A REVIEW OF *BACTROCERA BRYONIAE* (TRYON) AND REVISED DISTRIBUTION IN ASIA AND AUSTRALIA, WITH A FOCUS ON NEW SOUTH WALES

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Summary

Bactrocera bryoniae is commonly found in Northern Australia with occasional detections in New South Wales (NSW). We reviewed host records and the distribution in Asia, Australia and particularly NSW. We reviewed 19 years of NSW surveillance records and revised the eastern and southern distribution. We conclude that there are resident populations as far south as Coffs Harbour with two annual population peaks. There was little evidence for a resident population inland at Guyra. The populations in the Newcastle/Sydney/Wollongong region were transient in most years with one annual peak (November) in 2019. Since then, we detected significant populations occurring between October and April in 2020/2021 with two peaks in November and January.

Keywords fruit fly host, morphological identification, molecular, host susceptibility index

INTRODUCTION

Many *Bactrocera* fruit flies are economically important pests of fruit and vegetable commodities and these cause disruption to domestic and international trade (Clarke *et al.* 2011; Dominiak and Mapson 2017). In Australia during 1995, there was an increased surveillance for exotic fruit flies after the detection of *Bactrocera papaya* (Drew and Hancock) in Cairns and *B. philippinensis* (Drew and Hancock) in Northern Territory (Gillespie 2003; Hancock 2013). This increased surveillance provided additional data on the fruit fly species already in Australia.

In eastern Australia, Queensland fruit fly, *Bactrocera tryoni* (Froggatt) (Qfly) is the most important fruit fly pest of horticulture (Dominiak and Daniels 2012). There are up to 243 known or suspected commercial and native *B. tryoni* host plants (Hancock *et al*. 2000). Much of the early fruit fly research focused on major commercial crops and particularly on higher value or more susceptible hosts. However, the needs of market access and the impact of climate change have necessitated a review of all fruit fly distributions in eastern Australia. *Bactrocera bryoniae* (Tryon) is one species not recently reviewed. Therefore, we reviewed this fruit fly to better understand its current position in the Australian tephritids.

There were two main aims of this review. Firstly, we reviewed the known information on *B. bryoniae*, including reported distribution, hosts and pest status. Second, we reviewed the more recent New South Wales (NSW) surveillance data to assess if breeding populations are likely to exist in NSW regions and to identify possible seasonal trends.

LURES AND SURVEILLANCE

Bactrocera bryoniae is attracted to cuelure (Drew 1974; Drew and Hooper 1981; Drew 1989; Raghu *et al*. 2000; Tan 2006; Hancock, 2013; Sulaeha *et al*. 2020) and melolure in north Queensland (Royer 2015). In Sydney, *B. bryoniae* has only been trapped in cuelure baited traps and not in melolure or methyl eugenol baited traps, but populations were low (Dominiak *et al*. 2015a).

Additionally, Tan (2006) reported that *B. bryoniae* was attracted to raspberry ketone. In the Cairns area of north Queensland, Fay (2012) found *B. bryoniae* was much more attracted to raspberry ketone than to cuelure. However, cuelure is about three times more attractive than raspberry ketone in far north Queensland (Royer *et al*. 2020). Both cuelure and raspberry ketone are considerably more attractive than anisyl acetone or zingerone (Royer *et al*. 2020).

Fay (2012) did not report any trapping with zingerone. However, zingerone was recorded as a lure, along with cuelure (Doorenweerd *et al.* 2018). *Bactrocera bryoniae* was not attracted to cuelure and methyl eugenol combination lures (Drew and Hooper 1981). More recently, Royer and Mayer (2018) found *B. bryoniae* was significantly more attracted to cuelure than to mixtures of cuelure and methyl eugenol, based on research in Australia and Papua New Guinea. *Bactrocera bryoniae* was not attracted to liquid food lures such as orange-ammonia or protein hydrolysate (Drew and Hooper 1981).

