Current distribution, preferred habitat, behaviour, and biology of the Inland Hairstreak, *Jalmenus aridus* Graham & Moulds, 1988 (Lepidoptera: Lycaenidae) in the Eastern Goldfields region of Western Australia

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ABSTRACT – The Inland Hairstreak, *Jalmenus aridus* Graham & Moulds, 1988, is a Priority 1 listed butterfly endemic to Western Australia. It was previously recorded only from its type locality near Lake Douglas, 12 km SW of Kalgoorlie; however, a recent mining tenement fauna survey near Kalgoorlie uncovered a new breeding site. The discovery prompted a renewed effort to determine if there were additional breeding sites nearby. This paper details the results of our survey efforts and what we have learned about the distribution, preferred habitat, behaviour, and biology of *J. aridus* during two flight seasons. *Jalmenus aridus* is now recorded from 10 locations within an area of approximately 5,000 km^2 (121 km N–S by 42 km E–W). Their preferred habitat is summarised as open woodland with mature *Senna artemisioides* ssp. *filifolia* as well as mixed flowering shrubs with open areas of well drained exposed ground adjoining the hostplants. The ant *Froggattella kirbii* (Lowne, 1865) must be present. We hope this paper will aid environmental consultants and encourage others to visit the region to further broaden the distribution and our knowledge of this elusive butterfly.

KEYWORDS: Kalgoorlie, *Froggattella kirbii*, *Senna artemisioides filifolia*, *Acacia tetragonophylla,* myrmecophily, thermoregulation

INTRODUCTION

The Inland Hairstreak, *Jalmenus aridus* Graham & Moulds, 1988 (Lepidoptera: Lycaenidae) is a Priority 1 listed butterfly in Western Australia; Priority taxa are 'Possibly threatened species that do not meet survey criteria, or are otherwise data deficient, are added to the Priority Fauna Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened' (EPA 2023). *Jalmenus aridus* was previously known only from its type locality near Lake Douglas approximately 12 km SW of Kalgoorlie (Graham and Moulds 1988). It was discovered in November 1983 by Prof. Alan Graham breeding on a single *Acacia tetragonophylla* tree, but soon after its discovery the tree died, and the butterflies disappeared (Williams et al. 1998). Over the following years entomologists regularly searched the immediate surrounds and collected several specimens on a second *A. tetragonophylla* tree, a short distance from the original tree, and then from a *Senna artemisioides* ssp. *filifolia* shrub (recorded as *Senna nemophila*) at 7 Mile Hill approximately 12 km south-west of Kalgoorlie and only 1 km from the original *A. tetragonophylla* tree (Williams et al. 1998). As with all *Jalmenus* species that have obligate associations

with their attendant ants, *J. aridus* has a mutualistic association with the small dolichoderine ant *Froggattella kirbii* (Lowne, 1865). When *J. aridus* larvae feed on the flowers and phyllodes of their hostplant the ants are in constant attendance (Graham and Moulds 1988). The larvae of *Jalmenus* spp. produce sweet secretions in the form of amino acids and sugars from a Newcomber's Organ on the seventh abdominal segment, from which the ants feed via trophallaxis (Maschwitz et al. 1975; Kitching 1983). In return, the presence of the ants protects the butterfly larvae from parasitoids and predators. In the wild, *Jalmenus* larvae may have an attrition rate up to 100% without their attendant ants (Pierce and Nash 1999).

Jalmenus aridus are difficult to survey because adults are present for only a few weeks each year. Most specimen records are in October, but a few are recorded in November and one in April (Braby 2000, 2016). Due to the paucity of baseline data on the species, it has been impossible to predict when and where they might occur. Consequently, there are no methods recommended by the Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) to survey for the butterfly. The attendant ant *F. kirbii* has a wide distribution throughout open woodland areas across all Australian mainland states (Shattuck 1999) and the two hostplants, *A. tetragonophylla* and *S. artemisioides* ssp. *filifolia* both have very broad distributions across Western Australia (WA Herbarium 1998). So, the combined presence of the ants and the plants, although critical for the butterfly's survival, cannot be used as the sole indicator for a likely breeding site. Regular survey efforts by numerous entomologists, including Alan Graham who lived in Kalgoorlie from 1982 to 2002, have not recorded any additional locations for *J. aridus* in the 40 years since it was discovered. In fact, since 1999 only a handful of specimens have been collected at the Lake Douglas site, the last one in 2011 (R.P. Weir, pers. comm. 2022).

