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Populations of North American bean thrips, *Caliothrips fasciatus* (Pergande) (Thysanoptera: Thripidae: Panchaetothripinae) not detected in Australia

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Abstract *Caliothrips fasciatus* is native to the USA and western Mexico and overwintering adults are regular contaminants in the 'navel' of navel oranges exported from California, USA to Australia, New Zealand and elsewhere. Due to the long history of regular interceptions of *C. fasciatus* in Australia, a survey for this thrips was undertaken around airports, seaports, public recreational parks and major agricultural areas in the states of Queensland, New South Wales, Victoria, South Australia and Western Australia to determine whether *C. fasciatus* has successfully invaded Australia. Host plants that are known to support populations of *C. fasciatus*, such as various annual and perennial agricultural crops, urban ornamentals and weeds along with native Australian flora, were sampled for this thrips. A total of 4675 thrips specimens encompassing at least 76 species from a minimum of 47 genera, and three families were collected from at least 159 plant species in 67 families. *Caliothrips striatopterus* was collected in Queensland, but the target species, *C. fasciatus*, was not found anywhere. An undescribed genus of Thripidae, Panchaetothripinae, was collected from ornamental *Grevillea* (var. Robyn Gordon) at Perth (Western Australia) Domestic Airport, and is considered to be a native Australian species. This survey has provided valuable information on the background diversity of thrips species associated with various native and exotic plant species around major ports of entry and exit for four of five states in Australia. We suggest that the major reason *C. fasciatus* has not established in Australia is due to high adult mortality in navels that are kept at low storage temperatures (2.78°C) during an 18- to 24-day transit period from California to Australia.

Key words CLIMEX, cold disinfestation, degree-days, incursion management, invasive species, quarantine.

INTRODUCTION

The Australian Quarantine Inspection Service has, on a number of occasions, detected adult *Caliothrips fasciatus* (Pergande), the North American bean thrips, in the navels of oranges imported from California. These detections have serious economic impacts, actual and potential, on both the exporting and importing territories. Preventing the establishment of potentially noxious pest species in new locales is the most important first step in managing the incursion of unwanted species. Exclusion is enforced by many countries in the form of quarantine regulations that govern the importation of foreign material that has associated with it some level of biological risk. Typically, exclusion practices involve some type of physical and visual inspection of any imported material that is likely to act as an unwanted conduit for translocating organisms from one area of the world to another. The global movement of plant material, including fruit, presents major risks to importing countries, because contaminant organisms are often small, cryptic and extremely difficult to detect by visual inspection. This is particularly true for Thysanoptera, whose adults and larvae are very small, highly thigmotactic, and often lay minute eggs within plant material (e.g. petioles, stems, leaves and fruit) making rapid visual detection impossible (Mound 2005; Morse & Hoddle 2006).

The bean thrips is native to North America, with a known range extending from Florida to Idaho into California and parts of western Mexico. Reports of *C. fasciatus* populations elsewhere are considered dubious, a fact that has not changed since 1933 (Bailey 1933). In California, *C. fasciatus* was once considered to be a serious pest of a variety of agricultural crops, including alfalfa, beans, cantaloupes, cotton, lettuce, pears, peas and walnuts. Bean thrips can breed on various weed species including thistles, cheeseweed and fennel (Bailey 1938). The significance of this insect as an agricultural pest in California has waned substantially since Bailey's (1933, 1937, 1938) treatises were published. The reasons for this decline are unclear, but could be due to the development of integrated pest management programs, more effective insecticides used on crops that are most vulnerable to *C. fasciatus* outbreaks, and development of resistant cultivars.

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A current problem with *C. fasciatus* concerns the contamination of Californian grown navel oranges by adult thrips that overwinter inside the navel from early November to late March (Bailey 1933). Overwintering *C. fasciatus* are quiescent and will break dormancy to feed when winter temperatures reach approximately 24–27°C for short periods (Bailey 1933). Concealed *C. fasciatus* provide a major quarantine issue for countries, including Australia, that import fresh navels from California, although this is not a new problem. Overwintering *C. fasciatus* were first found in navels exported from California to Nebraska, Illinois and Hawaii in 1899, 1907 and 1929, respectively (Bailey 1933). Contamination issues prompted early studies on the efficacy of fumigation treatments (Woglum & Lewis 1936), and research is now focusing on replacements for the fumigant methyl-bromide including one promising approach using ozone (Leesch *et al*. 2004).

