THE DISTRIBUTION AND ECOLOGY OF THE SOUTHERN PINK UNDERWING MOTH *PHYLLODES IMPERIALIS SMITHERSI* SANDS (LEPIDOPTERA: EREBIDAE) IN NEW SOUTH WALES

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Abstract

The distribution, ecology and conservation status of the Southern Pink Underwing Moth *Phyllodes imperialis smithersi* Sands and its larval food plant Carronia Vine *Carronia multisepalea* F. Muell. was investigated in New South Wales (NSW) from 2016 to 2021. The moth is listed as Endangered by the Australian and NSW governments. *Phyllodes imperialis smithersi* and its specific food plant were found in two disjunct regions; the Northern Rivers and Bellinger-Orara. *Carronia multisepalea* occurred in subtropical rainforest, was common in the Northern Rivers but patchily distributed in the Bellinger-Orara region. *Phyllodes imperialis smithersi* was surveyed by searching the food plant for eggs and larvae. Although considered to be very rare at the commencement of this study, *P. i. smithersi* was found at 48% of sites containing *C. multisepalea* and across the geographic and environmental range of the food plant. Larvae were located at a mean height of 61 cm, on younger leaves (81% from the current season) in low light situations (62% canopy cover) and 5–790 m above sea level. In the Northern Rivers, *P. i. smithersi* was found in major tracts of forest (McPherson Range, Wollumbin and Nightcap) and in 20 smaller remnants. We estimated 34,055 ha of potential habitat in the region and consider *P. i. smithersi* to be currently secure in the Northern Rivers. In the disjunct Bellinger-Orara region, *P. i. smithersi* was found in nine new locations, with abundant larvae and host plants at some sites. In many areas, rainforest appeared to be regenerating from past disturbance, with intact canopies beginning to provide suitable breeding conditions for the moth. However, the potentially isolated Bellinger-Orara population of *P. i. smithersi* remains relatively limited in extent and increasingly threatened from intense drought and fire.

Keywords: invertebrate conservation, endangered species, Australian moths

Introduction

Moths in the genus *Phyllodes* Boisduval occur in many tropical regions north of Australia and on islands of the Pacific. In Australia, *P. imperialis* is a large moth (with a wingspan up to 12 cm) that is represented by two subspecies. The Northern Pink Underwing Moth *P. i. meyricki* Olliff occurs in northeastern Queensland and the Southern Pink Underwing Moth *P. i. smithersi* Sands (Fig. 1) in southeastern Queensland and northeastern NSW (Sands 2012a). The larvae of *P. imperialis* are well known for their dramatic warning display (Hunter 1939) (Fig. 2).

Phyllodes spp. are taxonomically related (Zahiri *et al*. 2010) to fruit piercing moths (e.g. *Eudocima* Billberg spp.). Adults of *Phyllodes* spp. and *Eudocima* spp. often share the leaf mimicry of forewings and bright colouration of hindwings. Adult fruit piercing moths are capable of piercing firm fruit with the barbed apices of their proboscis (Sands and Liebregts 2005). In contrast, *Phyllodes* and many other non-piercing genera, known as fruit sucking moths, are without sclerotized apices and instead have fine setae on the apex of the proboscis. Fruit sucking moths feed on rotting or damaged fruit (Sands 1999, 2012b) that is still hanging (Fig. 3).

The larvae of *Phyllodes* spp. and many fruit piercing moths favour vines of the family Menispermaceae as food plants (Zahiri *et al*. 2010), having adapted to feed on alkaloids present in the leaves (Fay 1996). *Phyllodes* spp. and *Eudocima* spp. are often host-plant specific. The larvae of *P. i. meyricki* feed on the tropical vine *Pycnarrhena novoguineensis* Miquei and larvae of *P. i. smithersi* feed only on *Carronia multisepalea* F. Muell. (Sands 2012a). The fruit piercing moth *Eudocima fullonia* Clerck also uses *C. multisepalea* as one of its larval food plants. This rainforest vine is known to occur from near Gympie in Queensland to Bellingen in NSW. Mature *C. multisepalea* can be very large vines with multiple stems and foliage in the rainforest canopy. Shoots arising from underground rhizomes can also be common across the rainforest floor, although these are likely to be suppressed until there is an opportunity to exploit a gap in the canopy. The vine can grow profusely in gaps and edges of rainforest.