REPORTED DISTRIBUTION EXCLUDING NEW SOUTH WALES

Some authors report the distribution of *B. bryoniae* as Australia and Papua New Guinea without further details (Hardy 1969; Vargas *et al.* 2015; Kim and Kim 2016). Drew (1989) reported that *B. bryoniae* was widespread and abundant in Queensland, and was present in the northern coastal areas in Western Australia, Northern Territory, Papua New Guinea and the Torres Strait islands. Also, Huxham (2002) reported *B. bryoniae* was one of 43 Australian native species trapped in the Torres Strait islands. Drew (1989) listed the distribution as Indonesia, Papua and New Guinea, Torres Strait islands, and Australia (Queensland, northern Western Australia, and Northern Territory) and this paper was cited by subsequent reports (Hancock *et al*. 2000; Plant Health Australia 2011; Hancock 2013; Sulaeha *et al*. 2020). In Indonesia, *B. bryoniae* was detected in Bali (Devi *et al*. 2017) and reported for the first time south of Sulawesi (Sulaeha *et al*. 2020). This distribution of locations fits into the Wallacea, New Guinea and Australia zones described by Hancock and Drew (2015). *Bactrocera bryoniae* is likely to have specific habitat requirements as it was almost exclusively trapped in rainforest habitat (Raghu *et al*. 2000). Many other tropical species are trapped also in open sclerophyll and suburban habitats (Raghu *et al.* 2000).

REPORTED DISTRIBUTION INCLUDING NEW SOUTH WALES

Many reports describe the distribution on the eastern Australian coast as "down to Sydney" (Hancock *et al*. 2000; Plant Health Australia 2011; Sulaeha *et al.* 2020; Noushini *et al.* 2020; Sultana *et al*. 2020). Hancock (2013) reported *B. bryoniae* in NSW but did not specify further.

Distribution infers an established population, but establishment requires the appropriate hosts and climate. Historically, *B. bryoniae* was not known to be established in Sydney (Gillespie 2003) but this report is at variance with the later reports mentioned above. Largely consistent with Gillespie (2003), Dominiak (2021) reported less than ten *B. bryoniae* trapped during each year in Sydney in eight of ten years between 2010 to 2019. By the standards of *B. tryoni*, these populations are not consistent with the levels required for a breeding population (Dominiak *et al.* 2011).

NEW SOUTH WALES REVIEW

A fruit fly surveillance monitoring array has been active in NSW for decades. Traps were created and inspected by NSW Department of Primary Industries (DPI) staff. After establishment, the number of traps in an area rarely changes. At each site, there were three traps in separate trees using the standard attractants of cuelure, methyl eugenol or an attractant for Mediterranean fruit fly (Dominiak *et al* 2015a). In 2000, NSW fruit fly trap inspections and fruit fly identifications were digitised and housed in the NSW internal fruit fly database "PestMon" (see Dominiak *et al.* (2007) for details). Trap inspection activities were recorded on hand held bar code readers and downloaded onto the PestMon database. Fruit fly identifications were conducted by NSW DPI staff and transferred into Pestmon matching up with trap inspection reports. Most traps were usually inspected fortnightly. The PestMon records were examined and the results for *B. bryoniae* extracted. We reviewed the results for three different fruit fly surveillance programs. Firstly, on the far north coast of NSW, surveillance was conducted at four sites (Coffs Harbour, Iluka, MacLean and Yamba) from 2003 to 2007 when surveillance ceased (Figure 1). At Guyra, surveillance started in 2010 and continues into 2021. Finally, in the Newcastle/Sydney/Wollongong region, digital data are available from 2002 and continue into 2021. These three sets of data were retrieved from PestMon using standard queries.

In north coast of NSW and based on the detected populations in Table 1, we suspect that it is likely that *B. bryoniae* is resident at Coffs Harbour and Yamba at least (see Figure 1). Also, it is likely that breeding populations exist at Iluka and Maclean. There were two annual observation peaks on average with a larger peak on October-November and a smaller peak in May-June.

During most years at Guyra (Figure 1), only Qfly or *Dacus newmani* (Perkins) were trapped. A single *B. bryoniae* was trapped in March 2015 and a single fly in February 2020. In 2021, *B. bryoniae* were trapped in January (11), February (5), and March (30). The most westerly longitude for these observations was 151.70535 °E.

At Newcastle, north of Sydney (Figure 1), there was an average of 3.5 *B. bryoniae* trapped annually between 2002/03 and 2018/19. There were 61 specimens trapped in the 2019/20 year and 141 specimens in 2020/21.

Table 1. Numbers of *B. bryoniae* detected in different months and different years in the northern New South Wales surveillance array.

