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Establishment of the biological control agent *Hypocosmia pyrochroma* for *Dolichandra unguis-cati* (Bignoniaceae) is limited by microclimate

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Abstract

Cat's claw creeper, *Dolichandra unguis-cati* (Bignoniaceae), a perennial woody vine native to tropical America, is a target for biological control in Australia and South Africa. The cat's claw creeper leaf-tying moth *Hypocosmia pyrochroma* (Lepidoptera: Pyralidae) from tropical South America was released as a biological control agent for cat's claw creeper in Australia from 2007 to 2010. A total of 2,277 adults, 837 pupae and 77,250 larvae were released at 40 sites in Queensland and New South Wales. Releases were made mostly in open fields (85%), and at limited sites (15%) in insect-proof cages erected over naturally occurring cat's claw creeper infestations in the field. Sampling was conducted annually in spring and autumn to monitor the establishment and dispersal of *H. pyrochroma*. Establishment of *H. pyrochroma* was first noticed in 2012 at three release sites and since then the number of established sites has increased to 80 in 2020. Establishment was evident on both 'short-pod' and 'long-pod' forms of cat's claw creeper and was more widespread in sites where releases were made within insect-proof field cages (50%) than in sites with open field releases (9%). The moth was active from late spring to late autumn with peak larval activity in late summer. To date, all field establishments have been in areas predicted by a CLIMEX model as climatically suitable but restricted mostly to riparian environment (93% of establishment), where the moth has continued to spread from 1.5 to 23 km from release sites. In contrast, there is the only limited establishment and spread in non-riparian corridors, highlighting the role of microclimate (riparian) as a limiting factor for establishment and spread. Future efforts will focus on redistribution of the agent to river/creek systems where the moth is currently not present.

KEYWORDS

CLIMEX model, dispersal, *Dolichandra unguis-cati*, leaf-tying moth, riparian, cat's claw creeper

1 | INTRODUCTION

Cat's claw creeper, *Dolichandra unguis-cati* (L.) L.G. Lohmann (Bignoniaceae), a perennial woody climbing vine native to tropical America, is a Weed of National Significance in Australia (Dhileepan, 2012). The invasive vine poses a significant threat to biodiversity in riparian and rainforest communities in Queensland and New South Wales (Downey & Turnbull, 2007; Vivian-Smith & Panetta, 2004). Cat's claw creeper is also an invasive weed in several other countries, including South Africa, India, Mauritius, China, Hawaii and Florida in the USA, and New Caledonia (Dhileepan, 2012; King et al., 2011).

Cat's claw creeper is a structural parasite that grows vigorously, sprawling over other standing vegetation including large trees and shrubs, eventually causing canopy collapse (Downey & Turnbull, 2007). The vines also grow along the ground and form a dense mat, which precludes the growth and seed germination of understory vegetation (Downey & Turnbull, 2007). Cat's claw creeper produces an enormous number of seeds annually in summer (Dhileepan, 2012). It does not have a persistent seed bank, so while it spreads through seeds, it persists through its subterranean tuber bank (Osunkoya et al., 2009; Vivian-Smith & Panetta, 2004).

Two morphologically and phenologically distinct cat's claw creeper varieties occur in Australia (Boyne et al., 2013; Buru et al., 2016; Shortus & Dhileepan, 2011; Taylor & Dhileepan, 2012). A 'short-pod' variety with smaller shiny leaves with a smooth leaf margin is widespread throughout Queensland and New South Wales; while a less-abundant 'long-pod' variety with broad hairy leaves having serrated margins and with fruit pods twice as long as those of the 'short-pod' variety occurs at 14 sites, all in south-eastern Queensland.

The cat's claw creeper leaf-tying moth *Hypocosmia pyrochroma* Jones (Lepidoptera: Pyralidae), native to tropical South America (Williams, 2003), was approved for release in Australia (Dhileepan et al., 2007) and South Africa. (King et al., 2011). Feeding and leaf tying by *H. pyrochroma* larvae severely damage foliage (Williams, 2003) and result in reduced plant growth and tuber production (Snow et al., 2006). Climate matching (Rafter et al., 2008) and thermal (Dhileepan et al., 2013) models have predicted that the inland regions in Australia are less favourable for *H. pyrochroma* than the coastal areas, and *H. pyrochroma* is more likely to establish in the coastal areas of Australia where most of the cat's claw creeper infestations occur. In South Africa, *H. pyrochroma* was released from 2010 to 2021, but its field establishment status is yet to be confirmed (King et al., 2011; Anthony King, personal communication). This paper describes the life cycle, rearing and field release methods, field establishment status and future dispersal prospects of *H. pyrochroma* in Australia. A more robust CLIMEX model based on its native range distribution was developed to test whether the restricted establishment and dispersal of *H. pyrochroma* is climate-related. We propose that microclimate is the chief limiting factor restricting the field establishment and dispersal of *H. pyrochroma* in Australia to riparian corridors.

