a psyllid attacking *Leucaena leucocephala* was detected in North Queensland and presumed to have established after being blown in from SE Asia (Table 14).

The only likely source of vector arthropods by either direct wind-assisted flight is from Papua New Guinea to the Torres Strait Islands and by island hopping to mainland Australia. Indonesian territory is thought to be too distant (Brown, 1998). The nearest pathogen of concern is *Liberibacter asiaticum* and its vector psyllid *Diaphorina citri*. The possibility of its future spread from Indonesia into PNG and perhaps eventually to Australia is probably one of the bigger concerns when considering natural movement of pathogens of citrus into Australia.

There are a number of arthropod vectors of exotic pathogens of citrus (see Table 12).

Table 12: Arthropod Vectors of Exotic Pathogens of Citrus

Pathogen	Means of dispersal	Distribution	Proximity of pathogen host country	Wind direction
Citrus chlorotic dwarf virus	*Parabemisia myricae* (Japanese bayberry whitefly) Active vector	Turkey.	Distance is too great.	Unfavourable
Citrus leprosis rhabdovirus	*Brevipalpus californicus, B. obovatus* and *B. phoenicis* (false spider mite) Inactive vectors	Argentina, Brazil, Paraguay, USA, Uruguay and Venezuela.	Distance is too great.	Unfavourable
Citrus tristeza closterovirus (mandarin stem-pitting strain)	*Toxoptera citricida, T. aurantii, Aphis gossypii* and *A. spiraecola*. Active vectors	Thailand and Malaysia.	Possible. ?	Unfavourable
Liberibacter africanum	*Trioza erytreae* (psyllid) Active vector	Africa, Saudi Arabia and Yemen.	Possible, but very unlikely because of the distance between Africa and Australia.	Favourable westerlies from Africa.
Liberibacter asiaticum	*Diaphorina citri* (psyllid) Active vector	Bangladesh, China, India, Indonesia, Japan, Malaysia, Mauritius, Nepal, Pakistan, Philippines, Reunion, Saudi Arabia, Thailand and Vietnam.	Possible, especially from Indonesia.	Favourable
Spiroplasma citri	*Circulifer tenellus* (USA), *Neoaliturus haemoceps* and *N. opacipennis* (Mediterranean area), *N. tenellus*, *Scaphytopius delongi* and *S. nitridus* (leafhoppers). Active vectors	Found in parts of: Africa, the Middle East, Europe, the Mediterranean, North and South America, New Zealand.	Possible, but very unlikely because of the distance between Africa and Australia.	Westerly winds could be favourable for vectors from Africa.
Witches' broom disease of lime	Suggested: *Hishimonus phycitis* (leafhopper). Active vector	Sultinate of Oman and the United Arab Emirates, India.	Too distant.	No favourable wind currents.
Xylella fastidiosa (all pathotypes)	*Homalodisca coagulata* (Glassy-winged sharpshooter) Active vector Possible vectors include several species of sharpshooters and sucking pests that feed predominantly on xylem fluid.	Parts of South America, USA, Canada, China, Costa Rica, India, Mexico.	Too distant.	No favourable wind currents.

2.6.2 Windborne spores

While the possibility of windborne spores acting as a pathway for entry of exotic pathogens into Australia may seem remote, the incursion of sugar cane smut was thought to have entered and established in the Ord River area by spores blown from Java. Such movement of wind borne spores around the globe and into Australia is determined by general atmospheric circulation, and partly by cyclones.

Exotic pathogens of citrus that are windborne are presented in Table 13.

Table 13: Exotic Pathogens of Citrus with Windborne Spores Suitable for Long Distance Dispersal