Phyllodes imperialis smithersi was listed nationally as Endangered in 2002 (Threatened Species Scientific Committee 2002), when it was known from only four locations in South East Queensland and an outlying location over 300 km south in NSW in Dorrigo National Park (NP). Two specimens (1973, 1990) from this reserve were lodged with the Australian National Insect Collection, CSIRO Canberra. When Sands (2012a) described *P. i. smithersi*, there were only eight sites known in Queensland (including the northern range limit at Kin Kin Creek near Gympie, Conondale Range, Mary Cairncross Scenic Reserve, Blackall Range, D'Aguilar Range, Springbrook, Currumbin Valley and the Lamington Plateau) and seven in NSW (in the Northern Rivers region and the isolated southern range limit at Bellingen (Britton 2006)). The southern subspecies was considered Critically Endangered by Clark and Spier-Ashcroft (2003) and was listed as Endangered in NSW in 2003 (NSW Scientific Committee 2003).

Adult *P. i. smithersi* are not strongly attracted to light and rarely caught in light traps (Sands, in Roads and Maritime Services 2013). Lachlan (2014) conducted many nights of light-trapping over several years within the habitat of the moth for only four captures, all on one night. Also, at Coolgardie, no adult moths were observed at fruit baits deployed in habitat known to be occupied by the species (Lloyd *et al*. 2019). Due to the difficulty of surveying adult moths, the larval stage was the focus of this study. We (i) recorded the distribution and abundance of *C. multisepalea* in rainforest remnants in NSW, (ii) investigated the distribution, ecology and abundance of *P. i. smithersi* larvae, (iii) recorded habitat characteristics at each location where *P. i. smithersi* was found, and (iv) noted potential threats and possible management responses.

Methods

Rainforest survey sites were selected to encompass the geographic and altitudinal range of *C. multisepalea*, the largest rainforest remnants and a representative sample of small remnants. Potential survey sites were identified using NSW BioNet records of *C. multisepalea*, vegetation mapping, aerial imagery and

Figs 1–3. The Southern Pink Underwing Moth *Phyllodes imperialis smithersi*: (1) a male collected (as a larva) by D.P.A. Sands in 1988 at Mary Cairncross Scenic Reserve, Maleny, QLD and held in the Australian National Insect Collection (CSIRO) Canberra; (2) the warning display of the fifth instar larva (Photo: P.G. Richards); (3) an adult moth interrupted while feeding on damaged fruit of the introduced Rose Apple *Syzygium jambos* (L.) Alston, and flashing its pink hindwing as a warning—the forewing camouflage is also illustrated, resembling a leaf or bark, including insect scars (Photo: M.S. Graham).

topographic mapping. Sites on public land were most accessible and logistically efficient to survey, although several private properties were also surveyed. *Phyllodes imperialis smithersi* and *C. multisepalea* occur in two coastal regions: the Northern Rivers region (north of the Richmond River and centred on the rainforests of the Mount Warning caldera and 'Big Scrub' remnants) and the Bellinger-Orara region (Fig. 4).

At each site, a search for *C. multisepalea* was conducted and the duration recorded. When *C. multisepalea* was found, a timed search was carried out for *P. i. smithersi* larvae and eggs. Searches involved an inspection of leaves (particularly undersides) and stems of all plants within the immediate area. Vines were searched thoroughly to a height of 2.5 m. Above that height, binoculars were used to inspect vines where possible; canopy foliage was rarely seen and therefore not surveyed. Data recorded at each site were: (i) time searching for *C. multisepalea*, (ii) number, height and age class of vines, (iii) presence of old or freshly browsed leaves, (iv) time searching for *P. i. smithersi* larvae, (v) number and instar of larvae, (vi) age class of leaves eaten by larvae, (vii) height of larvae above ground, (viii) number of eggs, (ix) vegetation type, and (x) percentage crown cover of overstorey.

