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Pest risk assessment of insects in sea cargo containers

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Abstract A survey of the floors of 3001 empty sea cargo containers in storage was undertaken to estimate the quarantine risk of importing exotic insect pests into Australia, with special reference to pests of timber. More than 7400 live and dead insects were collected from 1174 containers. No live infestations of timber-feeding insects were recorded, but feeding damage detected in one floor indicates a low risk of importing colonies of timber pests in containers. The survey collection of dead insects demonstrates that containers are regularly exposed to economically important quarantinable insects, including timber pests (bostrichids, curculionids, cerambycids, siricids and termites), agricultural pests (including *Adoretus sinicus*, *Adoretus* sp., *Carpophilus obsoletus* and *Philaenus spumarius*), and nuisance pests (vespids and *Solenopsis* sp.). Stored product pests were found in more than 10% of containers. The assessment of pest risk associated with shipping containers is discussed in terms of the quantity and quality of opportunities for exotic insects to establish via this pathway.

Key words pest risk analysis, quarantine, shipping containers, timber pests.

INTRODUCTION

One of Australia's great natural advantages with respect to quarantine and the introduction of pest species has been its relative isolation. The importance of preventing entry of potential pest species was recognised early in the formation of the Australian Quarantine and Inspection Service (AQIS). Although many deliberately and accidentally introduced species have become pests, many potential pest species have yet to establish in Australia, either by chance or design. *Quarantine Proclamations* (1998) of the Quarantine Act (1908) (the regulations that govern quarantine in Australia) cover a very broad range of insect and pathogen pests. The threat that these species pose to our biosecurity, if introduced, has rarely been estimated. Part of that assessment is to ascertain the likely pathways of introduction, and to determine just how many insects arrive by various means.

With the adoption of the General Agreement on Tariffs and Trade (GATT) in the Uruguay round of negotiations in 1993, a fundamental change occurred in the discipline of plant quarantine and its administration. The prime purpose of the GATT negotiations was the reduction of tariff barriers and, in recognition that technical barriers to trade may be erected where others had been removed, the GATT included an agreement on Sanitary and Phytosanitary matters (the SPS Agreement). The drawing up of import restrictions in the context of liberalisation of trade has led to quarantine considerations becoming of major significance. Essentially the SPS agreement recognised that technically formulated restrictions on the movement of commodities were justified, but that the systems should operate within a set of standards. A country that formulated import restrictions according to these standards would not be challenged under the GATT (now the World Trade Organisation (WTO)).

The GATT recognised that it did not have the technical expertise to set plant quarantine standards and indicated that the International Plant Protection Convention (IPPC) should be the body to set international standards in relation to phytosanitary matters. Since 1992 the IPPC Secretariat located within the Plant Protection Service, Food and Agriculture Organization (FAO) Rome, has administered a standard setting procedure based on a system of Technical Working Groups, consultation with regional plant protection organisations, government consultation and final international adoption through the FAO Conference system.

The IPPC is based on the principles of scientifically justifiable and transparent quarantine measures. The convention also incorporates the principle of necessity. The present paper shows that the wooden components of sea cargo containers are constantly exposed to timber-infesting insects from many sources, not the least being from dunnage (low-grade timber used for packing and stabilising goods). There is a necessity to preclude the container wooden components from infestation because they can be in service for many years. The requirement for all wooden components of cargo

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containers entering Australia to be treated has not been previously reviewed.

Approximately 25 years ago, when sea cargo containers were mostly composed of wooden material, AQIS introduced a requirement that wooden components of cargo containers had to be either registered as permanently treated to AQIS standards or inspected every time that container was landed in Australia. Inspection required the container to be stopped, fully unloaded and approved free of pests prior to release regardless of whether the cargo was of quarantine concern or not. By 1995 more than 5 million containers were registered as treated to AQIS's standards.

In more recent years cargo containers have been built mainly of steel with plywood or timber floors (dry boxes). This reduction in risk has been offset by a significant increase in the amount of container traffic, which has made it almost impossible to detect unregistered containers entering Australia. In 1996 approximately 770 000 shipping containers entered Australian ports, 88% of which were designated as dry boxes. Containers that had approved floor treatments registered with AQIS were considered to be low risk and given immediate FCL (full container lot) release. Containers without floor treatments registered with AQIS were considered to be untreated. Although most of these containers had some floor treatment applied, the quality of the treatment was not guaranteed by the container owners, which placed them in a high-risk category. Previously there has been no assessment of what sort of quarantine risk is in fact posed by dry boxes entering Australia. The outcome of this review is that AQIS requires treatment of wooden components of sea cargo containers (to the standard set by AQIS), but the treated containers are no longer required to be registered. Verifications will be carried out by random inspection of containers and sampling with analysis of the wooden components.

A report into quarantine in Australia was carried out by Nairn *et al*. (1996). The outcomes of the container review coincide with the recommendations of that report. The report emphasised issues such as the continuum of quarantine (pre-border, border and post-border) methods. The treatment of wooden components keeps the risk of infestation offshore, and minimises the risk of the container floors carrying timber-infesting insects into Australia as well as facilitating speedy movement of cargo because the containers themselves are not stopped to be inspected.

Here, we assess the probability of importing harmful exotic insects in the floors of containers by undertaking a survey of imported dry boxes. Incidental to the original purpose of the review to investigate infestations or potential infestations of timber insects in the wooden components of containers, large numbers of non-timber-infesting insects were found both live and dead. These were also identified and are included in the present report.

METHODS

After destuffing, containers are stored until they are required. The turnaround time for a container can vary from a few days to a few months. Our survey was carried out at nine container parks around Brisbane from 28 February 1996 to 20 August 1996. We inspected 2500 unregistered and 501 registered containers of unknown origin. Both 6-m and 12-m containers were inspected. The time spent searching the floors of each 6-m container ranged from approximately 3 min for a washed plywood floor, to 30 min for containers with residual material and large numbers of insects. The time taken to inspect 12-m containers was approximately double that for a 6-m container.