To lessen reliance on mandatory fumigation for *C. fasciatus* by California exporters and Australian importers, a two-tier pre-clearance inspection system for navels grown in California was implemented in 2005. The first tier of the inspection begins with yellow sticky card monitoring in navel orange orchards. One trap is deployed every 5 acres of citrus and a log of captured *C. fasciatus* is updated weekly. If trap catches exceed 10 thrips per card then that block is ineligible for export to Australia. Prior to harvest, 50 randomly selected fruit are destructively sampled, and detection of *C. fasciatus* makes the orchard ineligible for export. The second tier of inspection occurs in the packing house where 175 oranges from grower lots are destructively sampled for *C. fasciatus*, and all fruits to be exported are kept at 18.33°C for 8 h to encourage adult thrips movement from navels. Any lots contaminated with even one bean thrips are ineligible for export (Australia Phyto Requirements 2005). As a consequence of increasing phytosanitary regulations, navel exports to Australia from California have decreased by 65% over the period 1998–2005. Fruit that pass the pre-clearance are shipped within 3–4 days of harvest; the transit time by sea from California to Australia is 18–24 days, and fruit are stored at 2.78°C in an unmodified atmosphere (B Norby pers. comm. (Sunkist Growers) 2005).

Successful incursion and establishment by a new species is affected by many variables that are difficult to predict (Williamson 1996). One important factor affecting establishment success is propagule pressure. Repeated initial introductions can enhance the gene pool of founding populations, and temporally stratified introductions are more likely to coincide with benign environmental conditions that ease barriers to establishment (Kowarik 2003). Large volumes of navel oranges have been shipped regularly to Australia from California since at least the early 1960s (B Norby pers. comm. (Sunkist Growers) 2005). Exports of navels to Australia from California start in November and end in March (B Norby pers. comm. (Sunkist Growers) 2005), and this coincides with the period *C. fasciatus* is overwintering in California. Conditions during the time of importation into Australia, the southern early to late summer, would be very favourable for establishment of *C. fasciatus* as the climate would be suitable and potential host plants abundant. Over the period November 2004–April 2005, 29 interceptions of *C. fasciatus* on Californian citrus were made in Australia equating to a rate of approximately 6.6% of imported shipments being contaminated (M Guidicipietro (USDA-APHIS) pers. comm. 2005). In New Zealand, over the period December 2003–March 2004, 15 interceptions of *C. fasciatus* on imported Californian citrus were made (A Flynn (MAF) pers. comm. 2005).

Given the long history of navel imports into Australia from California, the regular contamination of fresh fruit with overwintering *C. fasciatus*, and the high probability that the receiving environment at some stage would be favourable for the incursion of the thrips, it seemed curious that this insect had not been recorded as established in Australia (Mound 1996). Areas in Australia with suitable year-round climate for bean thrips survival were chosen for surveying based on the results from CLIMEX models (Sutherst *et al*. 2004) that were parameterised from regression analyses of Bailey's (1933) temperature studies on bean thrips development and survival rates. Consequently, surveys for bean thrips were conducted during summer 2005 around pre-selected major Australian cities and agricultural areas, to determine whether *C. fasciatus* had established in Australia despite being unrecorded. The results of these surveys are reported here.

MATERIALS AND METHODS

Calculating degree-day values and development thresholds for *C. fasciatus*

In many instances, *a priori* determination of ecosystem vulnerability to invasion can be assessed in terms of top-down effects mediated primarily by climatic conditions (Sutherst 2000). The accumulation of sufficient degree-days to complete development and begin reproduction in a new area may indicate how vulnerable that region is to invasion by an exotic organism (Sutherst 2000; Baker 2002), and whether incursion will be transient due to unfavourable conditions for prolonged periods or potentially permanent due to favourable year-round conditions (Baker 2002). Bailey (1933) provides developmental times and survivorship rates for *C. fasciatus* larvae, pupae and adults at several different temperatures, but no data for eggs. Data for larvae and pupae were subject to analyses to calculate the minimum temperature above which development would occur, optimum developmental and upper lethal temperatures. Minimum temperature for development was calculated with linear regression where mean accumulative developmental rate (1/days in stage) for both larval and pupal stages combined was plotted against temperature. The reciprocal of the line slope indicated degree-day accumulation in stages, and developmental temperature threshold was calculated by solving for $y = 0$ (Campbell *et al*. 1974). Optimal temperature for development, and upper lethal developmental temperature were calculated by plotting total survivorship of pre-adult stages (excluding eggs) against temperature, fitting a quadratic curve, and solving for $y = 0$ and $y = \max$ survivorship. Lower lethal temperature for development was estimated at 4.4°C as 0% pupae survived to adulthood at this temperature (Bailey 1933). Additionally, survivorship times, provided by Bailey (1933) for adult *C. fasciatus* at eight different temperatures, were subjected to regression analysis to determine whether a significant relationship existed.