Pathogen	Means of dispersal	Distribution	Proximity of pathogen host country	Wind direction
Alternaria limicola	Airborne conidia.	Mexican lime-producing states on the Pacific coast of Mexico.	Distance may be too far.	No favourable wind currents.
Colletotrichum acutatum (KLA strain)	Possibly by wind-blown rain, usually splash dispersed.	Wetter parts of the Caribbean, Zanzibar, the Americas.	Distance may be too far.	Westerly winds could be favourable for spores from Zanzibar.
Colletotrichum acutatum (SGO strain)	Possibly by wind-blown rain, usually splash dispersed.	Argentina, Brazil, Columbia, Dominica and Panama.	Distance may be too far.	No favourable wind currents.
Elsinoe australis	Wind-carried water droplets.	Argentina, Bolivia, Brazil, Cook Islands, Eucador, Fiji, Niue, Paraguay, Samoa, Uruguay.	Possible (?)	No favourable wind currents.
Elsinoe fawcettii	Wind-borne conidia. Only viable for the following night.	The Florida Broad Host Range pathotype is found in the USA, Argentina and Uruguay.	Distance may be too far.	No favourable wind currents.
Mycosphaerella horii	?	Japan, possibly USA (suspected to be mistakenly reported).	Distance may be too far.	No favourable wind currents.
Oidium tingitaninum	Windborne conidia.	Vietnam, India, Florida, Sri Lanka, Uganda, Brazil, Cuba, India, Indonesia, Nepal, Poland, Philippines, Israel, Taiwan, California, Guatemala, Honduras and Mexico.	Possible, especially from Indonesia.	Favourable

Pathogen	Means of dispersal	Distribution	Proximity of pathogen host country	Wind direction
Phaeoramu-laria angolensis	Long-distance dispersal of the fungus is by windborne conidia.	Restricted to the humid tropics in Africa, and Yemen.	Distance may be too far.	Westerly winds could be favourable
Phoma tracheiphila	Birds and animals are suspected of being vectors.	Algeria, Tunisia, Cyprus, Georgia, Middle East, Europe, Mediterranean countries, Russian Federation.	Distance is too far, though dependent on whether bird vectors are migratory.	No favourable wind currents.

Oidium tingitaninum seems to be the only citrus pathogen with windborne spores that is near enough to Australia to permit entry by this means. The conidia of *O. tingitaninum* are reported to be easily dispersed by wind (Narasimhan, 1988), but there are no suggestions that it has been widely dispersed in this way, with little work having been done on its epidemiology.

Dispersal of spores of *Phaeoramularia angolensis* is problematic, even though the direction of wind currents from Africa seems to be favourable for long distance dispersal.

Examples of pathogens and insect pests that are thought to have entered Australia on wind currents are shown in Table 14.

Table 14: Historical Examples of Windborne Introductions into Australia

Pest/pathogen	Means of movement	Detection	First detection
Heteropsylla cubana (Insect)	Windborne from Indonesia.	Northern Queensland	1986
Ustilago scitaminea (Pathogen)	Possibly by airborne spread from Java.	Ord, Western Australia.	20/07/1998
Leeuweni Karny (Insect)	Windborne from Indonesia.	Northern Territory, Cobourg Peninsula.	31/08/1999 (Delimiting survey)
Anascirtothrips sp. (Insect)	Windborne from Indonesia.	Northern Territory, Cobourg Peninsula.	31/08/1999 (Delimiting survey)
Ramphothrips pandens, Pericaria filiformis (Insects)	Windborne from Indonesia.	Northern Territory.	31/08/1999 (Delimiting survey)

2.7 Summary of Pathway Analysis

All pathogens could be introduced on illegal budwood and possibly fruit for some. However, from those pathogens highlighted as threats to citrus in Australia by pathologists, nine were assessed as having a probable pathway for entry into

Australia. These are listed in Table 15. In this matrix, 'No' indicates that entry, while possible, is not assessed as probable. 'Yes' indicates that entry is probable via the pathway indicated.

Table 15: Summary of Pathway Analysis of Exotic Pathogens of Citrus

Pathogen	Legal fruit	Illegal fruit	Illegal leaves	Illegal budwood	Natural	Economic importance	Entry potential
Citrus chlorotic dwarf virus	No	No	No	Yes	No	High	Medium
Citrus tristeza closterovirus (mandarin stem-pitting strain)	No	Yes, but would not go any where	Yes	Yes	No	High	High on illegal budwood from Asia, Florida and South America
Liberibacter asiaticum	No	Yes	Yes *	Yes	Yes	High	High on illegal budwod
Oidium tingitaninum	Yes	Yes	Yes	Yes	Yes	Medium-high	Medium
Phoma traceiphila	Yes, lemon pedunc -les	Yes	Yes	Yes	No	High	High on budwood from Mediterrane an, especially from Italy
Satsuma dwarf virus	No	No	No	Yes	No	Medium	Medium
Spiroplasma citri	No	Yes, but would not any where	No	Yes	No	Medium	Medium
Virus-like Impietratura	No	No	No	Yes	No	Medium	High on budwood from Mediterrane-an
Xanthomonas axonopodis pv. *citri*	No	Yes	Yes	Yes	No	High	Very High

* *Diaphorina citri*, vector of *Liberibacter asiaticum* is a threat.