We used a torch to search the wooden components of containers for timber insects, bore holes, timber damage and frass. All holes in the timber were inspected thoroughly and excavated for signs of current insect activity. All insects collected (including non-timber insects) were identified to order or family, and preserved in 80% ethanol before being sent for further identification to the Biological and Chemical Research Institute (BCRI) in New South Wales (NSW) at Rydalmere. The full collection of insects that arrived intact was mounted and is now housed at the Orange Agricultural Institute.

Containers may be stored for extended periods and many insects were in poor condition due to predation and decay. Specimens that were unlikely to be identified to a useful level were not collected unless they were from groups that posed a high risk to timber, such as the Isoptera, Siricidae, Bostrichidae and Cerambycidae. Although we aimed to collect all insects from every container, the diminishing returns of insects collected for the amount of time spent searching made this untenable. A proportion of small insects (< 2 mm) are likely to have been missed, as well as some insects that are likely to be found in crevices in wood. On a few occasions, containers with large amounts of organic residue carried hundreds of dead insects. When it was not feasible to collect all individuals, representatives of each species encountered were taken and a count or an estimate was made of total numbers. If large numbers of live insects were encountered, the container was swept clean and all living insects were removed and preserved.

RESULTS

Description of the collection

A total of 7861 arthropods was recorded from the interior of containers sampled. The majority (7426) were adult or immature insects, or remnants of insects (wings, pupal cases, etc.). Insects were found in 1174 (39%) of the 3001 containers inspected. Live insects accounted for 19% (1339) of the total, and were found in 176 containers (6%). Approximately half of the live insects were immatures. The collection encompasses 18 insect orders and at least 114 families. Most of the taxa identified to species or genus were detected in only one or two containers (Fig. 1).

Other groups collected were spiders (72), isopods (39), mites (25), millipedes (16), centipedes (3), scorpions (3) and

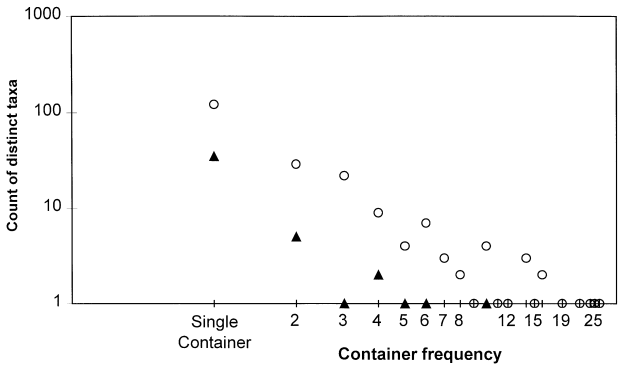

Fig. 1. Total number of (○) distinct insect taxa identified to genus and species, and (▲) total number of all exotic insect groupings found in each container frequency class. *Tribolium castaneum*, which was found in 248 containers, is not included in the figure.

ticks (1). Three exotic isopods from the genus *Oniscus* (Oniscidae) were found in one container. The great majority of the 271 specimens that were not identified to class are likely to be of insect origin.

Due to the poor quality of some of the material, approximately 10% of the insects (773) broke up in transit from Brisbane to Rydalmere and were neither mounted nor identified. An inventory of the insects collected is included in Appendix I, and there is still an opportunity to identify many of the specimens further.

Timber pests

No live exotic timber-feeding insects, or signs of active timber infestations, were found in the wooden floors of any containers in our survey. Assuming that the containers surveyed constitute a random sample, the probability of encountering no live infestations for a given proportion of infested containers (P) will follow a binomial distribution:

$$P[X = x] = \left\lceil \begin{matrix} n \\ x \end{matrix} \right\rfloor p^x(1-p)^{n-x} \quad \text{where:}$$

n is the number of containers inspected, x is the number of containers found containing an infestation and p is the actual proportion of all containers infested.

For our purposes, we need to calculate the probability (P) of finding no infested containers (x = 0) in 2500 (n). The equation reduces to

$$P[X = 0] = (1-p)^{2500}$$

Considering only unregistered containers, there is a 95% probability that we would encounter an infestation if the proportion of infested containers was greater than 1 in 835. At the current rate of 230 000 unregistered containers imported annually, we estimate that less than 300 of these would contain live insect infestations in their timber components.

Although no live infestations were detected, feeding damage to a plywood floor was found in one unregistered container that had been fumigated with methyl bromide in Kuala Lumpur, Malaysia, 1 month earlier. Parts of the bostrichid beetle, *Xylothrips religiosus* (Boisduval), were found in the holes that extended through the first ply of wood but stopped at the first line of glue and were shallow enough to leave the beetles exposed to physical damage. The floor treatment listed on the approval plate of this container (Celcure A) was unsuitable for the treatment of plywood floors. Chemical analysis of the floor material, carried out by the Queensland Department of Primary Industries Forestry Branch, indicated that the floor had been treated to very low levels of copper (0.006%), chromium (0.001%) and arsenic (0.003%). These levels are well below the standard required by AQIS.

Insects that have the potential to infest timber were found in 104 (3.5%) of the containers inspected and 15% of these containers had more than one species of timber pest (Table 1). Only one of these was found alive, an unidentified weevil from the subfamily Scolytinae, which was well represented in the survey. Although no infestations were found in the floors of containers, 45 dead insects that are timber pests of quarantine concern were discovered on the floors of shipping containers. The bostrichids *Heterobostrychus aequalis* (Waterhouse) and *Sinoxylon anale* Lesne were the most commonly encountered species that were fully identified. The large number of termites (87) found in 28 containers may include some exotic species.

Quarantinable insects and stored-product pests

Excluding timber pests, 79 insects from exotic taxa were found in 50 containers (Table 2). Only one live exotic insect was found, the lathridiid beetle *Aridius nodifer* (Westwood), a fungus feeder not considered to be of economic importance.

A number of exotic pest species that are aggressive colonisers were recovered from containers. The most significant agricultural pests collected were *Adoretus sinicus* Burmeister, *Adoretus* sp., *Carpophilus obsoletus* Erichson, *Exitianus indicus* (Distant) and *Philaenus spumarius* Linnaeus. Nuisance pests included several species of Vespidae and an unidentified species of *Solenopsis*.