Selecting sampling sites in Australia to survey for *C. fasciatus*

The Mediterranean template in CLIMEX was parameterised with temperature data calculated above for *C. fasciatus* (see below). The standard output for CLIMEX is a series of maps for the computed index of interest showing 'dots' at locations of meteorological stations. The size of the 'dot' indicates the relative magnitude of the index. For example, CLIMEX generates an Ecoclimatic Index (EI) that is the combination of two indices: growth (i.e. species response to prevailing annual temperatures and moisture) and stress (i.e. extreme environmental effects on population growth and persistence). The EI is scaled from 0 to 100. Locations with an EI >25 are very favourable for species population growth and year-round persistence; EI = 10–25 indicates favourable areas; EI <10 indicates areas of marginal suitability; and EI = 0 indicates the species of interest can not persist in an area under average prevailing climatic conditions (Sutherst *et al*. 2004). Based on CLIMEX results, areas around Brisbane (Queensland), Sydney (New South Wales), Melbourne (Victoria), Adelaide (South Australia) and Perth (Western Australia) were selected for *C. fasciatus* surveys. Specifically sampled for thrips were: air and sea ports, major agricultural districts, and public parks where possible discarding of *C. fasciatus* adults in navel orange peels in rubbish receptacles might result in localised establishment.

Selection of host plants, sampling techniques and thrips identifications

Lists of plants identified as supporting reproducing populations of *C. fasciatus* were compiled from published records (Bailey 1933, 1937, 1938) and included agricultural crops, ornamental and wild hosts (Table 1). This list was used to direct sampling efforts on targeted plant species growing in Australia that were known to be suitable breeding hosts for bean thrips in its home range. Additionally, native Californian and randomly selected Australian native plants were sampled, although there are no data from either Bailey (1933, 1937, 1938) or more recent surveys indicating whether *C. fasciatus* can feed and reproduce on native Australian plants. Selected plants in surveyed areas were sampled by hitting foliage against a white tray. Dislodged thrips were collected with a fine paint brush and preserved in 95% ethanol in labelled 5 mL centrifuge vials. Locality (Global Position System coordinates, altitude, township, etc.), date of collection, host plant data and collector name were recorded in a field note book. Sampling was conducted 26–29 December 2004 in Queensland; 31 December 2004 to 3 January 2005 in New South Wales; 5–10 January 2005 in Victoria; 11–16 January 2005 in South Australia; and 17–20 January 2005 in Western Australia. This time period over summer was considered the most likely to detect *C. fasciatus* if it were present. Unidentified plants that were sampled were digitally photographed and cross-referenced to collection data and later named by experts at the Australian National Botanic Gardens in Canberra. All collected thrips were returned to the thrips laboratory at the Australian National Insect Collection, at CSIRO Entomology, Canberra, and identified to species where possible.

RESULTS

Day-degree estimates and CLIMEX modelling for *C. fasciatus*

Linear regression analysis of Bailey's (1933) developmental times data for *C. fasciatus* larvae and pupae indicated that development would occur above a temperature of 12.15°C and 208.33 day-degrees above this threshold are needed to complete development from first-instar larva to adult (Fig. 1A). Analysis of Bailey's (1933) survivorship data across different

Table 1 Host plants lists compiled from Bailey (1933, 1937, 1938) that guided sampling efforts in Australia for *Caliothrips fasciatus*