Location	Years					Annual total and average (in brackets)
	2003	2004	2005	2006	2007	
Coffs Harbour	144	37	67	4	22	274 (54.8)
Iluka	16	11	2	5	1	35 (7)
Maclean	10	2	15	0	3	28 (4)
Yamba	29	38	27	2	11	107 (21.4)
Months						
January	1	16	3	0	1	21 (4.2)
February	5	5	3	0	0	13 (2.6)
March	4	2	1	1	3	11 (2.2)
April	2	7	6	2	0	17 (3.4)
May	9	9	23	4	21	66 (13.2)
June	38	10	5	0	2	55 (11)
July	7	8	1	1	0	17 (3.4)
August	6	3	0	1	4	14 (2.8)
September	18	8	4	1	0	31 (6.2)
October	68	8	18	0	3	97 (19.4)
November	36	11	41	0	3	91 (18.2)
December	5	1	6	1	0	13 (2.6)
Total	199	88	111	11	37	

Figure 1. Map of New South Wales showing surveillance sites and extreme west longitude and southern latitudes.

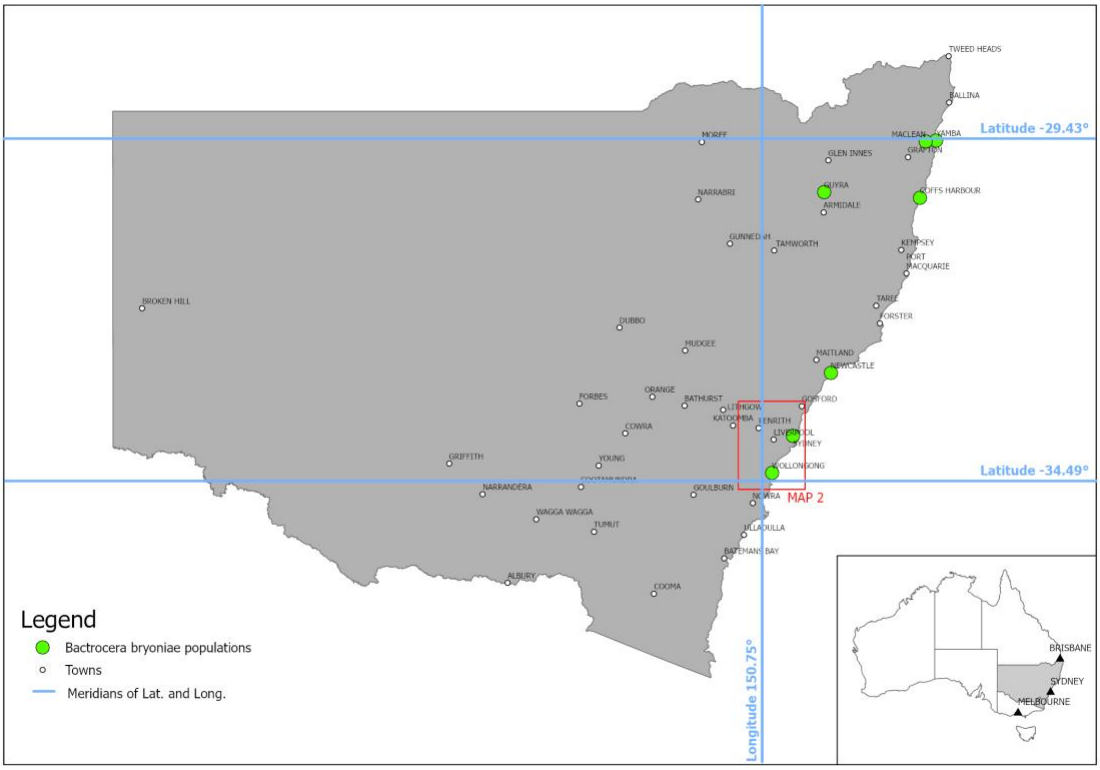

Figure 2. Map of the Sydney/Wollongong basin showing detections of *Bactrocera bryoniae* and size of total detections in 2020/2021.

