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Review of the impacts of fire on
the ecology and population
persistence of the Purple Copper
Butterfly (*Paralucia spinifera*).

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Literature Review

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Review of the impacts of fire on the ecology and population persistence of the Purple Copper Butterfly (*Paralucia spinifera*)

Executive summary

The Purple Copper Butterfly (*Paralucia spinifera*) of the family Lycaenidae is an endemic Australian butterfly. It is listed as ‘vulnerable’ under the Commonwealth Environment Protection and Biodiversity Conservation Act, 1999 and ‘endangered’ under the New South Wales Threatened Species Conservation Act 1995.

The larval stage of the butterfly exhibits a mutualistic relationship with the ant *Anonychomyrma itinerans* that attends to larvae and host pupae within their nests. Another exclusive association exists between *P. spinifera* and the plant *Bursaria spinosa* subsp. *lasiophylla*, in which larvae feed on. The interaction between butterfly, attending ant and larval food plant is considered to be important to the persistence of *Paralucia spinifera* populations, however this relationship is not completely understood.

Paralucia spinifera has a limited distribution, and is only found between Bathurst, Hartley, Lithgow and Mudgee on the Great Dividing Range. Its limited distribution may be due to its comparatively low dispersal capability. This low dispersal may reduce the ability of *Paralucia spinifera* to recover after disturbances such as land clearing, grazing and the introduction of exotic plants because it limits opportunities for recolonisation of vacant patches. Low connectivity between habitat patches due to land clearing may also limit dispersal opportunities.

Factors that drive population recovery after fire are poorly known. Based on studies of other butterfly species, the proximity to other occupied patches, the extent, intensity, frequency and timing of burning may all contribute to the likelihood of populations recovering after fire. In general the ecology of *Paralucia spinifera* is poorly known and this limits the ability to make predictions regarding the impact of fire. We therefore recommend a two step experimental design. Step 1 seeks to model occupancy patterns of *P. spinifera* and *Anonychomyrma itinerans*

in relation to the spatial arrangement of habitat patches, fire history and local patch characteristics such as vegetation condition, patch area, and weediness. Step 2 establishes an experimental design to test the extent of recovery of populations following hot fires. This design allows for the continued monitoring of the larvae, ant and plant response to fire over time and presents options for different levels of replication depending on patch availability. Based on studies of other butterfly species, the recovery and persistence of *Paralucia spinifera* after fire should be maintained provided that no more than 50% of a patch is burnt at any one time. The use of fire for insect habitat management in Australia has received increased attention and fire may play a critical role in habitat management and the subsequent prevalence of this butterfly.

Species overview

The genus *Paralucia* is endemic to Australia and contains three species, *Paralucia spinifera*, *P. aurifera* and *P. pyrodiscus lucida*. Both *Paralucia aurifera* and *P. pyrodiscus lucida*, have wide distributions extending from Southern Queensland through Victoria (Braby 1990; Braby *et al.* 1999; Braby 2000; New & Sands 2002; Sands & New 2002), however *P. spinifera* has a limited range and is confined to a single region in New South Wales (Braby 2000; New & Sands 2002). It is locally endemic to the Central Tablelands of New South Wales between the townships of Bathurst, Hartley, Lithgow and Mudgee (New & Sands 2002; NPWS 1999; NPWS 2001) and is restricted to areas with elevation above 850 metres (NPWS 1999; Braby 2000; NPWS 2001). There are fewer than forty *P. spinifera* populations within this 200km range (New & Sands 2002). Additionally, *P. spinifera* has a very low dispersal capability (NPWS 2001; Braby 2004), which can increase the risk of inbreeding depression due to low recolonisation (NPWS 2001). *Paralucia spinifera* varies greatly in its numbers from year to year at each site. Unpublished findings revealed at one site individuals were present in hundreds, where few were observed the previous year (cited in Sands & New 2002). Subsequently, *P. spinifera* is one of the rarest and least known butterfly species in Australia (New 1990; New & Sands 2002; Sands & New 2002).