3. A TARGET LIST OF EXOTIC PATHOGHENS OF CITRUS

The large number of exotic pathogens of citrus makes it difficult for industry to take pre-emptive steps to address the possibility that any one of these may enter and establish in Australia—the resources are simply not available to do this. On the other hand, industry and government can take steps to prepare for the more serious threats—the jargon used by plant heath scientists is target lists.

There is some debate in the ecological literature about the value of target lists, with some people stressing the need to identify priority pests based on careful analysis of entry potential, ecology and potential to adversely impact on the industry (or the environment). Others argue that the track record of those who have sought to identify likely invaders is not good. They also point to crises arising from the invasions of pests and pathogens that cause only minor damage in centres of origin. Be that as it may, the project team sought to develop a target list of high priority exotic pathogens of citrus. The analysis was based on the answers to the questions posed below:

1. Pathway – yes/no

a) Does Australia import the commodity from any of the countries where the pathogen/pest exists? And if so, what is the pathway category? **no/germplasm/fruit/**
b) What is the travel frequency between Australia and any country where the pest/pathogen exists? **high/medium/low**
c) Does the pathogen exist in the Mediterranean, Thailand and/or Vietnam where illegal/traditional trade is known to occur? **yes/no**
d) Have previous interceptions of the pest/pathogen been made and recorded on the Pest and Disease Interception (PDI) database? **yes/no**
e) Is there any evidence of interceptions/incursions that have occurred overseas? **yes/no**
f) Is any country where the pest/pathogen exists located in close proximity to Australia to enable natural introduction? **yes/no**
g) Are there alternate hosts? If so, are any of the alternate hosts imported into Australia from any country where the pest/pathogen exists? **yes/no**

2. Entry potential – high/medium/low

a) What is the chance of the pest/pathogen survival during pre-shipment treatment, transport and quarantine import treatment? **high/medium/low**
b) Ease of detection of the pest/pathogen at entry points? **easy/medium/difficult**
c) Are the morphological characteristics of the pest that will enable natural introduction? **yes/no**

3. Establishment potential – high/medium/low

a) Is the climate in Australia suitable for pest/pathogen establishment? **yes/no**
b) Are there limiting factors (eg. a pathogen might require injury) to pest/pathogen establishment? **yes/no**
c) Is there a history of establishment in Australia and/or overseas? **yes/no**
d) Intended use of citrus import?
e) Is the pest/pathogen likely to be easily detected in the field? **easy/medium/difficult**
f) Are there many hosts of the pest that occur in Australia? **yes/no**
g) What is the reproductive rate and fertility of the pest? **high/medium/low**

4. Spread potential – high/medium/low

a) Is the climate in Australia suitable for spread? **yes/no**
b) Is there evidence of spread into new areas (history overseas)? **yes/no**
c) Are there any known vectors? **yes/no**

d) If so, are they present in Australia? **yes/no**
e) Are there natural enemies of the pest/pathogen in Australia? **yes/no**
f) Are there morphological characteristics of the pest that will enable efficient dispersal? **yes/no**

5. Economic importance – high/medium/low
a) Is there evidence of yield loss and/or biodiversity damage? **yes/no**
b) Severity of the yield loss/biodiversity damage? **high/medium/low**
c) Will the pest/pathogen have an impact on trade? **yes/no**
d) Will there be an increase cost to the current production system? **yes/no**

6. Difficulty of pest control management – easy/difficult
a) Are there efficacious and economically plausible control procedures available? **yes/no**
b) Are the control procedures likely to fit into current Integrated Pest Management strategies? **yes/no**
c) Is there evidence of successful eradication of the pest/pathogen? **yes/no**

The project team's assessments are contained in Table 16, and summarised in Table 17 where exotic pathogens are listed in order of priority for attention by the citrus industry.