While *J. aridus* was known only from a single site it was thought that it may be more widespread but difficult to find in the vastness of the Western Australian arid and semi-arid zones. In October 2021, the chance discovery of a large *J. aridus* breeding site (39 ha) on a mining tenement near Kalgoorlie during a baseline fauna survey, raised the prospect that the butterfly might be more widespread in the Eastern Goldfields region despite the lack of contemporary records. As a result, a concerted effort, supported by a local mining company was undertaken to determine if additional breeding sites could be found, particularly in areas with some level of habitat protection. Here, we describe our efforts to find new locations for *J. aridus*, to document their preferred breeding habitat and to learn more about the species' biology and behaviour.

METHODS

For the purposes of this study, we define a *J. aridus* 'breeding site' as a location where the species is resident and reproducing, and separated from other such sites by at least 5 km. We identified the sites by the presence of *S. artemisioides* ssp. *filifolia* and *F. kirbii* together with *J. aridus* butterflies including freshly emerged adults; and/or female oviposition behaviour on the trunk or lower stems of a hostplant; and/or the presence of larvae, pupae or pupal exuviae. We consider that these assumptions are reasonable, based on known *Jalmenus* spp., behaviour including a spatially patchy distribution of breeding sites and adult natal site fidelity (Pierce & Nash 1999; Braby 2011).

Based on our experience, the only realistic method to survey for *J. aridus* breeding sites is to search for adult butterflies. Searching broadly for immature stages (larvae or pupae) is not practical since they are extremely localised and there are far too many *S. artemisioides* ssp. *filifolia* hostplants to sample in the semi-arid landscape. Timing of our search effort was restricted to a period between late September and late October based on known flight times as well as our observations at the recently discovered site on the mining tenement near Kalgoorlie. Field surveys were conducted as follows:

1. Immediately following the initial discovery near Kalgoorlie in October 2021, several locations in the surrounding districts were visited opportunistically.
2. An additional baseline fauna survey on a mine-site near Coolgardie, approximately 40 km SW of Kalgoorlie, was conducted in mid-December 2021.
3. Between 25 March and 1 April 2022, a planned field survey was undertaken to locate potential breeding sites with stands of *S. artemisioides* ssp. *filifolia* in 16 DBCA managed parks and reserves within a nominal 100 km radius of Kalgoorlie. A total of 1,600 km was traversed by 4WD vehicle and on foot assessing and mapping potentially suitable habitat for a follow-up survey later in the year when it was hoped the adults would be flying.
4. On 10–17 October 2022, a survey covering more than 50 km^2 of the mining tenement adjoining the breeding site near Kalgoorlie was undertaken along pre-planned transects in potential habitat determined from existing vegetation mapping.
5. A final field survey for adult *J. aridus* in potential habitats identified during the March survey (see point 3) was undertaken between 21–27 October 2022. Suitable weather was a major consideration and when conditions were unsuitable during the survey, a more refined habitat assessment was made at selected sites to determine if reinspection under more favourable conditions was warranted.
6. The breeding site near Kalgoorlie was also re-visited during 21–27 October 2022 to make additional observations on *J. aridus* biology and habitat features.

RESULTS AND DISCUSSION

DISTRIBUTION

A single specimen reportedly collected on Ngaanyatjarra lands approximately 705 km NE of Lake Douglas in 1987 (ALA 2023) is incorrect. It was based on a preserved larva (K255464) in the Australian Museum with locality data 'Australia, Western Australia' and with coordinates of 25°19'41"S, 122°17'54"E (the mid-point of Western Australia) with low precision (radius greater than 100 km). The coordinates of -26°, 126.0° given on ALA is close to the western boundary of Ngaanyatjarra lands, presumably cited as the nearest community under 'Additional political boundaries information'. An additional location recorded incorrectly as 17 Mile Hill on specimens collected by Alan Graham in 1993 should read 7 Mile Hill.