Pests of stored products were found in at least 333 containers and live insects were found in 20% of these containers. The number is likely to be higher considering that many of the immature insects could not be identified to species. At least 49 of these containers (15%) were infested with more than one species of stored product pest. The most frequently found insects in the survey were the cosmopolitan stored product pests, *Tribolium castaneum* Herbst, *Dermestes maculatus* De Geer, *Lasioderma sericorne* (Fabricius), *Necrobia rufipes* (De Geer) and *Oryzaephilus mercator* Fauvel. These were often associated with residual foodstuffs, mostly cereals, that had not been cleaned from containers.

Table 1 Timber pests and potential timber pests taken from containers

Order/Family	Species	No. insects (containers)	Pest status	Hosts and other information
Coleoptera				
Anobiidae	*Anobium punctatum*	1 (1)	Serious timber pest	Pest of pine timber in southern Australian states
Bostrichidae	*Dinoderus minutus*	15 (2)	Mainly stored products pest	Hosts (bamboo, maize, rice, dried cassava)
	*Heterobostrychus aequalis**	17 (10)	Pest of seasoned timber	Hosts (rattan, reeds, *Koompassia malaccensis*, rubber wood). Considered to be an exotic species of concern. Limited establishment in Australia. Commonly intercepted by quarantine in timber products.
	Lyctus brunneus	7 (6)	Serious timber pest	Hosts (karri and jarrah, *Agathis*, seasoned timbers, plywood, hardwoods)
	Lyctus sp.	1 (1)	Serious timber pests	
	Minthea rugicollis	4 (4)	Serious timber pest	Hosts (building and furniture timbers, cotton stalks, reeds)
	*Sinoxylon anale**	8 (6)	Timber pest	Hosts (*Dalbergia sissoo*, *Acacia tortillis*, fuel wood, *Delonix regia*, cashew wood, rubber wood)
	Unknown sp.	4 (3)	Serious timber pests	
	Xylopsocus sp.	2 (2)	Minor pests of logs	Hosts (*Endospermum peltatum*)
	Xylothrips religiosus	3 (1)	Occasional pest	Hosts (seasoned timber). Occasional serious pest in dead trees in Papua New Guinea
	Xylothrips sp.	1 (1)	Pests of logs	
Cerambycidae	*Arhopalus* sp.*	7 (4)	Serious pests	*A. rusticus*, *A. tristis* and *A. syriacus* are pests of *Pinus* spp.
	*Aromia moschata**	2 (1)	Minor pest	Hosts (willow)
	Clytus sp.	1 (1)	Minor pest of trees	
	Phoracantha semipunctata	2 (2)	Serious pest of trees	Hosts (many eucalypt species). Still colonising countries establishing *Eucalyptus* plantations
	Phoracantha sp.	1 (1)	Serious pest	Hosts (eucalypts). *P. semipunctata* is the major pest but *P. recurva* can also cause serious damage
	*Tetropium castaneum**	1 (1)	Serious timber pest	Hosts (spruce (*Picea abies*), conifers, larch)
	Unknown sp.	16 (13)	Serious timber pests	
Curculionidae	(Scolytinae) unknown sp.	24 (15)	Many serious pests	
	Euwallacea sp.	20 (3)	One minor timber pest	*E. fornicatus* is a major pest of tea but has been recorded causing damage to forest plantations of *Gmelina arborea* and *Paraserianthes falcataria* in India.
	Hypothenemus sp.	1 (1)	One major, some minor pests	*H. hampei* (coffee, macadamia); *H. obscurus* (macadamia, acacia wood, rubber); *H. areccae* (fruit crops); *H. birmanus* and *H. sundaensis* (*Sapodilla*)
	Ips grandicollis	10 (1)	Major pest of trees	Hosts (*Pinus radiata* and *P. pinaster*). Introduced to Australia, SA 1943, WA 1952, Eastern States 1980–85
	Xyleborus sp.	16 (4)	Many pests of trees and logs	*X. dispar* (*Crataegus* and *Sorbus*); *X. perforans* (logs); *X. affinis, X. spinulosus* and *X. ferrugineus* (tropical pines); *X. lecontei* (coffee); *X. barbatus* and *X. metacuneolus* (shade trees)
Platypodidae	*Platypus parallelus*	3 (2)	Pests of recently killed trees	Borers of trunks and large branches of recently killed trees and may cause economic damage to unmilled logs or standing dead timber. First recorded in Queensland 1968
	Unknown sp.	8 (2)	Minor timber pests	
Hymenoptera				
Formicidae	*Camponotus* sp.	6 (1)	Serious timber pests	
Siricidae	*Sirex juvencus**	3 (2)	Potential major pest	Hosts (*Pinus* spp., silver fir)
	*Urocerus gigas**	1 (1)	Potential major pest	Hosts (larch, *Pinus* spp.) Damaged trees may be attacked by *U. gigas* which introduces a sap wood decay fungus, *Amylostereum chailletii*
	Urocerus sp.*	2 (2)	Potential major pest	
Isoptera				
Kalotermitidae	Unknown sp.*	4 (1)	Major timber pests	
Rhinotermitidae	*Coptotermes* sp.	20 (1)	Major timber pests	
Rhinotermitidae	Unknown sp.	45 (15)	Major timber pests	
Unknown	Unknown sp.	18 (11)	Many serious timber pests	

*Insects known to be exotic or of quarantine concern.