Typical narrow range endemics, such as the *P. spinifera*, are food plant specialists (New & Sands 2002). *Paralucia spinifera* is dependent on the larval host plant *Bursaria spinosa* subsp. *lasiophylla* (Cayzer *et al.* 1999; Braby 2000; Braby 2004). *Bursaria spinosa* is a rhizomatous and vigorous multi stemmed shrub (Cayzer *et al.* 1999) which has nectar rich flowers that are attractive to many insects (Fairley & Moore 1995; Cayzer *et al.* 1999). As well as acting as a larval food source, male *P. spinifera* adults establish territories by using low growing plants, which include the larval host plant *Bursaria spinosa* subsp. *lasiophylla*, grasses and debris (Braby 2000; Braby 2004). Likewise, the plants are used as perching structures for adult butterflies to bask in the sun (Braby 2000; Braby 2004; NPWS 2001).

Larval ecology

The larvae of *P. spinifera* graze exclusively on the host plant *Bursaria spinosa* subsp. *lasiophylla* (Braby 2000; Braby 2004; NPWS 2001). Females deposit eggs on small, compact specimens of *B. spinosa* subsp. *lasiophylla* which may provide an advantage to offspring by reducing the distance between food resources, though this remains an untested hypothesis (Braby 1990). *Paralucia spinifera* larvae avoid traversing open ground to reach other host plants. Rather, they disperse using the intertwining branches of closely situated *B. spinosa* subsp. *lasiophylla* (NPWS 2001). This behaviour is similar to that exhibited by *P. lucida* larvae which remain and graze on the same host plant foliage from which they hatched (Braby 1990). Not all sites that contain the larval host plant *Bursaria spinosa* subsp. *lasiophylla* support *P. spinifera* (NPWS 2001; New & Sands 2002), thus the combination of its sedentary behaviour and low dispersal ability may be determining factors in its distribution. An additional and fundamental association also exists between the butterfly larvae and an ant.

Several larvae of Lycaenid butterflies associate with Formicid ants (Cushman *et al.* 1994; Eastwood & Fraser 1999; Fiedler 2001; Schmidt & Rice 2002; Collier 2007; Nowicki *et al.* 2007) in addition to specific larval food plants (Sands & New 2002; New & Sands 2004). Cushman *et al.* (1994) identified that ant (*Iridomyrmex nitidiceps*) and butterfly (*P. aurifera*) interactions benefited the survivorship of both taxa. By providing protection for the butterflies, the ant received nutrients from specialised larval glands (Cushman *et al.* 1994). A similar and mutualistic relationship exists between *Paralucia spinifera* and the ant, *Anonychomyrma itinerans* (NPWS 1999; NPWS 2001; Braby 2004). In return for a nutritious secretion from *P. spinifera* larvae, *A. itinerans* provide the larvae with protection from predation and host the pupae within their nest (NPWS 2001).

Little is known about the attending ant *Anonychomyrma itinerans*. It is abundant in the cool and wet regions of southern and eastern Australia (Eastwood & Fraser 1999) and is primarily omnivorous and nests in the ground (Shattuck 1999). *Anonychomyrma itinerans* is very active and responds rapidly to available food resources (Eastwood & Fraser 1999). It is an aggressive

species and consequently its behaviour is known to affect other ants within the same locality (Eastwood & Fraser 1999).

The larvae of *P. spinifera* are usually found with large numbers of *A. itinerans* present and spend part of their development period within the nest of *A. itinerans*, however there is inadequate information regarding to the level of attendance carried out by the ant (Eastwood & Fraser 1999). The attending ant, *A. itinerans*, has not been found at all the *P. spinifera* sites (NPWS 2001), although this may be due to the lack of surveys to locate and identify ants.

The complex association between *P. spinifera*, attendant ant and host plant is common for butterflies of the genus *Paralucia* e.g. *P. pyrodiscus lucida* (Braby 1990) and *P. aurifera* (Cushman *et al.* 1994). In the case of the many Lycaenidae whose larvae are associated with ants, the management of populations should consider the complex interactions between butterfly and specific larval food plant and specific host ant associations (New & Sands 2004). The importance of food plant availability, due to the strong dependency of larvae on the host plants, can be a limiting factor for butterfly distribution (Thomas *et al.* 2001). The loss of a habitat which supports a food plant or a mutualistic ant may have adverse effects on specialist butterflies that rely on these resources (Sands & New 2002).