Following the initial discovery near Kalgoorlie, our ad hoc surveys in October–November 2021 uncovered two additional locations approximately 40 km and 80 km from Kalgoorlie, one of which was confirmed as a breeding site and adults at the second were likely to be breeding nearby. The mining tenement survey near Coolgardie in mid-December 2021 also revealed another breeding site with adults recorded in two places approximately 500 m apart. However, the 50 km^2 survey in early October 2022 on the mining tenement adjoining the initial breeding site near Kalgoorlie failed to find any additional *J. aridus* despite extensive stands of *S. artemisioides* ssp. *filifolia* and *F. kirbii* ants being present. Following the preliminary surveys in March, the field surveys within 100 km of Kalgoorlie on 21–27 October 2022 uncovered five more breeding sites on DBCA managed lands and on additional mining tenements. A potential site SW of Coolgardie identified in the October 2022 survey was confirmed as a breeding site in October 2023. Thus, there are now 10 known sites for *J. aridus* within an area just over 5,000 km^2 (121 km N–S by 42 km E–W). The mean distance between closest pairs of *J. aridus* sites is 21 km with a range of 6.6–36.6 km. Six of the *J. aridus* locations were within the Eastern Goldfields subregion (C003) of the IBRA Coolgardie bioregion (DCCEEW 2020) and the remaining four locations were in the adjoining Eastern Murchison subregion (MUR01) of the IBRA Murchison bioregion (DCCEEW 2020).

The breeding site on the mining tenement near Kalgoorlie covers approximately 39 ha and during four visits in the first season in 2021 we recorded 114 adults. Only one shrub with breeding activity was identified with 14 live pupae and several pupal exuviae hidden in debris around the base. The follow-up surveys (four visits) in October 2022 recorded approximately 120 adults, 17 pupae, 65 larvae and six additional active hostplants on site. Little time was spent exploring the other nine regional sites on single visits, but the total number of *J. aridus* recorded was 76 adults plus 2 pupae. Butterfly numbers sighted ranged from one to 23 adults per site and these numbers appear to be proportional to the sampling effort rather than the size of the local *J. aridus* site. The shortest visit was approximately 15 min and the longest just over 1 h. At least four of these sites have the potential to be quite large based on data collected so far. Over the two field seasons, 53 adult specimens were collected representing all the known sites and these are lodged in the Western Australian Museum and the Australian National Insect Collection, Canberra. Five breeding sites were recorded in DBCA controlled land and the remaining five were found on mining tenements. We are unable to provide detailed location information due to the sensitive nature of the findings and to discourage attempts to enter restricted and potentially dangerous mining operations.

PREFERRED HABITAT

The habitat assessment was continually updated with the discovery of each new site and by the end of the surveys we were able to identify a breeding site with 100% accuracy (n = 5) while driving along a road or track. Based on our surveys of *J. aridus* breeding sites within 100 km of Kalgoorlie, the preferred habitat for *J. aridus* larvae feeding on *S. artemisioides* ssp. *filifolia* consists of the following components (in order of apparency) (Figure 1):

1. Open woodland.
2. A stand of mixed young and mature *Senna* shrubs in an area of 2000 m^2 or more. *Senna* shrubs grow to 2.5-3.0 m in height and the older plants often have gnarled or twisted multi-stemmed branching trunks.
3. A variety of flowering shrubs such as *Eremophila, Scaveola,* and *Maireana,* which are used as nectar sources for adult butterflies.
4. Some scattered taller vegetation (e.g. *Allocasuarina*, *Santalum*), which creates wind breaks and sheltered microhabitats where adult butterflies congregate.
5. Open areas of exposed ground as well as corridors around the shrubs that *J. aridus* use for thermoregulation and mate location.
6. Good drainage, especially around the older *Senna* shrubs.
7. Substrate and soil suitable for the *Senna* hostplants include sandy-loam, clay-loam with or without ironstone pebbles, or even a rocky substrate. Most breeding sites have been found on clay loam on relatively flat ground or adjoining seasonal floodplains (n = 7). Two sites were on rocky ridges with a hard packed rocky substrate and the remaining site was somewhat in between.
8. *Senna* shrubs with loose bark and/or debris accumulated in forks or on the ground surrounding the trunk or around adjoining shrubs.
9. Presence of *F. kirbii* ants at the base of the *Senna* shrub.

FIGURE 1 A–D) Views of *Jalmenus aridus* open woodland habitats in the Eastern Goldfields region, Western Australia. Note the presence of *Senna artemisioides* ssp. *filifolia* shrubs, mixed vegetation and exposed ground forming flight paths around the hostplants, together with scattered taller vegetation forming windbreaks. Only a few flowers remained on *S. artemisioides* ssp. *filifolia* by mid-October.