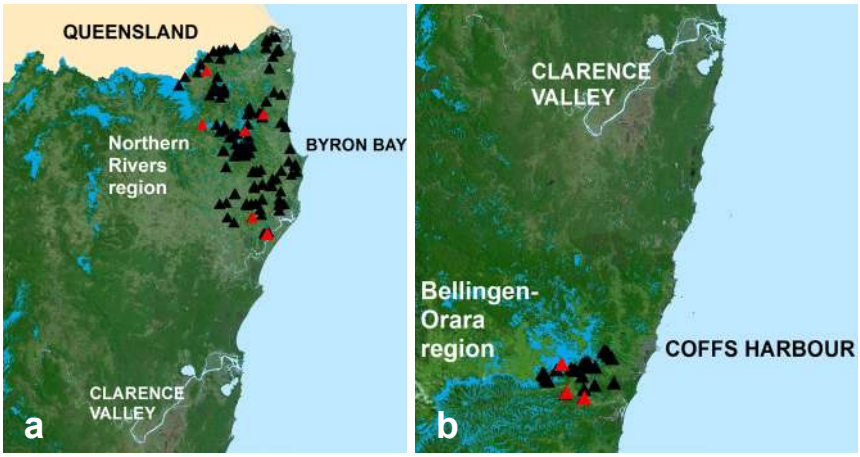

Fig. 4. The two disjunct *Phyllodes imperialis smithersi* populations in northern NSW, defined by the distribution of its larval food plant *Carronia multisepalea* (black triangles, from the NSW BioNet) and the nine locations of *P. i. smithersi* known prior to this study (red triangles): (a) Northern Rivers; (b) Bellinger–Orara. The disjunction between them tracks the pattern of the distribution of coastal rainforest (blue).

A broad assessment of the extent of potential *P. i. smithersi* habitat in NSW was obtained from the extent of subtropical rainforest mapping (Office of Environment and Heritage 2010) in the catchments containing *P. i. smithersi* and *C. multisepalea* records.

Results

Between 28 November 2016 and 26 March 2021 (five seasons), 143 sites were surveyed over 64 days. *Carronia multisepalea* was recorded at 130 sites (91% of those surveyed), although many of these sites were targeted for survey because they were known to contain the vine. An average of 22 vines were located per site; 15 young vines, 6 intermediate vines and 0.4 old vines (it is likely that many of the 'young' and 'intermediate' vines emerge from underground rhizomes, so this is not a count of different plants, but different stems). Of the sites where *C. multisepalea* was recorded, 92% exhibited old browse scars on the leaves and 60% had fresh scars (not necessarily from *P. i. smithersi*).

A total of 395 *P. i. smithersi* larvae were recorded at 61 sites and 132 eggs at 16 sites (Table 1). Eggs were recorded at two sites (Inner Pocket NR and Pine Creek (Tobys Rd)) where no larvae were found. Therefore, *P. i. smithersi* was found at 63 of the 130 sites containing *C. multisepalea* (48%). The species had not previously been recorded at 59 of these sites. A further nine new sites were collated from bush regenerators and others. Locating each larva required on average 14 minutes of searching *C. multisepalea* vines. However, the distribution of larvae was typically clumped and after the first larva was found, subsequent