Family	Scientific name	Common name
Crop plants		
Asteraceae	*Lactuca sativa* L.	Lettuce
Chenopodiaceae	*Beta vulgaris* L.	Beets
	Beta vulgaris L.	Swiss chard
Cruciferae	*Brassica oleracea* L.	Cabbage
	Brassica oleracea (L.)	Cauliflower
	Brassica oleracea L.	Kale
	Raphanus sativus L.	Radishes
	Brassica rapa L.	Turnips
Ebenaceae	*Diospyros* L.	Persimmon
Gramineae	*Zea mays* L.	Corn (young shoots)
Lauraceae	*Persea americana* Miller	Avocado
Leguminosae	*Medicago sativa* L.	Alfalfa
	Phaseolus sp.	Beans
	Trifolium pratense (L.)	Clover, red
	Pisum sativum L.	Peas

Table 1 Continued

Family	Scientific name	Common name
Liliaceae	*Allium cepa* L.	Onions
Malvaceae	*Gossypium* (L.)	Cotton
Oleaceae	*Olea europaea* L.	Olive
Rosaceae	*Prunus amygdalus* Batsch	Almond
	Malus sylvestris L.	Apple
	Prunus persica Batsch	Peach
	Pyrus communis L.	Pear
	Prunus domestica L.	Prune
Rutaceae	*Citrus sinensis* (L.) Osbeck	Orange
	Citrus reticulata (Blanco)	Tangerine
Solanaceae	*Solanum tuberosum* L.	Potato
	Lycopersicon esculentum P. Mill	Tomatoes
Vitaceae	*Vitis* sp.	Grape
Ornamental and wild host plants		
Amaranthaceae	*Amaranthus retroflexus* L.	Pigweed
Asclepiadaceae	*Asclepias mexicana* Cav.	Milkweed
Asteraceae	*Lactuca serriola* L.	Prickly lettuce
	Lactuca serriola var. integrata Gren. & Godr.	Prickly lettuce
Boraginaceae	*Heliotropium currassavicum* L.	Chinese pulsey
Cannaceae	*Canna* sp. (P. Mill)	Wild canna
Chenopodiaceae	*Atriplex* sp.	Saltbush
	Chenopodium murale L.	Nettleleaf goosefoot
Compositae	*Aster* sp.	Aster
	Bidens pilosa L.	Beggar's ticks
	Cirsium edule (Nutt.)	Edible thistle
	Crepis sp. (L.)	Hawksbeard
	Erigeron canadensis (L.) Cronq.	Horseweed
	Helianthus annuus L.	Common sunflower
	Sonchus oleraceus L.	Sow thistle
Convolvulaceae	*Convolvulus arvensis* L.	Field bindweed
Cruciferae	*Brassica rapa* L.	Common yellow Mustard
Cucurbitaceae	*Echinocystis* sp.	Wild Cucumber
Fabaceae	*Lotus scoparius* (Nutt.) Ottley	Deerweed
	Vicia sp.	Wild vetch
Geraniaceae	*Erodium cicutarium* (L.) L'Hérit.	Stork's bill
	Geranium sp.	Cranesbill
Gnaphalium	*Gnaphalium californicum* DC.	Calif. everlasting
Gramineae	*Arundinaria japonica* (Sieb. & Zucc.) Mak.	Bamboo
	Eleusine indica (L.) Gaertn.	Wire grass
Iridaceae	*Iris germanica* L.	Purple flag
Labiatae	*Mentha* sp.	Mint
Leguminosae	*Cassia* sp. (Michx.) Greene.	Golden cassia
	Indigofera decora (Lindl.)	Spanish clover
	Lupinus sp.	Lupin
	Medicago polymorpha L.	Bur clover
	Melilotus alba Desr.	White melilot
	Pueraria hirsuta Maesen. & S.M. Almeida.	Kudzu
Liliaceae	*Tulipa* sp.	Tulip
Lythraceae	*Cuphea viscosissima* (Jacq.)	Tarweed
Malvaceae	*Malva parviflora* L.	Cheeseweed
Melanthiaceae	*Chamaelirium luteum* (L.) A. Gray.	Blazing star
Musaceae	*Musa paradisiaca* L.	Banana
Nyctaginaceae	*Mirabilis laevis* (Benth.) Curran	Wishbone bush
Papaveraceae	*Eschscholtzia californica* Cham.	California poppy
Passifloraceae	*Passiflora mollissima* (H.B.K) Bail.	Passion flower
Portulacaceae	*Montia perfoliata* Donn.	Miner's lettuce
Rosaceae	*Eriobotrya japonica* (Thunb.) Lindl.	Loquat
	Pyracantha sp. M.J. Roemer.	Firethorn
Scrophulariaceae	*Verbascum virgatum* Stokes ex with.	Mullein
Solanaceae	*Nicotiana glauca* Graham.	Tree tobacco
Tropaeolaceae	*Tropaeolum majus* L.	Nasturtium
Umbelliferae	*Foeniculum* sp.	Fennel