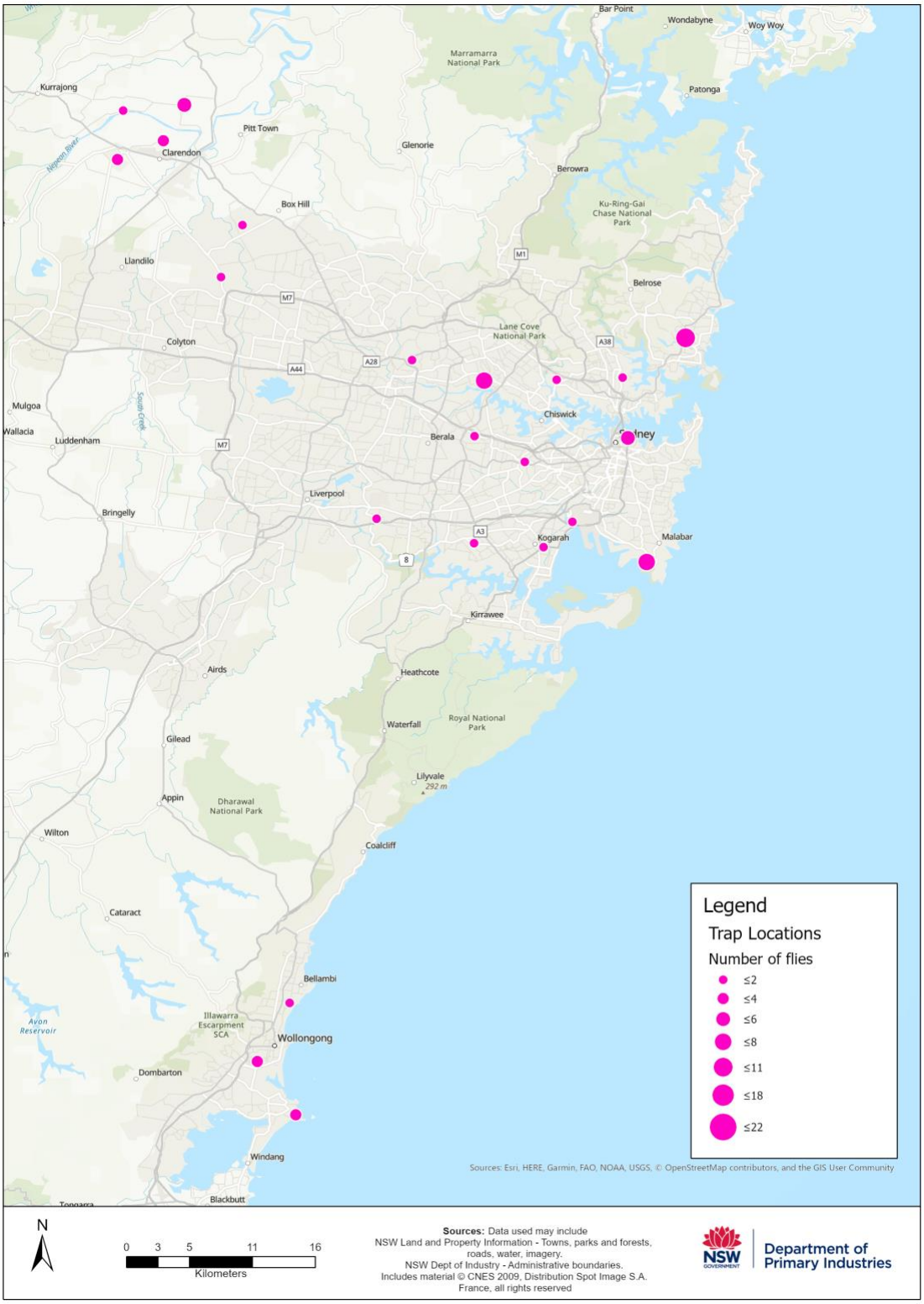

Table 2. Numbers of *B. bryoniae* detected in different months and different years in the Newcastle/Sydney/Wollongong surveillance array.