2 | MATERIALS AND METHODS

2.1 | Life cycle

Biological studies of *H. pyrochroma* were conducted using potted cat's claw creeper plants in a glasshouse (20–27°C; 65% RH and natural photoperiod). A pair of newly emerged male and female ($N = 10$) were transferred on to a potted cat's claw creeper plant enclosed in a cylindrical transparent Perspex tube (34 cm high and 12 cm diameter) with a gauze cap at the top for ventilation. Adults were transferred on to a fresh cat's claw creeper plant each week, and the longevity, pre-oviposition period, and the number of eggs per female per day were recorded. In the glasshouse, under natural photoperiod, the pupae entered prolonged pupal diapause in the soil from mid-autumn (April). The adults emerged from late spring (November) and the emergence continued until mid-summer (January).

2.2 | Rearing and field release

H. pyrochroma was mass-reared for field releases in a climate-controlled glasshouse (27°C, 65% RH and 14 hr light: 10 hr dark). Supplementary light in the glasshouse from autumn to spring prevented pupal diapause. *H. pyrochroma* was reared on potted plants (both long-pod and short-pod varieties), raised from field-collected subterranean tuberlings (seedlings with a single tuber). Twenty to 30 un-sexed newly emerged moths were added to a mesh-covered insect rearing cage (90 cm × 80 cm × 75 cm) filled with potted cat's claw creeper plants grown to at least 15 cm tall (28 plants in 125 mm pots). Adults were fed on diluted honey and water. After two weeks, all the foliage with developing larvae in the rearing cages were harvested and transferred into large transparent plastic boxes (50 L; 60 × 40 × 32 cm) containing freshly cut cat's claw creeper foliage, placed on the top of wire mesh (with the holes large enough for the larvae to drop down) with sterilized sand at the bottom of the box for pupation. Holes were drilled in the bottom of the box for draining excess water. Insect-proof mesh cloth was used to cover the floor of the box for ease of pupal collection. Larvae in boxes were fed with fresh foliage as needed (twice a week). After 4 weeks, mature larvae were field released, and the sand in the bottom of the boxes was sieved to remove pupae. Pupae were stored in transparent plastic boxes (17 cm × 12 cm × 7 cm) and emerging adults were either field released or used to maintain the colony.

Field releases of *H. pyrochroma* commenced in October 2007 and continued until December 2010. *H. pyrochroma* was released as late (fourth instar) larvae, pupae or adults (Table S1). Field releases were made across 40 sites, from Grafton in northern New South Wales to Mackay in northern Queensland, and from Nerang and other coastal sites in the east to Taroom in the west, covering both non-riparian and riparian sites (Table S1; Figure 1). The release sites were all large infestations (4–>100 ha) and were not subjected to other management (mechanical or chemical) treatments. Releases were made on both 'short-pod' and 'long-pod' varieties of cat's claw creeper, either directly in the open field or within large insect-proof cages erected over cat's claw creeper infestations in the field (Table S1).

2.3 | Field monitoring

All release sites were monitored twice a year, in spring (October–November) and autumn (March–April), from 2007, for leaf-tying symptoms (Figure 2) with establishment confirmed by larval recoveries. In each site, a minimum of 10 host trees with cat's claw creeper

