Conservation Assessment of the purple copper butterfly *Paralucia spinifera* Edwards and Common, 1978 (Lycaenidae)

Matt Saunders 15/08/2024
Conservation Policy and Programs Division
NSW Department of Climate Change, Energy, the Environment and Water

Purple copper butterfly *Paralucia spinifera* Edwards and Common, 1978 (Lycaenidae)
Distribution: Central Tablelands, NSW
Current EPBC Act Status: Vulnerable
Current NSW BC Act Status: Endangered
Proposed listing on NSW BC Act: Endangered

The NSW Threatened Species Scientific Committee published a notice of final determination for *Paralucia spinifera* in 1996 (NSW Scientific Committee 1996). This Conservation Assessment report has found that there is no change to the listing status of this taxon on the *Biodiversity Conservation Act 2016* schedules. The report provides an updated assessment for the risk of extinction for the taxon against the criteria in the *Biodiversity Conservation Regulation 2017* using the Common Assessment Method. The Common Assessment Method is the agreed method for assessing the extinction risk of species by the Australian Government and all state and territory governments. This document should be read in conjunction with the 1996 final determination.

Summary of Conservation Assessment

Paralucia spinifera was found to be Endangered under IUCN Criterion B1b(ii,iii,iv,v)c(iv)+2b(ii,iii,iv,v)c(iv).

The reasons for the species being eligible for listing in the Endangered category are that (1) the species has a highly restricted geographic range with an area of occupancy (AOO) estimated to be 152–176 km^2 and an extent of occurrence estimated to be 1693–1823 km^2, (2) there is an estimated and inferred continuing decline in the AOO, area, extent and quality of habitat, number of locations or subpopulations, and number of mature individuals due to habitat loss from vegetation clearing and modification, low frequency fire, weed invasion, feral animals, and adverse land management practices, and (3) the species undergoes extreme population fluctuations.

Paralucia spinifera in Walang, NSW. Image: David Roma/DCCEEW.

Description and taxonomy

The purple copper butterfly, *Paralucia spinifera* Edwards & Common, 1978, also known as the Bathurst copper, Lithgow copper, or Yetholme copper, is a small butterfly in the family Lycaenidae. The species was described from a small number of individuals collected near the village of Yetholme approximately 20 km east of Bathurst, New South Wales (NSW).

Paralucia spinifera has a wingspan of approximately 20 mm (Braby 2000, Braby 2004). Males are distinguished by: shiny purple wings with a scale-fringe chequered black and white, a series of small blue subterminal spots, black veins, costa and termen of the forewings broadly black, margins of the hindwings broadly black with the tornus slightly produced (Braby 2000). Females possess black or deep brown wings with the central area suffused with bronze, the basal area sometimes a deep shiny purple or blue, a variable series of small blue subterminal spots, and a scale-fringe chequered black and white (Braby 2000; NPWS 2001). In both sexes, the underside of the wings varies from greyish brown to dark rusty-brown with variable markings and bands, while the upperside of the wings exhibits variability in the intensity of the wing edging and may lack the blue subterminal spots on the forewing entirely (Braby 2000). *Paralucia spinifera* is also distinguished by male genitalic morphology, and a non-articulated, spine-like process that extends over the base of the tarsus of each fore tibia, present in both sexes (Edwards & Common 1978).

Eggs are hemispherical, 0.8 mm wide, 0.4 mm high, initially pale green and later changing to pale cream (Edwards and Common 1978). The mature larva is approximately 14 mm long, with a grey body marked with brown middorsal, dorsolateral and lateral lines, each segment possessing an oblique subdorsal band separated by a whitish oblique band, short black dorsal hairs and colourless lateral hairs, abdominal segment seven with a dorsal nectary organ and abdominal segment eight with pronounced dorsolateral projections, each bearing a laterally eversible organ (Braby 2000).

The pupa is approximately 13 mm long, head and thorax brown, abdomen pale greenish-brown with thinly scattered brown dots particularly on the wings, and distinctly blackened antennae (Edwards and Common 1978; Braby 2000).

The genus *Paralucia* Waterhouse and Turner, 1905 is endemic to Australia and contains four species: *Paralucia spinifera* Edwards & Common, 1978, *P. aurifera* (Blanchard, 1848), *P. pyrodiscus* (Doubleday, 1847), and *P. crosbyi* Braby, 2024 (Dexter and Kitching 1993; Braby 2000; Braby 2024). *Paralucia aurifera* and *P. pyrodiscus* are widely distributed, being found from southern Queensland to Victoria (NPWS (2001), while *P. crosbyi* is restricted to Namadgi National Park, ACT, and adjacent parts of NSW (Braby 2024). *Paralucia spinifera* and *P. aurifera* have been observed cohabiting at several sites on the outskirts of Lithgow (NPWS 2001).

In 2021, a new population of *Paralucia* was discovered in the ACT and was initially thought to be *P. spinifera* (Bond and Varden 2022). However, this population has now been described as a distinct species, *P. crosbyi* (Braby 2024).

Distribution and abundance

Paralucia spinifera is restricted to the Central Tablelands of NSW, between the townships of Bathurst, Oberon, and Hartley (DPIE 2020a), where it occurs on the traditional lands of the Wiradjuri people (Aboriginal Affairs NSW n.d.; AIATSIS 2023). This area has been surveyed for *P. spinifera*, revealing 61 sites (comprising approximately 65 ha of habitat), of which 57 are considered extant. Approximately 75% of these sites are located on freehold land, with the rest occurring on various land tenures including Nature Reserve, National Park, State Forest, Travelling Stock Reserve, and Crown lands managed by the Councils of Lithgow, Oberon and Bathurst (NPWS 2001; Mjadwesch 2016).

The population of *Paralucia spinifera* is highly fragmented, both naturally as a result of being altitudinally restricted, and artificially, through clearing for a variety of land-use purposes (Dexter and Kitching 1993). The distribution of *P. spinifera* is limited by the combined presence of its host plant, *Bursaria spinosa* subsp. *lasiophylla* and its attendant ant, *Anonychomyrma itinerans* (NPWS 2001).

<u>Area of occupancy and extent of occurrence</u>

The area of occupancy (AOO) is 152–176 km^2 and the extent of occurrence (EOO) is 1693–1823 km^2. The AOO is based on 2 x 2 km grid cells, the scale recommended for assessing area of occupancy by IUCN (2024), and the EOO is based on a minimum convex polygon enclosing all mapped occurrences of the species, the method of assessment recommended by IUCN (2024). AOO and EOO and were calculated using ArcGIS (Esri 2015) and based on cleaned spatial datasets from BioNet and Atlas of Living Australia (BioNet 2023; ALA 2023). AOO and EOO are provided as a range to accommodate the uncertainty around several sites at which local extinction has been documented (Mjadwesch 2016).

Population size and trends

It is difficult to estimate the population size of *Paralucia spinifera* due to its cryptic nature and life-history traits. The species exhibits great variation both in its 'apparent' presence or absence and its actual numbers from year to year at each site (Sands and New 2002), a characteristic of irruptive species in which subpopulations sporadically increase to peak numbers followed by a decline (Schowalter 2006). Murphy and Nally (2004) suggest this may indicate a possible underlying metapopulation structure, implying that gene flow is, or was, occurring between sites or subpopulations. Although the dispersal abilities of *P. spinifera* appear limited, rarely being observed more than 10–15 m from their preferred habitat (Mjadwesch and Nally 2008; DPIE 2020a), the rapid irruptive expansion of subpopulations after fire, and the recorded active and passive wind-assisted dispersal of lycaenid butterflies (*e.g.* Pierce 1984) support the possibility of historic or current metapopulation processes (S. Nally *in litt.* August 2023).

