Morales-Rodriguez et al. *New Zealand Plant Protection 75* (2022) 19–24
https://doi.org/10.30843/nzpp.2022.75.11752
Published: 16/05/2022

Update on the establishment of *Thripoctenus javae* in New Zealand and new locality records in Bay of Plenty kiwifruit orchards

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(Original submission received 21 January 2022; accepted in revised form 5 May 2022)

Abstract The larval parasitoid, *Thripoctenus javae* (Hymenoptera: Eulopidae), was introduced into New Zealand in 2001 as a biological control agent for greenhouse thrips, *Heliothrips haemorrhoidalis*. We have re-evaluated the establishment of *T. javae* at the release sites from Kerikeri to Gisborne and surveyed kiwifruit orchards in the Bay of Plenty to determine how widespread the parasitoid has become. Release sites were surveyed in autumn 2017 for greenhouse thrips. Foliage samples were collected from numerous host plants, where greenhouse thrips were found, and the number of *T. javae* pupae on each leaf were recorded. In 2018, a second survey for *T. javae* was conducted in Bay of Plenty; samples of cryptomeria (*Cryptomeria japonica*) shelterbelt foliage were collected from 65 kiwifruit orchards. Foliage samples were washed and pupae of *T. javae* were counted. *Thripoctenus javae* were recorded at 80% of the original release sites from Kerikeri to Gisborne. The parasitoid was found at all sites in Whangarei and Bay of Plenty, 50% of sites in Kerikeri, 33% of revisited sites in Gisborne as well as the single site in Auckland. No host populations of greenhouse thrips were found at four release sites (Kerikeri = 2 and Gisborne = 2). In Bay of Plenty, *T. javae* were found at 32 kiwifruit orchards (49% of the total surveyed). All of these orchards are new locality records for *T. javae*. The furthest distance *T. javae* was found from a release site was 55.4 km. The introduction of *T. javae* into New Zealand has been successful with the parasitoid recorded at 80% of the original release sites after 17 years. Dispersal is evident in the Bay of Plenty where we have detected *T. javae* at 32 new locations on kiwifruit orchards.

Keywords Parasitoid, greenhouse thrips, *Heliothrips haemorrhoidalis*, shelterbelts, *Cryptomeria japonica*

INTRODUCTION

Greenhouse thrips (*Heliothrips haemorrhoidalis* (Bouché, 1833) Thysanoptera: Thripidae) is a polyphagous pest and one of the most widely distributed thrips species worldwide (Nakahara et al. 2015), causing silvering to the leaves of subtropical fruit trees, ornamental plants as well as shelter tree species cryptomeria and pine (Froud & Stevens 2004; Logan et al. 2021). In New Zealand, greenhouse thrips is a pest of multiple fruit crops including avocado (*Persea americana*), citrus (*Citrus* spp.) and kiwiberry (*Actinidia arguta*) (Blank & Gill 1997; Stevens et al. 1999; McKenna et al. 2009). Feeding by greenhouse thrips causes scars on fruit skin and renders the fruit unacceptable for export. Greenhouse thrips is classified as a market-access pest for kiwifruit (*Actinidia* spp.) as immature thrips on kiwifruit, detected in the packhouse, cannot be identified to species level (Hintze 2020). The fruit cannot be exported to 17 overseas markets (Hintze 2020) and is consequently redirected to lower returning markets creating complications for inventory management as well as having a financial impact (Pers. comm. Jessie Bong, Zespri Group Limited).

Options for management of greenhouse thrips in kiwifruit crops are limited because thrips population numbers peak in April (Autumn), synchronising with harvest, which begins in March (Logan et al. 2021). Insecticide applications are constrained by the risk of unacceptable residues on fruit, so other approaches including the use of natural enemies as biological control agents requires investigation. A larval parasitoid *Thripoctenus javae* (Girault, 1917) (Hymenoptera: Eulophidae), imported into New Zealand in 2001 from Italy, is currently the most promising natural enemy of greenhouse thrips and has been the focus of research (Froud & Stevens 2004; Jamieson et al. 2008). There are also native generalist predators of greenhouse thrips in New Zealand, however none of these are considered capable of reducing thrips populations (Froud & Stevens 2004). An egg parasitoid, *Megaphragma* sp. (Hymenoptera: Trichogrammatidae), is also ineffective against greenhouse thrips in New Zealand (Vardy 1987; Froud & Stevens 2004).