Table 2 Exotic insects other than potential timber pests found in shipping containers

Order/Family	Species	No. insects (containers)	Pest status	Hosts and other information
Blattodea				
Blattidae	Unknown sp.	1 (1)		
Coleoptera				
Brentidae	*Baryrhynchus* sp.	1 (1)		
Coccinellidae	*Adalia bipunctata*	4 (4)		Insect predator
	Coccinella septempunctata	2 (1)		Insect predator
	Unknown sp.	1 (1)		
Cryptophagidae	*Cryptophagus varus*	1 (1)	Minor stored product pests	
Curculionidae	Unknown sp.	1 (1)		
Dermestidae	*Trogoderma megatomoides*	4 (1)		
Lathridiidae	*Aridius nodifer*	9 (5)		Fungus feeder
	Thes bergrothi	1 (1)		
Nitidulidae	*Carpophilus obsoletus*	1 (1)	Stored product pest	Hosts (*Phoenix dactylifera*, figs, garlic, *Litchi chinensis*, maize, onions)
Scarabaeidae	*Adoretus sinicus*	2 (1)	Major agricultural pest	Larvae attack the roots of over 255 plant species including: apples, ginger, maize, *Phaseolus vulgaris*, *Pinus strobus*, raspberries, roses, snap beans, strawberries, turf. An unsuccessful biological control program was carried out against this species in Hawaii
	Adoretus sp.	1 (1)	Includes major agricultural pests	*Adoretus* spp. are serious quarantine threats. *A. versutus* Harold has been recently been introduced to various Pacific islands. *A. fusculus* Fåhraeus (sugarcane), *A. ictericus* Burmeister (pineapple), *A. testaceus* Hope (rice) and *A. versutus* (cocoa, *Hibiscus tiliaceus*)
Silvanidae	*Silvanus platanus*	4 (1)	Minor stored product pests	Distribution limited to Canada, Northern Russia
Tenebrionidae	Unknown sp.	2 (2)		
Trogositidae	*Lophocateres pusillus*	2 (2)	Minor stored product pests	
Hemiptera				
Aphrophoridae	*Philaenus spumarius*	1 (1)	Occasional pest	Hosts (*Eucalyptus?*, lucerne, *Anaphalis margaritacea*, grasses, *Cirsium arvense*, *Calluna vulgaris*). Introduced to New Zealand 1960
Cicadellidae	*Arawa* sp.	1 (1)		
	Exitianus indicus	1 (1)	Occasional pest	Wide range of economically important hosts
Delphacidae	*Toya* sp.	7 (1)	Includes some pest species	*Toya propinqua* (Fieber) is a widespread species recorded as a pest of bermudagrass, cotton and oats. Other species recorded as pests
Flatidae	Unknown sp.	1 (1)		
Hymenoptera				
Chrysididae	*Chrysis ignita*	1 (1)		
Formicidae	*Anoplolepis* sp.	2 (1)	Potential pest	*A. longipes* (Jerdon) and *A. custodiens* F. Smith, are predatory ants that have been recorded as pests as well as biocontrol agents
	Cardiocondyla sp.	1 (1)		
	Ectatomma sp.	1 (1)		
	Odontomachus sp.	1 (1)		
	Solenopsis sp.	1 (1)	Serious nuisance pests	*S. invicta* Buren and *S. richteri* Forel, are targets of intensive control programs in the USA after establishing from South America
Ichneumonidae	*Rhyssa persuasoria*	1 (1)	Beneficial predator	Parasitoid released unsuccessfully in Australia for the control of *Sirex noctilio* Fabricius
Megachilidae	Unknown sp.	1 (1)		
Vespidae	*Polistes gallicus*	3 (3)	Nuisance pest	
	Vespula austriaca	1 (1)	Nuisance pest	
	Vespula rufa	1 (1)	Nuisance pest	
	Vespula sp.	2 (2)	Nuisance pests	Species of *Vespula* are aggressive colonisers
Lepidoptera				
Lycaenidae	*Jamides* sp.	1 (1)	Some minor pests	*J. alecto* (Felder) is a minor pest of cardamom
Nymphalidae	*Nymphalis milberti*	1 (1)		
Sphingidae	*Deilephila* sp.	1 (1)	Some minor pests	*D. elpenor* (L.) is a minor pest of *Pinella ternata* and other herbs and *D. nerii* (L.) is a pest of oleander and closely related plants

DISCUSSION

Insects found in the present survey include species that pose a threat to Australian agriculture, forestry and amenity. The number of containers searched represents the equivalent of less than 2 days of container imports for Australia. Quarantine pest risk assessment deals with the likelihood of rare events occurring and, despite surveying 3001 containers, we are likely to have encountered only a small fraction of the range of insect species that are associated with containers. From biodiversity studies we would expect that the frequency of insect species found would resemble a log-normal distribution. That is, that most species would be found in a very low proportion of containers while a relatively few species would be found in a high proportion of containers. If the present survey had yielded a large proportion of the total insect fauna associated with containers, we would not expect the overwhelming predominance of insect species found only in single containers. Low interception rates prevent us from quantitatively assessing the risk posed by individual taxa, a problem common to most quarantine pest risk assessments (Nunn 1997). The data taken together, however, indicate the scale at which risk assessment via this pathway needs to be investigated.

Analysis of timber floors as a pathway for the introduction of exotics can be examined directly by the presence of active infestations, and indirectly by the determination of container contents susceptibility and the exposure rate of floors to species of quarantine concern. The proportion of containers imported with active infestations of exotic timber pest in their floors is extremely low. Considering the high volume of container traffic and the frequency with which containers come into contact with potentially serious timber pests, the risk associated with untreated wooden components is not negligible. Although many species of wood-boring insects are unable to be detected until they emerge (Wylie & Yule 1977), the lack of apparent damage to the floors of containers suggests that the timber pests collected are more likely to be associated with the cargo carried in containers, particularly timber dunnage, rather than the floors themselves. Introductions of exotic timber pests are known in dunnage (Ciesla 1993), so it is essential that dunnage is removed from containers and destroyed regardless of the treatment applied.

The only species found attacking container floors, *Xylothrips religiosus* (Boisduval), is recorded from northern Australia, Melanesia, Indonesia and the tropical Pacific (Fisher 1950) and the Malayan Peninsula, and is not considered a serious quarantine concern. It has been intercepted by NSW quarantine twice in shipments of hardwood from New Guinea and Melanesia in the 1950s (Chadwick & Nitikin 1968), and has been recorded from shipments entering through the Port of Brisbane from 1969 to 1976 (Wylie & Yule 1977) and from 1977 to 1985 (Wylie & Peters 1987). Detection of this beetle indicates that floors of containers are susceptible to attack by insects if they are improperly treated.