There is evidence that the species undergoes extreme fluctuations, apparently in response to the phenology of the larval host plant (Sands and New 2002). This is consistent with studies of other lycaenid species which have been documented to undergo significant fluctuations due to resource availability or environmental factors (Swengel and Swengel 2005; Arnold 2022). At one site near Yetholme, hundreds of individuals were recorded where less than five were recorded the previous year (D.P.A. Sands, in Sands and New 2002). Similarly, the large subpopulation at Kennedy Park (B14) experienced a collapse between 2009 and 2015 (Mjadwesch 2016; DPIE 2020a) and was not observed again until 2019, in much smaller numbers and more discrete patches (DPIE 2020a). Kennedy Park is an isolated site; therefore, it is unlikely that it was recolonised from other sites. More likely the species persisted at undetectably low levels from 2015 to 2019.

Estimates of relative abundance at each site rely on counts of larvae, rather than adults. Mortality rates may mean few larvae survive to maturity, therefore larval counts have limited relevance to estimating effective population size, but they are useful in identifying habitat occupation patterns and quantifying relative usage levels (Mjadwesch and Nally 2008). Mjadwesch (2016) made abundance estimates for all known sites based on systematic larval counts taken at one site over a period of four years, resulting in a total larval estimate of 337,145–670,735. Larval abundance estimates for the five SOS monitoring sites range from 292,000 (DPE unpublished data) to 322,000 (Mjadwesch 2016). All life stages of the species are subject to natural mortality, with mortality rates of late instar larvae likely to be 70% or higher (D.P.A. Sands pers. comm., in NPWS 2001); therefore, the population of adults is likely to be significantly less. The evidence outlined above is that this is an irruptive species that undergoes extreme fluctuations, with a population that varies substantially both temporally and spatially.

Cultural significance

The cultural significance of *Paralucia spinifera* is currently undocumented, however, Aboriginal knowledge of bushfoods, plants, and animals is passed down through traditional songs and dances (Woodward *et al*. (Eds.) 2020), and in other communities these include reference to butterflies (Douglas 2015; Turpin and Fabb 2017).

This assessment is not intended to be comprehensive of the traditional ecological knowledge that exists for *Paralucia spinifera*, or to speak for Aboriginal people. Aboriginal people have a long history of biocultural knowledge, which comes from observing and being on Country, and evolves as it is tested, validated, and passed through generations (Woodward *et al*. (Eds.) 2020). Aboriginal peoples have cared for Country for tens of thousands of years (Bowler et al. 2003; Clarkson et al. 2017). There is traditional ecological knowledge for all plants, animals and fungi connected within the kinship system (Woodward *et al*. (Eds.) 2020). Traditional ecological knowledge referenced in this assessment belongs to the relevant knowledge custodian and has been referenced in line with the principals of the NSW Indigenous Cultural and Intellectual Property protocol (ICIP) (Janke and Company 2023).

Ecology

<u>Habitat</u>

Paralucia spinifera is restricted to areas above *c.* 870 m above sea level (a.s.l.), based on GIS analysis of all records. The species occurs in or on the edge of open grassy eucalypt woodland (Dexter and Kitching 1993; Braby 2000). The topographic position of known *P. spinifera* sites varies considerably: some sites occur on exposed ridges which experience regular winter snow events, while other sites occur on foothills and valley floors where cold air accumulates and results in regular severe frosts (NPWS 2001). A commonality between sites is the extremely cold temperatures (winter daytime temperatures of 1–12°C but as low as -9°C at night) (NPWS 2001). Many sites are associated with high levels of disturbance which help maintain the open vegetation structure and abundance of *Bursaria spinosa* subsp. *lasiophylla* in the understorey and includes cattle grazing, roadsides, mining, or frequent fire (Mjadwesch 2016). Sites are generally situated in areas in which *B. spinosa* subsp. *lasiophylla* receives high levels of solar radiation for much of the day (NPWS 2001), generally with a west to northwest aspect (Braby 2000; NPWS 2001). Sites with a southern aspect are shallowly sloping, with full exposure to sun (NPWS 2001). Sites are located on a range of substrates including sandy soils with granite outcropping, basalt-derived soils, sandstone soils and on coal measures (NPWS 2001).

Paralucia spinifera is strictly associated with two other species: the sole larval food source is *Bursaria spinosa* subsp. *lasiophylla* (New 2011) and the larva is obligately myrmecophilous (mutualistic) with the ant species *Anonychomyrma itinerans* (Lowne, 1865) (Eastwood and Fraser 1999). Both taxa are widespread in southeast Australia (ALA 2024a, 2024b). *B. spinosa* subsp. *lasiophylla* is an altitudinal form of the species, occurring on heavier clay soils at higher altitudes on the tablelands and lower mountain ranges of south-eastern Australia (Cayzer *et al*. 1999), where it grows to around 2 m in height (New 2011). It occurs mostly above 900 m a.s.l. (NPWS 2001) but has been found as low as 500 m (Cayzer *et al.* 1999). Habitat containing *B. spinosa* subsp. *lasiophylla* has been cleared extensively, resulting in small remnant patches, which restricts the distribution of *P. spinifera* (New 2011). *Anonychomyrma itinerans* nests either in the ground or in dead wood and is more widely distributed than *P. spinifera* but is also generally restricted to altitudes above 870 m in New South Wales (Dexter and Kitching 1993). The realised niche of *Paralucia spinifera* is determined by the presence of the host plant and attendant ant, and cold climate (DPIE 2020a).

There may have been a significant historical reduction in the distribution of the species with the present distribution now representing climate refugia (Dexter and Kitching 1991 in NPWS 2001).

<u>Life history</u>

Paralucia spinifera is univoltine (Dexter and Kitching 1993) and has a generation length of one year (New 2011). Adults emerge from pupation in August at lower sites and slightly later at higher sites (Braby 2004; New 2011). There is variation in the time adults emerge, even at sites within the same general area, probably influenced by site variables such as aspect (NPWS 2001). Activity peaks around September and persists as late as early December but typically only spans a few weeks at any site (New 2011). Adults are on the wing for approximately two weeks during this period (DPIE 2020a).

Adults only fly when conditions are sunny, staying within one metre of the ground or proximate to the host plants (Edwards and Common 1978; Braby 2000). Adults feed on floral nectar from several species, including *Daviesia* spp. and *Hardenbergia violacea* (Fabaceae) and often settle on grass, low shrubs, or debris on the ground to bask with wings open towards the sun (Braby 2000, 2004). Males establish territories on grass or low shrubs where they court passing females (Braby 2000, 2004).

After mating, females oviposit on or near *Bursaria spinosa* subsp. *lasiophylla* associated with the attendant *Anonychomyrma itinerans* (Dexter and Kitching 1993), amongst grass, leaf litter, stones, or soil (Braby 2000). Low plants with profuse new foliage are favoured (Braby 2000). On the host plant, eggs are typically deposited on the lower third (Dexter and Kitching 1993; Braby 2000). Eggs are laid singly or in groups up to five (Dunn *et al*. 1994). Eggs take approximately 14 to 17 days to hatch (NPWS 2001), during which the attendant ants constantly search the host plant, possibly seeking newly hatched larvae (Dexter and Kitching 1993).

The host ant establishes underground nest chambers at the base of the host plant (New 2011). On hatching, the larva, attended by a single ant (NPWS 2001), feeds diurnally during the morning and afternoon and retreats into the ant nest at midday and dusk (Dexter and Kitching 1993). Larvae feed on young growth of the host plant and prefer clumps of plants with intertwining branches, as larvae do not traverse open ground between plants (NPWS 2001). After the third instar, both larvae and ant become nocturnal, feeding by night and retreating by day to the ant nest (Dexter and Kitching 1993; Braby 2000). The larvae develop an organ which produces honeydew, upon which the ants feed (Mjadwesch and Nally 2008; DPIE 2020a). The ants protect the larvae from predators, responding to threats by releasing an alarm pheromone, attacking the threat by biting, and shepherding the caterpillars into the ant nest (Mjadwesch and Nally 2008).