Table 16: Target List: Pathogens of Citrus

Y = YES, N = NO; H = HIGH, M = MEDIUM, L = LOW; E=EASY, D = DIFFICULT, b = budwood, f = fruit, l = leaf

	Pathway							**Entry**		**Establishment**					**Spread**					**Econ.**				**Control**		
Pathogen of concern / Priority	**1a**	**1b**	**1c**	**1d**	**1e**	**1f**	**1g**	**2a**	**2b**	**3a**	**3b**	**3c**	**3d**	**3e**	**4a**	**4b**	**4c**	**4d**	**4e**	**5a**	**5b**	**5c**	**5d**	**6a**	**6b**	**6c**
Xanthomonas axonopodis pv. *citri* **Bacterium** High priority	Y b, c,l	H	Y	Y	Y	Y	Y?	H	M	Y	N	Y	b,f ,l	D	Y	Y	N	N	N	Y	H	Y	Y	N	N	Y
	YES							HIGH		HIGH in NT, Qld					MEDIUM. HIGH in NT, Qld					HIGH				MED-DIFF.		
Liberibacter asiaticum **Bacterium** High priority	Y b,f	H	Y	N	Y?	Y	Y?	L	D	Y	N	Y	b,f ,l	D	Y	Y	Y	N	N?	Y	H	Y	Y	N	N	N
	YES							MED.		HIGH in north					HIGH					HIGH				DIFFICULT		
Xylella fastidiosa **Bacterium** Low-Medium priority	Y b,f	H	N	N	Y	N	Y?	L, H b	E	Y	N	Y	b,f	N	Y	Y	Y	N	N	Y	H	Y	Y	N	?	N
	YES							LOW		MEDIUM					HIGH					HIGH				DIFFICULT		
Xylella fastidiosa (CVC pathotype) **Bacterium** Low-Medium priority	N	M	N	Y	Y	N	N?	L, H b	E	Y	N?	Y	b,f	N	Y	Y	Y	N	N	Y	H	Y	Y	N	N ?	N
	YES							LOW		MEDIUM-HIGH					HIGH					HIGH				DIFFICULT		
Colletotrichum acutatum SGO strain (Post bloom fruit drop) **Fungus** Low priority	Y, b	M	N	N	Y	N	N?	M ?	D?	Y	Y	Y	b	Y	Y	Y	Y	N	N	Y	H	Y ?	Y	Y	Y	N
	YES, illegal fruit							MED.-DIFF		MEDIUM (high in tropics)					MEDIUM –HIGH (in tropics)					HIGH				MED-DIFF.		
Colletotrichum acutatum KLA strain (Lime anthracnose) **Fungus** Low priority	N	L	N	N	N	N	N	M	M	Y	Y	N	-	Y	Y	N	N	N	N	Y	M	Y ?	Y	N	Y	Y
	NO							MED.		MEDIUM. In backyards, lot of West Indian Limes in NT					LOW					MEDIUM				DIFFICULT		
Liberibacter africanum **Bacterium** Low-Medium priority	Y b	L	N	N	N	N	Y	M	D	Y	Y	N	b	D	Y	Y	Y	N	N?	Y	H	Y	Y	N	N	N
	YES							MED.		MEDIUM					MEDIUM					HIGH				DIFFICULT		
Citrus tristeza closterovirus (CTV) (mandarin stem-pitting strain) **Virus** Medium-High priority	Y, b	H	Y	Y	Y	Y	Y	L	M ?	Y	N	Y	b,f	N	Y	Y	Y	Y	N?	Y	H	Y	Y	Y	N ?	Y/ N
	YES							LOW		HIGH					HIGH					HIGH				MED-DIFF.		