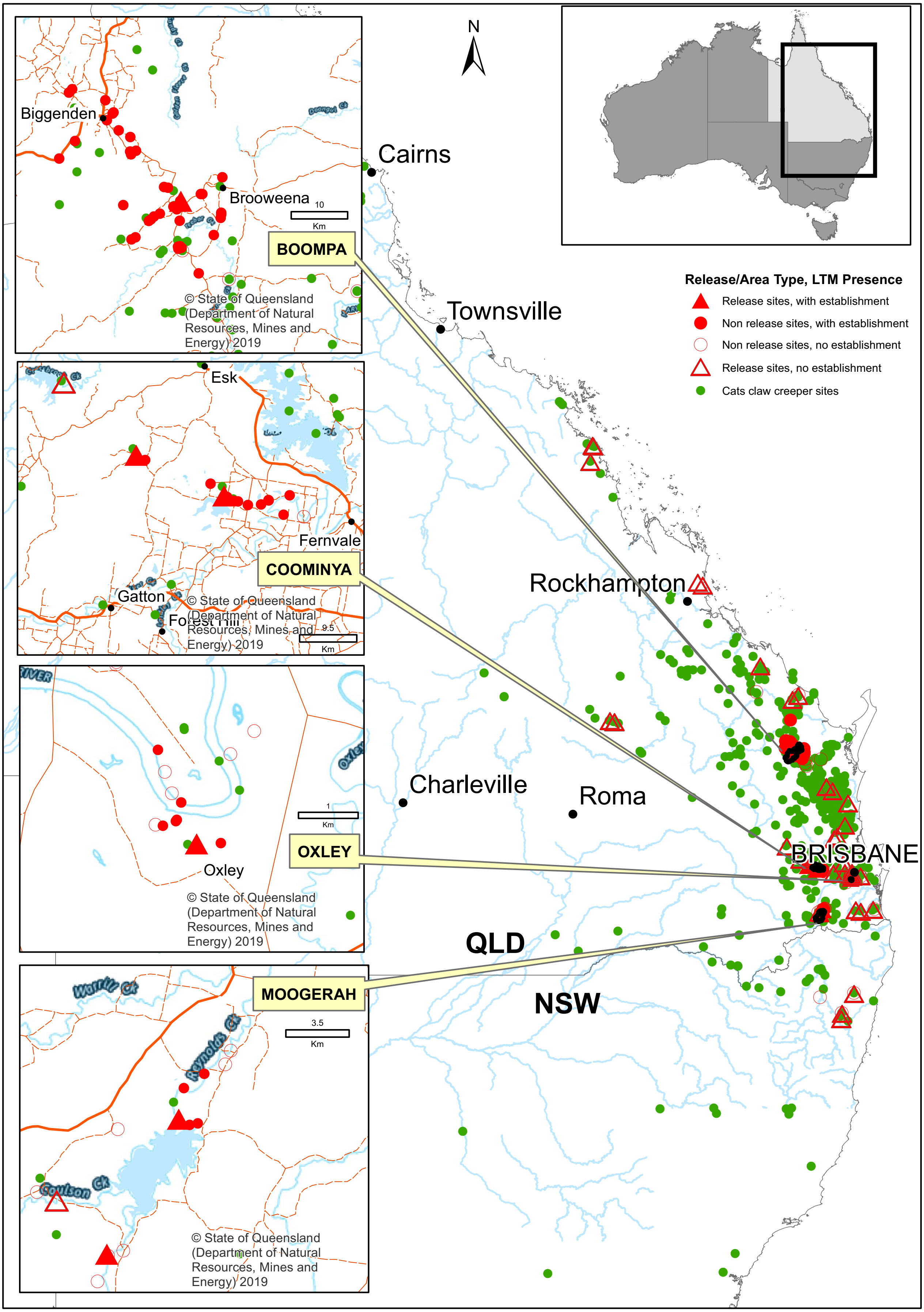

FIGURE 1 Cat's claw creeper infestations and *Hypocosmia pyrochroma* release and establishment sites in Queensland and New South Wales, Australia. Field establish is evident in four clusters (inserts)—Boompa (riparian); Coominya (riparian); Lake Moogerah (riparian) and Oxley (non-riparian), all in southeast Queensland [Colour figure can be viewed at wileyonlinelibrary.com]

infestation were randomly sampled, and the number of leaf-tying symptoms (Figure 2) was recorded. If no evidence of leaf-tying symptom was recorded in the 10 sampled trees, sampling was continued (>20 trees) to ensure there was no evidence of field establishment of *H. pyrochroma* at the site. In addition, the cat's claw creeper prostrating along the ground, and the vines hanging down from the host tree canopies were also checked for *H. pyrochroma* leaf-tying symptoms. In sites where field establishment was evident, non-release sites at various distances from the original release sites were checked (Figure 1), to monitor the extent of spread. In each site, a minimum of 10 trees were sampled and the proportion of trees with *H. pyrochroma* leaf-tying symptoms and the number of leaf-tying symptoms per tree visible from ground level were recorded.