Most of the timber insects identified to species level are known from Australian records, although several have established only in the last 50 years. *Heterobostrychus aequalis* and *S. anale* have been found in localised colonies in Australia and are of quarantine concern, although they are not quarantinable because they are not subject to official control (AQIS 1992; Brenton Peters, QDPI Forestry, pers. comm. 1997). Several of the exotic timber species collected are known from quarantine collections. For instance, the siricids *Urocerus* spp. have been intercepted by quarantine in NSW (Chadwick & Nitikin 1969) and the Port of Brisbane (Wylie & Peters 1987). A number of potential timber pests were unable to be identified to species and it is likely that some of these are exotic. Of special note are the Bostrichidae, Cerambycidae, Scolytinae and a large number of Isoptera.

Many of the exotic species found are considered to be innocuous, although some serious quarantinable pests were collected that have recently established in Pacific countries. Two specimens of Chinese rose beetles, *A. sinicus,* were collected, as well as another beetle identified to the same genus. An unsuccessful biological control program was carried out against *A. sinicus* in Hawaii, while other *Adoretus* spp. have recently been introduced to various Pacific islands (Beardsley 1993; Tsutsumi *et al*. 1993). *Philaenus spumarius* Linnaeus is another pest coloniser that was introduced into New Zealand (Hamilton & Morales 1992). Vespidae are mainly nuisance pests, although *Vespula vulgaris* (Linnaeus), which has established recently in Australia, reduces honey production through hive robbing and competition (Clapperton *et al*. 1989). Many species in this family are aggressive colonisers and their prevalence in shipping containers suggests this as a possible pathway for their arrival in Australia.

Organic residues were found in many of the containers which may have attracted and supported insect colonies, especially stored product pests. Containers that harbour infestations of local insects may threaten Australia's international quarantine relationships when they are exported. For example, the cerambycid *Phoracantha semipunctata* (Fabricius) has breached quarantine in countries with established eucalypt plantations and become a significant pest (Ciesla 1993). Maintaining container cleanliness will reduce the likelihood of exporting quarantine threats, as well as reduce the potential for colonies of exotic species or strains to increase in size and establish. There is a need to shift the onus for pest risk management onto commercial operators. Interception of pests by quarantine inspectors on high volume commodities cannot be expected to act as a significant barrier to pest establishment, where the proportion of exotics detected can only ever be a small fraction of those imported. Despite low interception rates, containers that pose a high quarantine risk must be identified for inspection to ensure that treatments comply with Australian quarantine standards.

The quantity of other exotic insects found in containers, including some major agricultural pests and aggressive colonisers, establishes that this is a pest risk pathway that warrants attention. To further quantify the risk, we need to experimentally determine the proportion of quarantinable insects that arrive alive, and whether deaths en route can be attributed to transport conditions, quarantine treatments, storage conditions or predation. Quantifying establishment potential of newly arrived exotics after they disperse in search of resources

is problematic and carries the most uncertainty in virtually all quarantine pest risk assessments. Determination of entry rates can be achieved with relatively low degrees of uncertainty, and in some cases this may be enough to give us enough confidence in our risk management strategies to forgo anything more than a qualitative assessment of establishment potential. It is essential that national plant protection organisations collect, collate and disseminate information from intensive systematic inspections if we are to achieve quantitative analyses of pest risk that satisfy international trade requirements.

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APPENDIX 1

Inventory of insects collected in a survey of 3001 sea cargo containers stored in Brisbane container parks from February to September 1996*

Species	No. containers	No. insects
BLATTODEA		
Blattellidae		
Blattella germanica (L.)	2	4
Blattella sp.	1	2
Robshelfordia sp.	1	3
Unknown sp.	15 (1)	19 (100)
Total Blattellidae		128
Blattidae		
Periplaneta americana (L.)	1	1
Periplaneta australasiae (Fabricius)	2	2
Periplaneta sp.	18 (7)	28 (9)
Polysosteria sp.	1	1
Unknown sp.	18 (2)	28 (4)
Unknown sp.†	1	1
Total Blattidae		74
Ectobiidae		
Ectobius sp.	1	1
Unknown sp.	1	1
Total Ectobiidae		2
Unknown family		
(Ectobiidae cont.)		
Unknown sp.	37 (11)	44 (12)
Total unknown family		56
Total Blattodea		260
COLEOPTERA		
Anobiidae		
Anobium punctatum (De Geer)	1	1
Lasioderma serricorne (Fabricius)	22 (5)	130 (11)
Lasioderma sp.	1	1
Ptinus fur (L.)	1	1
Ptinus sp.	1	1
Stegobium paniceum (L.)	3	3
Unknown sp.	7	11
Total Anobiidae		159
Anthicidae		
Anthicus sp.	2	2
Unknown sp.	7 (3)	41 (3)
Total Anthicidae		46