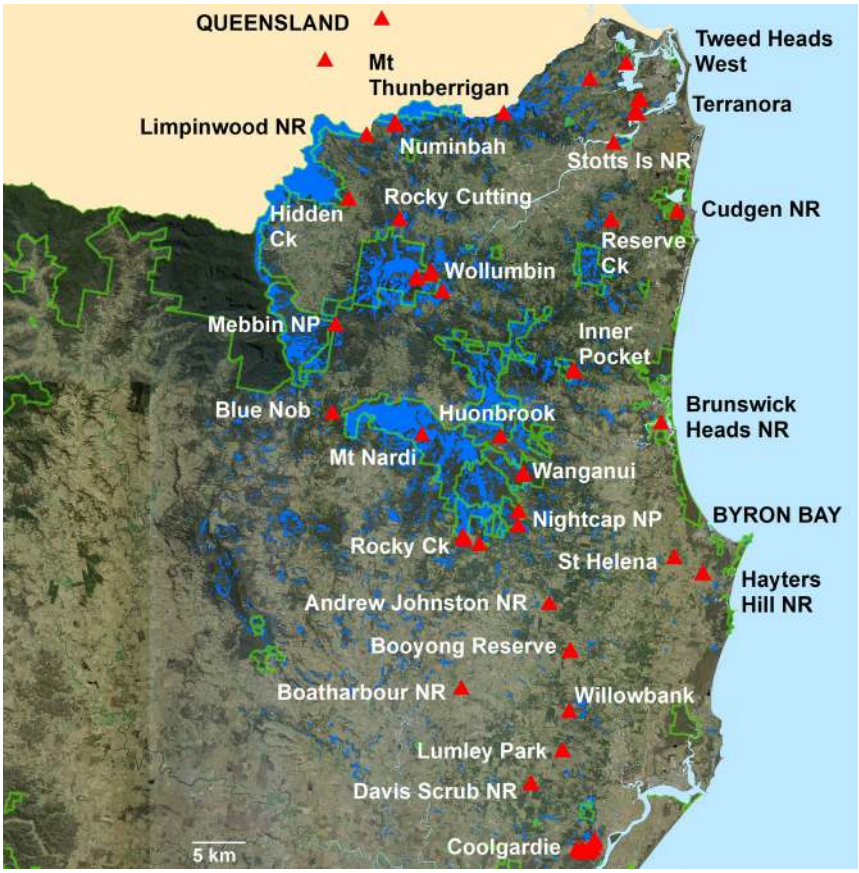

Fig. 5. The 29 localities known to be occupied by *Phyllodes imperialis smithersi* during this study in the Northern Rivers region (red triangles are records from the NSW BioNet) and the estimated extent of potential habitat (blue).

larvae were often found quickly. A better estimate of effort is that it required on average 64 minutes of searching vines to find the first larva at a site.

Larvae were found at an average height of 61 cm (n=317) and on *C. multisepalea* vines that were of median height 80 cm (n=269). Larvae preferred intermediate-age leaves (current season leaves that were not new). These comprised 74% of observations, while old leaves (hardened) comprised 19% and new leaves 7%. Since most larvae found were early instars (Table 1), these results reflect the feeding behaviour of early instars. There were 29 locations known to be occupied by *P. i. smithersi* during this study in the Northern Rivers (Fig. 5) and 10 in Bellinger-Orara (Fig. 6). Surveys were also undertaken by volunteers on Bellingen Island. They recorded *P. i. smithersi* larvae in November 2016 and

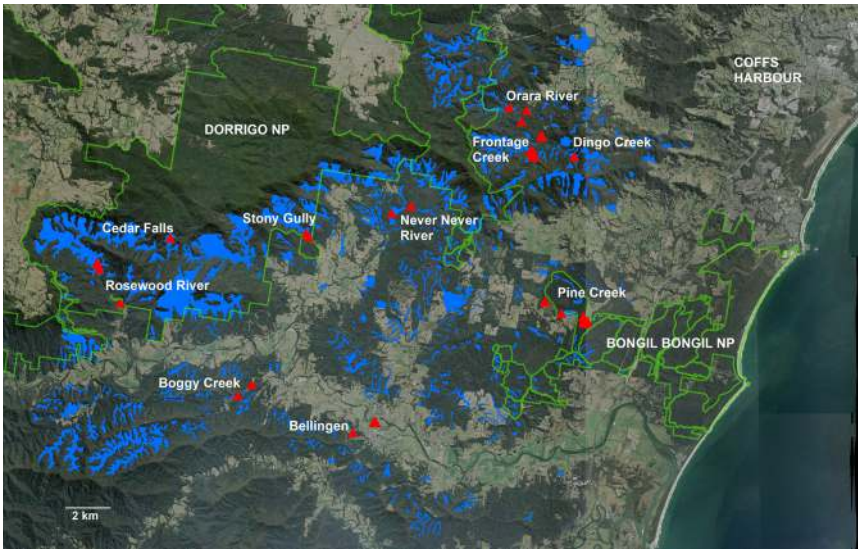

Fig. 6. The 10 localities known to be occupied by *Phyllodes imperialis smithersi* during this study in the Bellinger-Orara region (red triangles are records from the NSW BioNet) and the estimated extent of potential habitat (blue).