2.4 | CLIMEX model

CLIMEX version 4 was used to predict the potential distribution of *H. pyrochroma* in Australia based on records from its native geographic range (Brazil, Paraguay and Argentina) in tropical South America. The climate profile of *H. pyrochroma* was determined by recursively testing various sets of parameter values until the model's distribution matched its recorded distribution in tropical South America. The estimated parameters (Table 1) were then used to predict its potential distribution in Australia. The suitability of an area was expressed in terms of its Eco-climatic Indices (EI) with areas having an EI of>30 considered as climatically suitable (Kriticos et al., 2015).

2.5 | Data analysis

SigmaStat version 4 was used in all statistical analyses. One-way ANOVA was used to compare the longevity of *H. pyrochroma* adults (male versus. female) under glasshouse conditions. Regression analysis and One-way ANOVA were used to compare changes in the incidence (proportion of trees with leaf-tying symptoms) and intensity (number of leaf-tying symptoms per tree) of damage by

FIGURE 2 Leaf-tying symptoms of *H. pyrochroma* larvae in the field. (a) Early-stage larval feeding symptoms in Coominya release site (December 2018); (b) larval feeding and leaf tying resulting in complete leaf loss in Moogerah release site (February 2019); progression of leaf-tying symptoms from December 2018 (c) to January 2019 (d) in Spring Creek, a non-release site [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 The indices and parameters used in the development of CLIMEX model for *Hypocosmia pyrochroma* from its native range distribution in South America

Index	CLIMEX parameters	Value
Temperature Index (TI)	Limiting low temperature (DV0)	10
	Lower optimal temperature (DV1)	15
	Upper optimal temperature (DV2)	30
	Limiting high temperature (DV3)	34
Moisture Index (MI)	Limiting low moisture (SM0)	0.25
	Lower optimal moisture (SM1)	0.5
	Upper optimal moisture (SM2)	1.5
	Limiting high moisture (SM3)	2.5
Cold Stress (CS)	Cold stress temperature threshold (TTCS)	10
	Cold stress temperature rate (THCS)	−0.0008
Heat Stress (HS)	Heat stress temperature threshold (TTHS)	35
	Heat stress temperature rate (THHS)	−0.00001
Dry Stress (DS)	Dry stress threshold (SMDS)	0.25
	Dry stress rate (HDS)	−0.001
Wet Stress (WS)	Wet stress threshold (SMWS)	2.5
	Wet stress rate (HWS)	0.001
Diapause Index (DI)	Diapause induction day length (DPD0)	11
	Diapause induction temperature (DPT0)	20
	Diapause termination temperature (DPT1)	12
	Diapause development days (DPD)	70
	Diapause summer or winter indicator (DPSW)	0
Day-degree (PDD)	Cold stress day degree threshold temperature (DVCS)	10
	Heat stress day degree threshold temperature (DVHS)	34

H. pyrochroma at the end of the season (autumn) (data from all sites pooled) from 2015 to 2020 and the means compared using Tukey's Test. One-way ANOVA were also used to compare the incidence (proportion of host trees with leaf-tying symptoms) and intensity (number of leaf-tying symptoms per tree) of damage by *H. pyrochroma* between riparian and non-riparian sites (data from all sites in all years pooled) and the means compared using Tukey Test. All results in the text are presented as means ± standard error (*SEM*).

3 | RESULTS

3.1 | Life cycle

Males (12.7 ± 0.7 days) lived longer than females (10.6 ± 0.6 days) ($F_{1,38}$ = 4.65. p = 0.038). Females laid 151 ± 13.7 eggs (range, 42–270), singly on the undersides of leaves and on the stems. Eggs hatched in 12 ± 0.1 days (range 10–12 days) and the larvae completed six instars in 29 ± 1.6 days (range: 23–37 days) at 27°C. Larvae fed destructively on cat's claw creeper by tying leaves together by silk webs (Figure 2a), which create silken tunnels. Fully-grown larvae pupated in the soil, 2 to 3cm below the soil surface. Pupation during summer (when not in diapause) lasted for 30 ± 0.8 days (range: 25–37 days). Under natural photoperiod, the larvae entered pupal diapause from late autumn (April–May) and adults emerged from mid-spring (October) to mid-summer (January).