APPENDIX 1 *continued*

Species	No. containers	No. insects
Bostrichidae		
Dinoderus minutus (Fabricius)	2	15
Dinoderus sp.	1	1
Heterobostrychus aequalis (Waterhouse)†	10	17
Lyctus brunneus (Stephens)	6	7
Lyctus sp.	1	1
Minthea rugicollis (Walker)	4	4
Rhyzopertha dominica (Fabricius)	6 (2)	7 (2)
Rhyzopertha sp.	6	9
Sinoxylon anale Lesne†	6	8
Unknown sp.	3	4
Xylopsocus sp.	2	2
Xylothrips religiosus (Boisduval)	1	3
Xylothrips sp.	1	1
Total Bostrichidae		81
Brentidae		
Baryrhynchus sp.†	1	1
Total Brentidae		1
Cantharidae		
Unknown sp.	1	1
Total Cantharidae		1
Carabidae		
Unknown sp.	25	39
Total Carabidae		39
Cerambycidae		
Arhopalus sp.†	4	7
Aromia moschata (L.)†	1	2
Clytus sp.	1	1
Phoracantha semipunctata (Fabricius)	2	2
Phoracantha sp.	1	1
Tetropium castaneum (L.)†	1	1
Unknown sp.	13	16
Total Cerambycidae		30
Chrysomelidae		
Cryptocephalus iridipennis Chapuis	1	1
Lema trivittata Say	1	2
Unknown galerucerine	3	4
Unknown halticine	7	11
Unknown sp.	8	10
Total Chrysomelidae		28
Cleridae		
Necrobia ruficollis (Fabricius)	1	1
Necrobia rufipes (De Geer)	21 (2)	60 (52)
Unknown sp.	5	7
Total Cleridae		120
Coccinellidae		
Adalia bipunctata (L.)†	4	4
Coccinella septempunctata L.†	1	2
Coccinella transversalis Fabricius	5	5
Coelophora inaequalis (Fabricius)	1 (1)	1 (1)
Unknown sp.	10 (2)	11 (6)
Unknown sp.†	1	1
Total Coccinellidae		31
Cryptophagidae		
Cryptophagus varus Woodroffe & Coombs†	1	1
Unknown sp.	1	2
Total Cryptophagidae		3
Cucujiidae		
Cathartus sp.	1	2
Cryptolestes sp.	2	6
Total Cucujiidae		8
Curculionidae		
Euwallacea sp.	3	20
Hypothenemus sp.	1	1
Ips grandicollis (Eichhoff)	1	10
Mandalotus sp.	1	1
Sitona lineatus L.	1	1
Sitophilus oryzae (L.)	5 (1)	5 (1)
Sitophilus sp.	14 (5)	46 (18)
Sphenophorus brunnipennis (Germar)	1	1
Unknown scolytine	14 (1)	23 (1)
Unknown sp.	18 (1)	26 (1)
Unknown sp.†	1	1
Xyleborus sp.	4	16
Total Curculionidae		172
Dermestidae		
Anthrenocerus sp.	1	1
Anthrenus sp.	2 (2)	2 (2)
Attagenus sp.	4	12
Dermestes ater De Geer	1	1
Dermestes maculatus De Geer	11 (3)	46 (253)
Dermestes sp.	2	21
Trogoderma megatomoides Reitter†	1	4
Trogoderma sp.	1	1
Unknown sp.	8 (3)	23 (5)
Total Dermestidae		371
Dytiscidae		
Rhantus suturalis Macleay	1	1
Unknown sp.	1	1
Total Dytiscidae		2
Elateridae		
Agrypnus sp.	1	1
Conoderus sp.	1	1
Unknown sp.	9	14
Total Elateridae		16
Laemophloeidae		
Cryptolestes sp.	2	3
Laemophloeus sp.	2	2
Unknown sp.	4	7
Total Laemophloeidae		12
Lathridiidae		
Aridius nodifer (Westwood)†	4 (1)	8 (1)
Corticaria sp.	3	3
Lathridius minutus (L.)	5	12
Thes bergrothi (Reitter)†	1	1
Unknown sp.	1	1
Total Lathridiidae		26
Mordellidae		
Unknown sp.	1	1
Total Mordellidae		1
Mycetophagidae		
Typhaea stercorea (L.)	5 (1)	11 (2)
Total Mycetophagidae		13

APPENDIX I *continued*

Species	No. containers	No. insects
Nitidulidae		
Brachypeplus sp.	0 (1)	0 (2)
Carpophilus hemipterus (L.)	5 (1)	18 (1)
Carpophilus obsoletus Erichson†	1	1
Carpophilus sp.	4	6
Unknown sp.	13 (1)	21 (10)
Total Nitidulidae		59
Platypodidae		
Platypus parallelus Fabricius	2	3
Unknown sp.	2	8
Total Platypodidae		11
Scarabaeidae		
Adoretus sinicus Burmeister†	1	2
Adoretus sp.†	1	1
Dasygnathus sp.	1	1
Harmogaster sp.	1	1
Heteronychus arator (Fabricius)	1	3
Heteronyx sp.	1	1
Onthophagus sp.	1	1
Phyllotocus macleayi Fischer	1	1
Sericesthis sp.	1	1
Unknown sp.	16	22
Total Scarabaeidae		34
Silvanidae		
Ahasverus advena (Waltl)	15 (4)	22 (6)
Oryzaephilus mercator (Fauvel)	10 (5)	36 (10)
Oryzaephilus surinamensis (L.)	4 (7)	6 (22)
Oryzaephilus sp.	1	1
Silvanus platanus Germar†	3	6
Silvanus unidentatus Olivier	6	11
Silvanus sp.	1	1
Unknown sp.	4 (1)	12 (1)
Total Silvanidae		134
Staphylinidae		
Unknown sp.	23 (6)	31 (6)
Total Staphylinidae		37
Tenebrionidae		
Alphitobius diaperinus (Panzer)	10	19
Alphitobius laevigatus (Fabricius)	9 (1)	14 (1)
Alphitobius sp.	1	1
Gonocephalum sp.	3	6
Mesomorphus sp.	3	4
Tribolium castaneum (Herbst)	228 (41)	734 (112)
Tribolium sp.	15 (11)	332 (48)
Unknown sp.	28	52
Unknown sp.†	2	2
Total Tenebrionidae		1325
Tenebrionoidea		
Unknown sp.	0 (1)	0 (6)
Total Tenebrionoidea		6
Trogositidae		
Lophocateres pusillus (Klug)†	2	2
Total Trogositidae		2
Unknown family		
Unknown sp.	220 (19)	626 (36)
Total unknown family		662
Total Coleoptera		3430
COLLEMBOLA		
Unknown family		
Unknown sp.	1	4
Total unknown family		4
Total Collembola		4
DERMAPTERA		
Forficulidae		
Unknown sp.	3	5
Total Forficulidae		5
Unknown family		
Unknown sp.	39	67
Total unknown family		67
Total Dermaptera		72
DIPTERA		
Anthomyiidae		
Unknown sp.	3	3
Total Anthomyiidae		3
Asilidae		
Unknown sp.	1	3
Total Asilidae		3
Calliphoridae		
Lucilia sp.	7	9
Unknown sp.	11	55
Total Calliphoridae		64
Cecidomyiidae		
Unknown sp.	2	3
Total Cecidomyiidae		3
Ceratopogonidae		
Unknown sp.	2	2
Total Ceratopogonidae		2
Chironomidae		
Unknown sp.	21 (1)	31 (1)
Total Chironomidae		32
Culicidae		
Aedes vigilax (Skuse)	2 (1)	2 (1)
Aedes sp.	1	1
Culex annulirostris Skuse	3	3
Culex australicus Dobrotworsky & Drummond	1	1
Culex quinquefasciatus Say	7	9
Culex sp.	1	65
Unknown sp.	36	46
Total Culicidae		128
Dolichopodidae		
Unknown sp.	3	3
Total Dolichopodidae		3
Drosophilidae		
Unknown sp.	3	26
Total Drosophilidae		26
Empididae		
Unknown sp.	1	1
Total Empididae		1