Spatial ecology and dispersal

Dispersal ability can influence an organism's geographic distribution, its ability to colonise available habitats patches and to recolonise patches following local extinctions. International studies show that most Lycaenid butterflies occur in localised populations and do not disperse widely (New 1993). As a result, populations may be highly localised and colonisation of habitat patches can be limited. For example, Nowicki *et al.* (2007) found that Lycaenid *Maculinea alcon* was unlikely to successfully colonise nearby habitat patches and as a result was not located in all available habitat patches. Many Lycaenid butterflies also exhibit a high level of site fidelity, for example *Cupido minimus* in southern Belgium, typically remains within the same habitat patch during flight periods (Baguette *et al.* 2000) or travel less than 40 metres from the patch (Asher *et*

al. 2001). Similar to the Lycaenid butterflies, *Coenonympha hero* is a rare slow-flying small which also exhibits high levels of site fidelity with individuals rarely moving more than 100 metres from the site of first capture (Cassel-Lundhagen & Sjögren-Gulve 2007).

Adult *Paralucia spinifera* fly low to the ground (<1m) (Braby 2000; Braby 2004) and remain close to core habitat with few individuals having been observed further than fifteen metres from a habitat patch (NPWS, 2001; Mjadwesch & Nally, 2008). The males are more rapid in flight and fly greater distances compared to their female counterparts, which remain in the locality of the larval host plant *Bursaria spinosa* subsp. *lasiophylla* (Braby 2000; NPWS 2001)

Factors influencing butterfly movement

The movement patterns and dispersal rates of butterflies may be influenced by the condition and composition of the surrounding landscape as well as the spatial arrangement of habitat patches. Individuals occupying highly fragmented patches are less likely to disperse than those occupying well connected patches (Hill *et al.* 1996). Chronic isolation can lead to morphological changes such as increased abdomen and decreased wing size as populations trade off their dispersal ability in favour of increased reproductive effort (Hill *et al.* 1999). Specialist butterfly species are also sensitive to the type of vegetation and level of disturbance in areas surrounding habitat patches (Fischer *et al.* 1999). Patches that are surrounded by cleared agricultural land may have lower recolonisation rates than patches surrounded by taller “weedy” vegetation (Schtickzelle & Baguette 2003).

High levels of site fidelity and restricted movement can also arise when resources within the patch are not limiting. For example patch occupancy and abundance of Lycaenid *Cupido minimus* can be driven by the abundance of its host plant within a patch rather than the distance between patches (Krauss *et al.* 2004, Krauss *et al.* 2005). Similarly, Fleishman *et al.* (2002) showed that abundant adult and larval resources determined patch occupancy over patch area or isolation for a North American butterfly.

Habitat availability is also an important factor influencing both dispersal patterns and population persistence. For example, the size of patches and availability of resources within them is the most significant factor when predicting abundance of the specialist Lycaenid, *Cupido minimus* (Baguette *et al.* 2000; Krauss *et al.* 2004). Similar relationships exist for another specialist Lycaenid, *Maculinea* spp., of Europe which requires specific food plants and host ants during the larval period (Nowicki *et al.* 2005; Nowicki *et al.* 2007). There is a paucity of studies on factors that influence the movement of *Paralucia spinifera* and other Australian butterflies.

Population structure of butterflies

Metapopulation structures are common amongst butterflies as they often have specialised habitat requirements and limited dispersal capabilities (Hanski 1994; Thomas 1995; Fleishman *et al.* 2002; Hanski & Gaggiotti 2004). The metapopulation concept describes a “population of populations” of species existing as a number of small, localised subpopulations that are interconnected through dispersal (Thomas & Harrison 1992; Hanski 1994; Thomas 1995; Baguette *et al.* 2000). The persistence of the metapopulation as a whole is influenced by the number of patches and their spatial arrangement within the landscape. The movement of individuals between habitat patches allows for recolonisation of vacant patches following local extinctions, which can increase the long-term persistence of the metapopulation as a whole (Hanski & Simberloff 1997). Small and isolated patches often have higher rates of extinction and less chance of recolonisation (Fischer *et al.* 1999; Binzenhöfer *et al.* 2008).

