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Review

Important issues facing insect conservation in Australia: now and into the future

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Abstract Studies of insect biodiversity and conservation in Australia have been severely limited by the many undescribed species and paucity of taxonomists and insect ecologists. In this review, I discuss important issues facing insect conservation, namely, key threatening processes, threats to habitats and ecological communities, the importance of maintaining insect interactions, the value of vegetation remnants in agricultural ecosystems and the importance of community participation, and provide recommendations for the conservation management of invertebrates and their habitats. Major threats to insect biodiversity continue from habitat loss through broadscale clearing of native vegetation, invasion by weeds, habitat fragmentation, loss of natural corridors and inappropriate fire regimes. Other threats include disturbance of plant communities on hilltops, creek embankments and in water courses, pesticide regimes, trampling and grazing by stock and feral animals, and exotic predators. Climate change affects those insects constrained by their thermal and moisture tolerances (climate envelopes), potentially influencing their distribution, development and reproduction, by disrupting diapause and aestivation or inducing torpor. Protected areas under State jurisdiction are at risk without Commonwealth protection and increasingly threatening those insects occurring only in national parks and other conservation areas. For effective conservation of mainland national parks, overarching national *EPBC Act* legislation is needed to protect parks for conservation of animal and plant diversity and natural landscapes. Retention of native vegetation as refuges for beneficial insects near farmlands is known to contribute to environmentally clean pest control. Information on conservation of beneficial insects and their dependence on native plants as habitats is needed by farmers to promote identification and protection of natural refuges for pollinators, parasitoids and predators and to support the case against indiscriminate tree clearing. Important community conservation activities are underway in several States and Territories, but to be effective, increased support and funding from appropriate agencies is required.

Key words agricultural ecosystem, community participation, insect conservation, insect interaction, key threatening process, taxonomy, threatened habitat.

INTRODUCTION

The Australian Entomological Society, through its Standing Committee on Conservation and Environmental Quality, made submissions to the House of Representatives Select Committee on Wildlife Conservation (Marks & Mackerras 1972), recommending inclusion of insects with other wildlife regulations. Eventually the *Endangered Species Protection Bill* (*ESP Act*) was passed to protect threatened plants, animals and endangered communities, to identify key threatening processes (Nelson & Sullivan 1992) and to list species most likely to become extinct should the threats continue. Recovery Plans were included in the *Act*, but this section applied only to Commonwealth-owned lands and waters, and not to States. The *Act* provided the trigger for requirement of environmental impact statements accompanying development proposals on government lands and to evaluate threats to listed species or communities or 'impede their recovery' (Nelson & Sullivan 1992). The *Act* included a schedule for national Threat Abatement Plans, and the *Environmental Protection and Biodiversity Conservation Act* (EPBC 1999) replaced the *ESP Act*. Lists of threatened species including insects were provided with categories of threat (Critically Endangered, Endangered or Vulnerable). State regulations then followed, but the assessment methods, categories of threat and species listed sometimes differed from the Commonwealth categories, e.g. Critically Endangered was not applied to threatened taxa in Queensland (Curtis *et al*. 2012; Braby 2018; Taylor *et al*. 2018).

Progress with insect conservation has been hindered by several impediments (Cardoso *et al*. 2011) including a 'taxonomic impediment' (Taylor 1983) or lack of taxonomic information for many insect orders, and an 'ecological impediment' (New & Samways 2014), or failure to consider the importance of insect interactions (New & Yen 1995). The vast numbers of insect species, with few described and the interactions so poorly understood, have led to difficulties for agencies when distinguishing the conservation needs of insects from those of vertebrates and plants. A consequence of these impediments is that most insects listed are without Management or Recovery

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Plans and others likely to be threatened have been ignored or referred to as Data Deficient. Many important groups and species requiring conservation studies in Australia have been neglected, e.g. Hymenoptera, an order with extraordinary species richness (>115 000 described) and biological complexity (Austin & Dowton 2000) and with many species of conservation significance (Andersen *et al*. 2014).

Insect habitats are increasingly threatened by human disturbance, invasive weeds including grasses (Van Klinken *et al*. 2013), deliberately lit fire regimes (Clarke 2008; Driscoll *et al*. 2010; Croft *et al*. 2016), inappropriate use of pesticides, exotic natural enemies, habitat fragmentation (Braby & Edwards 2006) and rapidly changing climate (Sutherst *et al*. 2007; Burwell *et al*. 2011; Greenslade & Kitching 2011). Insect habitats including many refuges for beneficial insects have been lost from land clearing, a practice increasingly detrimental to agricultural ecosystems (New 1991b, 2005). Native vegetation is particularly important as refuges for invertebrate natural enemies in Australia (Parry *et al*. 2015; Gagic *et al*. 2018) and other countries (Van Driesche *et al*. 2010).

The purpose of this review is to address a broad range of conservation issues for insects, propose reasons for their relevance and importance and provide recommendations for environmental management compatible with and currently implemented for the conservation of other fauna and flora. Throughout this review, Lepidoptera, the group having received considerable conservation focus for insects in Australia, is predominately referred to when providing examples and guidance for developing conservation strategies for other insect Orders. Unpublished observations are summarised (Table S1) to engender future research.

IMPEDIMENTS IN INSECT CONSERVATION – TAXONOMIC AND ECOLOGICAL ISSUES

Taxonomic identity and relationships

When compared with vertebrates, the numbers of insect species in Australia are vast, with relatively few ecological interactions understood, and the contributions of most insects to ecosystem health are greatly underestimated. For example, the Australian Lepidoptera with 11 000 described species has an estimated diversity of 20 000–30 000 species (Zborowski & Edwards 2007). Identifying insects at risk of extinction and the taxonomic relationships for known threatened taxa (Raven & Yeates 2007) has been slowed by the large numbers of undescribed taxa, and gradual decline in the taxonomic expertise needed for identifications and descriptions (Braby & Williams 2016). The relatively small size, rarity and variation in seasonal apparency of stages, with unknown life histories and complex interactions of invertebrates (Marks 1969; Key 1978), has hindered the identification of many likely to be threatened with extinction. Additionally, the seasonal apparency and longevity of immature stages may impede estimates of population size and in distinguishing natural and seasonal variations in abundance from changes due to human interventions.