between late October 2017 and February 2018 recorded at least 53 larvae and 25 unhatched eggs. In repeated surveys in 2018, it was estimated that there was a 90% decrease in larvae numbers from early to late instars.

The broad assessment of the extent of potential *P. i. smithersi* habitat resulted in an estimate of 34,055 ha in the Northern Rivers (Fig. 5) and 5,230 ha in the Bellinger-Orara region (Fig. 6). The area of breeding habitat would be a small percentage of these figures due to the patchy distribution of *C. multisepalea*. The locations known to be occupied by *P. i. smithersi* during this study and potential habitat are relatively well reserved with almost half in National Parks and Nature Reserves (Table 2).

Discussion

At the commencement of this study, it was incongruous that the distribution of *P. i. smithersi* appeared to be highly restricted, while its larval food plant, *C. multisepalea*, was widely distributed. This study has revealed that the two distributions correspond quite closely.

A disjunct occurrence pattern, with the Northern Rivers population separated by 160 km from Bellinger-Orara, is not uncommon for a wet forest species and follows the distribution of coastal rainforest plant communities. The pattern of rainforest occurrence is a response to past volcanism centred on Wollumbin (Northern Rivers) and Ebor (Bellinger-Orara), that has produced a mountainous

Table 1. The number of each *Phyllodes imperialis smithersi* instar found, showing the predominance of early instars (80% third instar or earlier). First instars can be confused with *Eudocima fullonia*. However, since *E. fullonia* was rare in this study, we have assumed 'probable' *P. i. smithersi* first instars when they co-occurred with later *P. i. smithersi* instars. This has resulted in an under-estimate of the number of first instars, although the low number could also be partly explained by the inconspicuousness of this stage.

	No. of larvae	**% of total**
First instar	53	17
Second instar	129	40
Third instar	73	23
Fourth instar	35	11
Fifth instar	29	9
TOTAL	**319**	
Eudocima fullonia	8	

Table 2. The tenure of the 39 *Phyllodes imperialis smithersi* locations known to be occupied during this study, as well as the tenure of the mapped potential habitat. *NPWS: New South Wales National Parks and Wildlife Service.

Tenure	**Occupied Locations**			**Potential Habitat (ha)**		
	Northern Rivers	**Bellinger-Orara**	**Total**	**Northern Rivers**	**Bellinger-Orara**	**Total**
NPWS* estate	14 (48%)	4 (40%)	18 (46%)	16,940 (50%)	2,455 (47%)	19,395 (49%)
Council reserve	4 (14%)	1 (10%)	5 (13%)	64 (0.2%)	10 (0.2%)	74 (0.2%)
State Forest estate		5 (50%)	5 (13%)	126 (0.4%)	1,683 (32%)	1,809 (5%)
Private	11 (38%)		11 (28%)	16,925 (50%)	1,082 (21%)	18,007 (46%)
TOTAL	**29**	**10**	**39**	**34,055**	**5,230**	**39,285**

and fertile landscape in these two regions, separated by the broad dry, less fertile expanse of the Richmond River and Clarence River valleys.

The rainforest habitat of *P. i. smithersi* is dominated by the White Booyong *Argyrodendron trifoliolatum* F. Muell. lowland subtropical rainforest alliance (Floyd 1990), with three suballiances predominating: (i) White Booyong, (ii) Pepperberry-Giant Stinger-Fig-Hoop Pine, and (iii) Black Bean-Rosewood. At

higher elevations, while the habitat is still related to these three suballiances, it is also characterised by the presence of 'cool' subtropical species such as Black Booyong *Argyrodendron actinophyllum* F.M. Bailey. We consider that under normal environmental conditions these rainforest communities should provide enough fruit resources for the highly mobile adult moths.