Paralucia spinifera may share several characteristics of other Lycaenid butterflies, such as *Cupido minimus* and *Maculinea alcon* which occur as metapopulations. *Paralucia spinifera* has a low dispersal capability and occupies discrete habitat patches of *Bursaria spinosa* subsp. *lasiophylla*. (Sands & New 2002) noted “colonisation, contraction, temporary extinctions and recolonisation of microhabitats over a 15 year period was normal for this species”. Although metapopulation has been suggested for the population structure of *P. spinifera*, it has not been formally tested. Clarke and Grosse (2003) conducted genetic analysis on *P. spinifera* populations and found that genetic diversity within populations was high and population numbers and gene

flow was sufficient to maintain genetic variation. Clarke and Grosse (2003) also indicated that the overall structure of *Paralucia spinifera* populations behaved as a large population using multiple habitats, however cautioned readers that their findings were suggestive rather than conclusive due to the small sample size used.

Habitat loss and alteration

The distribution of *Paralucia spinifera* has remained relatively stable since its discovery; however there is no information available on its original distribution prior to this (Sands & New 2002). Consequently it is not possible to determine its historical range or rate of decline (New & Sands 2002). Clearing of the larval host plant *Bursaria spinosa* subsp. *lasiophylla* has been extensive so local extinctions are likely (NPWS 2001). The continued alteration and fragmentation of *Bursaria* habitats is a threat to *P. spinifera* populations (NPWS 2001).

Many butterfly species are threatened with local or complete extinction from altered land use and habitat degradation (Thomas 1995; Sands & New 2002; Austin *et al.* 2004). Sedentary butterfly species are particularly vulnerable to high rates of patch turn over because their poor dispersal ability reduces the rate of recolonisation (Fischer *et al.* 1999). For example, the destruction of natural permanent moorland habitat typically used by the Lycaenid *Lycaena helle* through land clearing, created alternative ephemeral man made habitats (abandoned moist meadows) which were subsequently used by the butterfly (Fischer *et al.* 1999). Consequently, *Lycaena helle* adapted poorly to patch disturbance, in part because it is generally associated with habitats that remain constant over time and because the distance between populations acted as a dispersal barrier, with butterflies generally unable to recolonise patches further than 1000 metres from adjacent populations (Fischer *et al.* 1999).

Habitat loss and alteration can impact upon populations in a number of ways, decreasing habitat availability, increasing edge effects, and increasing levels of patch isolation (Saunders *et al.* 1991). Habitat quality and availability is also particularly important for specialist butterflies in fragmented landscapes because it is a primary driver of recruitment success and extinction risk (Thomas *et al.* 2001). Canopy closure and introduced plants can negatively impact the quality

and availability of patch resources. For example Krauss *et al.* (2004) identified that competing shrubs reduced availability of larval food plant habitats for the endangered *Cupido minimus*. Canopy closure and weed infestation also was a threat to sites that contained the host plant *Bursaria spinosa* which supported *P. pyrodiscus lucida* (Braby 2000; New *et al.* 2000) and is comparable with threats by blackberry (*Rubus fruticosus*) and scotch broom (*Cytisus scoparius*) to *B. spinosa* subsp. *lasiophylla* at the *P. spinifera* habitat sites (Braby 2000).

Habitat fragmentation can alter the spatial arrangement of habitat patches which can reduce dispersal and recolonisation following disturbance (Wiegand *et al.* 2005). Though there are no published studies, the loss and fragmentation of habitat has probably caused declines and the local extinctions of the *P. spinifera* because available habitats exist as a series of disconnected and often small sites of varying quality (NPWS 2001).

Response to fire

Fire is a prevalent and common natural disturbance in Australia (Gill 1996; Bradstock *et al.* 2002). Natural fire regimes of differing intensities often result in a mosaic of habitats containing vegetation at different stages of post fire succession (York 1996). Thus fire plays an important role by spatially and temporally altering the abundance and distribution of species, generating heterogeneity at a range of scales (Whelan 1995; Barrow *et al.* 2007). Low intensity fires may be beneficial because they maintain a mosaic of patchy unburnt habitats and stimulate vegetative growth (York 1996). Fire may assist in the regeneration and quality of *Bursaria spinosa* subsp. *lasiophylla* habitats (Cayzer *et al.* 1999; NPWS 2001; Mjadwesch & Nally 2008) and has been used to maintain habitat for other butterfly species. For example the ‘hottest possible’ fires were used to open up the canopy within *Paralucia pyrodiscus lucida* habitat which successfully promoted regeneration from *Bursaria spinosa* rootstock and rhizomes (New *et al.* 2000).