Cardoso *et al*. (2011) identified seven impediments or dilemmas, including the taxonomic impediment or Linnaean shortfall, relating to invertebrate conservation. Put simply, the key taxonomic needs are to identify, recognise and consistently diagnose threatened insects (New 2008) and to define local endemism and faunal richness of habitats. With the emphasis on ecology, insect conservation actions require updated knowledge of the distributions and areas occupied for each target taxon evaluated and for habitat estimates for faunal richness, monitoring populations at appropriate intervals (Pleasants *et al*. 2017) and identifying recovery actions (Braby & Williams 2016; Braby 2018; Taylor *et al*. 2018).

Some agencies have been reluctant to evaluate unnamed taxa, and in some States, the subspecies, morphological, geographical and biologically distinct populations, including many considered 'lower risk', are not evaluated despite evidence of declines, threats and likelihood of extinctions that would have influenced status determinations for named taxa. In a recent taxonomic revision of Western Australian sun moths *Synemon* spp., several species of conservation significance were identified (Williams *et al*. 2016), as have recent studies on the distribution of rainforest carabid beetles (Table S1). Many undescribed ants have symbiotic associations with Lycaenidae of conservation interest (Eastwood & Fraser 1999), but the conservation status of many of these ants has not been evaluated (Table S1).

Morphologically based taxonomy, supplemented by molecular data for identifying insect taxa of conservation significance, can now be used for matching immature stages (eggs and larvae) for monitoring populations at times of the year when adults are not observable. Distinctive populations of taxa including genotypes, biotypes, evolutionary significant units (ESU), clines and hybrid populations may need conservation assessment when considered threatened, not only to address conventional threats but also to monitor the likely responses to climate change and disruption of genetic signatures of adjoining populations. For such studies, collectors are encouraged to remove and store appropriate material for future DNA studies, e.g. a leg from voucher specimens, with cross-referenced specimen labels (e.g. Eastwood & Hughes 2003).

Lack of compliance by some jurisdictions concerning the requirements of the *International Code of Zoological Nomenclature* (ICZN), e.g. gender of species names, has caused confusion in the past with regard to threatened species.

Conservation of units below species level

All identity units below the level of species (i.e. subspecies, ESUs, biotypes and hybrid zones) are in need of recognition for conservation evaluations if those populations of a taxon are at risk of extinction. While subspecies are readily recognised for conservation and listing, there is a reluctance to recognise its significance, even though presence of a cline does not automatically invalidate subspecies determinations (Torre-Bueno 1978), and subspecies described for populations within a cline, unless formally synonymised, may have conservation values. Subspecies restricted regionally, or near a State border and not previously considered threatened, may also require special evaluations for listing. Populations of several apparently morphologically distinctive subspecies of Lepidoptera have been targeted for listing and recovery actions, e.g. the Eltham copper, *Paralucia pyrodiscus lucida* Crosby (Lycaenidae), listed in Victoria (FFG 1988; Butcher *et al*. 1994), is recognised as threatened, whereas populations of *P. pyrodiscus pyrodiscus* (Rosenstock) in New South Wales and Queensland are not considered threatened. Braby *et al*. (2012) recommended restricting use of the trinomial system to allopatric populations of a species, with fixed diagnostic characteristics, and recommended subspecies within a cline to be eligible for synonymy. Without molecular evidence, the conservation significance of morphologically distinct populations is difficult to determine, unless 'hard wired' genetically, and the variation is distinguishable from phenotypic plasticity.

Recognising the conservation significance of hybrid populations and tension zones may be justified when species overlap or share sympatric distributions and when the 'parent' taxa are not deemed to be threatened. Such taxonomic complexes might be better understood using DNA techniques. Hybrid zones and hybrid speciation, and recognition for their conservation significance, may require molecular methods to resolve the taxonomic affiliations for some little-known skipper butterflies (e.g. Sands & Sands 2017).

Establishing the identities of beneficial insects and their native hosts in agricultural ecosystems

Whereas many parasitoids introduced in classical biological control programs have been identified taxonomically (Waterhouse & Sands 2001), the identities and importance of native generalist predators and their geographical distributions remain poorly recorded. Yet the majority of beneficial arthropod predators attacking pests on Australian farmlands are native species and hence of substantial economic importance (Parry *et al*. 2015; Gagic *et al*. 2018). The need to review identities of beneficial arthropods from each crop and each geographical region, and native arthropods that are hosts or prey to the beneficials, is a priority. The identities of the arthropod hosts of native parasitoids known to attack pest species need review and the information made available for pest management in agricultural ecosystems.

KEY THREATENING PROCESSES

Conservation of insect biodiversity depends on protecting sufficient habitats and areas occupied by each species and to sustain breeding by each species. Threats leading to extinctions may differ for each, but key threatening processes affecting survival, reproduction and development include habitat loss and disturbance, competition and alien natural enemies, inappropriate fire regimes and climate change. Conservation needs of insects sometimes differ from those of vertebrates or plants, and sometimes threatened invertebrates may require specific recovery actions.

Habitat loss and threats to protected areas

Mature and old growth habitat trees

Land clearing, logging and removal of old-growth and senescing trees continue to threaten arthropods, including some of the most specious orders: Coleoptera, Lepidoptera, Diptera and Hymenoptera. Agencies when carrying out conservation assessments for potentially threatened insects often fail to recognise the importance of protecting habitats without specific plant forms, or the phenotypic expressions and variation in plants needed by some insects to colonise an area (Table 1).