3.2 | Rearing and field release

Field releases of *H. pyrochroma* commenced in October 2007 and continued until December 2010. As rearing was conducted in climate-controlled cabinets under optimum temperature (27°C), high humidity (65% RH) and longer photoperiod (14 hr light: 10 hr dark), the larvae did not undergo pupal diapause. As a result, rearing and field releases were continued throughout the year. Instead of allowing larvae to pupate, the majority of the mature larvae were field released, and only a small number of larvae were allowed to pupate for colony maintenance,

A total of 2,252 adults, 837 pupae and 77,250 larvae were released at 40 sites in Queensland and New South Wales (Table S1). The number of larvae, pupae and adults released at a site ranged from 110 to 785, and the number of releases in each site ranged from one to 15 (Table S1). Field releases continued throughout the year, including the winter months when releases were made only as larvae. In most of the release sites (88%) the number of releases made was either one (N = 22) or two (N = 8) or three (N = 5) and in only five sites there were more than three releases (Table S1). More field releases were made in riparian sites (78%; N = 31) than in non-riparian sites (22%; N = 9); and in sites with 'short-pod' form (95%; N = 38) than in sites with 'long-pod' form (5%; N = 2) (Table S1). Field releases were made mostly in open fields with naturally grown cat's claw creeper plants (85%, N = 34), and in limited sites (15%; N = 6), releases were made in insect-proof field cages erected over naturally occurring cats claw creeper plants in the field.

TABLE 2 Establishment of *Hypocosmia pyrochroma* in release and non-release sites, in four clusters in Queensland, Australia with details of site characteristics, established creek/river systems and spread rates

					Establishment status in 2020					
Establishment region	Riparian/ Non-riparian	Release site	Year of establishment	Established river/ Creek/lake systems	Number of creeks/ rivers/ lakes	Maximum distance from release site (km)	spread rate (km/ year)	Established sites–riparian	Established sites–non-riparian	Total establihsed sites
Cluster 1: Boompa	Riparian	Sandy Creek	2012	Munna Creek sub-catchment: Aramara Creek; Clifton Creek; Yaroombah Creek; Munna Creek; Sandy Creek; Eel Creek; Teebar Creek; Dry Creek; Spring Creek; Ramsay Creek. Degilbo Creek sub-catchment: Degilbo Creek; Oakey Creek; Rollinson Creek; Mungore Creek; Coachhorse Creek; Swindle Creek; Rocky Creek.	19	23	2.8	58	1	59
Cluster 2: Coominya	Riparian	Buaraba Creek	2012	Buaraba Creek; Locker Creek.	2	14	1.8	15	1	16
Cluster 3: Moogerah	Riparian	Coulson Creek	2014	Coulson Creek; Reynolds Creek; Moogerah lake.	3	13	1.6	8	2	10
Cluster 4: Oxley	Non-riparian	Fort Road Reserve	2012	Brisbane river.	1	1.5	0.2	2	2	4

3.3 | Establishment and spread

Larval recoveries were first made in 2012 in three release sites—Oxley (non-riparian), Boompa (riparian; Sandy Creek) and Coominya (riparian; Buaraba Creek); and subsequently at Lake Moogerah (riparian; Coulson Creek) in 2014 (Table 2). Establishment was evident on both 'short-pod' (five out of 38 release sites) and 'long-pod' (one out of two release sites) forms of cat's claw creeper (Table S1, Table 2). Leaf-tying symptoms of *H. pyrochroma* was found only on cat's claw creeper vines climbing on trees, fence posts and on fallen trees (with an underlying supporting structure for the leaf-tying moth larvae to tie the leaves), but not on the vines hanging from tree canopies or on vines growing along the ground. Leaf-tying symptoms of *H. pyrochroma* was evident up to 15 metres high on cat's claw creeper vines climbing in host trees. Field establishment was more widespread in sites where releases were made within insect-proof field cages (50%) than in sites with open field releases (9%) ($\chi^2 = 3.937$; $p = 0.047$). Additionally, field establishment did not differ significantly between sites, irrespective of the number of field releases (one, two, three or more than three) made in each site ($\chi^2 = 5.266$; $df = 3$; $p = 0.153$).