The relationship between *Bursaria spp.* regeneration and condition and fire indicates that fire may be a valuable management tool to maintain the quality of *Paralucia* butterfly habitat (New *et al.* 2000; Mjadwesch & Nally 2008). If fires were to remove an entire *Bursaria spinosa* subsp.

lasiophylla habitat there could be devastating consequences for the butterfly, as it is the primary food source of *P. spinifera* larvae and the poor dispersal ability of adults may limit recolonisation. Small controlled fires may allow the regeneration of fresh *Bursaria spinosa* subsp. *lasiophylla* plants, and younger more compact growth (Braby, 2000). New *et al.* (2000) observed successful recovery by both *Bursaria spinosa* and *Paralucia pyrodiscus lucida* after a once off high intensity burn that was undertaken on a large portion of each of the two sites studied (75% western colony site and 50% of the eastern colony site). Thus fire has been used to increase the quality of existing *Bursaria spinosa* habitat and the overall population of *P. pyrodiscus lucida* in Eltham, Victoria (New *et al.* 2000).

While fire may be beneficial for plant growth, data on the direct effects of fire on invertebrates are limited (Friend 1996; Gill 1996; York 1996; Underwood & Fisher 2006; Barrow *et al.* 2007; Möllenbeck *et al.* 2008). In some cases it may be a risky strategy when dealing with an endangered species due to the threat of mortality. However the use of fire for insect habitat management has recently been acknowledged and is now receiving increased attention (New *et al.* 2000; Relf & New 2008) and there are a number of different strategies to minimise the risk to invertebrate populations during controlled burns.

Immense care must be taken when using fire as a management tool as unnatural burning regimes may have severe impacts on butterflies (Friend 1996; Sands & New 2002). Friend (1996) reported that lepidopterans consistently showed a decrease in abundance after high intensity fires. The early stages of butterflies could be adversely affected by the burning of food plants and can potentially be destructive to butterfly habitats (Sands & New 2002).

Information about butterfly response to fire in Australia is scarce (*e.g.* New *et al.* 2000; Relf & New 2008) and available literature mainly covers species from Europe and America (*e.g.* Fleishman 2000 (USA); Huntzinger 2003 (USA); Waltz & Covington 2004 (USA); Möllenbeck *et al.* 2008 (Germany); Swengel & Swengel 2007 (USA)). The effect of fire on butterflies is variable and is further confounded by fire regime characteristics such as frequency, seasonality and intensity. The results of international studies on butterfly responses to fire are mixed, with

some studies showing an increase (Panzer & Schwartz, 2000; Vogel *et al.* 2007), decrease (Cleary 2003; Cleary & Mooers 2006) or no difference (Fleishman 2000) in butterfly diversity. This variation in response can be due to differences in habitat specialisation with narrow range endemics and habitat specialists been more susceptible to habitat loss by fire than habitat generalists (Vogel *et al.* 2007). For example, in Nevada USA, Fleishman (2000) found that butterfly richness was not affected by fire, though the number of sample sites was small. In the USA, Huntzinger (2003) who found higher butterfly diversity in burned sites than control sites suggested that butterflies were responding to sunlit patches made available by fire opening up the forest canopy and cautioned that this newly created habitat could behave as a mortality sink as no food was available immediately for larva or adult. Equally, New *et al.* (2000) observed high numbers of surviving *P. pyrodiscus lucida* larvae post fire which resumed feeding on regrowth of the regenerating host plant and concluded that direct mortality to fire of larvae was low.

In addition to differences in habitat specialisation, differences in experimental design have also lead to differences in experimental outcomes. For example, butterfly species richness and population densities were found to be similar or higher on frequently burned sites when compared to sites excluded from fire in a study of 26 burnt and 18 unburnt sites on prairies in the USA (Panzer & Schwartz 2000). However this may have been due to differences in detection rates between the more open burnt sites and structurally complex unburnt sites. In contrast, Vogel *et al.* (2007) found that adult butterfly abundance was lowest on fire managed sites when compared to grazed and the combination of grazed and fire managed sites, but butterfly diversity was greatest on sites that were managed with fire only. The differences in outcomes between different studies may be due to the way fire frequency is classified and the areas burnt. Vogel *et al.* (2007) surveyed study sites that were variable in size (ranging between 10 and 167 hectares), but prescribed burn frequency (in applicable treatments) occurred only once and up to four times in an eight year period with entire treatments burned (Vogel *et al.* 2007). Panzer & Schwartz (2000) categorised frequently burned sites as those which had been burned at least twice in five years and at least eight times in the preceding 20 years, whilst unburned sites were excluded from fire for at least five years and had only endured fire twice in 20 years (Panzer & Schwartz 2000).