Cones of the kauri, *Agathis robusta* (C. Moore ex F. Muell.) F.M. Bailey, from south-eastern Queensland provide habitats for the immature, diapausing stages of the very rare and primitive moth, *Agathiphaga queenslandensis* Dumbleton (Zborowski & Edwards 2007), as larvae feed on the seeds (Common 1990). However, none of the moth stages have been recovered from recently collected seeds. In the past, mature kauri, a timber once considered the most attractive of Australian cabinet timber (Francis 1970), was heavily logged. This moth meets requirements for assessment as critically endangered due to declines in the densities of mature host trees producing cones and absence of specimens collected in recent years (ED Edwards pers. comm.). It has yet to be nominated under the *EPBC Act*.

Logs and fallen timber

Forest floor and saproxylic insects mostly depend on fallen and dead timber as larval habitats and soil beneath decomposing

Table 1 Examples of insects (Coleoptera, Lepidoptera and Hymenoptera) dependent on old-growth mature trees

Insect species	Plant species	Reference
Pseudotaenia ajax Saunders (Coleoptera: Buprestidae)	*Acacia harpophylla* F. Muell. Ex Benth	R Mayo pers. comm.
Pseudotaenia salamandra (Thompson) (Coleoptera: Buprestidae)	*Acacia harpophylla* F. Muell. Ex Benth	R Mayo pers. comm.
Temognatha similis (Saunders) (Coleoptera: Buprestidae)	*Allocasuarina luehmannii* (R.T. Baker) L.A.S Johnson	R Mayo pers. comm.
Jalmenus eubulus (Miskin) (Lepidoptera: Lycaenidae)	*Acacia harpophylla* F. Muell. Ex Benth, *A. melvillei* Pedley	Eastwood *et al*. (2008) and Sands *et al*. (2016)
Hypochrysops piceatus Kerr, Macqueen and Sands (Lepidoptera: Lycaenidae)	*Allocasuarina luehmannii* (R.T. Baker) L.A.S Johnson	Braby (2000)
Anonychomyrma sp., *itinerans* – group (Hymenoptera: Formicidae)	*Allocasuarina* spp., & *Angophora leiocarpa* (L.A.S Johnson ex G.J. Leach) K.R. Thiele & Ladiges	Braby (2000) and DPA Sands (unpublished data)
Anonychomyrma biconvexa (Hymenoptera: Formicidae)	*Eucalyptus* spp.	Braby and Armstrong (2018)

logs. For example, the endangered Tasmanian stag beetle, *Lissotes latidens* Westwood (Meggs & Munks 2003), and several other species are of conservation concern (Grove & Stork 1999; Grove *et al*. 2002). Such fallen dead wood is often removed for fire wood or turnery and prone to replacement by weeds and exotic grasses. These habitats are refuges (c.f. Croft *et al*. 2016) for many insects including ants that attend host larvae of lycaenid butterflies. For example, in Victoria, the host ant attending larvae of the threatened lycaenid butterfly *Hypochrysops ignitus* (Leach) and also host to the myrmecophagous larvae of *Acrodipsas myrmecophila* Waterhouse & Lyell (Braby 2000) is dependent on logs and stumps for its nests and byres on the stems. Similarly, the ant *Anonychomyrma* sp., *itinerans* – group attending larvae of the threatened bulloak jewel, *Hypochrysops piceatus*, builds its nests in cracks and hollows in logs, often upright dead limbs or sections of timber in living trees, with nesting habits similar to that of *Anonychomyrma biconvexa* (Santschi) noted by Braby and Armstrong (2018), information important for the recovery plan for the bulloak jewel butterfly (Lundie-Jenkins & Payne 2000).

Insecure tenure for protected areas

Ecosystem-based management of reserves improves the prospects for long-term conservation of biodiversity (Noss 1966), but protected areas in Australia have been insufficient in number and with inadequate areas of land protected (Valentine 2009; Taylor *et al*. 2018). Many species of Australian insects are only found in areas referred to as national parks, but few inventories have been prepared for species found in those parks. There remains the need to carry out surveys in each park in each State to find out what insects are present (Sands & New 2003) and if management needs to be adjusted for their indefinite conservation. Historically, national parks in Australia were designated to 'to preserve, intact, segments of the natural environment' and to 'preserve land, plant and animal life in the balanced relationship' (Morcombe 1974). National parks, although currently under State administration, provide the most secure tenure for protecting insect habitats (New & Sands 2003a). However, purpose and use of national parks have changed recently with an emphasis on use for sport, recreation and sometimes commercial activities. Public awareness and concerns voiced in *The Age* by Greer (2013) forecasted many changes now threatening the environmental security and biodiversity of Australia's most important protected areas, those referred to as 'national' parks. In several States, varying detrimental activities are now permitted by State agencies, and in Queensland, management of protected areas has changed from the initial intention of protecting fauna and flora to permitting environmentally intrusive activities including livestock grazing, horse and mountain bike riding and often accompanied by reduced field management by rangers. Grazing by cattle exacerbated by drought can reduce soil crusts in *Acacia* woodlands (Williams *et al*. 2008) and is a major source of invasive grass seeds with no control measures feasible once infestations have replaced native ground-surface ecosystems (Sands *et al*. 2015).

Threatened ecological communities

Without adequate and nationally linked criteria for conservation of animals, plants and natural landscapes, including indefinite security of tenure, the conservation of national parks is at risk from States changing the management criteria. Nationally listed Threatened Ecological Communities appear to be the most secure category for protecting arthropod habitats, but there remains a need to synchronise the Commonwealth categories with the IUCN (1993, 1996) Red List categories as Key Biodiversity Areas. In the absence of environmental protection under Commonwealth or State umbrellas, secure tenure and management of insect habitats may depend on future private initiatives, e.g. Australian Bush Heritage and Australian Wildlife Conservancy and indigenous communities.