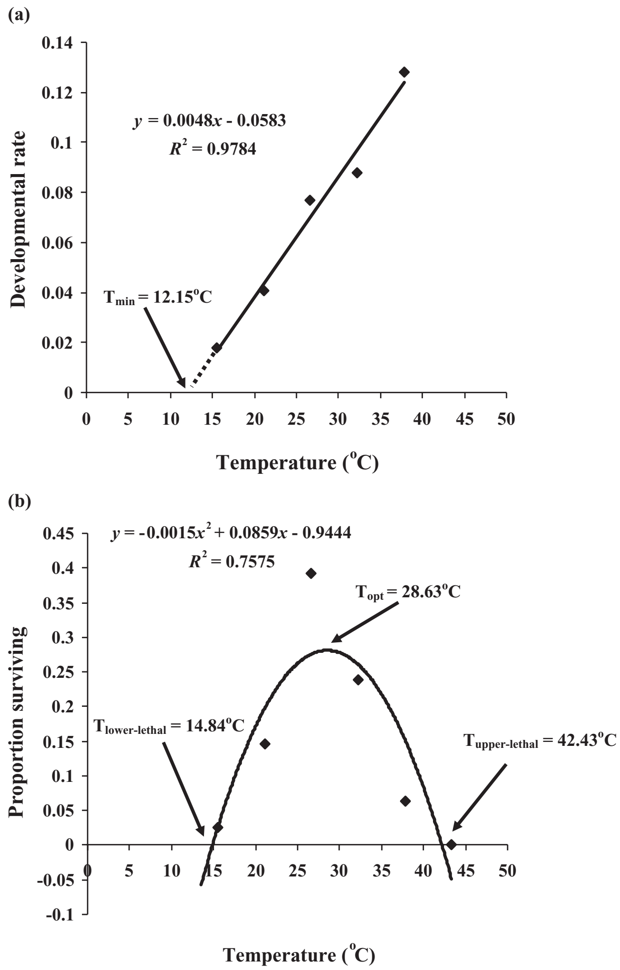

Fig. 1. Linear regression of developmental rate data for *Caliothrips fasciatus* against temperature (a) and estimation of optimum and upper lethal developmental temperatures for *C. fasciatus* using larval and pupal survivorship rates for *C. fasciatus* (b). Data are from Bailey (1933).

Table 2 Parameters used in CLIMEX that provided the best-estimated distribution of *Caliothrips fasciatus* in Australia derived from analysis of developmental and survivorship data for *C. fasciatus* at various temperatures from Bailey (1933) †

	CLIMEX parameter	Value
Soil moisture	SM capacity	100
	Evapotranspiration coefficient	0.8
Temperature	DV0	4.40
	DV1	12.15
	DV2	28.63
	DV3	42.43
Moisture	SM0	0.10
	SM1	0.40
	SM2	0.70
	SM3	1.50
Cold stress	TTCS	4.40
	THCS	–0.005
	DTCS	12.15
	DHCS	–0.001
	TTCS1	4.40
	THCS1	–0.001
Heat stress	TTHS	28.63
	THHS	0.002
	DTHS	0
	DHHS	0
Dry stress	SMDS	0.02
	HDS	–0.05
Wet stress	SMWS	1.6
	HWS	0.0015
Hot wet stress	DTHW	23
	MTHW	0.5
	PHW	0.075
Cold stress DD threshold		8.28
Degree-days per generation		312

†Parameter acronyms and definitions are provided in Sutherst *et al.* (2004).