Year	Months of the year												Total
	July	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	
2001-2002							0	0	0	0	1	0	**1**
2002-2003	0	0	0	0	0	1	3	3	5	1	1	0	**14**
2003-2004	0	0	0	1	22	8	15	25	5	1	1	0	**78**
2004-2005	0	0	0	0	3	0	1	0	1	0	0	0	**5**
2005-2006	0	0	0	1	30	9	4	2	0	0	0	0	**46**
2006-2007	0	0	0	0	0	1	0	0	2	0	6	1	**10**
2007-2008	0	1	0	0	2	0	2	0	0	0	0	0	**5**
2008-2009	0	0	0	1	0	0	0	0	1	0	0	0	**2**
2009-2010	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2010-2011	0	0	0	0	2	1	1	0	0	0	0	0	**4**
2011-2012	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2012-2013	0	0	0	0	1	1	0	0	0	0	0	0	**2**
2013-2014	0	0	0	2	0	0	0	0	0	0	0	0	**2**
2014-2015	0	0	0	0	1	0	0	0	0	0	0	0	**1**
2015-2016	0	0	0	0	1	0	0	0	0	0	0	2	**3**
2016-2017	0	0	0	3	3	5	2	0	0	0	0	0	**13**
2017-2018	0	0	0	2	0	0	0	0	1	3	0	0	**6**
2018-2019	0	0	0	2	0	0	3	1	0	0	0	0	**6**
2019-2020	0	0	0	4	78	10	7	5	6	0	0	0	**110**
2020-2021	0	0	1	24	58	18	72	34	31	7	0	0	**245**
Total	**0**	**1**	**1**	**40**	**201**	**54**	**110**	**70**	**52**	**12**	**9**	**3**	

In the Newcastle/Sydney/Wollongong region, the monthly detections of *B. bryoniae* vary from zero to 78 (Table 2). Population thresholds such as the "5-fly" were developed for *B. tryoni* (Dominiak *et al.* 2011) and we adopt these thresholds for *B. bryoniae* in the absence of equivalent thresholds for *B. bryoniae*. In most years, the 5-fly levels for a *Bactrocera* outbreak was not breached and therefore, *B. bryoniae* cannot be considered established in those years. Alternatively, the Sydney region may be an area of low pest prevalence in those years (Dominiak *et al.* 2015b). There were several years when this

pattern was broken. There were 78 flies trapped in 2002/2003, 46 in 2005/2006, 110 in 2019/2020 and 245 flies in 2020/2021. It is likely that there are two population peaks in November and January (Table 2). Locations of the detections in 2020/2021 are provided in Figure 2. The most westerly detection was 150.74847 °E and the southern-most detection was -34.48841 °N.

PEST STATUS, HOST RANGE AND NSW POSSIBILITIES

There are varying views on the pest status of *B. bryoniae*. Drew (1989) reported that there were no records of this species reared from edible fruits and it could not be considered an economic pest. The pest status is low in Queensland but not in Western Australia or Northern Territory (Plant Health Australia 2011). *Bactrocera bryoniae* is reported to have some pest status (Royer and Mayer 2018). In Papua New Guinea, *B. bryoniae* has pest status as causing moderate damage (the middle ranking on a three-point scale) (Leblanc *et al.* 2001).

Bactrocera bryoniae is oligophagous (Vargas *et al.* 2015; Kim and Kim 2016). Hardy (1969) listed six hosts and subsequently Drew (1989) reported eight hosts with only one commercial host (*Capsicum annum* L.). Subsequently, Hancock *et al*. (2000) reviewed the historical reports of *B. bryoniae* and reported ten possible hosts in five families including that Cucurbitaceae, Loganiaceae, Musaceae, Passifloraceae and Solanaceae. Most hosts are wild plants. There are two "major" wild hosts of *B. bryoniae* (Hancock *et al.* 2000).

Diplocyclos palmatus L. (Cucurbitaceae) striped cucumber is a tropic plant species (Huxham 2002) and a major host (Hancock *et al*. 2000). Hardy (1969) reported this host as *Bryonopsis lacinosa* L. This host is native to rainforests and dry rainforests. *Diplocyclos palmatus* flowers during August-October and is found in Western Australia, Northern Territory, Cape York Peninsula, Queensland and southward to northern eastern NSW (Atlas of Living Australia 2021).

The second "major" host listed by Hancock *et al*. (2000) is corky passionfruit (*Passiflora suberosa* L.) (Passifloraceae) which occurs down to Sydney (Atlas of Living Australia 2021). This weed flowers and fruits throughout the year (Atlas of Living Australia 2021). LeBlanc *et al.* (2013) found that 7.14 adults/kg of fruit emerged from *P. suberosa.* Therefore, this host is ranked as "moderately good" by Follett *et al*. (2021).

Hancock et al. (2000) listed four other wild hosts. Stinking passionflower, *P. foetida* (L.), is reported as an invasive vine and a pest of the tropics (Jucker *et al*. 2020). Stinking passionflower is known to occur down to about Coff's Harbour and flowers from July to August (Atlas of Living Australia 2021).