Thripoctenus javae was first identified as a parasitoid of thrips in Indonesia (*Epomphale javae* (Girault 1917)); it is acknowledged to be widespread across the Oriental, Australasian and Afrotropical regions after the synomisation with the thrips parasitoid found in Africa (*Thripobius semiluteus* (Bouček 1976)) and India (*Thripoctenus maculatus* (Waterston 1930)) (Triapitsyn 2005). *T. javae* parasitises first and early second instar greenhouse thrips larvae. It was incorporated into classical biological-control programmes against greenhouse thrips on avocados in California in 1986 (McMurtry & Badii 1991) and in Israel in 1991 (Wysoki et al. 1997) as well as in public gardens in Italy in 1995 (Viggiani et al. 2000). In all three programmes, *T. javae* established at the release sites and was recovered 2–4 years later at these locations.

In 2000, *T. javae* was approved by the Environmental Risk Management Authority for release into New Zealand to control populations of greenhouse thrips (Froud & Stevens 2004; Jamieson et al. 2008). At different times during the following year, over 100,000 *T. javae* pupae were distributed across 21 citrus, avocado, kiwifruit or mixed-crop orchards throughout the North Island of New Zealand (Kerikeri, Whangarei, Auckland, Bay of Plenty and Gisborne) (Jamieson et al. 2008).

Since the last survey of the release sites in 2007 (Jamieson et al. 2008), there has been no research on the establishment and efficacy of *T. javae* in commercial orchards. The aim of this latest survey was to update the records of establishment for *T. javae* at the release sites and determine how widespread *T. javae* is in Bay of Plenty kiwifruit orchards. As kiwifruit is a deciduous vine, we sampled orchard shelterbelts of *Cryptomeria japonica* ('cryptomeria'). Cryptomeria is a known host plant of greenhouse thrips (Logan et al. 2021) and may provide a better habitat for *T. javae* to parasitise hosts year round due to being evergreen.

MATERIALS AND METHODS

Recovery of *Thripoctenus javae* at release sites

All but one of the sites where *T. javae* was released in 2001, (Jamieson et al. 2008), were re-visited in autumn 2017 (April–May), Table 1. Site 19 in Gisborne was not visited in 2017 due to insufficient contact information. At each site, a 30-minute timed search for greenhouse thrips was conducted in each of three habitats: the fruit crop; shelterbelts; and ornamental plants. Host plants were visually scanned, at human height, for silvering on mature leaves; a sign of thrips feeding damage. Silvered leaves were turned over to confirm the presence of greenhouse thrips. Adult greenhouse thrips were identified in the field as macroapterous terebrantians with pale forewings, legs and antennae. If no greenhouse thrips were found in the first 15 minutes, the search was discontinued in that habitat. When greenhouse thrips were detected, a sample of up to 50 silvered leaves was collected from the host plant, put into a labelled sealable plastic bag (25 cm x 38 cm) and stored at 18–20°C. The number of *T. javae* pupae on each leaf was counted under a stereo microscope and recorded after 7 days. Due to the large distances between release sites, different teams of researchers collaborated following the same protocol.

Survey for *Thripoctenus javae* in Bay of Plenty kiwifruit orchards

Cryptomeria shelterbelts on commercial kiwifruit orchards were surveyed to determine the presence of *T. javae*. A letter to organic and conventional kiwifruit producers was sent through the Certified Organic Kiwifruit Association (COKA) and Seeka Limited, explaining the objective of the survey and asking for their participation. Sixty-five kiwifruit growers, with orchards located in the Bay of Plenty, expressed interest in participating. One kiwifruit block with a cryptomeria shelterbelt on at least one border was selected from each participating orchard. Kiwifruit orchards were visited from late March to May 2018, when greenhouse thrips are most abundant (Logan et al. 2021) and *T. javae* is known to be present. At each orchard, 20 foliage samples (approximately 80 g each) were randomly collected along the cryptomeria shelterbelt and placed into sealed bags. Each sample was weighed and then washed for 30–45 sec in a bucket containing 6 L of hot water and 1–2 drops of dishwashing liquid 1–2 days after the collection. The washing water was then poured through a fine muslin mesh cloth to collect the *T. javae* pupae, which were counted using a stereo microscope.