Corridors and habitat fragmentation

The conservation significance of corridors and rainforest patches for insects was summarised by Hill (1997). Corridors provide environmental connectivity between geographical features specific with patches of vegetation, such as hilltops, rainforests, gullies and riparian habitats. Loss of naturally vegetated corridors and isolation of habitat patches disrupts metapopulations, leads to inbreeding and loss of intact refuges and limits the ability to recolonise after extirpation events, such as fires or local seasonal stresses. Habitat fragmentation in coastal and sub-coastal areas is most susceptible to replacements of food plants by weeds and severe climatic events.

Inbreeding depression

Habitat fragmentation and isolation of breeding insect populations, leading to inbreeding or unsustainable genetic variation in insect populations, have become increasingly important, raising several issues relating to management and recovery of threatened butterflies (Orr 1994; Saccheri *et al*. 1998; Roitman *et al*. 2017). Orr (1994), e.g. noted that inbreeding occurred in several swallowtail butterflies, affecting the egg hatch, larval survival and development times. Subsequently, population declines, and extirpations of Richmond birdwing butterfly in Burleigh Heads and Neurum Creek National Parks and other localities in south-eastern Queensland (Sands 1999; Sands & New 2013), were attributed to inbreeding depression in habitat fragments. Inbreeding problems can also be exacerbated on islands by relatively small reductions in area of breeding sites, resulting from human disturbance or tropical cyclone damage (Sands & New 2008a). Inbreeding experiments have shown that release of progeny from outcrossed larvae of the Richmond birdwing (*Ornithoptera richmondia*) has rehabilitated butterflies in several areas of south-eastern Queensland (I Gynther, J Seal, Queensland Department of Environment & Science pers. comm.).

Genetic interchange between populations via corridors may be important for threatened insects at risk and include the hilltops at Mt Piper in Victoria, a hilltop west of Grafton, NSW, Spring Mountain, south-eastern Queensland, and Commodore Peak, in southern inland Queensland. Such inbreeding may threaten insects using hilltops, sand dune summits and patches of rainforests, wetlands and grasslands that although relatively intact become isolated by clearing, urban or commercial development.

Invasive weeds

Introduced grasses

Since European settlement many exotic plants have become invasive, including 154 grasses (Poaceae) now naturalised, about 20% have become weeds of farmlands and indigenous ecosystems (Van Klinken *et al*. 2004b). These weeds invade insect habitats and displace food plants, and many habitats of invertebrates are now affected as the weeds expand in distribution, displace food plants, prevent seedling recruitment by native species and retard natural regrowth by limiting the access of light. Tropical, subtropical and temperate habitats affected include grasslands, wetlands, moist forests, woodlands and rainforests, and invasiveness increases following tree removal, vegetation clearing, burning and grazing by cattle, sheep and goats. Many grasses including Buffel grass (Martin *et al*. 2015) are moving inland and southwards from subcoastal areas as a result of global warming. Most invasive grasses originally from Africa and the Americas (Table 2) were introduced to enrich pastures for grazing, displace unpalatable indigenous grasses, control erosion, bind sand dunes and improve saline soils (Tothill & Hacker 1983). Some competitive African grasses exhibit allelopathy, e.g. Whisky Grass *Andropogon virginicus* L., a species rich in oxalates that affects domestic stock.

Invasive grasses have widespread effects on native insects (Van Klinken *et al*. 2013; Table 2). Affected most are subsurface and habitat specialists, including Lepidoptera, Coleoptera, Orthoptera, Isoptera, Blattodea, Protura, Diplura and Collembola. Buffel grass has become a major concern for conservation of biodiversity, and although a beneficial addition to the pastoral industry (Walker & Weston 1990), it has become an aggressive invader of native ecosystems (Van Klinken *et al*. 2004a, 2004b), covering about two-thirds of the Australian mainland, replacing native grasses, closing the natural spaces between arid plants (e.g. *Triodia* spp.) and forming uniform biomasses with high fuel loads (Butler & Fairfax 2003). Many uncommon insects are affected by Buffel grass, by accumulation of its senescent leaves that promote sub-surface flammability (Table 2), and some grasses repel insects when they attempt to settle on the foliage (Table S1). Chilean needle grass, *Nassella neesiana* (Trin.& Rupr.) Barkworth, is known to displace native insect food plants including *Austrodanthonia* sp., hosts for the endangered Golden sun moth *Synemon plana* Walker, but it is possible that larvae of this species have adapted to feed on this weed species as well as its native food plant (Braby & Dunford 2006; Richter *et al*. 2009).

The impacts from burning grasses have become threatening processes for fauna and flora, particularly in the subtropical and tropical regions of Australia (Van Klinken *et al*. 2004a; Satterfield *et al*. 2013; Sands *et al*. 2015). These grasses increase the flammability of understorey plants, particularly grasslands, wetlands and woodlands, and some species (e.g. *Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs) may invade moist forests and replace weakly flammable understorey insect food plants.