temperatures indicated a quadratic relationship between temperature and proportion of larvae surviving to adulthood with 28.63°C and 42.43°C being the optimal and upper lethal temperatures for *C. fasciatus* survivorship, respectively (Fig. 1B). *Caliothrips fasciatus* pupal stages failed to survive for even 1 day at 4.4°C and this temperature was the assumed lower lethal temperature for this thrips (Bailey 1933). Cold stress DD threshold was set as 8.28°C (mid-point between 4.40 (lower lethal temperature for pupae) and 12.15°C (lower developmental temperature for immature motile stages)) and degree-days per generation were 312 (degree-days for eggs were estimated at 50% (i.e. 104) of that required for larvae and pupae and added to the larval-pupal degree-days estimate). These data were used as the temperature parameters in the CLIMEX model (Table 2). The output of the CLIMEX model indicates that areas around Brisbane, Sydney, Melbourne, Hobart, Adelaide and Perth have average year-round climates that could support *C. fasciatus* populations (Fig. 2). The linear relationship between temperature and average survivorship times for adult *C. fasciatus* was not significant ($F = 1.24$; d.f. = 1,6; $P = 0.31$), but a positive linear trend was observed (Fig. 3).

Survey results for *C. fasciatus*

The number of thrips specimens collected totalled 4675, encompassing at least 76 species from a minimum of 47 genera and three families. These specimens were taken from at least 159 plant species in 67 families (Table 3 and see http://www.biocontrol.ucr.edu/beanthrips.pdf for complete collection records). The vast majority of the thrips specimens taken were members of the family Thripidae, and 50% of these Thripidae species were either adventive or exotics, and most of them were collected from exotic weeds and crop plants. When considering the Australian thrips fauna it is useful to distinguish between 'exotic' species that have entered Australia from the Americas or from the northern hemisphere since the arrival of Europeans, in contrast to 'adventive' species that are shared with south-east Asia and have possibly entered Australia over a longer period of time (Mound 2004). In this connection it should be noted that the number of Thripidae species collected in the Brisbane area totalled 26, considerably higher than around Sydney and Melbourne, and twice as many as around Adelaide or Perth (Table 3). Moreover, detailed collection records indicate that both *Frankliniella occidentalis* and *Fr. schultzei* were found much less frequently around Melbourne than around the other major cities (Table 3 and see http://www.biocontrol.ucr.edu/beanthrips.pdf for complete collection records). An undescribed genus of Panchaetothripinae was collected from an ornamental *Grevillea* (var. Robyn Gordon) at Perth (Western Australia) Domestic Airport, but this thrips has been found subsequently in central Queensland and is considered to be an endemic Australian species. The only *Caliothrips* species that was found during the survey was *C. striatopterus*, a species that is known to be widespread in tropical Australia and south-east Asia. The target species, *C. fasciatus*, was not found at all.

DISCUSSION

Caliothrips fasciatus was not found in Australia during this survey. This result does not conclusively prove that this thrips is absent in Australia, although it seems unlikely that it would have remained undetected if sizeable populations were present, especially if causing economic damage. A critical question regarding *C. fasciatus* is: why has it failed to establish outside of its home range? Bean thrips is common in California, polyphagous, and infests a variety of commodities that are exported; qualities that could easily predispose it to an invasive lifestyle (Morse & Hoddle 2006). Similarly, *Thrips imaginis* and *T. obscuratus*, native to Australia and New

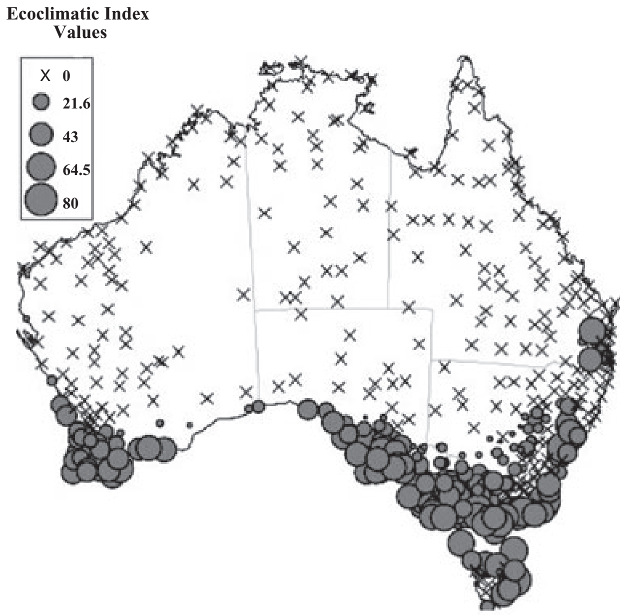

Fig. 2. CLIMEX-generated Ecoclimatic Index (EI) values using the Mediterranean template and developmental temperature values for *Caliothrips fasciatus* as calculated from Bailey (1933). The larger the EI dots, the better the average year-round climate for *C. fasciatus*.