Analysis

Parasitoid presence or absence was mapped on a New Zealand geographic shapefile using GIS software (ArcGIS Pro 2.7.1). A test of two proportions was carried out to explore the differences in the presence of *T. javae* at conventionally managed orchards and certified organic orchards using Minitab 18th edition (Minitab 2015).

Calculation of dispersal distance

The dispersal distance of *T. javae* was estimated by measuring the direct distance between kiwifruit orchards surveyed and the nearest release site. We used the formula posted by (BlueMM 2007) in Microsoft Excel®:

```
Distance=ACOS(COS(RADIANS(90-Lat1))
*COS(RADIANS(90-Lat2)) + SIN(RADIANS(90-
Lat1))*SIN(RADIANS(90-Lat2))
*COS(RADIANS(Long1-Long2))) *R
```

Where: Lat1 = Latitude of the release point; Lat2 = Latitude of the sampling point; Long1 = Longitude of the release

Table 1 *Thripoctenus javae* recovery from release sites during searches of host plants in 2017. Latitude and longitude co-ordinates are the World Geodetic System 1984.

Region	Site	Latitude, Longitude	Host plants	Total number leaves sampled	Total number *T. javae* pupae
Kerikeri	1	-35.190912, 173.951919	Citrus	0	*
	2	-35.174919, 173.932237	Avocado	25	0
			Citrus	23	0
			Kiwifruit	25	14
	3	-35.242803, 173.952540	Kiwifruit	45	187
			Persimmon (*Diospyros* spp.)	25	30
	4	-35.194709, 173.958783	Citrus	0	*
Whangarei	5	-35.750324, 174.265666	Avocado	14	0
			Shelterbelt photinia ‘Red Robin’	50	111
			Ornamentals *Clethra arborea* and *Inga edulis*	50	64
	6	-35.746878, 174.251929	Avocado	3	0
			Shelterbelt Acmena	1	1
			Ornamental *Hydrangea* spp.	32	192
	7	-35.734120, 174.219160	Avocado	50	30
			Shelterbelt cryptomeria	41	32
			Ornamental *Magnolia* spp.	50	79
	8	-35.649613, 174.396047	Avocado	6	0
			Shelterbelt cryptomeria	6	5
			Ornamentals *Cornus capitate* and *Wisteria* spp.	20	11
Auckland	9	-36.891345, 174.726248	Apple (*Malus* spp.)	53	71
			Citrus	3	0
			Shelterbelt Acmena	50	52
			Ornamentals *Prunus* spp., *Inga edulis* and unidentified sp.	50	233
Bay of Plenty	10	-37.709523, 176.079279	Ornamental spp.	30	28
	11	-37.611956, 175.899386	Avocado	41	0
			Ornamental spp.	23	13
			Ornamental Citrus	1	0
	12	-37.599973, 175.947776	Avocado	2	0
			Shelterbelt cryptomeria	24	191
			Ornamentals *Hydrangea* spp. and unidentified sp.	20	15
	13	-37.715099, 176.274481	Kiwifruit	24	6
			Shelterbelt Redwood	24	48
	14	-37.650532, 175.992905	Avocado	1	0
			Shelterbelt spp.	18	34
			Shelterbelt cryptomeria	14	41
	15	-37.515477, 175.957969	Avocado	4	0
			Shelterbelt spp.	2	0
			Single Persimmon tree (*Diospyros* spp.)	45	230
	16	-37.686157, 176.028392	Avocado	46	80
			Ornamental spp.	63	142
	17	-37.530636, 175.925364	Avocado	50	2
			Ornamentals Rhododendron, *Hydrangea* spp., *Geranium* spp., Conifer and unidentified sp.	44	32
Gisborne	18	-38.667080, 177.951240	Ornamental Coprosma (*Coprosma repens*)	21	0
	19	-38.677317, 177.946171	Citrus	*	*
	20	-38.634289, 177.853655	Citrus	0	*
			Shelterbelt cryptomeria	0	*
			Ornamental species	0	*
	21	-38.745786, 177.901549	Avocado	23	7
			Ornamentals *Rubus* spp. and Citrus	23	0