Fires have been linked with some butterfly population extinctions (Sands & New 2002). When the amount of available patches is already limited, which is the situation of the *P. spinifera*, fire may have catastrophic consequences on the existing populations. The impacts of fire can also be exacerbated by other disturbances such as drought (Relf & New 2008). In Victoria, surveys of burnt and unburnt habitats of the Lycaenid butterfly *Hesperilla flavescens flavescens* coincided with a period of severe drought which may have contributed to the very low numbers recorded (Relf & New 2008).

The persistence of populations during burning can be increased if there are nearby patches for recolonisation or translocation. For example New *et al.* (2000) regarded the use of fire to enhance *P. pyrodiscus lucida* habitat as a risky management strategy because the response *P. pyrodiscus lucida* to fire was largely unknown and unpredictable and survival of *P. pyrodiscus lucida* larvae was threatened. However this burn was successful probably because of the availability of nearby patches (New *et al.* 2000). In Wisconsin USA, Swengel & Swengel (2007) recommended the provision of unburnt refuge within sites that were burned for butterfly conservation. These unburnt refuge sites could be maintained by using less demanding methods such as mowing or slashing. In a study of a single colony, Dover and Rowlingson (2005) recommended mechanical disturbance over fire induced disturbance to promote the regeneration of host plants for the Western Australian Lycaenid *Hypochrysops halyaetus*. There was concern that although the pupae could survive fire in attendant ant nests, the species had also been observed to pupate in leaf litter and the use of fire was considered potentially detrimental to the population (Dover & Rowlingson 2005).

In the case of *Paralucia spinifera*, some disturbance is required to maintain the larval host plant *B. spinosa* subsp. *lasiophylla* which becomes an unsuitable habitat for *P. spinifera* as they senesce (Braby 1990; Braby 2000). *Bursaria spp.* becomes more compact when burnt (Cayzer *et al.* 1999; New *et al.* 2000) however other disturbance regimes such as cutting can also maintain compact new growth. It is not known whether *P. spinifera* pupate in the leaf litter like *Hypochrysops halyaetus* described by Dover & Rowlingson (2005) and if this is so then fire may

have a greater impact on their mortality than if they only pupate in the attending ant nest. Accordingly, fire management of *Paralucia spinifera* habitats must also consider the attending ant *Anonychomyrma itinerans*.

Ants vary in their sensitivity to fire which is important when planning fire management. For example, ants studied at Kapalga in Kakadu National Park increased in abundance after experimental fire regimes which ranged in intensity, timing and frequency and decreased in the absence of fire (Andersen *et al.* 2005). As ant nests are generally located deep in the soil this can provide refuge during fire. In contrast, York (2000) investigated the long term effects of frequent low intensity fire on forest ant communities in south eastern Australia by comparing frequently burnt sites with long unburnt control sites and found that although the richness of ant communities remained largely unchanged, the composition of ant assemblages differed substantially between treatments. In Australian savannah systems, Barrow *et al.* (2007) observed variation in the resilience and response to fire by 126 different ant species. Their study highlighted the need to be aware of how different habitats respond to fire and of the implications of appropriate fire management for different ecosystems (Barrow *et al.* 2007). The response to fire by the attending ant nests (*A. itinerans*) of *Paralucia spinifera* is poorly known, however its recovery after fire has been recorded (Braby 2000).

In summary, populations of *Paralucia spinifera* are known to recover after fire (Cayzer *et al.* 1999; Braby 2000; New *et al.* 2000). Several populations of *P. spinifera* have been exposed to both deliberate and naturally occurring fires. After a severe, one off burn, an initial decline occurred in the affected population of *P. spinifera*, though along with associated ants exhibited a strong recovery after two seasons (Braby 2000; New *et al.* 2000). The main obstacle to planning fire management regimes for *P. spinifera* is the lack of empirical studies on the impacts of fire. As a consequence it is not known what factors contributed to their recovery after fire because nearly all information is based on incidental surveys. Furthermore, it is not clear when populations may not have recovered. More systematic work is required to achieve this information.