BEHAVIOUR

Adults emerge in the morning and by 1000 h they are particularly active around their breeding sites on warm sunny mornings, but the activity decreases after that time. On cold but sunny mornings adults can be found perched on the ground thermoregulating on heat absorbed by the dark iron stones and red-brown soil in exposed areas near their hostplants. Depending on weather conditions, this behaviour can continue throughout the day. Newly emerged males and females are found in this situation and copulations may occur on the exposed ground or on very short vegetation (Figure 2). Males actively patrol near their natal hostplants and around low vegetation, especially the blue bush (*Maireana* sp.) in clearings adjacent to their hostplants. No obvious territorial sites have been observed, but male-male conflict occurs regularly. It appears that *Jalmenus* females release a pheromone when about to eclose (Pierce & Nash 1999) since up to 10 males were observed patrolling around the base of some hostplants. Females were observed probing in grooves and around scars on the *S. artemisioides* ssp. *filifolia* stems between 100–500 mm from the base and were possibly searching for oviposition sites.

Adults display strong natal hostplant fidelity, so they are extremely localised. This can result in dense accumulations of adult butterflies, with 20 or more active in a small clearing near their *Senna* hostplants, but none to be seen only a few metres away from the ‘hot spot’. When clouds obscure the sun, adults are almost impossible to find as they crawl down the stems of plants to rest where they are well hidden in the shrubbery amongst the branches and leaves. As soon as the sun emerges, they start flying again. *Jalmenus aridus* is quite cryptic, often flying less than 1 m from the ground or close to vegetation. Adults may be easily confused with several other species flying in the same habitat such as *Nacaduba biocellata* (C. Felder & R. Felder, 1865), *Theclinesthes serpentata* (Herrich-Schäffer, 1869), *T. miskini* (Lucas, 1889), *Zizina labradus* (Godart, 1824), and *Lampides boeticus* (Linnaeus, 1767).

FIGURE 2 *Jalmenus aridus* in copula on low vegetation near the exposed ground with ironstone pebbles where the butterflies thermoregulate during cool sunny mornings.

BIOLOGY

During the surveys we found small numbers of *A. tetragonophylla* but no *J. aridus* adults or early stages were associated with the plants. Thus, all our behavioural and phenological data are based on *J. aridus* feeding on *S. artemisioides* ssp. *filifolia*.

Observations on the early stages are consistent with earlier publications (Graham and Moulds 1988; Braby 2000). However, some additional observations are worth noting. No larvae were recorded feeding on the pinnate *S. artemisioides* ssp. *filifolia* leaves. Graham and Moulds (1988) reported that the larvae 'feed in full sunshine, eating the flowers and spikey phyllodes of the food plant', but this comment referred to their feeding on *A. tetragonophylla*. Occasionally, larvae were found chewing tracks in fresh seed pods even though flowers were still present on the hostplant. Larvae were only found on older plants between 1.2–2.5 m tall, although Braby (2000) reported them being found on young plants. Some older hostplants may be shorter in stature, but they all have structural features at the base with more pupation sites than the younger plants.

Larvae are not gregarious, but we found up to 30 larvae feeding singly in inflorescences scattered around the periphery of a single *S. artemisioides* ssp. *filifolia* hostplant. Small larvae are attended by a few *F. kirbii* ants (1–2) but final instar larvae may be attended by 10 or more ants (Figure 3). Most final instar larvae are predominantly green with contrasting longitudinal stripes as described by Graham and Moulds (1988); however, we found other colour morphs including yellow and brown base colours with contrasting markings along the dorsal ridge. Several red-brown fifth instar larvae with faint white markings were seen searching for pupation sites at the base of the hostplants. Pupation sites are chosen opportunistically, including borers holes, scars in the trunk, in forks near the base of the shrub, under loose bark and in debris

FIGURE 3 *Jalmenus aridus* mature larva with attendant *Froggattella kirbii* ants on *Senna artemisioides* ssp. *filifolia*.

FIGURE 4 *Jalmenus aridus* prepupa with attendant *Froggattella kirbii* ants in debris near the base of *Senna artemisioides* ssp. *filifolia* hostplant (some debris removed).

FIGURE 5 *Jalmenus aridus* prepupa with attendant *Froggattella kirbii* ants on an inflorescence of *Senna artemisioides* ssp. *filifolia*.

around the base (Figure 4). Pupae have also been found under rocks up to 1 m from the base and in debris caught in and around adjoining vegetation. One pupa and one prepupa (Figure 5) were found in separate inflorescences on the hostplant. Pupae are always attached to the substrate by a cremaster and girdle and are attended by a few ants (3–4). They usually pupate singly, although they may aggregate in suitable pupation sites.