Larvae go through up to 8 instars (Dexter and Kitching 1993) with the larval period lasting approximately 6–10 weeks (New 2011). Pupation commences between December and February and takes place within ant nests (New 2011). Pupae spend up to 9 months in the ant nest until spring. Ants attend to emergent butterflies while their wings dry (Mjadwesch and Nally 2008).

Population structure

The concept of metapopulations has been applied to *Paralucia spinifera*, particularly within the Lithgow Valley Area (Dexter and Kitching 1991, in NPWS 2001). A metapopulation can be described as a ‘population of populations’ (Harrison 1991; Hanski and Simberloff 1997). Persistence of the population as a whole depends on parameters which influence extinction and colonisation rates, such as the number of habitat patches, migration rates, reproductive success, and the spatial arrangement of patches within the landscape (Harrison 1991; Healy and Wassens 2008).

Although gene flow between habitat patches has not been formally investigated in *Paralucia spinifera*, a preliminary genetic analysis conducted by Clarke and Grosse (2003) indicated high genetic diversity within sites. The results indicated low genetic differentiation between the Lithgow and Yetholme sites and greater differentiation for the Mount David site southwest of Oberon (Clarke and Grosse 2002, in Murphy and Nally 2004). While cautioning that their study was limited by small sample sizes, Clarke and Grosse (2003) suggested: “that there are few, if any, genetic concerns for the species at this stage. If habitat loss and fragmentation are impacting this species, the effects are not reflected in the genetic architecture of the species at this point in time, suggesting that subpopulation sizes and/or levels of gene flow, are sufficiently large to maintain genetic diversity and variation.”

However, any local declines or extinctions are likely reinforced through the continued fragmentation of habitat, with the probability of recolonisation diminishing as habitat patches become smaller and more isolated (NPWS 2001). Many sites which support *Paralucia spinifera* are comprised of a mosaic of discrete *Bursaria* patches (DPIE 2020a) and dispersal between sites has been observed infrequently, with individuals rarely flying beyond patches by even 15 m (*e.g.*, across a road) to feed (Mjadwesch and Nally 2008). Considering the preliminary nature of the genetic study undertaken by Clarke and Grosse (2003), it is not possible to infer if rates of gene flow between habitat patches are sufficient to maintain metapopulation structure, particularly given the ongoing fragmentation and reduced connectivity of the landscape. The fact that more isolated sites exhibit greater genetic differences suggests that if dispersal does occur between sites, it may be limited by the spatial configuration and/or the level of connectivity between sites. Strong winds may play a role in dispersal and gene exchange between sites, thereby overcoming the apparent limited dispersal abilities of *P. spinifera*. Coupled with the concept of temporary habitats, such a mechanism could help reconcile how a species which is thought to have limited dispersal abilities could sustain gene flow in a metapopulation structure. Temporary habitats are likely to present the opportunities for genetic exchange between core habitat, through either creating connections through continuous temporary habitat, or by allowing for wind-blown dispersal (S. Nally *in litt.* August 2023). Given that males are territorial (Braby 2000, 2004), and that the gravid females of some Lepidopteran species lay a portion of their eggs in their natal habitat before dispersing (Rhainds 2020), there are behavioural drivers for active dispersal, even if undetectable (S. Nally August 2023). While the species may have operated historically as a metapopulation, habitat fragmentation is likely to have reduced gene flow between habitat patches.

It is unclear which sites are connected by movement over time. Sites which occur close together, such as those around the township of Lithgow, may be interconnected colonies over longer time frames, while other sites may be entirely isolated and lack genetic exchange with other colonies (S. Nally pers. comm. 2016, in DCCEEW 2016). As the sites within the Lithgow Valley area are considered a single subpopulation, where individual sites are a maximum of 2 km from their nearest neighbour, a distance-based method for delineating subpopulations has been applied here.

For the purposes of this assessment, *Paralucia spinifera* is considered to occur within 16 subpopulations, or 18 subpopulations if including sites at which it is now considered extinct. These subpopulations have been delineated purely on a basis of sites being more than 2 km from their nearest neighbour, as this distance is considered unlikely to be crossed even under strong wind conditions.

<u>Attendant ant</u>

The mutualistic relationship shared by *Paralucia spinifera* and the ant *Anonychomyrma itinerans* appears to be critical to the survival of the butterfly in the wild (NPWS 2001; Sands and New 2002). Ant surveys of known butterfly sites indicate that *P. spinifera* does not utilise host plants within or adjacent to sites that lack the presence of the ant (Dexter and Kitching 1993). *Anonychomyrma itinerans* is not generally visually active over autumn and winter while *P. spinifera* pupate in the ant nests, becoming active again when the *P. spinifera* larvae emerge in spring (Murphy and Nally 2004).

<u>Host plant</u>

Paralucia spinifera larvae feed solely on the foliage of *Bursaria spinosa* subsp. *lasiophylla*. *Paralucia spinifera* has not been recorded feeding on *B. spinosa* subsp.

spinosa, although there are stands of it adjacent to *B. spinosa* subsp. *lasiophylla* (NPWS 2001). All taxa in the genus *Bursaria* are vigorously rhizomatous with stands of shoots with a 5 m radius assumed to be a single genetic individual (Cayzer *et al.* 1999). The rhizomatous nature of the species enables it to respond positively to disturbance, including clearing, herbicide application, and fire (NPWS 2001). The species is an aggressive coloniser of marginal or disturbed sites and post-disturbance regeneration from rhizomes can be rapid and extensive (Cayzer *et al.* 1999).

Host plants occurring within known *Paralucia spinifera* habitat frequently grow in a suppressed or juvenile form (NPWS 2001). The larvae of *P. spinifera* typically graze on the *Bursaria* until the shoots die, causing the shrubs to resprout from the base or main stems (NPWS 2001).

Bursaria spinosa is a resprouter in response to fire and its spread is positively influenced by fire at the expense of fire-sensitive plant species (New *et al*. 2000). However, the density of *B. spinosa* populations is influenced by fire frequency. For an irruptive species, landscape-scale fire frequency may be important to maintaining inter-subpopulation gene flow during periods of irruption.

Threats

Paralucia spinifera is threatened by habitat loss from vegetation clearing and modification; low frequency fire resulting in habitat senescence; habitat degradation from weed invasion, feral animals, and grazing from livestock; and adverse land management practices. Increasing temperatures from climate change is a probable future threat. All listed threats have the potential to adversely affect the attendant ant *Anonychomyrma itinerans*, the loss of which is a threat to *Paralucia spinifera* itself.

<u>Habitat loss, degradation, and modification</u>

Over the past century and a half, native vegetation in the Central Tablelands has been cleared extensively for farming and more recently for radiata pine (*Pinus radiata*) plantation (NPWS 2001). Prior to this, Aboriginal people used fire to maintain the landscape in a mosaic of grassland and woodland to maximise food resources (Gammage 2012). This clearing is likely to have contributed to the highly fragmented distribution of *Paralucia spinifera* whilst always maintaining some suitable habitat within the region (Dexter and Kitching 1993). A substantial proportion of remnant vegetation which supports *P. spinifera* is restricted to road verges, Crown lands, and small areas of private tenure (NPWS 2001). One site has been lost through the repeated intentional bulldozing of habitat under a powerline easement by an adjacent landholder (Mjadwesch 2016). Although the vegetation at this site has recovered since last being bulldozed in 1999, the site has not been recolonised by *P. spinifera* (Mjadwesch 2016), despite being located just over one kilometre from other records. In another well-documented case in 2004, a road realignment project led to the destruction of a site near Lidsdale, prompting a relocation effort to salvage the remaining site (Mjadwesch and Nally 2008). The continued clearing of *P. spinifera* habitat is one of the most serious threats to the species (NPWS 2001). Isolation of habitat patches disrupts movements, leads to inbreeding, and prevents recolonisation after local extirpation events (Sands 2018).