In eastern and northern Australia, introduced grasses often reduce the densities and modify the phenotypes of other food plants, reaching levels that fail to attract oviposition of once common Lepidoptera (Sands *et al*. 2015). Vigorous growth of exotic grasses after fires prevents seedling recruitment, increases competition and reduces light, destroys soil crusts, replaces sedges, indigenous grasses and habitats for invertebrates that provide food for small animals and destroys the epigaeic detritivores needed to break down leaf litter and recycle the nutrients. Rapid regrowth by invasive African grasses is promoted by fires, as these grasses increasingly invade grasslands, wetlands, woodlands and the

Table 2 Invasive exotic grasses (Poaceae) displacing insect habitats and their flammability index

Common name	Species	Flammability index
Perennial mission grass	*Pennisetum polystachion* (L.) Scult.	> +++
Annual mission grass	*Pennisetum pedicellatum* Trin.	> +++
Buffel grass	*Pennisetum ciliare* (L.) Link	> +++
Gamba grass	*Adropogon gayanus* Kunth	> +++
Whisky grass	*Andropogon virginicus* L.	++
Guinea grass	*Megathyrsus maximus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs & vars.	+++
Signal grass	*Urochloa decumbens* (Stapf) R.D. Webster	++
Molasses grass	*Melinis minutiflora* P. Beauv.	> +++
African pigeon grass	*Setaria sphacelata* (Schumach.) Stapf & C.E. Hubb.	+
African lovegrass	*Eragrostis curvula* (Schrad.) Nees	++
Giant rats tail grass	*Sporobolus natalensis* (Steud.) T. Durand & Schinz	+++
Coolatai grass	*Hyparrhenia hirta* (L.) Stapf	++
Paspalum	*Paspalum mandiocanum* Trim	?
Paspalum	*Paspalum urvillei* Steud.	?
Chilean needle grass	*Nassella neesiana* (Trin. & Rupr.) Barkworth	+

Flammability index was subjectively categorised based on visual estimates by comparison with flame height for *Themeda triandra* Forssk. '+' means approximately 1 m.

understorey of moist woodland and rainforests, replacing plant communities supporting natural ecosystems including insect habitats. Soil crusts, understorey and subsurface ecosystems are increasingly affected by invasive and highly flammable African grasses.

Introduced vines

Several invasive vines (Table 3) are known to smother, constrict stems and reduce sap flow of insect food plants, while others including the South American moth vine, *Araujia hortorum* (Apocynaceae), produces flowers that trap and kill Lepidoptera (Holmes 1966), by clamping the proboscises when they attempt to feed on nectar in flowers (Leiper *et al*. 2008). Infestations of the vine have been observed invading protected areas including Ravensbourne National Park, Queensland, where the increasing infestations of the vine have become an insect conservation issue (P Grimshaw pers. comm.). Silver-leafed desmodium, *Desmodium uncinatum* (Jacq.) DC. (Fabaceae) and *Desmodium intortum* (Mill.) Urb., trap insects and other small animals with apical hooks on dense hairs arising from stems and where naturalised in New South Wales and Queensland have become increasingly important by invading rainforests (Harden *et al*. 2007). The stems of *Stylosanthes hamata* (L.) Taub. and other *Stylosanthes* spp. are clothed in adhesive hairs known to trap arthropods, including ticks (Sutherst *et al*. 1982), and in areas where these vines are abundant, have been observed to trap ants and other small insects (Table S1).

Toxicity of the leaves of some introduced vines is known to kill the immature stages of butterflies that mistakenly oviposit on them (Straatman 1962). The South American Dutchman's Pipe *Aristolochia elegans* Mast. has escaped cultivation and invaded subtropical rainforests in eastern Australia, attracting oviposition by the Richmond birdwing *O. richmondia* (Gray), but leaves are toxic to larvae when they feed (Sands & New 2013) (Table S1).

Understorey and sub-surface weeds

Many introduced shrubs, including more than 10 varieties of lantana *Lantana camara* L. and *Lantana montevidensis* (Spreng.), are known to replace native food plants (Table 4). Biological control of *L. camara* has only been partially successful (Day *et al*. 2003; Zalucki *et al*. 2007). In the absence of native flowering plants, the nectar from lantana flowers is often imbibed by Lepidoptera (Day 1965).

Invasive trees

Clearing native vegetation for pine plantations *Pinus* spp.: *Pinus radiata* D. Don and *Pinus ellottii* Engelm, and hybrids, has destroyed wide areas of insect habitats in several States and the ACT. The pines have become invasive in natural areas after seeds disperse into nearby woodlands and wetlands, where maturing trees shade out and replace insect food plants such as *Gahnia* spp., *Lomandra* spp. and various sunlit grassland habitats. In eucalypt woodlands, needles carpeting the understorey do not decompose readily and can replace the habitats for woodland epigaeic detritivores (Gunther & New 2003). Other competitive introduced subtropical woody weeds (Fielder 2011) observed destroying insect habitats include Camphor laurel, *Cinnomomum camphora* (L.) J. Presl.,

Table 3 Invasive exotic vines detrimental to plant communities supporting insect habitats

Common name	Species	Invaded plant communities
Madeira vine	*Anredera cordifolia* (Ten.) Steenis	Riparian, moist and dry woodlands and rainforest
Climbing asparagus	*Asparagus africanus* Lam.	Moist woodlands and dry rainforest
Cat's claw creeper	*Macfadyena unguis-cati* (l.) A.H. Gentry	Moist woodlands and rainforest
Rubber vine	*Cryptostegia grandiflora* R. Br.	Moist tropical woodlands
Dutchman's pipe	*Aristolochia elegans* Mast.	Riparian woodlands and rainforests
Balloon vine	*Cardiospermum grandiflorum* Sw.	Moist woodlands and rainforest
Convolvulus	*Ipomoea purpurea* (L.) Roth	Moist woodlands and rainforest
Glycine	*Neonotonia wightii* (Graham ex Wight & Arn) J.A. Lackey	Moist woodlands and rainforest