Carronia multisepalea was found to be a common species in the rainforests of the Northern Rivers and was often locally abundant. *Phyllodes imperialis smithersi* larvae were found along drainage lines (e.g. Booyong Reserve), on ridges (e.g. Limpinwood Nature Reserve (NR)), steep slopes (e.g. Mt Thunberrigan), flat land (e.g. Davis Scrub NR) and from 5 m above sea level at Coolgardie to the highest known occurrence of 790 m at Mt Nardi. There are also relatively high elevation records along the McPherson Range in Limpinwood NR (510 m), Numinbah NR (400 m) and Mt Thunberrigan (350 m), plus a Queensland record less than 6 km north of the border at Binna Burra at 780 m (Lachlan 2014). Although patchily distributed, it appears likely that *P. i. smithersi* is a relatively common species in rainforest at all elevations along the McPherson Range.

Carronia multisepalea is also known from 590 m in Wollumbin NP where it has not been surveyed for *P. i. smithersi*. There is a high likelihood that *P. i. smithersi* occurs there, given its presence at lower elevations within the reserve. *Phyllodes imperialis smithersi* was recorded in major tracts of forest of the Wollumbin caldera, as well as 20 small remnants. Furthermore, of the 222 specific locations of records of *P. i. smithersi* in NSW (NSW BioNet), 89 are from monitoring at Coolgardie, conducted for the Pacific Highway Upgrade (Lloyd *et al*. 2019). The relatively large number of locations resulting from an increased survey intensity at Coolgardie supports our opinion that *P. i. smithersi*, while patchily distributed, is a widespread and relatively common species in the Northern Rivers.

Carronia multisepalea and *P. i. smithersi* are less common in the Bellinger-Orara region, although there are local concentrations, such as the lower Rosewood River in Dorrigo NP, Bellingen Island, Pine Creek and in the upper Orara River catchment. *Phyllodes imperialis smithersi* was found in most areas containing significant numbers of *C. multisepalea*, although there appeared to be a greater focus on riparian habitat than in the Northern Rivers. *Carronia multisepalea* appears to be absent from the high elevation rainforests in the region, although both species were recorded at an elevation of 470 m in Dorrigo NP.

Searching *C. multisepalea* vines for larvae was a labour-intensive technique, requiring an average search time of 64 minutes to locate a larva at a site. We have demonstrated, however, that it can be implemented successfully to survey *P. i. smithersi*. Larvae have been found from late October to early April (171 days), which aligns with the species having two generations per year and a lifespan of about 80 days: egg 8 days, larva 18 days, pupa 25 days and adult 30 days (based on 5 individuals reared at 25° C, Sands unpublished data, Sands 1999). Eggs (Fig. 7) were located at 16 sites. They were generally laid in small numbers (commonly one or two eggs on a leaf underside), but occasionally larger

Fig. 7. A typical egg of *Phyllodes imperialis smithersi* (approximately 2 mm in diameter) on the underside of a *Carronia multisepalea* leaf (Photo: P.G. Richards).

Fig. 8. Defoliation of a *Carronia multisepalea* plant: (a) Multiple second instar *Phyllodes imperialis smithersi* feeding, until (b) there are no leaves left on the plant (Photos: S.R. Ruming).

numbers (up to 35). Where large numbers of larvae hatch onto a plant, the result can be complete defoliation (Fig. 8).

An advantage of the focus on larvae is that all locations found are breeding sites. The sites were characterised structurally by rainforest with an average crown cover of 62%. This level of crown cover was often obtained in old growth rainforest, which Sands (2012a) found to be preferred habitat. Within these old growth forests, however, *C. multisepalea* favoured edges or canopy gaps, either naturally created (e.g. by tree fall) or anthropogenically created (e.g. by roads). Canopy gaps and edges promote the recruitment of a suite of other colonising species, including Lawyer Vine *Calamus muelleri* H. Wendl. and in some places weed species such as Lantana *Lantana camara* L. that may out-compete *C. multisepalea*. In these circumstances, management actions may be required to ensure the persistence of *C. multisepalea*.