APPENDIX I *continued*

Species	No. containers	No. insects
Micropezidae		
Unknown sp.	1	2
Total Micropezidae		2
Muscidae		
Unknown sp.	42	82
Total Muscidae		82
Mycetophilidae		
Unknown sp.	3	3
Total Mycetophilidae		3
Neriidae		
Unknown sp.	1	1
Total Neriidae		1
Phoridae		
Unknown sp.	41 (5)	269 (405)
Total Phoridae		674
Piophilidae		
Unknown sp.	12	406
Total Piophilidae		406
Platystomatidae		
Pogonortalis doclea (Walker)	1	2
Total Platystomatidae		2
Psychodidae		
Unknown sp.	12 (1)	85 (1)
Total Psychodidae		86
Sarcophagidae		
Unknown sp.	7	29
Total Sarcophagidae		29
Sciaridae		
Unknown sp.	7	12
Total Sciaridae		12
Sepsidae		
Unknown sp.	2 (1)	61 (1)
Total Sepsidae		62
Stratiomyidae		
Hermetia illucens (L.)	3	6
Hermetia sp.	3	19
Unknown sp.	5	9
Total Stratiomyidae		34
Syrphidae		
Unknown sp.	3	3
Total Syrphidae		3
Tabanidae		
Unknown sp.	1	1
Total Tabanidae		1
Tachinidae		
Unknown sp.	1	6
Total Tachinidae		6
Tipulidae		
Unknown sp.	15	15
Total Tipulidae		15
Unknown family		
Unknown sp.	261 (1)	564 (1)
Total unknown family		565
Total Diptera		2248
EMBIOPTERA		
Oligotomidae		
Unknown sp.	2	2
Total Oligotomidae		2
Unknown family		
Unknown sp.	1	1
Total unknown family		1
Total Embioptera		3
EPHEMEROPTERA		
Caenidae		
Unknown sp.	1	1
Total Caenidae		1
Unknown family		
Unknown sp.	1	1
Total Unknown family		1
Total Ephemeroptera		2
HEMIPTERA		
Anthocoridae		
Unknown sp.	2 (2)	6 (17)
Total Anthocoridae		23
Aphididae		
Unknown sp.	1	1
Total Aphididae		1
Aphrophoridae		
Philaenus spumarius L.†	1	1
Philagra parva (Donovan)	1	1
Total Aphrophoridae		2
Aradidae		
Unknown sp.	1	1
Total Aradidae		1
Cicadellidae		
Arawa sp.†	1	1
Exitianus indicus (Distant)†	1	1
Pascoepus illawarrus Webb	1	1
Recilia hospes Kirkaldy	1	1
Unknown sp.	2	2
Total Cicadellidae		6
Cydnidae		
Unknown sp.	1	1
Total Cydnidae		1
Delphacidae		
Nilaparvata lugens (Stål)	1	1
Peregrinus maidis (Ashmead)	1	1
Toya sp.†	1	7
Total Delphacidae		9
Flatidae		
Unknown sp.†	1	1
Total Flatidae		1

APPENDIX I *continued*

Species	No. containers	No. insects
Largidae		
Physopelta sp.	1	1
Total Largidae		1
Lygaeidae		
Geocoris sp.	3	3
Nysius vinitor Bergroth	1	2
Unknown sp.	16 (2)	26 (2)
Total Lygaeidae		33
Meenoplidae		
Nisia sp.	1	1
Total Meenoplidae		1
Miridae		
Unknown sp.	2	3
Total Miridae		3
Nabidae		
Unknown sp.	1	2
Total Nabidae		2
Pentatomidae		
Eumecopus sp.	1	1
Nezara viridula (L.)	1	1
Unknown sp.	5	5
Total Pentatomidae		7
Reduviidae		
Unknown sp.	1	1
Total Reduviidae		1
Rhopalidae		
Unknown sp.	1	1
Total Rhopalidae		1
Unknown family		
Unknown sp.	64 (2)	99 (3)
Total unknown family		102
Total Hemiptera		195
HYMENOPTERA		
Apidae		
Apis mellifera L.	1	1
Total Apidae		1
Apoidea		
Unknown sp.	3	3
Total Apoidea		3
Braconidae		
Unknown sp.	17	27
Total Braconidae		27
Chalcididae		
Unknown sp.	1	1
Total Chalcididae		1
Chrysididae		
Chrysis ignita L.†	1	1
Unknown sp.	1	1
Total Chrysididae		2
Colletidae		
Unknown sp.	1	1
Total Colletidae		1
Diapriidae		
Unknown sp.	1	1
Total Diapriidae		1
Evaniidae		
Unknown sp.	1	1
Total Evaniidae		1
Formicidae		
Anoplolepis sp.†	1	2
Camponotus sp.	1	6
Cardiocondyla sp.†	1	1
Crematogaster sp.	3	11
Ectatomma sp.†	1	1
Iridomyrmex sp.	9 (3)	30 (7)
Odontomachus sp.†	1	1
Paratrechina sp.	2	2
Pheidole sp.	11 (4)	28 (44)
Polyrhachis sp.	4 (1)	14 (1)
Solenopsis sp.†	1	1
Technomyrmex sp.	1	1
Tetramorium sp.	1	1
Unknown ponerine	2	4
Unknown sp.	84 (9)	169 (65)
Total Formicidae		389
Ichneumonidae		
Lissonota sp.	1	3
Netelia sp.	1	1
Rhyssa persuasoria (L.)†	1	1
Rhyssa sp.	4	5
Unknown sp.	1	1
Total Ichneumonidae		11
Megachilidae		
Unknown sp.†	1	1
Total Megachilidae		1
Pteromalidae		
Unknown sp.	1	1
Total Pteromalidae		1
Siricidae		
Sirex juvencus (L.)†	2	3
Urocerus gigas (L.)†	1	1
Urocerus sp.†	2	2
Total Siricidae		6
Sphecidae		
Sceliphron sp.	2	3
Unknown sp.	2	2
Total Sphecidae		5
Tiphiidae		
Anthobosca sp.	1	1
Total Tiphiidae		1
Unknown family		
Unknown sp.	23	44
Total unknown family		44
Vespidae		
Delta campaniforme (Fabricius)	1	1
Polistes gallicus (L.)†	3	3
Ropalidia socialistica (Saussure)	1	1