Elsinoe australis **Fungus** Medium priority	Y, b	M	N?	N	Y	N	N	M	E/D	Y	Y	Y?	b,f	Y/N	Y	N	N	N	N?	Y	H	Y	Y	Y	N?	N?
	YES							MED.		MEDIUM					LOW					HIGH				EASY-MED		
Oidium tingitaninum **Fungus** Medium priority	Y b,l	H	Y	N	Y	Y	N	M	D	Y	Y	Y	b	M	Y	Y	N	N	Y	Y	M	N	Y	N	N?	Y
	YES							MED.		MEDIUM-HIGH					MEDIUM-HIGH					MED.				MEDIUM		
Radopholus citrophilus (*R. similis* race) **Nematode** Low-Medium priority	Y, b	M	N	N	N	N	Y?	L	D	Y	N	N	b	D	Y	N?	N	N	N	Y	M	N?	Y	N	N	N
	YES							LOW-MED.		MEDIUM-HIGH					LOW-MEDIUM					MED.				DIFFICULT		
Witches' broom disease of lime **Mycoplasma-like organism** Low-Medium priority	N	L	N	N	N	N	N	H b	D	Y	N	Y	b	Y?	Y	Y	Y?	N?	N	Y	H	Y	Y	N	N	N
	NO							HIGH		HIGH					HIGH					HIGH				DIFFICULT		
Xanthomonas axonopodis pv. *citrumelo* **Bacterium** Low priority	Y, b	M	N	N	N	N	Y?	H	D	Y	Y	N?	b,f	Y	Y	Y	N	N	N	Y	M	N?	Y	Y/N	Y	N
	YES							HIGH		MEDIUM-HIGH					MEDIUM					MED.				DIFFICULT		
Virus-like Impietratura **Virus-like** (uncharacterised) Medium priority	Y f,b	M	Y	Y	Y	N	N	H b	D	Y	N	Y	b,f	Y?	Y	Y	N	N	N	Y	M	N	Y	N	Y	Y
	YES							HIGH		MEDIUM					MEDIUM					MEDIUM				MEDIUM		
Phaeoramularia angolensis **Fungus** Low priority	N	L	N	N	Y	N	N	M/H	M	Y	Y?	Y	N	M?	Y?	Y?	N	N	N	Y	H	Y?	Y	Y	Y	N
	NO							MED.		LOW-MEDIUM					MEDIUM					HIGH				EASY		
Spiroplasma citri **Mycoplasma-like organsim** High priority	Y, f,b	M	Y	N	Y?	N	Y?	H	D	Y	N	Y	b	M	Y	Y	Y	N	N	Y	M/H	N	Y	N	N	N
	YES							HIGH		MEDIUM					HIGH					MED.				DIFFICULT		
Satsuma Dwarf **Virus** Low-medium priority	Y f,b	M	N?	N	N	Y	Y?	H	D	Y	Y?	Y	b	N?	N?	Y	Y?	N	N	Y	M	N	Y	N	Y	N
	YES							HIGH		MEDIUM					MEDIUM					MED.				DIFFICULT		
Phymatotrichopsis omnivora **Fungus** Low priority	Y f,b	M	N	N	N?	N	Y	L	D	Y?	Y	N	f,b	N?	Y	N	N?	N	N	Y	M	N	Y	N	N	N
	YES							LOW-MED.		LOW-MEDIUM					LOW-MEDIUM					MED.				DIFFICULT		

Citrus leprosis rhabdovirus (CiLV) **Bacilliform virus** Low-Medium priority	Y f,b	M	N	N	N?	N	N?	M ?	?	Y	Y	Y	b	M	Y	Y	Y	Y	N	Y	H	Y	Y	N ?	N ?	N ?
	YES							MED.		MEDIUM					HIGH					HIGH				MEDIUM		
Phoma tracheiphila **Fungus** Medium-High priority	Y f,b	L	Y	N?	Y?	N	Y?	H	D	Y	Y	N?	b,f	N?	Y	Y	N	N?	N?	Y	H	N	Y	N	N	N
	YES							HIGH		LOW-MEDIUM					MEDIUM-HIGH					MEDIUM-HIGH				DIFFICULT		
Mycosphaerella horii **Fungus** Low priority	Y, b	M	N	N	N	N	Y?	M ?	M ?	Y	N?	N	b	Y?	Y	N	N	N	N	Y ?	M	N	Y	Y	Y	N ?
	YES							MED.		LOW					LOW					LOW				EASY		
Alternaria limicola **Fungus** Low priority	N	L	N	N	N?	N	Y	L	D	Y	N?	N	b	Y	Y	N	N	N	N	Y	H	N	Y	Y	Y	N
	NO							LOW- MED.		LOW					LOW					MEDIUM				MED-DIFF.		
Citrus chlorotic dwarf virus **Virus** Medium priority	N	L	Y	N	N	N	N	M	M	Y	N	Y	b	Y?	Y	Y	Y?	Y	N?	Y	H	N	Y	Y ?	Y ?	Y ?
	NO							MED.		HIGH					HIGH					MEDIUM-HIGH				MEDIUM		
Badnavirus associated with citrus yellow mosaic virus **Virus** Low priority	N	L	N	N	N	N	N	L	D	Y	N	N	b?	Y?	Y	N	Y	Y	N	Y	M	N	Y	N	Y	N
	N							LOW		LOW					LOW-MEDIUM					MED				DIFFICULT		
Elsinoe fawcettii (various strains) **Fungus** Medium-High priority	Y, b	H	Y	Y	Y	Y?	N?	M	E	Y	Y	N?	b,f ?	Y	Y	N	N	N	N	Y	H	Y	Y	Y ?	Y	Y ?
	YES							MED.		HIGH					LOW-MEDIUM					HIGH				EASY-MED		