Table 4 Invasive understorey and sub-surface weeds

Common name	Species	Insect habitats affected
Lantana	*Lantana camara* L.	Dry, moist and riparian woodlands and rainforests
Creeping lantana	*Lantana montevidensis* (Spreng.) Briq.	Dry woodlands and slopes
Boneseed	*Chrysanthemoides monilifera* (L.) Norlind	Woodlands
Bitou bush	*Chrysanthemoides monilifera* ssp. *rotunda* (DC.) Norlind	Sand dunes and coastal embankments
Singapore daisy	*Sphagneticola trilobata* (L.) Pruski	Moist and riparian slopes
Coral berry	*Rivina humilis* L.	Monsoon rainforest
Climbing asparagus	*Asparagus aethiopicus* L. cv. *Sprengeri*	Moist woodlands
Ochna	*Ochna serrulata* (Hochst.) Walp.	Moist woodlands
Wandering Jew	*Commelina benghalensis* L.	Moist and riparian slopes
Blackberry	*Rubus anglocandicans* A, Newton	Heathlands and woodland

broadleaf privet, *Ligustrum lucidum* W.T. Aiton, and Chinese elm, *Ulmus parvifolia* Jacq.

Inappropriate fire regimes

Deliberately lit fires

Burning understorey vegetation has been said to benefit plants (e.g. Tran 2009) by promoting floristic diversity, regrowth and seed germination and by reducing dead fallen timber, but 'management plans' are riddled with vague aspirational goals such as maintaining or enhancing "ecosystem health", "condition" or "vigour" ' (Clarke 2008). However, fuel-reduction fires are major threatening processes for many terrestrial invertebrates (Greenslade 1996; Driessen & Greenslade 2004) with the levels of threat dependent on the scale, frequencies and seasons of burns (New *et al*. 2010b). 'Fuel reduction burns' carried out in the cool and dry months can have impacts on the survival of insects at a time when the stages are seasonally dormant, when habitats are burnt regularly and extensively (New *et al*. 2010b) without leaving unburnt refuges and wherever exotic inflammable grasses have replaced or lowered the densities of understorey insect food plants. Invertebrate stages are least mobile in winter or early spring, when their survival is reduced or populations may become extirpated by fires when they are unable to escape and move to find shelters underground and beneath or between rocks.

The long-term effects of fires on some ants were said to have implications for fire management (York 1999), and several issues relevant to fires and conservation of invertebrates in south-eastern Australia were discussed by New *et al*. (2010b) and New (2014). Insects from many Orders are considered at risk from fire mismanagement, include native bees (Schwarz & Hogendoorn 1999), and Common (1994) noted that frequent winter burning regimes have become conservation issues, particularly when larvae of Oecophoridae breed mainly in winter (Zabrowski and Edwards 2007). Fires have increased the effects of land clearing and habitat fragmentation on insects, and many moths are thought to have become extinct during vegetation degradation carried out between the 1800s and early 1900s and continue to be vulnerable from injurious burning (Zborowski & Edwards 2007).

Frequent burning regimes have been justified to protect property and create fire breaks, and on farmlands to encourage 'green-pick', and 'open up' the understorey in forest management to encourage seed germination and regrowth from underground root stocks or epicormic buds. Planned fires lit for hazard or fuel reduction in bushlands have been widely thought to benefit biodiversity and health of animal habitats (Tran 2009). Legge *et al*. (2015) referred to the benefits of seasonally cool and limited scale patch burning to enhance the habitat for Gouldian finches at Mornington, Western Australia. Most fires referred to as 'ecological burns', and managed for protecting biodiversity, have focussed on the observed responses of plants (Robinson 2017) and overlooked threats to invertebrates and small insectivorous vertebrates (New *et al*. 2010a; Croft *et al*. 2016). When areas are frequently burnt the insects available as food for vertebrates may decline in densities and species, e.g. insects in rotting logs or beetle and moth larval borers in senescing and old-growth shrubs and trees.

Aborigines burnt some areas more frequently than the regimes practised in recent times (Greenslade 1996), but in the Northern Territory, although fire was used for many purposes, the past use of fire by aboriginal people was said to mainly '… stop fires from entering closed forests', '… within open forest …, to leave some unburnt areas each year' and '… conducted at a time of the year when scorch height and spatial spread were minimised' (Hayes 1985). The scale and patchiness of traditional burns differed considerably from those methods introduced by Europeans (Russell-Smith & Yates 2007), and included small-scale mosaic patch burning methods were used by the aboriginal community near Iron Range, Cape York, in the 1970s (Table S1).

Impacts of fires on plant communities

Frequent burning of the understorey reduces recruitment or regrowth but promotes spread and increases densities of the fire-adapted exotic grasses, resulting in a positive-feedback loop, the 'grass-fire cycle' (D'Antonio & Vitousek 1992, Rossiter *et al*. 2003) that exacerbates the abundance of exotic and highly flammable grass species, and can transform entire plant communities that support herbivorous invertebrates and their native food plants and increase the flammability of those exotic grasses better adapted to fire (Van Klinken *et al*. 2004a). Depending on the type plant community, recolonisation by insects after fires in woodlands sometimes takes 20 years or more before food plants reach a phenotypic stage acceptable for some insects (e.g. Hepialidae and Cossidae) as hosts (e.g. age, height, foliage density and shading), or many decades when senescent growth or dead branches are needed, while fires reduce the densities of regrowth, food plants often fail to attract female insects ovipositing even when the correct species is present. Many insects require specific forms of growth, including particular architectures and height of certain plant species before ovipositing or colonising, e.g. the phenotype needed by the green carpenter bee *Xylocopa aeratus* [Smith] on Kangaroo Island, SA (Glatz *et al*. 2015). An increase in the frequency of burns can prevent the growth or architecture of food plants required for feeding and reproduction by immature stages, or production of flowers or seeds. Losses of insects dependent on mistletoes have occurred in several States in this way (Table S1).