Braby (2000) suggested there may be two generations of *J. aridus* annually; however, there appeared to be only a single generation on their *Senna* hostplants around Kalgoorlie. The timing of adult appearances at different sites can vary depending on local environmental conditions and the flowering phenology of *S. artemisioides* ssp. *filifolia*. For example, adult *J. aridus* may be on the wing in mid September or as late as early November around Kalgoorlie, whereas at a rocky ridge site near Coolgardie in 2022, freshly emerged adults were flying in mid-December coinciding with the later flowering of their local *Senna host* plants. Complex egg diapause regimes influenced by local environmental conditions may contribute to the highly irregular appearance of adults in common with other *Jalmenus* species (Sands and New 2002). The record of *J. aridus* occurring in April (Graham and Moulds 1988) may have been breeding on *A. tetragonophylla* since we found no signs of *J. aridus* associated with their *Senna* hostplants near Kalgoorlie at the end of March 2022, nor on the *Senna* plants examined during our regional survey conducted at the same time. A specimen in the WAM collection from the H. Bollam butterfly collection but without a collector's name, labelled 'Kalgoorlie' and dated '16 Jan 1983' predates the November 1983 discovery by Alan Graham and this may have been breeding on *A. tetragonophylla*. It is also possible that *J. aridus* has a broader range of hostplants which is the case for many obligately ant associated butterfly species where the primary consideration is the species of ant associate (Valentine and Johnson 1988; Fiedler 1994; Eastwood 1999).

Based on our observations in the Kalgoorlie area, the modal timing of *J. aridus* life stages feeding on *S. artemisioides* ssp. *filifolia* is presented in Table 1. Peak larval activity is around late September–early October but tapers off quickly by mid-October when the *Senna* hostplant is mostly finished flowering. Pupae are present during October, and adults are generally more abundant in mid-October. There is clearly an overlap of life stages, suggesting variability in egg hatching times. Seasonal variations in the timing of rains and warm weather can have significant effects on the numbers and timing of *J. aridus* phenology as observed by Graham and Moulds (1988).

FIGURE 6 *Jalmenus aridus* adult killed by a jumping spider (Salticidae female) at the base of a *Senna artemisioides* ssp. *filifolia*.

Jumper or bull-ants (*Myrmecia* spp.) are widespread in the Goldfields and were found foraging on *S. artemisioides* ssp. *filifolia* plants including those with *J. aridus* larvae feeding. No predation was observed, but it is possible that *Myrmecia* ants could prey on *J. aridus* larvae as food for their brood. At one site, three male *J. aridus* were killed by jumping spiders (Salticidae) as they landed on sticks and on the trunk at the base of a *S. artemisioides* ssp. *filifolia* shrub (Figure 6).

CONCLUSIONS

The discovery of a large breeding site of *J. aridus* on a mining tenement near Kalgoorlie was a watershed moment. While it has long been hypothesised that the species would likely occur more widely in the Eastern Goldfields region based on known biology of other *Jalmenus* spp., *J. aridus* remained an elusive rarity from a remote site in the vast semi-arid landscape of Western Australia. The subsequent discovery of additional breeding sites has shown that *J. aridus* is indeed similar to other *Jalmenus* species with specific ecological requirements that result in very localised occurrences spread over a broad area.

Our documentation of the preferred habitat for *J. aridus* over two seasons at the 10 recently discovered locations enabled us to accurately predict suitable breeding sites based on floristics, topography, substrate, and other key features such as vegetation structure. It is hoped that our recent discoveries and preferred

TABLE 1 Modal timing estimates for life stage phenology of *Jalmenus aridus* feeding on *Senna artemisioides* ssp. *filifolia* in the Eastern Goldfields region.

Time period	Life stage	Evidence	Assumptions
Mid-August to early September	Eggs start hatching	*Senna* bushes starting to flower in early-mid August	Egg duration = 10–11 months (assuming univoltine life cycle)
End September	Most larvae finish feeding	*Senna* bushes starting to produce seed pods	Larval feeding and growth through to fifth instar = 17 days. Estimate based on data in Graham and Moulds (1988), prepupa = 2 days
Early-mid October	Pupae start eclosing	*Senna* food plant with 14 live pupae and several pupal exuviae in early October	Based on the numbers and condition of adult butterflies and the numbers of eclosed and live pupae it was estimated about 50–70% of adults had emerged by mid-October
Late October	Most pupae eclosed	Many freshly emerged adults flying in mid-October	Pupal duration = 20 days (Graham and Moulds 1988)
Early-mid November	Adults finish flying	Few butterflies observed in early November	Life span of adults = 10–12 days (estimated)

habitat description will aid environmental consultants in identifying and protecting *J. aridus* breeding sites and encourage others to spend time in the Eastern Goldfields region to further broaden the distribution and our knowledge of this elusive butterfly.

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