Suitable levels of canopy cover can also be achieved in regrowth forests and some locations were highly disturbed (e.g. Orara River, St Helena and Pine Creek). Weeds are a major problem in regrowth rainforest (Fig. 9) and rehabilitation may also be required at these sites. Seven of the sites surveyed had a canopy cover of 30% or less and despite the presence of abundant *C. multisepalea*, currently appear to be unsuitable breeding habitat for *P. i. smithersi*. Five of these sites were undergoing assisted restoration and could be expected to provide suitable habitat once adequate canopy cover is reinstated.

Larvae of *P. i. smithersi* were observed on average 61 cm above the ground. Of course, the search effort was at ground level; leaves in the canopy were not surveyed. However, there are reasons to expect that the core breeding zone is less than two metres in height: (i) during the survey, leaves above two metres were examined where possible, but only on two occasions were caterpillars observed, (ii) above the mean height of 61 cm, the number of larvae found declined progressively, despite vines being thoroughly searched to about two metres, and (iii) it is likely to be difficult for larvae to find sufficient cover in the canopy to avoid desiccation and predators, and fresh leaves would be exposed and harden quickly. Four structural forms of *C. multisepalea* give rise to leaf growth within about two metres of the ground. These are: (i) seedlings, (ii) short vertical stems arising from subterranean rhizomes (Fig. 10), (iii) a prolific ground cover or tangled low vine found in canopy gaps or forest edges, and (iv) new growth (often sparse) at the base of mature vines.

Early instar larvae were recorded on the underside of *C. multisepalea* leaves (Fig. 10) and later instar larvae were often observed lying along the stems of the vine (Fig. 11) or along the mid-rib of a leaf upon which it was feeding. There was a very strong preference for leaves produced in the current growing season (81% of observations of larvae). The almost ubiquitous presence of browsed leaves (95% of sites), although not necessarily due to browsing by *P. i. smithersi*, is further indication that the moth and vine co-occur widely.

Fig. 9. *Carronia multisepalea*, browsed by *Phyllodes imperialis smithersi*, above a carpet of the weed Trad *Tradescantia fluminensis* Vell (Photo: M. Andren).

Fig. 10. Early instar *Phyllodes imperialis smithersi* larvae on a short vertical *Carronia multisepalea* stem (60 cm) arising from a subterranean rhizome (Photo: P.G. Richards).

Since European settlement, lowland rainforest has undergone a large reduction in area due to clearing (Floyd 1990, NSW Scientific Committee 1999, 2006). Floyd (1990) estimated that the original 75,000 ha 'Big Scrub' lowland rainforest of the Lismore basalts has been reduced to only 300 ha (0.4%) and much of the lowland rainforest has been lost from the Tweed, Bellinger and Orara valleys. Most remaining stands occur as small remnants of variable quality which are often isolated within highly modified agricultural landscapes (Threatened Species Scientific Committee 2011). Lowland rainforest is listed under State and Commonwealth legislation as an Endangered or Critically Endangered Ecological Community (NSW Scientific Committee 1999, 2006, Threatened Species Scientific Committee 2011).

Surveys were carried out in 14 of the small and isolated Big Scrub remnants. *Carronia multisepalea* is ubiquitous in these remnants (recorded in all remnants, although found by others in Victoria Park NR and in Rotary Park in Lismore, only one small plant was located). The most isolated remnant occupied by *P. i. smithersi* was Boatharbour NR. It is approximately 15 km to the nearest known occupied habitat in Booyong Reserve, which, like Boatharbour, is on the Wilson River. *Phyllodes imperialis smithersi* is a large moth and likely capable of powerful flight and it may be that all the Big Scrub remnants and potentially all the Northern Rivers (as well as adjacent rainforest in Queensland), is a single connected metapopulation. This widespread metapopulation potentially enables the recolonisation of a small remnant in the region if there was a local extinction, as well as colonisation of newly rehabilitated rainforest containing *C. multisepalea*. Crossing an open agricultural matrix between small forest remnants, however, is likely to expose the moths to increased predation from microchiropteran bats.