Many sites of *Paralucia spinifera* are close to urban areas and roads. Recreational use of mountain bikes, trails bikes, and four-wheel drives has degraded a number of sites, causing erosion and damage to the host plants and associated ant colonies (NPWS 2001). Dust from road traffic has also been observed as a potential problem at some sites. Host plants adjacent to untarmacked roads have been documented with a thick layer of dust during the drier spring and summer months when the larvae are active, apparently resulting in these plants not being utilised by *P. spinifera* (NPWS 2001).

'Clearing of native vegetation' is listed as a Key Threatening Process under the *Biodiversity Conservation Act 2016*. 'Land clearance' is listed as a Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999*.

<u>Adverse fire regimes</u>

The exclusion of fire from *Paralucia spinifera* habitat is considered a threat to the species in the absence of other disturbances that promote the regeneration of *Bursaria* (NPWS 2001; R. Mjadwesch *in litt.* August 2023). There is evidence that *Paralucia spinifera* is fire-adapted and responds positively to fire events although there is a lack of knowledge of how fire season influences the outcomes. The Lithgow Valley supports the highest concentration of sites within the range of the species, many of which have a history of repeated fire events (NPWS 2001). Both low and high intensity fires have been shown to be beneficial to *P. spinifera*: a very low intensity fire at Yetholme produced a significant increase in abundance, as did a high intensity fire at another site in Lithgow (R. Mjadwesch, pers. comm. 2010, in Kerswell *et al*. 2010). Unpublished SOS monitoring data from 2020–2022 indicates that many of the Lithgow sites which burnt during the 2019–2020 fires still support *P. spinifera*, often in numbers greater than in previous years. *Bursaria* becomes senescent at sites in which fire has long been absent but may resprout from subterranean regenerative organs when burnt (Mjadwesch 2016; J. Peterie *in litt.* June 2023). Sporadic disturbance from fire may therefore promote a continuity of host foliage for the larvae (DPIE 2020a). Fire plays a role in establishing and maintaining regenerative forms of *Bursaria* which provide ample new growth favoured by the larvae (Mjadwesch and Nally 2008). Many of the sites affected by the extended absence of fire are on private property, some of which are isolated, being located in agricultural landscapes with little to no habitat connectivity. Modelling indicates fire frequency is likely to increase in the coming decades (AdaptNSW 2023).

'Fire regimes that cause declines in biodiversity' is listed as a Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999*.

<u>Weed invasion and competition with *Bursaria*</u>

Weed invasion is a threat to *Paralucia spinifera* requiring ongoing management (NPWS 2001; DPIE 2020a). The most significant weeds are blackberry (*Rubus* spp.) and scotch broom (*Cytisus scoparius*), which compete with the *Bursaria spinosa* subsp. *lasiophylla* and at high densities threaten to exclude *P. spinifera* (Braby 2000; NPWS 2001). Radiata pine (*Pinus radiata*) is invading from pine plantations at some sites and the trees threaten to shade out the habitat (NPWS 2001). Other weeds include hawthorn (*Crataegus monogyna*), briar rose (*Rosa rubiginosa*), cotoneaster (*Cotoneaster pannosus*), St. Johns wort (*Hypericum perforatum*), and sweet vernal grass (*Anthoxanthum odoratum*) (NPWS 2001; Mjadwesch 2016), with Japanese honeysuckle (*Lonicera japonica*) and willows (*Salix* spp.) observed invading at some sites (D.P.A. Sands, in Sand and New 2002). Weeds also affect the range of plants utilised by *P. spinifera* while on the wing, with some of them providing a source of nectar for feeding (NPWS 2001).

'Loss and degradation of native plant and animal habitat by invasion of escaped garden plants, including aquatic plants', 'Invasion and establishment of exotic vines and scramblers' and 'Invasion of native plant communities by exotic perennial grasses' are listed as Key Threatening Processes under the *Biodiversity Conservation Act 2016*. 'Loss and degradation of native plant and animal habitat by invasion of escaped garden plants, including aquatic plants' is listed as a Key Threatening Process under the *Environment Protection* and *Biodiversity Conservation Act 1999*.

<u>Habitat degradation from feral animals</u>

Feral pest animals are a significant threat to *Paralucia spinifera* at some sites (Dunn *et al.* 1994; NPWS 2001). Feral pigs (*Sus scrofa*) and goats (*Capra hircus*) degrade habitat by digging up or browsing on *Bursaria* plants (NPWS 2001). Feral pigs are particularly problematic as they uproot entire *Bursaria* plants (Dunn *et al.* 1994) and have been documented to impact up to 30% of the plants at one site (NPWS 2001). Pigs may also adversely affect the associated ant colonies (NPWS 2001). Feral pig control programs have been successfully implemented but require ongoing management to ensure feral animal disturbance remains minimal (DPIE 2020a). Feral deer have been shown to preferentially browse on *Bursaria spinosa* (Claridge 2016; Claridge *et al.* 2016), suggesting that deer are likely to degrade *P. spinifera* habitat if their numbers are not controlled. Feral deer are an increasing problem in the Central Tablelands (LLS 2018; M. Saunders pers. obs. December 2022, January 2023).

'Predation, habitat degradation, competition and disease transmission by feral pigs (*Sus scrofa*)' is listed as a Key Threatening Process under the *Biodiversity Conservation Act 2016*. 'Predation, Habitat Degradation, Competition and Disease Transmission by Feral Pigs', 'Competition and land degradation by feral goats' and 'Novel biota and their impact on biodiversity' are listed as Key Threatening Processes under the *Environment Protection and Biodiversity Conservation Act 1999*.

<u>Grazing by livestock and associated farming activities</u>

Livestock can trample and eat juvenile *Bursaria*, inhibiting recruitment and altering the spatial arrangement of the patch, leading to plant isolation (Dexter and Kitching 1993; Dunn *et al.* 1994). Larvae on isolated bushes may deplete their food supply so rapidly that they either starve or pupate prematurely (Dunn *et al.* 1994). Stock may also impact the attendant ant colonies by causing soil compaction and erosion (NPWS 2001). There is the potential for livestock to alleviate the adverse effects of invasive weeds if weeds are grazed more than *Bursaria* (NPWS 2001). Associated farming activities, such as the application of superphosphate to improve pasture species, can alter soil chemistry, affecting both the ant and the native plants utilised by *P. spinifera* (NPWS 2001).

Adverse land management practices

Many of the threats operating on *Paralucia spinifera* are being managed to varying degrees, particularly at protected sites, such as those in national parks. These threats require ongoing management to mitigate the impact they would otherwise have on *P. spinifera*. However, with approximately 75% of the sites of *P. spinifera* located on non-reserved lands, lack of appropriate management continues to be an issue. Therefore, ensuring that threats are managed on reserved lands will continue to play a critical role in the persistence of this species. Inappropriate weed management can pose a threat to *Paralucia spinifera* habitat. Powerline easement works adjacent to a restored site near Lidsdale resulted in herbicide use throughout the site, with *Bursaria* and other native plants affected (Nally and Mjadwesch 2019).