Table 17: Priority Ranking of Exotic Pathogens of Concern on Citrus

Priority ranking	Pathogen
High	*Liberibacter asiaticum*
	Spiroplasma citri
	Xanthomonas axonopodis pv. *citri*
Medium-High	*Elsinoe fawcettii* (various strains)
	Citrus tristeza closterovirus (mandarin stem-pitting strain)
	Phoma tracheiphila
	Citrus chlorotic dwarf virus
	Elsinoe australis
	Oidium tingitaninum
	Virus-like Impietatura
Low-Medium	Citrus leprosis rhabdovirus
	Liberibacter africanum
	Radopholus citrophilus (citrus race)
	Satsuma dwarf virus
	Xylella fastidiosa
Low	*Alternaria limicola*
	Badnavirus associated with citrus yellow mosaic disease
	Colletotrichum acutatum (KLA strain)
	Colletotrichum acutatum (SGO strain)
	Mycosphaerella horii
	Phaeoramularia angolensis
	Phymatotrichum omnivora
	Witches' broom of lime disease
	Xanthomonas axonopodis pv. *citrumelo*

4. REFERENCES

ACGI (1999). Statistics: Citrus fruits – fresh or dried. Imports cleared for home consumption: Twelve months to 30 June 1999. Australian Citrus Growers Incorporated. Paper No. 7-60/7-99, 20 July 1999.

AQIS Bulletin (1999). AQIS heads off threat to Australia's citrus industry… . AQIS Bulletin August 1999, p. 17.

Barkley, P. (1989). Citrus budwood multiplication. *Australian Citrus News* July/August 1989.

Broadbent, P. (1995). Quarantine in relation to Australian citrus imports and exports. *Australasian Plant Pathology* **24**: 145–156.

Brown, A.G.P. (1998). *Pest Risk Analysis of citrus species for the Northern Australian Quarantine Strategy*. A report prepared for the Australian Quarantine and Inspection Service, January 1998.

Brown, E. (1989). Target list of insect pests in Indonesia and Papua New Guinea. Report to NAQS, unpublished.

CAB INTERNATIONAL (1999). Crop Protection Compendium, Global Module. CAB International, Wallingford, Oxon, UK.

CABI/EPPO (1997). "*Xanthomonas axonopodis* pv. *citrumelo*". In: Quarantine Pests for Europe (Eds I.M. Smith, McNamara, D.G., Scott, P.R., Holderness, M. and Burger, B. Pp. 1109–113. CAB INTERNATIONAL, Wallingford, UK.

Farrow, R.A. and Drake, V.A. (1991). Migration. In*: The Insect of Australia: A textbook for students and research workers*. Second Edition. Volume 1. CSIRO Entomology. Melbourne University Press.

Graham, J.H., McGuire, R.G. and Miller, J.W. (1987). Survival *of Xanthomonas campestris* pv. *citri* in citrus plant debris and soil in Florida and Argentina*. Plant Disease* **71**: 1094–1098.

Nairn, M.E., Allen, P.G., Inglis, A.R. and Tanner, C. (1996). *Australian Quarantine: a shared responsibility*. Department of Primary Industries and Energy, Canberra.

Philemon, E.C. (1993). Diseases of citrus. Part 1: Bacterial and fungal diseases. *Harvest Port Moresby* **15**:17–21.

Philemon, E.C. (1994). Diseases of citrus. Part 2: Viral diseases. *Harvest Port Moresby* **16**: 5–9.

Thresh, J.M. (1983). The long-range dispersal of plant viruses by arthropod vectors. *Phil. Trans. R. Soc. Lond*. B **302**: 497–528.

Timmer, L.W., Garnsey, S.M., and Graham, J.H. 2000. *Compendium of Citrus Diseases*, 2nd Ed.. APS Press. St Paul, Minnesota, USA.

Vogelzang, B. (1999). Northern Australia Quarantine Strategy (NAQS) Scientific Program. In: *Plant Health in the New Global Trading Environment: Managing Exotic Insects, Weeds and Pathogens* (Eds C.F. McRae and Dempsey, S.M.). Proceedings of a workshop, Canberra, 23–24 February, 1999. National Office of Animal and Plant Health.