Areas burnt

The scale or extent of areas burnt can contribute to extirpations of native animals (Clarke 2008), particularly insects (e.g. New *et al*. 2010b), and plants in old-growth woodlands that take long periods to rejuvenate. Invertebrates adapted to rain forests are often extirpated when these areas are deliberately burnt, and insects of moist woodlands, wetlands and mountain heathlands likewise fail to survive unless they can find refuges, e.g. underground or beneath roots, as is the case with the larvae of *Ogyris subterrestris* Field (Field 1999). Woodland insects are often vulnerable due to the patchy selection of suitable habitats for breeding, their adaptation to a mosaic of food plant stages, often widely spaced, and metapopulation structure of breeding sites for many species. Rainforest and moist woodland insects, their food plants and habitats, are fire sensitive and easily destroyed by fires. Bowman *et al*. (1990) showed that some insects in Papua New Guinea required prolonged periods after fires to recolonise regrowth from unburnt areas and are dependent on adequate densities of food plants, stages and conditions of growth, and for detritivores and ground-dwelling species, the presence of fallen timber, rotting logs and deep leaf litter.

Fire frequency and season

In fire-prone plant communities such as grasslands and some woodland, invertebrates are particularly susceptible to fires during winter and spring, when fires will destroy all exposed immature stages. The seasonal patterns of mobility, feeding and whether univoltine, bivoltine or multivoltine have a bearing on the survival of stages affected by fires. For most oecophorid detritivores, adults are mostly active in the winter months, when 'cool' burns are often conducted and the densities are very slow to respond after habitats are burnt (ED Edwards pers. comm.). A serious example of an inappropriate season for a deliberately lit fire occurred at Daves' Creek, Lamington National Park, where the skipper butterfly, *Hesperilla crypsargyra binna* Johnson & Wilson, was only known to occur (Johnson & Wilson 2005). The skipper may have failed to survive this 'ecological burn' in September 2016 (PR Wilson pers. comm.) when the fire lit by national parks staff destroyed the only known montane heathland habitat on the eastern part of the Lamington National Park, south-eastern Queensland. The timing of the fire occurred when only late-stage larvae and pupae were present. No adults or immature stages have reappeared despite regrowth of its food plant, *Gahnia insignis* S.T. Blane (Cyperaceae). Inspections of other areas in south-eastern Queensland where *G. insignis* occurs have not revealed the presence of this butterfly (PR Wilson pers. comm.). After fires, long periods may be required before host plants reach the stage needed for recolonisation by herbivorous insects, e.g. those that require particular plant stages and growth, leaf toughness, nutrient content, architecture, age or senescence. Thus, the impacts and recovery of terrestrial invertebrates after fires differ considerably from the impacts of fires on habitats and food plants.

Fire and detritivores

Insect detritivores are important for reducing leaf litter and subsurface dead leaves, nutrient recycling and as food for vertebrates and invertebrates and reduce sub-surface vegetation in flammable plant communities. Frequent fires are recognised as a threatening process for epigaeic arthropods (Greenslade & Driessen 1999), and in particular Oecophoridae (Common 1994), with many species that break down dead leaves (including Myrtaceae, *Acacia* and *Banksia* spp.), reducing dead leaf biomasses and fuel loads (Zborowski & Edwards 2007). The detritus also reduces surface tension, increases sub-surface moisture and provides nutrients and moisture required for stable soil crusts (Bowker 2007). At several woodland sites monitored on the Sunshine Coast, Queensland, leaf litter was observed to build up in depth for 6 years following a fire and then decrease as detritivores, mainly larvae of oecophorid moths, reduced the depth of dead leaves as the by-products and faecal pellets from the moth became incorporated in the subsoil (DPA Sands, unpublished data). These observation and those by Croft *et al*. (2016) indicated fuel loads in woodlands and in open forests were no greater than those of long-unburnt vegetation or in woodlands unburnt for 100 or more years.

Impacts of fires on predators and parasitoids

Small parasitic Hymenoptera and Diptera are most susceptible to incineration during fires, and with comparatively weak flight, have little chance of finding refuges above ground. Pollinators of small terrestrial orchids, e.g. may not have time between fires to recolonise before surviving plants, are again burnt. For some species in subtropical woodlands, it may take 15 years or more for flowering and to produce seeds.

Fire avoidance by insects and recolonisation

Some Hesperiidae from unburnt refuges may recolonise native grasses and sedge regrowth after fires, with larvae taking advantage of the nitrogen-rich, soft leaves and where populations are able to build up rapidly when parasitism is low. Some insect species escape fires by sheltering underground, on cliffs, beneath rocks or under the bark of trees. Insects with subterrestrial habitats, e.g. some ants (Andersen *et al*. 2014), can survive underground during hot fires and afterwards browse on detritus and surface regrowth. The immature stages of the threatened Eltham Copper *Paralucia pyrodiscus lucida* avoid incineration by sheltering in subterranean chambers of the attendant ant *Notoncus* sp. at the base of the main stem of the food plant *Bursaria spinosa* Cav. (New 2011). Similarly, the threatened *Paralucia spinifera* was observed feeding on regrowth of its food plant after a fire near Bathurst, NSW, had destroyed above ground vegetation (DPA Sands, unpublished data). Above ground, the leaves occasionally protect insects from being burnt, e.g. in the Northern Territory; larvae of uncommon butterflies can survive low-intensity ground-level fires on the foliage of the fire retardant *Capparis umbonata* Lindl. (Brock 1988).

Where fires are needed to reduce fuel, 'micro-mosaic patch burning' (Sands & Hosking 2005; New *et al*. 2010b) needs acceptance for managing biodiversity by all State agencies, as the only way of managing fires without causing destructive nontarget impacts on fauna and flora. This basic method was used to manage a wetland site for the endangered *Hesperilla flavescens flavescens* Waterhouse, at Altona, Victoria (New 2011). Recommendations relating to the season, scale and frequency included autumn and early winter burns, limiting the area to be burnt to half of the habitat at any one time and the frequency of burning no less than at 5 year intervals.