Increasing temperatures from climate change

Paralucia spinifera may be threatened by global warming because of its association with cold sites within its range (NPWS 2001). In that range, mean temperatures are to rise by 0.7ºC by 2030 (AdaptNSW 2023), extreme temperatures are projected to increase with very high confidence, and frost risk days are expected to decrease with high confidence (CSIRO 2023). Increasing temperatures from climate change are already causing range contractions in some montane butterfly species at the lower limits of their elevational boundaries (Wilson *et al*. 2005; Franco *et al.* 2006; Rödder *et al.* 2021), resulting in local extinctions at lower elevations (Wilson *et al*. 2007). Extreme temperatures resulting from heat waves may be particularly detrimental to butterflies during early development and can reduce egg viability (Bauerfeind and Fischer 2014; Klockmann and Fischer 2017). If increasing temperatures adversely affect *P. spinifera*, it is suspected that the species may be unable to follow optimal isotherms uphill fast enough to counteract low elevation range contractions resulting from increasing temperatures.

The dependency of *Paralucia spinifera* on its mutualistic associations also makes it vulnerable to climate change (Beaumont and Hughes 2002), as changes in climate variables have the potential to cause phenological mismatches between the butterfly, plant, and ant (Moir *et al*. 2014), which could in turn lead to a community breakdown (Caddy-Retalic *et al*. 2019).

‘Anthropogenic climate change’ is listed as a Key Threatening Process under the *Biodiversity Conservation Act 2016*. ‘Loss of climatic habitat caused by anthropogenic emissions of greenhouse gases’ is listed as a Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999*.

Number of locations

The population of *Paralucia spinifera* is split across 61 small sites over 65 ha of habitat, averaging about 1.1 ha per site. Different sites are subject to different threats. Approximately 75% of the sites *P. spinifera* inhabits are on non-reserved lands: private property, mining lease, roadside verges, and powerline easements. The variety of land uses and land zoning types makes it difficult to predict the number of sites which would be at risk of clearing within a 3-generation (3 years) period. However, it is probable that there are >10 threat-defined locations between these sites alone. The remaining 18 sites occurring on NPWS estate, state forest, travelling stock reserve, and private properties protected by conservation covenants are not threatened by habitat loss and another method must be used to determine the number of locations. *Paralucia spinifera* on these protected tenure types is primarily threatened by weed invasion and feral animals. As these sites are geographically spread out and the threats operate on an individual site scale, the number of threat-defined locations is the same as the number of sites (18). In summary, there are more than 10 threat-defined locations, as per the definition in the IUCN Guidelines (2024).

Assessment against IUCN Red List criteria

For this assessment it is considered that the survey of *Paralucia spinifera* has been adequate and there is sufficient scientific evidence to support the listing outcome.

Criterion A *Population Size reduction*

<u>Assessment Outcome</u>: Data deficient.

<u>Justification</u>: Although larval population estimates have been made for many *Paralucia spinifera* sites, little is known about the number of mature individuals and there are insufficient data on population trends over time to quantify a population size reduction.

Criterion B *Geographic range*

<u>Assessment Outcome</u>: Endangered under B1b(ii,iii,iv,v)c(iv)+2b(ii,iii,iv,v)c(iv).

<u>Justification</u>: *Paralucia spinifera* has an area of occupancy of 152–176 km^2, meeting the threshold of <500 km^2 for Endangered, and an extent of occurrence of 1693–1823 km^2, meeting the threshold of <5,000 km^2 for Endangered. The application of coarse-scale grid cell data and population trends used in Red List assessments has been shown to strongly underestimate extinction risks in butterfly species (van Swaay *et al.* 2011; Maes *et al*. 2012), so this should be considered a conservative estimate of threat.

In addition to these thresholds, at least two of three other conditions must be met. These conditions are:

a) The population or habitat is observed or inferred to be severely fragmented or there is 1 (CR), ≤5 (EN) or ≤10 (VU) locations.

Assessment Outcome: Not met.

Justification: It is not possible to determine whether *Paralucia spinifera* is severely fragmented, as the species is irruptive and sites where it occurs may provide only temporarily suitable habitat. The lack of understanding around whether the species still operates in a metapopulation structure in the highly fragmented parts of its distribution further confound assessment of this condition. Therefore, there are insufficient data available to assess whether the species is severely fragmented.

Due to the species' disjunct distribution, which reduces the risk of threats operating on large parts of the species' range simultaneously, there are >10 threat-defined locations, as per the IUCN (2024) definition.

b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals

Assessment Outcome: Met for (ii), (iii), (iv), and (v).

Justification: *Paralucia spinifera* has an estimated and inferred continuing decline in the AOO, area, extent and quality of habitat, number of locations or subpopulations, and number of mature individuals, due to habitat loss, low frequency fire, weed invasion, feral animals, and adverse land management practices. Known sites have been lost through habitat clearing and through the long absence of fire leading to the senescence of the *Bursaria* (New 2011; Mjadwesch 2016). The loss of these sites represents not only continuing decline in the area, extent, and quality, but also continuing decline in AOO, locations or subpopulations, and number of mature individuals. Given the evidence of continuing decline that has already occurred, it is inferred that the high proportion of sites located on non-reserved lands will continue to be threatened by clearing and low frequency fire.

c) Extreme fluctuations.

Assessment Outcome: *Paralucia spinifera* undergoes extreme fluctuations.

Justification: *Paralucia spinifera* has been documented to undergo significant population fluctuations from year to year or over the course of several years. Several sites have documented extreme fluctuations in the number of individuals recorded, including the largest site at Bald Hill Creek in Winburndale Nature Reserve (B11), which supports up to 18.5–37% of the population, based on estimates made by Mjadwesch (2016). Monitoring data indicate significant swings ranging from 3 to 874 individuals, with each monitoring event showing greater than one order of magnitude difference from the previous monitoring event.

In at least one case, hundreds of individuals were observed at a site which had recorded only two or three individuals the year prior (D.P.A. Sands, in Sands and New 2002). *Paralucia spinifera* is an irruptive species with colonies which sporadically increase to peak numbers before declining again.

The once thriving population at Kennedy Park (B14) in Mount David collapsed, with a gap of several years before the species was recorded again by annual visits (DPIE 2020a). Kennedy Park is one of the most disjunct subpopulations in the species' range, being approximately 40 km from the closest established cluster of sites (O4 at Sodwalls, north of Oberon; Mjadwesch 2016), although a new site was discovered 8.7 km away in 2019, on the edge of Burraga Road to the northwest (BioNet 2023). These sites are located in an agricultural landscape with little connectivity. The genetic study undertaken by Clarke and Grosse (2002, in Murphy and Nally 2004), indicated that this site had greater genetic differentiation compared with sites in the Lithgow and Yetholme areas. The geographic isolation of this site combined with these genetic data suggests dispersal to or from this site occurs rarely, if at all. Therefore, the more plausible explanation is that the site underwent an extreme population fluctuation, persisting at very low levels after the population crash until conditions were favourable for the population to increase again.

The IUCN Red List Guidelines (2024) state that "if there is regular or occasional dispersal (of even a small number of individuals, seeds, spores, *etc*.) between all (or nearly all) of the subpopulations, then the degree of fluctuations should be measured over the entire population." Although it has been put forward that *Paralucia spinifera* has a metapopulation structure, evidence for this is limited and many sites are isolated from one another by both significant distance and lack of habitat connectivity. Therefore, it is unlikely that there is "regular or occasional dispersal…between *all (or nearly all)* of the subpopulations". The IUCN Guidelines go on to state "if dispersal is only between some of the subpopulations, then the total population size over these connected subpopulations should be considered when assessing fluctuations; each set of connected subpopulations should be considered separately". Due to the uncertainty around whether *P. spinifera* exists as a metapopulation, and if so, which site clusters would be considered singular subpopulations, fluctuations recorded at the site are assumed to be representative of the species' overall population dynamics.

Monitoring data for *Paralucia spinifera* are inconsistent and the timing of monitoring influences the success in finding the species; however, the data are sufficient to demonstrate extreme fluctuations (one order of magnitude or greater) at the site level. The uncertainty around the distance and frequency of dispersal in *P. spinifera* and the difficulty in collecting accurate population data for a small insect species warrants the application of the precautionary principal (Kriebel *et al*. 2001), under which *P. spinifera* should be considered to undergo extreme fluctuations.