* No data collected

point; Long2 = Longitude of the sampling point; and R = Earth's radius (mean radius = 6,371 km).

RESULTS

Recovery of *Thripoctenus javae* at release sites.

Thripoctenus javae were recovered at 16 of the 20 original release sites (80%) (Table 1). In Kerikeri, *T. javae* were found at two of four release sites. Foliage samples were not collected from two of the release sites because no greenhouse thrips were found. In Whangarei and Bay of Plenty, *T. javae* were found at all of the release sites (n=4 and 8, respectively). *Thripoctenus javae* were present at the single Auckland site, and at one of the four release sites in Gisborne. Two other Gisborne release sites were searched, but no leaf samples were collected as greenhouse thrips were not found. The fourth site in Gisborne was not visited.

Thripoctenus javae were found primarily in the shelterbelts and ornamental plants at the release sites. Shelterbelt species varied amongst sites, but the most common was cryptomeria which was present at five release sites. *Thripoctenus javae* were found on four out of five cryptomeria shelterbelts as well as on *Syzygium* spp. (= Acmena, two sites), photinia 'Red Robin' *(Photinia* spp.*)* and redwood *(Sequoia* spp.*)*. *Thripoctenus javae* were recorded parasitising greenhouse thrips on avocado foliage at 4/12 commercial avocado orchards (Sites: 7, 16, 17 and 21) and on kiwifruit foliage at all sites where kiwifruit were grown (Sites: 2, 3 and 13) (Table 1).

Survey of *Thripoctenus javae* in Bay of Plenty kiwifruit orchards

Thripoctenus javae were found at 32 of the 65 kiwifruit orchards (49.2%) surveyed across the Bay of Plenty (Figure 1, Table 2). Orchard elevation varied from 4–243m asl, and *T. javae* were found on orchards up to 179 m asl. *Thripoctenus javae* were recorded on a higher percentage of organically certified orchards (82%, n = 17) than on conventionally managed orchards (38%, n=48) (p=0.002). The furthest distance *T. javae* were found from an original release site, was 55.4 km in Edgecumbe (Table 2). Potential dispersal patterns from original release sites were not evident due to the clustering of surveyed orchards in areas dominated by kiwifruit production. Furthermore, locations of orchards where the parasitoid was not collected during this survey were geographically spread across Bay of Plenty and ranged from 1–98 km from the nearest release site.

DISCUSSION

The aim of the current study was to update the establishment the of *T. javae* in New Zealand and to determine how common the parasitoid is in kiwifruit orchards in the Bay of Plenty. We found that *T. javae* were established at 80% of the sites where they had been released 17 years before, which is more successful than the previous estimate of 52% establishment (Jamieson et al. 2008). Our data shows that there are well established populations of *T. javae* in Kerikeri, Whangarei and Bay of Plenty with multiple sites in each of these regions having the parasitoid present. In Gisborne, greenhouse thrips were difficult to find as was the parasitoid, however positive records at one release site show that *T. javae* is still present in the region. High numbers of parasitoid pupae were recorded at the Auckland site and it was identified in five Auckland home gardens and a public park which shows the parasitoid has dispersed from the original release site (unpublished data). In Bay of Plenty, *T. javae* was found at all eight release sites and 32 kiwifruit orchards. Previously, the parasitoid had only been recovered from three release sites in Bay of Plenty (Jamieson et al. 2008). The increase in recovery of *T. javae* from Bay of Plenty release sites may have been due to the inclusion of a wider range of host plants in the search.