In Cucurbitaceae, *Mukia maderaspatana* ((L.) M.roem.) and *Zehneria cunninghamii* (F. Muell.) are hosts. *Mukia maderaspatana,* rough bryony, flowers in summer and is also known as *Cucumis maderaspatana* (L.). In Australia, it occurs in Western Australia, Northern Territory and Queensland. *Zehneria cunninghamii* grows in monsoon and mountain rain forest and is known to occur in northern Queensland down as far as the Hunter Valley, just north of Sydney (Atlas of Living Australian 2021). *Zehneria cunninghamii* is also known as *Neoachmandra cunninghamii.*

Additionally, Drew (1989) listed another wild host, *Strychnos lucida* R.Br. (strychnine berry) in Strychnaceae, as a host but *S. lucida* was placed in Loganiaceae by Hancock et al. (2000). *Strychnos lucida* is known in central and northern Queensland, southeast Asia and Malesia (Australian Tropical Rainforest Plant 2021). This host rarely occurs south of Townsville (Atlas of Living Australia 2021).

In cultivated hosts, *B. bryoniae* were regularly bred from chilli (*Capsicum frutescens* L. – "Birdseye" and "Tabasco") in Papua New Guinea (Tenakanai 1997; LeBlanc *et al*. 2013). Damage in those crops can be as high as 80% (Leblanc *et al*. 2001). *Capsicum frutescens* (also known as "piri piri" or "African devil") is used to make tabasco sauce and thus is quite different to *C. annuum. Capsicum frutescens* is listed by Drew (1989) but not listed in Hancock *et al.* (2000) although *C. annum* is listed by Hancock *et al*. (2000) as chilli. Additionally, bananas (*Musa x paradisiaca* L.) past commercial stage are hosts (Hancock *et al*. 2000; LeBlanc *et al*. 2001). Bananas were listed as a host by Vargas et al. (2015).

After the review of Hancock *et al*. (2000), three additional hosts were reported. Fully-mature snake beans (*Phaseolus unguiculata*) were attacked by *B. bryoniae,* as are *Bryonopsis affinis* Cogn. (Curcurbitaceae) (Tenakanai 1997; LeBlanc *et al.* 2001). Also, *B. bryoniae* was found associated with watermelon plants (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) in Indonesia (Sulaeha *et al*. 2020). These three hosts are not listed by Hancock *et al*. (2000).

There are several possible hosts in NSW. Capsicum (*Capsicum annum* L) is grown in NSW and is listed as a host by Hancock *et al*. (2000) but considered a probable error. Chilli (*Capsicum annuum* L.) and tomato (*Lycopersicum esculentum* Miller) are listed as hosts and are grown in NSW. LeBlanc *et al.* (2013) found that 110 adults/kg emerged from chilli. Using the host ranking system proposed by Follett *et al*. (2021) and Dominiak *et al*. (2020), chilli would be ranked in the highest group (very good host). It is likely that there are *Capsicum* spp. hosts to support *B. bryoniae* populations in NSW and the Sydney region. Also, poorly managed bananas are likely to be hosts in NSW.

DISCUSSION

We infer that it is likely that there was a resident population in the Coffs Harbour in 2007 and far north coast area (Iluka, Maclean and Yamba). Additionally, we found two population peaks with a larger peak in early summer (October-November) and a smaller peak in late autumn (May-June). Therefore, we think it is highly likely that the distribution of a breeding population will extend down the east coast as far south as Coffs Harbour at a minimum. *Diplocyclos palmatus* is known to grow in northeastern NSW and is likely to support populations in Iluka, Maclean and Yamba. The possible role of *D. palmatus* at Coffs Harbour is unclear. The larger population peak in October-November is likely to reflect the flowering (and subsequent fruiting) of *D. palmatus* in August-October. Additionally, *P. suberosa* is known to exist there and is likely to support *B. bryoniae*. Similarly, *P. foetida* and *Z. maderaspatana* occurs at Coffs Harbour and is likely to support *B. bryoniae*. The cultivated hosts of *Capsicum* sp and *L. esculentum* are further likely to provide a host continuum for *B. bryoniae*.

Further inland at Guyra (Figure 1), we found two flies in a decade (2010 to 2020). It is likely that Guyra did not have an established *B. bryoniae* population. In 2021, there was a population peak from January to March. Sultana *et al.* (2020) predicted that climate change would result a change in suitable habitats into NSW.