Criterion C Small population size and decline

Assessment Outcome: Not met.

Justification: The total larval population is estimated to be 337,145–670,735 (Mjadwesch 2016). The counting of larvae is recognised to have limited relevance to estimating effective population size (Mjadwesch and Nally 2008) and juvenile mortality of the species is likely to be in the order of ≥ 70% (D.P.A. Sands pers. comm., in NPWS 2001). However, if only 3% of the estimated larval population survives until maturity, using the low end of the estimated range, the estimated mature population would be greater than 10,000, exceeding the population size threshold for Criterion C.

At least one of two additional conditions must be met. These are:

C1. An observed, estimated or projected continuing decline of at least: 25% in 3 years or 1 generation (whichever is longer) (CR); 20% in 5 years or 2 generations (whichever is longer) (EN); or 10% in 10 years or 3 generations (whichever is longer) (VU).

Assessment Outcome: Data deficient.

Justification: There are insufficient data to quantify the decline in mature individuals despite observed declines in habitat quality and the loss of several sites.

C2. An observed, estimated, projected or inferred continuing decline in number of mature individuals.

Assessment Outcome: Met.

Justification: *Paralucia spinifera* has estimated and inferred continuing decline the number of mature individuals.

In addition, at least 1 of the following 3 conditions:

a (i).Number of mature individuals in each subpopulation ≤50 (CR); ≤250 (EN) or ≤1000 (VU).

Assessment Outcome: Not met.

Justification: Using larval population estimates and a 3% survival rate, the total population of *Paralucia spinifera* would be over 10,000 mature individuals.

a (ii).% of mature individuals in one subpopulation is 90-100% (CR); 95-100% (EN) or 100% (VU)

Assessment Outcome: Not met.

Justification: The population of *Paralucia spinifera* is distributed between 16 subpopulations comprising 57 sites with no subpopulation supporting ≥90% of the total population.

b. Extreme fluctuations in the number of mature individuals

Assessment Outcome: Subcriterion met.

Justification: *Paralucia spinifera* undergoes extreme fluctuations at the site or subpopulation level.

Criterion D Very small or restricted population

Assessment Outcome: Not met.

Justification: Using larval population estimates and a 3% survival rate, the total population of *Paralucia spinifera* would be over 10,000 mature individuals, exceeding the population size threshold for Criterion D.

To be listed as Vulnerable under D, a species must meet at least one of the two following conditions:

D1. Population size estimated to number fewer than 1,000 mature individuals

Assessment Outcome: Not met.

Justification: The population of *Paralucia spinifera* is not thought to be fewer than 1,000 mature individuals.

D2. Restricted area of occupancy (typically < 20 km^2) or number of locations (typically < 5) with a plausible future threat that could drive the taxon to CR or EX in a very short time.

Assessment Outcome: Not met.

Justification: *Paralucia spinifera* has an AOO of >20 km^2, >10 threat-defined locations, and no plausible threat that could drive the species towards in CR or EX within a very short time.

Criterion E Quantitative Analysis

Assessment Outcome: Data Deficient.

Justification: No quantitative analysis has been undertaken to assess the extinction probability of this species.

Conservation and Management Actions

This species is currently listed on the NSW *Biodiversity Conservation Act 2016* and a conservation project has been developed by the NSW Department of Climate Change, Energy, the Environment and Water under the Saving our Species program. The conservation project identifies priority locations, critical threats and required management actions to ensure the species is extant in the wild in 100 years. *Paralucia* *spinifera* sits within the Site-managed species management stream of the SoS program and the conservation project can be viewed here: https://www.environment.nsw.gov.au/savingourspeciesapp/project.aspx?ProfileID=10586.

Activities to assist *Paralucia spinifera* currently recommended by the SoS program (NSW DCCEEW n.d.) include:

Habitat loss, disturbance and modification

- Continue to improve habitat protocols and implement ecological burns as required.
- Implement a pig trapping program.
- Physical and chemical control of weeds at key sites.

Survey and monitoring

- Regular monitoring of species abundance, extent and condition to determine population trends through time.
- Monitor extent and severity of threats to assess the effectiveness of management actions.

Research

- Investigate options to improve connectivity between sites, particularly the most disjunct ones.

Community engagement

- Undertake community engagement activities with landholders and land managers to promote conservation of the purple copper butterfly.
- Run a community awareness raising campaign in liaison with Rural Fire Service *e.g.*, local hotspots program.
- Community engagement and liaison activities to lead to voluntary conservation/landholder agreements for protection of habitat.

References

Aboriginal Affairs NSW (n.d.) Interactive Boundary Map [Online]. Available at https://www.aboriginalaffairs.nsw.gov.au/research-and-publications/interactive-boundary-map/ (accessed 29 June 2023)

AdaptNSW (2023) Interactive climate change projections map [Online]. Available at: https://www.climatechange.environment.nsw.gov.au/projections-map (accessed 9 June 2023)

Arnold RA (2022) Population Dynamics and Determinants of Annual Fluctuations of the Endangered Smith's blue butterfly, *Euphilotes enoptes smithi* (Lycaenidae). *The Journal of the Lepidopterists' Society*, **76**(2), 121–134.

Atlas of Living Australia (ALA) (2023) *Paralucia spinifera* records recorded until 25 May 2023 [dataset]. National Collaborative Research Infrastructure Strategy

(NCRIS) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Atlas of Living Australia (ALA) (2024a) *Bursaria spinosa* subsp. *lasiophylla* (E.M.Benn.) L.W.Cayzer, Crisp & I.Telford (Online). Available at: https://bie.ala.org.au/species/https://id.biodiversity.org.au/node/apni/2898464 (accessed 1 July 2024)

Atlas of Living Australia (ALA) (2024a) *Anonychomyrma itinerans* (Lowne, 1865) (Online). Available at: https://bie.ala.org.au/species/https://biodiversity.org.au/afd/taxa/ecb39d68-76ff-492f-b251-1ef1849e3ed2 (accessed 1 July 2024)

Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS) (2023) Map of Indigenous Australia [Online]. Available at: https://aiatsis.gov.au/explore/map-indigenous-australia (accessed 29 June 2023)

Bauerfeind SS, Fischer K (2014) Simulating climate change: temperature extremes but not means diminish performance in a widespread butterfly. *Population Ecology* **56**, 239–250.

Beaumont LJ, Hughes L (2002). Potential changes in the distributions of latitudinally restricted Australian butterfly species in response to climate change. *Global Change Biology* **8**(10), 954–971.

BioNet (2024). *Paralucia spinifera* records recorded until 25 May 2023 [dataset]. NSW Department of Climate Change, Energy, the Environment and Water.

Bond S, Vardon M (2022) Biodiversity accounts for the butterflies of the Australian Capital Territory. *Conservation Science and Practice* **5**(2):e12869.

Bowler JM, Johnston H, Olley JM, Prescott JR, Roberts RG, Shawcross W, Spooner NA (2003) New ages for human occupation and climatic change at Lake Mungo, Australia. *Nature*, **421**(6925), 837-840.

Braby MF (2000) ‘Butterflies of Australia: their identification, biology and distribution.’ (CSIRO Publishing)

Braby MF (2004) ‘The complete field guide to butterflies of Australia.’ (CSIRO Publishing)

Braby MF (2024) A new species of *Paralucia* Waterhouse & Turner, 1905 (Lepidoptera: Lycaenidae) from the highlands of south-eastern Australia. *Austral Entomology* **63**(2):224-43.

Caddy-Retalic S, Hoffmann BD, Guerin GR, Andersen AN, Wardle GM, McInerney FA, Lowe, AJ (2019) Plant and ant assemblages predicted to decouple under climate change. *Diversity and Distributions*, **25**(4), 551–567.