Prior to this study, *P. i. smithersi* was known from only two NPWS reserves in NSW (Davis Scrub NR and Dorrigo NP) and a council reserve (Bellingen Island). Of the 39 localities now known for the species, 18 (46%) are protected in 15 NPWS reserves (Table 2). A further 10 localities are on public land (i.e. a total of 72% on public land). The potential habitat of *P. i. smithersi* is also well protected with almost half within NPWS reserves. In the Northern Rivers, much of the rainforest habitat is steep, relatively inaccessible, generally in good condition and protected within conservation reserves. Only 13% of the potential habitat is in the Bellinger-Orara region, where *P. i. smithersi* is known from just 10 locations. There is likely to be a relatively large population in Dorrigo NP (where it is known from three locations) and there is an abundant localised population along Pine Creek in Bongil Bongil NP. Bellingen Island is a council reserve protected by an environmental zoning (Bellingen Shire Council 2010), but there is not a large amount of habitat on the island, and it is subject to flooding.

Six southern locations occur on State Forest (Scotchman, Tuckers Nob, Pine Creek and Orara West). Orara West State Forest contains an important population on Frontage Creek, Dingo Creek and the Orara River. While these sites benefit

Fig. 11. A fifth instar *Phyllodes imperialis smithersi* larva on a stem of *Carronia multisepalea* below a dead leaf, exhibiting a typical resting position along the stem and the effectiveness of its camouflage (Photo: P.G. Richards).

from the protection of riparian rainforest from logging under current State regulations, some of them are relatively heavily disturbed and have minor to major weed infestations. Management intervention may be required to secure the persistence of *P. i. smithersi* at some of these locations. Despite this, in these State Forests and Bongil Bongil NP, many of the now-protected rainforests are beginning to re-establish canopy cover and provide suitable breeding habitat for *P. i. smithersi*. Assuming protections remain in place, this habitat could potentially increase in quality and quantity.

Monitoring on Bellingen Island, although not comprehensive, indicated a 90% fall in numbers between early and late instars. Lepidopteran eggs and neonate larvae experience high predation rates and parasitisation of eggs occurs widely (e.g. by *Telenomus* sp. (Sands 1999)). Larvae of *P. i. smithersi* deploy a defensive strategy based on camouflage (Fig. 11) and, in the case of later instars, a dramatic warning display (Fig. 2). This suggests that *P. i. smithersi* does not utilise the alkaloids present in *C. multisepalea* for defence, unlike another large moth that feeds on the same plant, *E. fullonia*. Larvae of this species are coloured red and are much more active than *P. i. smithersi*, signifying to potential predators that it is unlikely to be palatable.

Clearing and weed invasion were important historical threats to *P. i. smithersi* and weed invasion remains a severe problem at many sites (Fig. 9). Unprecedented fires in 2019 burnt some of the rainforests in northeastern NSW (Nolan *et al*. 2019), including on Mt Nardi in Nightcap NP, which was the first time that such an event had been recorded. Fire is becoming an increasing threat to rainforest species and even a cool fire will threaten *P. i. smithersi*, with its breeding zone within two metres of the ground. During the drought conditions experienced from 2016 to 2019, at some time, most rainforest remnants in the region could potentially have sustained at least a leaf litter fire. Reduced productivity of *C. multisepalea* and reduced rainforest fruit production due to drought could also impact the species. Conversely, much of the rainforest habitat of *P. i. smithersi* is riparian and subject to flooding, which could become a serious threat if the frequency of flooding were to increase.

Phyllodes imperialis smithersi currently appears to be a secure species in the Northern Rivers, while in the Bellinger-Orara region, weed control and rainforest rehabilitation would help ensure its persistence. Along with many other species, however, it is becoming increasingly threatened by the intense droughts and fires that are consistent with the predicted consequences of anthropogenic climate change.

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