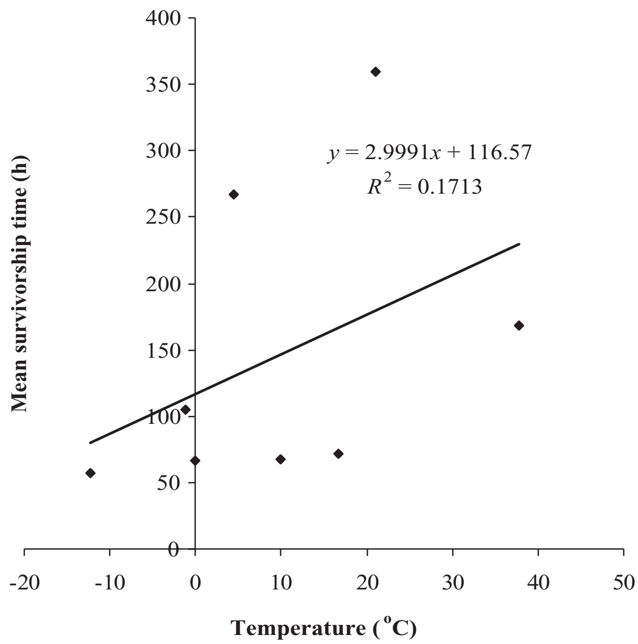

Fig. 3. Relationship between temperature and mean adult *Caliothrips fasciatus* survivorship times. Data are from Bailey (1933).

Table 3 Thrips taxa collected in Australia from the *Caliothrips fasciatus* survey

Thrips family and species	State from which thrips were collected				
	Qld	NSW	Vic.	SA	WA
Aeolothripidae					
Andrewarthaia kellyanus		+			
Desmothrips reedi		+			
Desmothrips tenuicornis			+	+	
Desmothrips sp.	+	+	+	+	+
Thripidae panchatothripinae					
Australothrips bicolor		+	+	+	
Caliothrips striatopterus†	+				
Heliothrips haemorrhoidalis†			+		
Phibalothrips longiceps†	+				
Selenothrips rubrocinctus†	+				
Gen et sp. n.					+

Table 3 Continued

Thrips family and species	State from which thrips were collected				
	Qld	NSW	Vic.	SA	WA
Thripidae dendrothripinae					
Dendrothrips sp.					+
Thripidae sericothripinae					
Hydatothrips sp.	+				
Neohydatothrips sp.	+				
Thripidae thripinae					
Anaphothrips cecili				+	
Anaphothrips obscurus†		+			
Anaphothrips occidentalis	+				+
Anaphothrips sudanensis†	+				
Anaphothrips sp.	+	+	+	+	+
Anascirtothrips sp.	+				
Apterothrips apteris†		+			
Aptinothrips rufus†		+	+		
Arorathrips mexicanus†	+				
Bolacothrips pulcher†	+				
Chaetanaphothrips signipennis†	+				
Chirothrips manicatus†		+	+		
Frankliniella lantanae†	+				+
Frankliniella occidentalis†	+	+	+		+
Frankliniella schultzei†	+	+	+	+	+
Limothrips angulicornis†		+	+	+	
Limothrips cerealium†			+		
Megalurothrips usitatus	+	+			
Microcephalothrips abdominalis†	+		+		
Odontothripiella sp.					+
Pezothrips kellyanus	+		+	+	+
Plesiothrips perplexus†	+				
Pseudanaphothrips achaetus	+	+		+	+
Rhamphothrips sp.	+				
Salpingothrips aimotofus†	+				
Scirtothrips drepanofortis				+	
Scirtothrips frondis			+		
Scirtothrips inermis			+	+	
Scolothrips sp.	+	+			+
Tenothrips frici†		+	+	+	+
Thrips australis		+	+	+	+
Thrips hawaiiensis	+				
Thrips hoddlei	+				
Thrips imaginis	+	+	+	+	+
Thrips nigropilosus†			+		
Thrips setipennis	+				
Thrips tabaci†	+	+	+	+	+
Trichromothrips bilongilineatus	+				
Phlaeothripidae idolothripinae					
Idolothrips spectrum		+			
Nesothrips propinquus	+	+	+		
Phlaeothripidae phlaeothripinae					
Adrothrips intermedius		+			
Apterygothrips sp.	+			+	
Baenothrips moundi			+		
Haplothrips gowdeyi†	+				
Haplothrips victoriensis			+	+	
Haplothrips spp.	+	+	+	+	+
Karnyothrips sp.			+		
Katothrips sp.		+			
Kellyia sp.			+		
Koptothrips flavicornis				+	
Membrothrips reuteri	+				
Podothrips sp.				+	
Strepterothrips tuberculatus			+		