The total number of establishment sites increased from three in 2012 to more than 80 in 2020 (Figure 1; Table 2). However, all establishment to date is restricted to four clusters—three in riparian zones (Boompa, Lake Moogerah and Coominya) and one in a non-riparian zone (Oxley) (Figure 1; Table 2). In riparian zones, *H. pyrochroma* spread from 13 to 23 km from the release sites in 10 years (Figure 1; Table 2). At Boompa, dispersal was more widespread, over 50 sites across 17 creek systems with a rate of spread of about 3 km per year. At Moogerah and Coominya, with only two creek systems each, the rate of spread was less than 2 km per year (Table 2). In contrast, at Oxley, a non-riparian site, the moth dispersed to only three sites in 10 years, all within 2 km from the release site. To date, all establishment has been in areas that were deemed climatically suitable by the CLIMEX model (Figure 3) but restricted mostly to riparian habitats (Figure 1).

Evidence of *H. pyrochroma* incidence (based on fresh leaf-tying symptoms and larval recoveries) was first recorded in late spring (November) and continued until mid-autumn (April), when all mature larvae entered pupal diapause in the soil. In areas where the moth has become established, there was an increasing trend in the incidence (proportion of host trees with leaf-tying symptoms, Figure 4a) and damage levels (number of leaf-tying symptoms per host tree, Figure 4b) from 2015 onwards. However, the proportion of host trees with leaf-tying symptoms (riparian = 79 ± 3.4%; non-riparian = 27 ± 6.2%; $F_{1.57} = 55.45$; $p < 0.001$) and the number of leaf-tying symptoms per host tree (riparian = 12.6 ± 10.7; non-riparian = 2.2 ± 2.9; $F_{1.65} = 14.8$; $p < 0.001$) were significantly higher in riparian sites than in non-riparian sites.

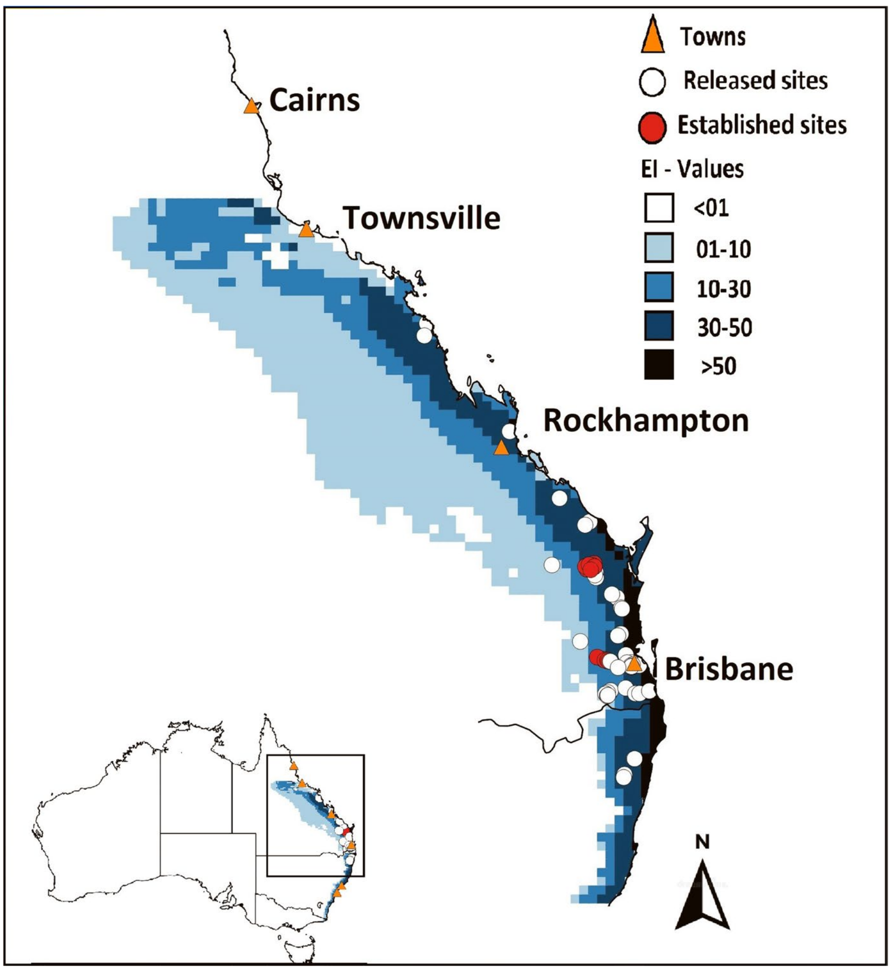

FIGURE 3 Climatic suitability of Queensland and New South Wales, Australia for *H. pyrochroma* estimated by interpolation of Eco-climatic index (EI) derived from a CLIMEX model (Table 1). Higher EI values indicate a more suitable climate [Colour figure can be viewed at wileyonlinelibrary.com]