Kiwifruit orchards were found to support populations of *T. javae* in Bay of Plenty, with almost half of the orchards surveyed confirming the parasitoid was present. *Thripoctenus javae* were found in areas dominated by kiwifruit production, particularly Pyes Pa and Te Puke despite it never being originally released in either location. In Pyes Pa, locations where *T. javae* was found were at least 8.9 km from the nearest release site and, in Te Puke, *T. javae* was found a minimum of 10.3 km from the nearest release

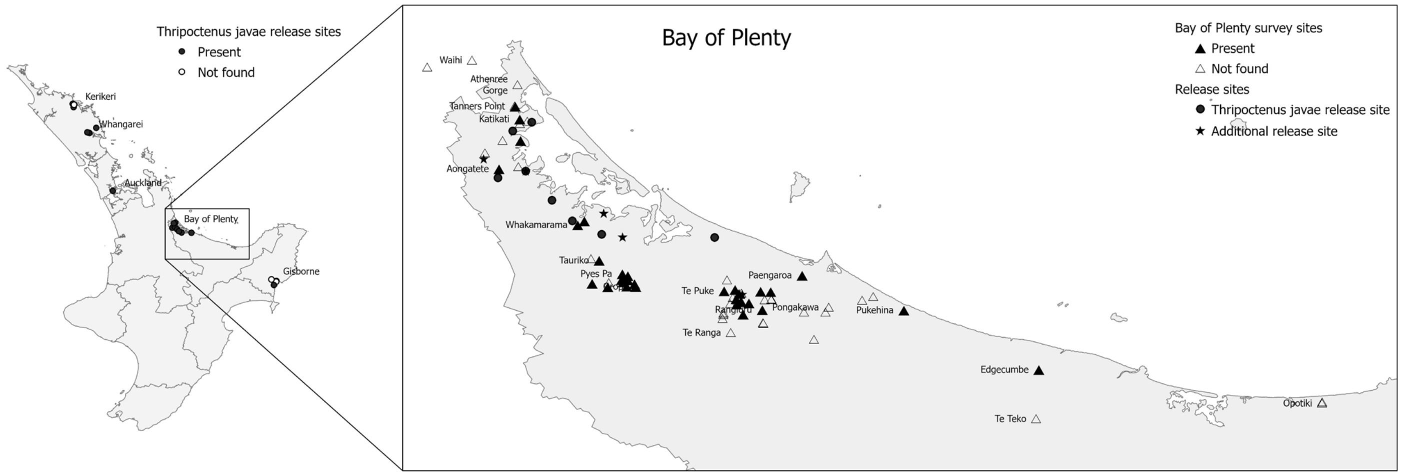

Figure 1 North Island, New Zealand map showing 21 sites where *Thripoctenus javae* was released in 2001. Insert shows Bay of Plenty region in greater detail with the locations of 65 kiwifruit orchards surveyed for *T. javae* in 2018.

Table 2 Collection of *Thripoctenus javae* pupae in kiwifruit orchards in the Bay of Plenty in 2018. Dispersal distance = distance between nearest release site and orchard surveyed. Orchards where *T. javae* was not found have been excluded (33 orchards: 3 organic, 30 conventional). Latitude and longitude co-ordinates are the World Geodetic System 1984.