APPENDIX 1 *continued*

Species	No. containers	No. insects
(Vespidae cont.)		
Vespula austriaca (Panzer)†	1	1
Vespula germanica (Fabricius)	2	2
Vespula rufa (L.)†	1	1
Vespula vulgaris (L.)†	3	13
Vespula sp.	1	1
Vespula sp.†	2	2
Total Vespidae		25
Total Hymenoptera		520
ISOPTERA		
Kalotermitidae		
Unknown sp.†	1	4
Total Kalotermitidae		4
Rhinotermitidae		
Coptotermes sp.	1	20
Unknown sp.	15	45
Total Rhinotermitidae		65
Unknown family		
Unknown sp.	11	18
Total unknown family		18
Total Isoptera		87
LEPIDOPTERA		
Arctiidae		
Utetheisa pulchelloides Hampson	1	1
Total Arctiidae		1
Carposinidae		
Unknown sp.	0 (1)	0 (3)
Total Carposinidae		3
Limacodidae		
Unknown sp.	1	1
Total Limacodidae		1
Lycaenidae		
Jamides sp.†	1	1
Total Lycaenidae		1
Lymantriidae		
Unknown sp.	1	1
Total Lymantriidae		1
Noctuidae		
Agrotis munda Walker	1	1
Helicoverpa armigera (Hübner)	2	2
Heliothis rubrescens (Walker)	1	1
Mocis trifasciata (Stephens)	1	1
Mythimna convecta (Walker)	5	8
Mythimna sp.	2	2
Pataeta carbo (Guenée)	1	1
Persectania ewingii (Westwood)	2	3
Plusia festucae (L.)	1	1
Spodoptera litura (Fabricius)	4	4
Spodoptera mauritia (Boisduval)	16	26
Spodoptera sp.	2	2
Unknown sp.	7 (1)	10 (1)
Total Noctuidae		63
Nymphalidae		
Nymphalis milberti (Godart)†	1	1
Total Nymphalidae		1
Pyralidae		
Cnaphalocrocis medinalis (Guenée)	1	1
Ephestia cautella (Walker)	5	18
Ephestia sp.	0 (1)	0 (1)
Herpetogramma licarsisalis (Walker)	12	28
Maruca testulalis (Geyer)	1	1
Plodia interpunctella (Hübner)	1	1
Unknown sp.	3 (1)	7 (1)
Total Pyralidae		58
Sphingidae		
Deilephila sp.†	1	1
Total Sphingidae		1
Tortricidae		
Unknown sp.	3 (1)	16 (2)
Total Tortricidae		18
Unknown family		
Unknown sp.	146 (9)	276 (9)
Total unknown family		285
Total Lepidoptera		433
NEUROPTERA		
Chrysopidae		
Unknown sp.	10	13
Total Chrysopidae		13
Unknown family		
Unknown sp.	2	2
Total unknown family		2
Total Neuroptera		15
ODONATA		
Coenagrionidae		
Unknown sp.	1	1
Total Coenagrionidae		1
Total Odonata		1
ORTHOPTERA		
Acrididae		
Aiolopus thalassinus Fabricius	1 (1)	1 (1)
Unknown sp.	1	2
Total Acrididae		4
Ensifera		
Unknown sp.	1	1
Total Ensifera		1
Gryllidae		
Acheta commodus Walker	2	3
Gryllodes sigillatus (Walker)	9 (2)	10 (2)
Gryllodes sp.	8 (1)	10 (1)
Lepidogryllus parvulus (Walker)	1	1
Metioche sp.	2 (1)	7 (1)
Teleogryllus sp.	3	3
Unknown sp.	23 (4)	36 (7)
Total Gryllidae		81
Tettigoniidae		
Pseudorhynchus sp.	1	1
Unknown sp.	1	1
Total Tettigoniidae		2

APPENDIX I *continued*

Species	No. containers	No. insects
Unknown family		
Unknown sp.	11 (1)	12 (1)
Total unknown family		13
Total Orthoptera		101
PSOCOPTERA		
Liposcelidae		
Liposcelis sp.	4 (1)	11 (4)
Unknown sp.	0 (1)	0 (1)
Total Liposcelidae		16
Trogiidae		
Unknown sp.	1 (1)	1 (1)
Total Trogiidae		2
Unknown family		
Unknown sp.	8 (4)	12 (5)
Total unknown family		17
Total Psocoptera		35
SIPHONAPTERA		
Unknown family		
Unknown sp.	1	1
(SIPHONAPTERA cont.)		
Total unknown family		1
Total Siphonaptera		1
THYSANOPTERA		
Phlaeothripidae		
Unknown sp.	1	1
Total Phlaeothripidae		1
Unknown family		
Unknown sp.	1	1
Total unknown family		1
Total Thysanoptera		2
THYSANURA		
Lepismatidae		
Ctenolepisma sp.	3	3
Unknown sp.	1	1
Total Lepismatidae		4
Unknown family		
Unknown sp.	8 (4)	9 (4)
Total Unknown		13
Total Thysanura		17

†Exotic.
*Numbers in parentheses indicate live specimens found in addition to dead specimens.