Synthesis and recommendations

Paralucia spinifera is likely to occur as a metapopulation. The spatial arrangement of habitat patches and the quality of intervening habitat may influence the ability of *P. spinifera* to recolonise patches after disturbance. The maximum distances travelled between patches by *P. spinifera* for recolonisation is also unknown as dispersal of this species has been observed infrequently (Mjadwesch & Nally, 2008). In addition poor knowledge exists on the actual number of patches that are available and occupied by the butterfly. Furthermore, little information is available about the food sources utilised by adults which can also influence the persistence of *P. spinifera* populations.

The fine scale characteristics within habitat patches that influence *P. spinifera* are also poorly understood. For example we know that adult females deposit eggs on compact growth (Braby 2000) but we don't know at what point *Bursaria* become unusable by the butterfly. It is not known whether *P. spinifera* pupate exclusively within attending ant nests or if they also pupate in leaf litter, similar to the Lycaenid *Hypochrysops halyaetus* observed by Dover & Rowlingson (2005). A better understanding of the relationship between the attending ant and *P. spinifera* may also render better recovery outcomes when using fire as a management tool.

Experimental design: step one habitat occupancy patterns

Three key pieces of information are required in order to predict the response of *P. spinifera* populations following a fire event: the proportion of the patch burnt, the number of habitat patches burnt and the distance to the nearest occupied (unburnt) patch. Crucially, the distance between habitat patches required to maintain recolonisation is not known so it is difficult to identify patches which are functionally isolated and may therefore be at greater risk of permanent extinction following fire. Prior to burning trials it would be useful to model the relationship between landscape and local patch characteristics and the probability of occupancy by *P. spinifera* and *A. itinerans*. These studies are relatively easy to conduct and can be incorporated into normal population monitoring and the differences between occupied and vacant patches can be modelled using logistic regression.

The measurements and assessments of this habitat should include:

- Area of patch
- The height and condition of plants
- Leaf litter
- The presence/abundance of other vegetation
- Fire history if known
- Distance to nearest patch
- Surrounding land use
- The presence of attending ant (*A. itinerans*)
- The presence of *P. spinifera* adults and larvae

Surveys measuring the impacts of fire on *P. spinifera* populations will be better understood and quantifiable if conducted after the initial step one surveys and should better provide an understanding of factors which assist in the recovery of *P. spinifera* populations after fire and provide insight if and when they are unable to persist after fire.

Experimental design: step two fire trial

Experimenting with fire is risky because the numbers of occupied patches are relatively low and the quantified response of *P. spinifera* is unknown to this type of land management (New *et al.* 2000). However, if several habitat patches are within the dispersal capability of *P. spinifera* individuals, then recolonisation of patches should indeed be possible (New *et al.* 2000). This has not been formally tested with *P. spinifera* however; it was considered when conducting the Eltham burns for improved larval food habitat for *P. pyrodiscus lucida* (New *et al.* 2000).

A small burn could be conducted on a proportion of a habitat patch using the ‘hottest possible’ intensity to optimise larval host plant regeneration as administered by New *et al.* (2000). No more than 50% of a habitat patch should be burned within a single year (NPWS 2001), though

New *et al.* (2000) achieved successful regeneration results of the larval host plant *Bursaria spinosa* when burning approximately 75% of a study patch without devastating the *P. pyrodiscus lucida* population.

The prescribed burning of habitat patches should target known *P. spinifera* populations in patches where *Bursaria spinosa* subsp. *lasiophylla* are senescing or occur in weed infested sites which are already impacting on the quality of patch habitats and therefore the *P. spinifera* populations. Furthermore, study sites within habitat patches that contain larval host plants of similar size, quality and quantity should be used to quantify treatments and obtain quality results. Within patch manipulations of fire could include three treatments: brush cut, burned and unburned (control). The inclusion of a non fire approach such as brush cutting can be useful when working with habitat patches located near adjacent urban settings or fire sensitive species (Dover & Rowlingson 2005). Monitoring attending ant and butterfly response to the different treatments should assist in determining whether fire is necessary to promote patch quality and subsequent butterfly populations.