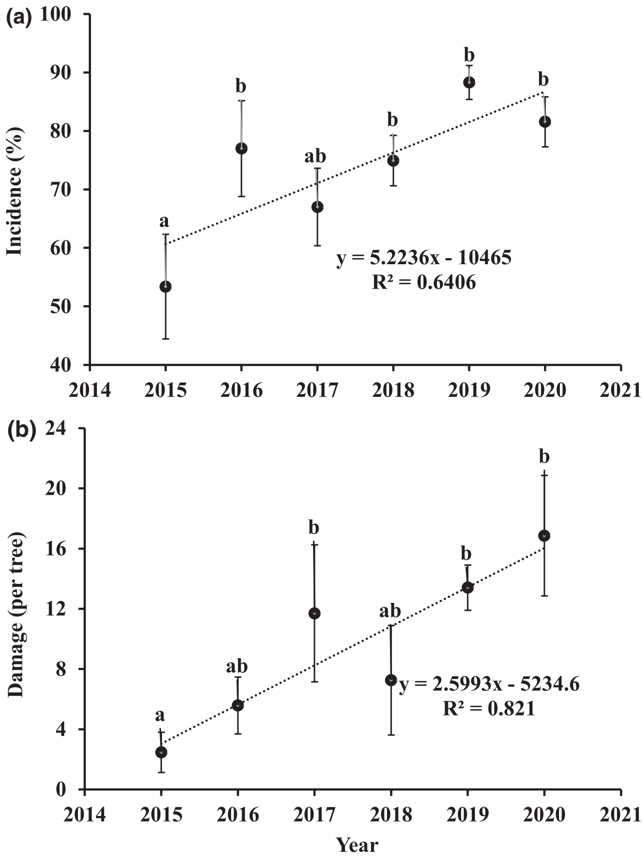

FIGURE 4 Incidence (proportion of host trees with leaf-tying symptoms) and intensity (number of leaf-tying symptoms per host tree) of leaf-tying symptoms by *H. pyrochroma* (Mean ± *SEM*) in southeast Queensland (2015–2020). One-way ANOVA: Incidence, $F_{5.59} = 4.7$, $p = 0.001$; Intensity, $F_{5.65} = 3.56$, $p = 0.007$). Values with same alphabets are not significantly different (Tukey test, $p < .05$)

4 | DISCUSSION

H. pyrochroma is a difficult insect for mass-raring and field release, due to prolonged pupal diapause, and the destructive nature of larval feeding that requires an enormous amount of cat's claw creeper foliage to complete larval development. In the glasshouse, larvae developing under natural photoperiod underwent pupal diapause from late autumn (April–May) until mid to late spring (October–November), in response to declining photoperiod. Photoperiod-induced larval and pupal diapauses in Pyralidae are well known (e.g. Huang et al., 2009; Roditakis & Karandinos, 2001; Xiao et al., 2010; Xu et al., 2014). When the entire larval developmental stages (from first larval instars) were exposed to prolonged photoperiod, it was possible to prevent pupal diapause. As a result, mass rearing and field releases of *H. pyrochroma* continued throughout the year.

H. pyrochroma was released on both 'short-pod' and 'long-pod' forms of cat's claw creeper, but the majority of the releases were in sites with the 'short-pod' form of cat's claw creeper. This was because of most of the cat's claw creeper infestations in Queensland and all infestations in New South Wales being the 'short-pod' form, with the 'long-pod' form occurring only in a few isolated localities in southeast Queensland (Buru et al., 2016, Buru et al., 2019). Most of the cat's claw creeper infestations in Queensland and New South Wales occur along riparian corridors (Figure 1), and hence, few field releases were done in non-riparian sites. Most of the releases were directly in the open field, though in some of the sites, the releases were made within large insect-proof cages erected over cat's claw creeper infestations in the field. This was to restrict the moth larvae to a small area where it would be easier for emerging adults to mate, to restrict adult dispersal, to minimize the risks of predation by spiders and to prevent damage by cattle. For species with a prolonged dormant stage, previous work has shown that releases in field cages provide protection from predators and environment (Briese et al., 1996) and restricted adult dispersal (Dray et al., 2001). This work supports these findings with significantly higher rates of establishment recorded from releases made into field cages. Such initial releases in field cages, have been widely used for several weed biological control agents (e.g. Hight et al., 1995; Briese et al., 1996; Dray et al., 2001; Anonymous, 2008).