Newcastle is the next trapping site south of Coff's Harbour. Very few *B. bryoniae* were trapped annually between 2002/03 and 2018/19. Based on the detections at Coff's Harbour, we suspect that the most southerly boundary of any breeding population was between Coff's Harbour and Newcastle up to 2018/19. This changed in 2019/20 with 61 detections and 141 detections in 2020/21. This pattern is largely similar to Sydney, further south (Table 2).

In the Newcastle/Sydney/Wollongong complex, there seems to be two population peaks (November and January) over the eight months from October 2020 to May 2021. Regarding possible Sydney hosts, *P. suberosa* occurs in Sydney and the flowering/fruiting habit throughout the year (Atlas of Living Australia 2021) and may explain mid-season detections in Sydney. *Mukia maderaspatana* is likely to support *B. bryoniae* populations, particularly Newcastle near the Hunter Valley. Poorly managed bananas are likely to provide additional hosts along coastal NSW down to Sydney.

Bactrocera bryoniae was likely to have a status of "transcience" according to SIPPC (2017). Based on Table 2, it is likely that in most years that the population was not expected to survive or may survive as an area of low pest prevalence (Dominiak *et al.* 2015b). There are no phytosanitary measures planned and therefore "transient: non-actionable" was the likely status. However, we think that the large number of detections and the widespread nature of the detections in 2020/2021 indicate that *B. bryoniae* may have established in the Sydney region, at least temporarily.

The limitation to *B. bryoniae* becoming established in Sydney and Guyra is likely to be climate and host related. Under climate change scenarios, Wan *et al*. (2020) found that *B. bryoniae* had a wide range of habitable regions, potentially occupying up to 23.04% of the global land surface area, among which 12.29%, 5.24% and 5.51% had high, moderate and low suitability respectively. The highly suitable habitats for *B. bryoniae* were mainly distributed in southern Asia, equatorial and south eastern Africa, southern North America, northern and central South America, and eastern coastal areas of Australia (Wan *et al.* 2020). Meats (2006) reported a widespread distribution of *B. bryoniae* in tropical rainforest and subtropical monsoon warm climate in eastern Australia.

Climate variations influenced the permanent distribution of *B. tryoni* (Froggatt) in southern NSW (Dominiak and Mapson 2017). The period 2010/2011 was the wettest two-year period on record and resulted in the development of large Qfly populations in southeastern NSW (Dominiak and Mapson 2017). However, *B. bryoniae* was trapped in low numbers in Sydney during this period. There were no *B. bryoniae* trapped at Guyra in 2010/2011. We

hypothesise that high rainfall alone does not result in increased detections of *B. bryoniae* in Sydney or Guyra. Sultana *et al.* (2020) predicted that the coastal distribution would expand further south by 2070.

In conclusion, we propose that there may be three host species not reported by Hancock *et al.* (2000); these are *Phaseolus unguiculata*, *Bryonopsis affinis* and *Citrullus lanatus*. Additionally, there needs to be clarification around the "chilli" hosts; is it *C. annuum* or *C. frutescens*, or both. We propose that a more accurate description of the *B. bryoniae* distribution is coastal NSW as far south as Coffs Harbour, consistent with Gillespie (2003). At Guyra, populations were recorded only in one year and it cannot be determined if there is a stable population at Guyra or if it is also transient. However, we suggest there may be a breeding population at Guyra, based the detections in 2021. This population would seem to be recently established but may be transient.

Populations in the Newcastle/Sydney/Wollongong complex should be considered transient until 2019. Given the detections in 2019/2020 and 2020/2021, it is likely that *B. bryoniae* is no longer considered transient in the Sydney region. It would seem more likely to be an area of low pest prevalence at very least or established. This status may change if climatic patterns revert to previous levels, however, this reversion seems unlikely given current climatic trends (Sultana *et al*. 2020; Simpson *et al.* 2020). Invertebrates are especially sensitive to climate conditions (Macfadyen *et al.* 2018) and we suspect that our results may be indicative *B. bryoniae* responding to climate change. Our detections in the large urban area of Sydney are inconsistent with Raghu *et al*. (2000) who found that *B. bryoniae* was trapped almost exclusively in rainforest habitats. Additional research is required to more fully understand the current changes in distribution of *B. bryoniae.* In particular, further research is required to evaluate if our reported range extension is similar in other Australian states.

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