Cayzer LW, Crisp M, Telford IRH (1999). *Bursaria* (Pittosporaceae): a morphometric analysis and revision. *Australian Systematic Botany* **12**(1), 117–143.

Claridge AW (2016) Ecological and agricultural impacts of introduced deer in the Australian Alps. A final report to the Australian Alps Liaison Committee. NSW National Parks and Wildlife Service, Queanbeyan.

Claridge AW, Hunt R, Thrall PH, Mills DJ (2016) Germination of native and introduced plants from scats of Fallow Deer (*Dama dama*) and Eastern Grey Kangaroo

(*Macropus giganteus*) in a south-eastern Australian woodland landscape. *Ecological Management & Restoration* **17**(1), 56–62.

Clarke GM, Grosse SP (2003) Genetic analysis of populations of the Bathurst copper butterfly, *Paralucia spinifera*. CSIRO, Entomology, Canberra, ACT.

Clarkson C, Jacobs Z, Marwick B, Fullagar R, Wallis L, Smith M, Roberts RG, Hayes E, Lowe K, Carah X, Florin S (2017) Human occupation of northern Australia by 65,000 years ago. *Nature*, **547**(7663), 306-310.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2023) Climate Change in Australia: East Coast South projection summaries (Online). Available at: https://www.climatechangeinaustralia.gov.au/en/projections-tools/regional-climate-change-explorer/super-clusters/ (accessed 7 August 2023)

Department of Climate Change, Energy, the Environment and Water (DCCEEW) (2016) Conservation Advice for *Paralucia spinifera* purple copper butterfly. Canberra.

Department of Planning Industry and Environment (DPIE) (2020b) Saving Our Species purple copper butterfly *Paralucia spinifera* Factsheet [Online]. Available at: https://www.environment.nsw.gov.au/research-and-publications/publications-search/purple-copper-butterfly-paralucia-spinifera (accessed 25 March 2023)

Department of Planning Industry and Environment (DPIE) (2020a) SoS conservation project monitoring plan for the purple copper butterfly, *Paralucia spinifera*. Unpublished monitoring plan.

Despland E (2018) Effects of phenological synchronization on caterpillar early-instar survival under a changing climate. *Canadian Journal of Forest Research* **48**(3), 247–254.

Dexter EM, RL Kitching (1993) The Bathurst Copper, *Paralucia spinifera* Edwards and Common. In ‘Conservation Biology of Lycaenidae (Butterflies)’. (Ed TR New) pp. 168–70. (Occasional Paper of the IUCN Species Survival Commission No.8, Gland, Switzerland)

Douglas J (2015) ‘Kin and knowledge: the meaning and acquisition of Indigenous ecological knowledge in the lives of young Aboriginal people in Central Australia.’ PhD thesis, Charles Darwin University, Australia.

Dunn KL, Dexter EM, Kitching RL (1994). The conservation status of Australian butterflies. A Report to Australian National Parks and Wildlife Service, Canberra ACT.

Eastwood R, Fraser AM (1999) Associations between lycaenid butterflies and ants in Australia. *Australian Journal of Ecology* **24**(5), 503–537.

Edwards ED, Common IF (1978) A new species of '*Paralucia*' Waterhouse and Turner from New South Wales (Lepidoptera: Lycaenidae). *The Australian Entomologist* **5**(4), 65–70.

Franco AM, Hill JK, Kitschke C, Collingham YC, Roy DB, Fox RI, Huntley BR, Thomas CD (2006) Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. *Global Change Biology* **12**(8), 1545–1553.

Gammage B (2012) 'The Biggest Estate on Earth: How Aborigines made Australia: How Aborigines made Australia' (Allen and Unwin, Sydney)

Hanski I, Simberloff D (1997) The metapopulation approach, its history, conceptual domain, and application to conservation. In 'Metapopulation biology: Ecology, genetics, and evolution'. (Eds A Hanski, ME Gilpin) pp. 5–26 (Academic Press, San Diego, CA)

Harrison S (1991) Local extinction in a metapopulation context: an empirical evaluation. *Biological journal of the Linnean Society* **42**(1-2), 73–88.

Healy S, Wassen S (2008) Review of the impacts of fire on the ecology and population persistence of the purple copper butterfly (*Paralucia spinifera*). Institute for Land, Water and Society, Charles Sturt University, NSW.

IUCN Standards and Petitions Subcommittee (2024) Guidelines for Using the IUCN Red List Categories and Criteria. Version 16 [Online]. Available at: http://www.iucnredlist.org/documents/RedListGuidelines.pdf (accessed on 03 June 2024)

Janke, T and Company (2023) 'Aboriginal Cultural and Intellectual Property protocol', Aboriginal Affairs NSW.

Kerswell A, Dixson I, Ginns A (2010) Climate change vulnerability assessment: key natural assets in the Hawkesbury Nepean catchment. Report prepared by Eco Logical Australia and Hawkesbury Nepean Catchment Management Authority.

Klockmann M, Fischer K (2017) Effects of temperature and drought on early life stages in three species of butterflies: Mortality of early life stages as a key determinant of vulnerability to climate change? *Ecology and Evolution* **7**(24), 10871–10879.

Kriebel D, Tickner J, Epstein P, Lemons J, Levins R, Loechler EL, Quinn M, Rudel R, Schettler T, Stoto M (2001) The precautionary principle in environmental science. *Environmental health perspectives* **109**(9), 871-876.

Local Land Services (LLS) (2018) Central Tablelands Regional Strategic Pest Animal Management Plan 2018–2023. Local Land Services, NSW. Available at: https://www.lls.nsw.gov.au/__data/assets/pdf_file/0010/820783/central-tablelands-pest-plan.pdf (accessed 8 August 2023)

Maes D, Vanreusel W, Jacobs I, Berwaerts K, Van Dyck H (2012) Applying IUCN Red List criteria at a small regional level: a test case with butterflies in Flanders (north Belgium). *Biological Conservation* **145**(1), 258-266.

Mjadwesch R (2016) The purple copper butterfly (*Paralucia spinifera*) species review, 2015 survey report and population status update. Report prepared for NSW Office of Environment and Heritage, Dubbo, NSW.

Mjadwesch R, Nally S (2008) Emergency relocation of a purple copper butterfly colony during roadworks: successes and lessons learned. *Ecological Management and Restoration 9*, 100–109.

Moir ML, Hughes L, Vesk PA, Leng MC (2014) Which host-dependent insects are most prone to coextinction under changed climates? *Ecology and Evolution* **4**(8), 1295–1312.

Murphy MJ, Nally S (2004) Case studies in implementing the NSW Threatened Species Conservation Act 1995 for invertebrate conservation. In Threatened species legislation: is it just an Act? (Eds P Hutchings, D Lunney, C Dickman) pp. 107–124 (Royal Zoological Society of New South Wales, Mosman, NSW, Australia)

Nally S, Mjadwesch RM (2019). Butterfly population persists 10 years after emergency habitat restoration and translocation – Update to EMR feature [Online]. Available at https://site.emrprojectsummaries.org/2019/09/30/butterfly-population-persists-10-years-after-emergency-habitat-restoration-and-translocation-update-to-emr-feature/#:~:text=In%202015%2C%20ten%20years%20after,number%20recorded%20for%20this%20site (accessed 14 June 2023)

National Parks and Wildlife Service (2001) Bathurst copper butterfly (*Paralucia spinifera*) recovery plan. National Parks and Wildlife Service, Sydney

National Parks and Wildlife Service (NPWS) (2023). NSW Fire History [spatial dataset]. (accessed using ArcGIS Desktop 10.8.2, Esri Inc. 1999-2021).