†Species considered adventive or exotic to Australia.
NSW, New South Wales; Qld, Queensland; SA, South Australia; Vic., Victoria; WA, Western Australia.

Zealand, respectively, exhibit similar biotic characteristics to *C. fasciatus*, and yet neither of these two species has established outside of their home range (Morse & Hoddle 2006). This suggests that *C. fasciatus* is not unique in this regard.

Bailey's (1933) data on adult survivorship times at different temperatures may provide an important clue as to why *C. fasciatus* shipped in navels from California to Australia has not established on that continent. Navels are shipped at 2.78°C and are held at this temperature during a transit of 18–24 days. At this temperature, the regression equation from Figure 3 estimates that *C. fasciatus* adults should live for approximately 5.20 days. It is possible that given the high variability in Bailey's (1933) *C. fasciatus* survivorship data, lack of statistical significance, and subsequent poor fit of the regression line ($r^2 = 0.17$) to data that a survival time of 5.20 days is an underestimate of *C. fasciatus* survival at 2.78°C. Tripling this estimate of survival time to 15–16 days would still suggest that the majority of bean thrips adults are likely to die before shipping containers can be landed and cleared through customs. Shipping navels at low temperatures (i.e. 2.78°C) for 18–24 days may actually be a very effective method of disinfestation for *C. fasciatus*. This hypothesis could be tested easily by infesting navels with *C. fasciatus* when these thrips are entering their overwintering phase in late October through November, and then checking survivorship rates of adults at 2.78°C over time.

If the cold storage-disinfestation hypothesis is incorrect, other intriguing possibilities regarding the invasion capabilities of *C. fasciatus* exist. These include: (1) determine whether overwintering *C. fasciatus* females in exported navel oranges are able to produce viable offspring after being subjected to conditions similar to those experienced during shipping. If adult survivorship is not impaired but reproduction is adversely affected then this would be a major impediment for transient adults to initiate incipient populations in new locales. (2) Determine what percentage, if any, female *C. fasciatus* are infected with *Wolbachia*, a bacterial endosymbiont that could facilitate parthenogenetic reproduction. Parthenogenesis would enable viable females to overcome barriers to population establishment that can result from an inability to locate males when incipient populations are at low densities (i.e. Allee effects). (3) Determine minimum viable population sizes of viable thrips shipped in navels that would be needed to establish a self-sustaining *C. fasciatus* population under ideal conditions. This would provide an estimate of propagule densities required to start new populations immune to adverse stochastic environment impacts. (4) Determine whether bean thrips can feed and reproduce on native Australian plants. A demonstrated inability to survive and reproduce on native Australian plants would limit resources available for invading adult bean thrips. Australian native plants in California could be surveyed for bean thrips and then studied to determine whether they are suitable for feeding and reproduction. In general, increased use of Australian native flora for ornamental plantings as an alternative to abundant and varied exotic ornamentals around major ports of entry (e.g. Brisbane Airport) may remove potential food sources for exotic invaders thereby increasing biotic resistance to invasion. (5) Ascertain whether *C. fasciatus* can interbreed with Australian *Caliothrips striatopterus* and whether these offspring are viable. Interspecific reproduction, should it happen, may prevent establishment of *C. fasciatus* if offspring are unviable. Such a situation would be the functional equivalent of sterile insect releases. When taken together, data from these five research objectives would provide a comprehensive view of the invasion potential of *C. fasciatus* into Australia, and may provide sufficient scientific data to guide management and regulation of California's exports of navel oranges to Australia and elsewhere in the world.

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