Area	Orchard	Orchard management practice	Latitude, Longitude	Total *Thripoctenus javae* pupae	Dispersal distance (Km)
Tanners Point	66	Conventional	-37.487500, 175.929444	4	4.0
Katikati	80	Conventional	-37.546800, 175.938652	10	2.1
Aongatete	77	Conventional	-37.595801, 175.901345	4	1.8
Whakamarama	30	Conventional	-37.685801, 176.049015	82	1.8
Tauriko	58	Conventional	-37.799722, 176.089722	6	10.1
	76	Conventional	-37.793877, 176.062547	12	9.5
Pyes Pa	72	Conventional	-37.777305, 176.114849	2	8.2
Te Puke	17	Conventional	-37.829814, 176.312781	1	13.2
	49	Conventional	-37.82583, 176.319722	1	12.9
	37	Conventional	-37.806913, 176.291021	2	10.3
	57	Conventional	-37.847222, 176.323888	2	15.3
	25	Conventional	-37.820555, 176.311944	3	12.2
	31	Conventional	-37.807694, 176.354229	5	12.5
	59	Conventional	-37.804444, 176.310000	290	10.4
Rangiuru	27	Conventional	-37.839419, 176.357174	2	15.6
	81	Conventional	-37.808213, 176.371674	2	13.4
Pukehina	48	Conventional	-37.840277, 176.602222	12	32.0
Edgecumbe	63	Conventional	-37.943026, 176.835862	31	55.4
Katikati	5	Organic	-37.509722, 175.937222	13	1.9
Whakamarama	53	Organic	-37.692714, 176.037550	78	1.1
Tauriko	55	Organic	-37.754166, 176.074722	48	5.0
Pyes Pa	45	Organic	-37.787747, 176.124418	1	9.6
	2	Organic	-37.798888, 176.122500	8	10.6
	73	Organic	-37.780743, 176.124375	8	8.9
	3	Organic	-37.791518, 176.11612	25	9.7
	74	Organic	-37.787418,176.113573	125	9.2
Oropi	1	Organic	-37.799444, 176.138055	12	11.3
	11	Organic	-37.794444, 176.135833	23	10.7
Te Puke	6	Organic	-37.824799, 176.320530	2	12.9
	46	Organic	-37.811381, 176.316806	2	11.3
	38	Organic	-37.827787, 176.333939	4	13.6
Paengaroa	39	Organic	-37.779938, 176.426069	151	15.2

site (see Table 2, Figure 1). Passive dispersal rather than active flight is more likely for the movement of *T. javae* to Te Puke, as the adult is only 0.6 mm in length (Loomans & Van Lenteren 1995) and the landscape between the release site and Te Puke is predominantly pastoral and cropping with fewer greenhouse thrips hosts across this area.

The furthest dispersal distance by *T. javae*, identified in this survey, was 55.4 km from the nearest release site. Orchard 63 is in Edgecumbe and isolated from the other new localities by a minimum of 24 km. It would be valuable to collect more data from kiwifruit orchards and home gardens in this area to determine whether this data point represents an isolated population or the current edge of population in Bay of Plenty.

This survey confirms *T. javae* is present in kiwifruit orchard environments during autumn when the population of greenhouse thrips peaks. In December and January, generation time of greenhouse thrips is short, and the population is still at a level that can be controlled. The phenology of *T. javae* in cryptomeria shelterbelts is still unknown, however the parasitoid needs to parasitise immature thrips from early summer to prevent greenhouse thrips reaching unacceptable levels. Future research is planned to investigate the phenology of *T. javae* and its effectiveness through the season as a biocontrol agent for greenhouse thrips.

CONCLUSIONS

The recovery of *Thripoctenus javae* from 16 of the 20 of the release sites, and 32 new locality records of *T. javae* in the Bay of Plenty, shows that the establishment of this parasitoid in New Zealand was successful. Seventeen years after release, *T. javae* has dispersed from the release sites and can be found on cryptomeria shelterbelts in both conventionally managed and certified organic kiwifruit orchards. However, the effectiveness of *T. javae* on greenhouse thrips populations in kiwifruit orchards is still unknown, this and its potential economic impact are both priorities for future research.

ACKNOWLEDGEMENTS

The authors would like to thank all kiwifruit growers and orchardists who allowed us access to their orchards and gardens. We also want to thank the Certified Organic Kiwifruit Association and Seeka Limited who facilitated communication with kiwifruit growers in Bay of Plenty. We would particularly like to acknowledge Mark Astill for his contribution to this paper. Mark has been a dedicated collaborator with our team in Te Puke and is remembered well throughout his extensive network of connections. The contribution by our Plant & Food Research colleagues Peter Lo, David Logan, Gonzalo Avila and the science publishing office is appreciated as well as the journal reviewers. This work was completed with the support of Plant & Food Research's Strategic Science Investment Fund (SSIF).

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