Some of the pyralid moths successfully used as weed biological control agents have become established within three to five years of field release (Mann, 1970; Mo et al., 2000; Winston et al., 2014). In Australia, the first evidence of sustained field establishment of *H. pyrochroma* was seen in three sites in 2012, in southeast Queensland, four years after the commencement of field releases. However, there is no evidence of establishment of *H. pyrochroma* in the central, western, and north Queensland and in northern New South Wales to date. This despite a climate-matching model predicting that the entire coastal region in Queensland and New South Wales would be climatically suitable (Dhileepan et al., 2013). A more robust CLIMEX model developed in the current study also supports the prediction that coastal areas are more favourable for *H. pyrochroma* than the inland regions (Figure 3). To date, all field establishments have been in areas that were deemed climatically suitable by the CLIMEX model (Figure 3) but restricted mostly to riparian environments (Figure 1). There appears to be some evidence of the requirement of a riparian environment in addition to climate suitability for its establishment. This would explain the limited establishment within some zones deemed suitable by the CLIMEX model (Figure 3). To date, there is no evidence of establishment of *H. pyrochroma* in South Africa (King et al., 2011).

After 12 years, *H. pyrochroma* has been found at over 80 sites in four clusters, mostly restricted to riparian zones in southeast Queensland. In the field, *H. pyrochroma* has spread slowly, and predominantly only along the riparian corridors. More widespread establishment and dispersal of the moth at the Boompa cluster (23 km from release site) was possibly due to the large number of closely linked creek systems (over 17 creeks) and close proximity of the adjoining drainage basins of the Mary and Burnett Rivers than at Lake Moogerah (13 km from release site) and Coominya (14 km from release site) clusters, each with only two Creek systems. In Oxley, (the only non-riparian established site), the dispersal of the moth over 10 years was less than 2 km from the release site. In Oxley, the moth moved to the nearest river (Brisbane River), and then continued to spread along the river, with no dispersal to cat's claw creeper infestations in non-riparian areas.

Cat's claw creeper is primarily an invader of moist forests and riparian areas with high humidity levels at a local scale (Dhileepan, 2012; Rafter et al., 2008). The establishment of *H. pyrochroma* primarily in riparian zones (Figure 1) was possibly due to the increased vegetation cover of these areas influencing the microclimate thereby buffering temperature extremes, by providing protection from frost and by maintaining increased soil moisture (Kriticos et al., 2003). Thus, microclimate effects of a riparian environment are a likely requirement for the establishment and dispersal of *H. pyrochroma* within those areas favoured by the CLIMEX model. The higher abundance and continuous occurrence of cat's claw creeper along riparian corridors than in non-riparian areas could have aided dispersal along the riparian corridors. Establishment of the moth in a non-riparian site (Oxley) was possibly due to a greater number of insects released (6,157), more often (15 releases), than in any other release site, though the incidence and abundance remained low, and with very low dispersal in comparison with riparian sites. Though the current establishment is limited to four clusters, with most dispersal restricted to riparian zones, it is likely that the agent will establish and spread in other coastal and subcoastal riparian corridors in Queensland and New South Wales, as predicted by the CLIMEX model. Hence, future efforts should focus on field collection and redistribution of *H. pyrochroma* larvae from the established sites to riparian sites in other river and creek systems in Queensland and New South Wales, where the moth currently does not occur. In South Africa as well, future release efforts for *H. pyrochroma* will need to focus more on riparian corridors than non-riparian infestations.

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CONFLICT OF INTEREST

We have no conflict of interest to declare.

AUTHOR CONTRIBUTION

KD conceived and implemented the research, secured funding, and wrote the manuscript; ELS, BS, KJ and KD conduced field monitoring; BG prepared ARCGIS map and WKADS prepared the CLIMEX model. All authors read and approved the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available at https://www.zenodo.org/record/4557151#.YGv5ATHitPY (https://doi.org/10.5281/zenodo.4557151).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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