Ultimately, the experimental design will depend on the number of patches available to be incorporated into the study. Two experimental options have been included because of the limited number of currently known habitat patches which support *Paralucia spinifera* populations. Three patches would be required to conduct experimental burns using experimental design option one (Figure 1), whilst nine patches would be required for design option two (Figure 2). Variables that need to be monitored include larvae, ant and plant response to fire and their recovery over time. This could be measured by undertaking monthly or quarterly surveys after the initial burn.

If the number of available patches is limited, then three replicated patches, each subject to Burnt, brush cut and unburnt treatment would still allow statistical comparison of the recovery of *P. spinifera*, *A. itinerans* and the host plant under different treatments (Figure 1). This level of within patch manipulation will not allow for assessments of the impacts burning on whole patches or factors influencing subsequent recolonisation, although some of these issues will be addressed in step 1.

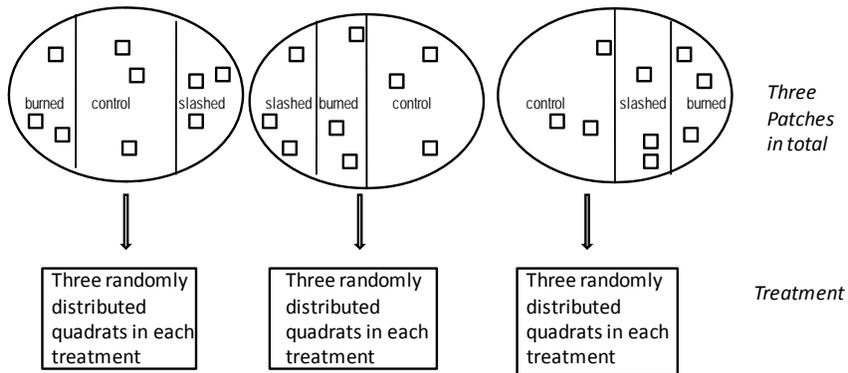


Figure 1. Experimental Design option one: three different management treatments within a patch.

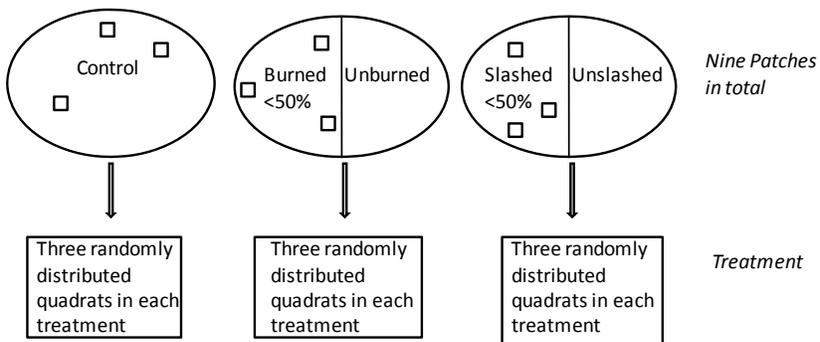


Figure 2. Experimental Design option two: three patches each with three different management treatments

Knowledge of *Paralucia spinifera* distribution, the number of populations and habitat occupancy are limited (New & Sands 2004). The limited distributions common in butterflies with poor dispersal capabilities can determine how far individuals can travel to reach patches, therefore patches selected for study should include those within close proximity of each other for potential recolonisation or future translocations (New *et al.* 2000). The selection of sites nearby other occupied patches may allow for dispersal between patches, whereas if patches are isolated there may only be movement within the patch. Because *Paralucia spinifera* occur only in a limited area surrounding relatively few habitat patches this may not always be possible and should be considered when conducting surveys and interpreting any results.

Numerous international studies on butterfly response to fire using burnt and unburnt (control) treatments (*e.g.* Fleishman 2000; Huntzinger 2003; Swengel & Swengel 2007) show variable responses to fire, however none reported extinctions as a direct result of fire. The limited numbers of studies that have been undertaken on the response to fire by threatened butterflies in Australia (*e.g.* New *et al.* 2000; Relf & New 2008) have reported no extirpations or considerable deviations from numbers collected prior to fire treatment. However, disturbance events such as fire may drive a threatened population to extinction if they remove a high proportion of available habitat. For this very reason there is a critical need to understand how *Paralucia spinifera* responds to such disturbance events so that these events can be managed to ensure its recovery.

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