New TR (2011) 'Butterfly Conservation in South-Eastern Australia: Progress and Prospects.' (Springer)

New, TR, Van Praagh BD, Yen AL (2000) Fire and the management of habitat quality in an Australian Lycaenid butterfly, *Paralucia pyrodiscus lucida* Crosby, the Eltham Copper. *Metamorphosis* **11**, 154–163.

NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) (n.d.) Saving our Species. Help save the Purple Copper Butterfly, Bathurst Copper Butterfly. (NSW DCCEEW: Parramatta)

Office of Environment and Heritage (2023) Purple copper butterfly, Bathurst copper butterfly – profile [Online]. Available at: https://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10586 (accessed 25 March 2023)

Pierce,NE (1984) Amplified species diversity: a case study of an Australian lycaenid butterfly and its attendant ants. In 'Biology of butterflies'. (Eds RI Vane Wright, PR Ackery) pp. 197–200 (Academic Press: London)

Rhainds M (2020). Variation in wing load of female spruce budworms (Lepidoptera: Tortricidae) during the course of an outbreak: evidence for phenotypic response to habitat deterioration in collapsing populations. *Environmental entomology* **49**(1), 238–245.

Rödder D, Schmitt T, Gros P, Ulrich W, Habel JC (2021) Climate change drives mountain butterflies towards the summits. *Scientific Reports* **11**(1), 1–12.

Sands DP (2018) Important issues facing insect conservation in Australia: now and into the future. *Austral Entomology* **57**(2), 150–172.

Sands DP, New TR (2002) 'The action plan for Australian butterflies.' (Environment Australia, Canberra)

Schowalter TD (2006) 'Insect ecology: an ecosystem approach (2nd edn).' Academic Press: Burlington, MA)

Swengel SR, Swengel AB (2005) Spatial synchrony in Wisconsin Karner blue (Lepidoptera: Lycaenidae) populations. *The Great Lakes Entomologist*, **38**(3 & 4), 135–154.

Turpin M, Fabb N (2017) Brilliance as cognitive complexity in Aboriginal Australia. *Oceania* **87**(2), 209-230.

van Swaay C, Maes D, Collins S, Munguira ML, Šašić M, Settele J, Verovnik R, Warren M, Wiemers M, Wynhoff I, Cuttelod A (2011) Applying IUCN criteria to invertebrates: How red is the Red List of European butterflies? *Biological Conservation,* **144**(1), 470–478.

Wilson RJ, Gutiérrez D, Gutiérrez J, Martínez D, Agudo R, Monserrat VJ (2005). Changes to the elevational limits and extent of species ranges associated with climate change. *Ecology Letters* **8**(11), 1138–1146.

Wilson RJ, Gutierrez D, Gutierrez J, Monserrat VJ (2007) An elevational shift in butterfly species richness and composition accompanying recent climate change. *Global Change Biology* **13**(9), 1873–1887.

Woodward E, Hill R, Harkness P and R Archer (Eds) (2020) 'Our Knowledge Our Way in caring for Country: Indigenous-led approaches to strengthening and sharing our knowledge for land and sea management, best practice guidelines from Australian experiences' (NAILSMA and CSIRO: Cairns, QLD)

Expert Communications

A/Professor Michael F Braby. Associate Professor / Visiting Scientist, Australian National Insect Collection, Australian National University, Canberra, ACT.

Jessica Peterie, Threatened Species Officer, Department of Planning and Environment, NSW Government.

Raymond Mjadwesch, Conservation Biologist, Mjadwesch Environmental Service Support, NSW.

Simon Nally, Assistant Director, Biodiversity Division, Department of Climate Change, Energy, the Environment and Water, Australian Government.

APPENDIX 1

Assessment against *Biodiversity Conservation Regulation 2017* criteria
The Clauses used for assessment are listed below for reference.

Overall Assessment Outcome: *Paralucia spinifera* was found to be Endangered under Clause 4.3(b)(e i,ii,iii,iv)(f i).

Clause 4.2 – Reduction in population size of species
(Equivalent to IUCN criterion A)
Assessment Outcome: Data deficient.

(1) - The species has undergone or is likely to undergo within a time frame appropriate to the life cycle and habitat characteristics of the taxon:			
	(a)	for critically endangered species	a very large reduction in population size, or
	(b)	for endangered species	a large reduction in population size, or
	(c)	for vulnerable species	a moderate reduction in population size.
(2) - The determination of that criteria is to be based on any of the following:			
	(a)	direct observation,	
	(b)	an index of abundance appropriate to the taxon,	
	(c)	a decline in the geographic distribution or habitat quality,	
	(d)	the actual or potential levels of exploitation of the species,	
	(e)	the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.	

Clause 4.3 - Restricted geographic distribution of species and other conditions (Equivalent to IUCN criterion B)
Assessment Outcome: Endangered under Clause 4.3(b)(e i,ii,iii,iv)(f i)

The geographic distribution of the species is:			
	(a)	for critically endangered species	very highly restricted, or
	(b)	for endangered species	highly restricted, or
	(c)	for vulnerable species	moderately restricted,
and at least 2 of the following 3 conditions apply:			
	(d)	the population or habitat of the species is severely fragmented or nearly all the mature individuals of the species occur within a small number of locations,	
	(e)	there is a projected or continuing decline in any of the following:	
		(i)	an index of abundance appropriate to the taxon,
		(ii)	the geographic distribution of the species,
		(iii)	habitat area, extent or quality,
		(iv)	the number of locations in which the species occurs or of populations of the species,
	(f)	extreme fluctuations occur in any of the following:	

		(i)	an index of abundance appropriate to the taxon,
		(ii)	the geographic distribution of the species,
		(iii)	the number of locations in which the species occur or of populations of the species.

Clause 4.4 - Low numbers of mature individuals of species and other conditions
(Equivalent to IUCN criterion C)
Assessment Outcome: Not met.

The estimated total number of mature individuals of the species is:					
	(a)	for critically endangered species	very low, or		
	(b)	for endangered species	low, or		
	(c)	for vulnerable species	moderately low,		
and either of the following 2 conditions apply:					
	(d)	a continuing decline in the number of mature individuals that is (according to an index of abundance appropriate to the species):			
		(i)	for critically endangered species	very large, or	
		(ii)	for endangered species	large, or	
		(iii)	for vulnerable species	moderate,	
	(e)	both of the following apply:			
		(i)	a continuing decline in the number of mature individuals (according to an index of abundance appropriate to the species), and		
		(ii)	at least one of the following applies:		
			(A)	the number of individuals in each population of the species is:	
				(I)	for critically endangered species	extremely low, or
				(II)	for endangered species	very low, or
				(III)	for vulnerable species	low,
			(B)	all or nearly all mature individuals of the species occur within one population,	
			(C)	extreme fluctuations occur in an index of abundance appropriate to the species.	

Clause 4.5 - Low total numbers of mature individuals of species
(Equivalent to IUCN criterion D)
Assessment Outcome: Not met.

The total number of mature individuals of the species is:			
	(a)	for critically endangered species	extremely low, or
	(b)	for endangered species	very low, or
	(c)	for vulnerable species	low.

Clause 4.6 - Quantitative analysis of extinction probability
(Equivalent to IUCN criterion E)
Assessment Outcome: Data deficient.

The probability of extinction of the species is estimated to be:			
	(a)	for critically endangered species	extremely high, or
	(b)	for endangered species	very high, or
	(c)	for vulnerable species	high.

Clause 4.7 - Very highly restricted geographic distribution of species–vulnerable species
(Equivalent to IUCN criterion D2)
Assessment Outcome: Not met.

For vulnerable species,	the geographic distribution of the species or the number of locations of the species is very highly restricted such that the species is prone to the effects of human activities or stochastic events within a very short time period.

Locked Bag 5022 Parramatta NSW 2124 (02) 9585 6940
scientific.committee@environment.nsw.gov.au