Climate change

The biological consequences of global warming applicable to insect conservation include (1) physiological – atmospheric effects on metabolism and development of animals; photosynthesis, respiration, growth and tissue composition in host plants, (2) effects on distribution including cooler higher altitudes and towards the poles, (3) effects on phenology and interactions between species and (4) adaptability in situ (Hughes 2000). Invertebrates and their distributions, including those of conservation significance, will be affected by thermal tolerances and changes in moisture regimes (Sutherst 2003), and without the ability to adapt to changes in climate, many Australian insects are likely to become extinct. Species adapted to particular elevations (Greenslade & Kitching 2011) may move to higher elevations where suitable habitats and food are available, while others may become extinct if there are no other suitable habitats at higher elevations. Insect species with narrow range endemicity will be prone to climatic pressures (New & Sands 2002a; Smith 2015), those adapted to low elevations may move to cooler southern latitudes and others will contract in distribution from their northern ranges. For species moving south or to higher elevations, the climate, habitat and food at new locations must be suitable for reproduction, and biological interactions such as natural enemies need to be compatible with new arrivals (Sutherst *et al*. 2007).

The abilities of Australian insects to adapt to changes in climate, or to find new habitats with food, are important issues for the conservation of insect biodiversity. Each insect species is 'hard wired' (genetically), and with its own 'climate envelope', can persist only where climate averages and extremes support development and reproduction, and beyond which it will become inactive, desiccated or die from torpor. Warming in subtropical and temperate parts of Australia is likely to affect invertebrates incapable of developing, feeding or reproducing outside of their specifically adapted climate envelopes (Kearney *et al*. 2009). Persistent temperatures beyond levels tolerated by a species, for the development of eggs, larvae and pupae, and the initiation and break in diapause (Sands & New 2008a) are likely to cause mortality, disrupt reproduction and drought-induced aestivation in adult insects, e.g. *Euploea* spp. (Canzano *et al*. 2006), and change migration or dispersal patterns (Dingle *et al*. 1999, 2000).

Parmesan *et al*. (1999) considered global warming responsible for changes in the distributions of several butterfly species, and in eastern Australia, several species of butterflies (DPA Sands, unpublished data) and dragonflies have been observed beyond their previously known ranges (R Natrass, pers. comm.). Overwintering by adults and oviposition and winter survival of immature stages of *Euploea tulliolus* (Fabricius) and *Euploea darchia* (W.S. Macleay) have been observed near Brisbane, Queensland, species not previously observed breeding at this southern locality. Many butterflies have been reported extending their southern ranges, but none are yet considered to be of conservation significance. New arrivals of butterflies in Torres Strait from Papua New Guinea (Meyer *et al*. 2017) and other northern countries are appearing (Lambkin 2017a), with some species likely to extend their range further south to the Australian mainland.

The timing, frequency and intensity of rainfall events can advance emergence times, disrupt diapause or promote immature mortality. For example, in the Richmond birdwing butterfly, widely spaced rainfall events separated by unseasonal drought appear to have the greatest impacts on survival, development and diapause (Sands & New 2013). An important effect following prolonged drought results from reduced terminal and nitrogen-rich growth and increased leaf toughness, unsuitable for feeding by young larvae of insect herbivores (Table S1). Climate change is likely to influence the survival of immature stages and affect the distributions of many insect species not currently considered of conservation concern. Few species are likely to benefit from climate change, but recent observations (2016–2017) of overwintering of pupae by the Richmond birdwing butterfly indicate that at high elevations (>600 m), populations may survive warmer and moist winters in the Border Ranges, where in the past cooler years they would have desiccated (Sands & New 2013).

Sea-level rise is an issue for those species occupying mangroves, wetlands, saline and coastal riparian plant communities when the supporting plant community cannot expand upstream along estuaries. For example, the mangrove habitat and ant host *Crematogaster* sp. of the endangered lycaenid butterfly *Acrodipsas illidgei* Waterhouse & Lyell (Samson 1993; Beale & Zalucki 1995) may well change following relatively small increases in sea level (Anon. 2017), where increased inundation will limit low-tide browsing by the ant. When assembling management plans for insects of conservation significance, the use of climate models such as CLIMEX (Sutherst *et al*. 2004) may be considered for species such as *A. illidgei* to predict future distributional patterns and consider if translocations are needed for recovery of threatened species.

Other threats

Pesticides and chemical sprays

Concerns have been expressed relating to the impacts on non-target insects, when inappropriate insecticides are applied to mangroves, wetlands and coastal water bodies for control of biting midges and mosquitoes. For example, Bt (*Bacillus thuringiensis* var. *israelensis* de Barjac) and *s*-methoprene are used for the control of *Aedes vigilax* (Skuse) and *Culex sitiens* Wiedmann. At the concentrations used, impacts on a range of non-target arthropods were said to be short lived and with few other significant effects (Russell *et al*. 2009), and these applications were thought unlikely to affect phytophagous insects. However, for predatory insects, short-lived risks may need further investigating. For example, pesticides were applied to mangroves of south-eastern Queensland and north-eastern New South Wales, where a specific ant (*Crematogaster* sp.) attends the larvae of the very rare and threatened butterfly (*A. illidgei*) (Samson 1993). These *Crematogaster* ants have been observed carrying off the cadavers of mosquito larvae that have potentially been in contact with the pesticides. Thus, the immature stages of ants and the predatory butterfly larvae may well be affected after ants return to their nests. Herbicides sprays for weed control from nearby farmlands and aerial drift of pesticides for mosquito control on wetlands were said to be threatening processes for *H. flavescens flavia* Waterhouse (Coleman &

Coleman 2000), and with urban development, may have contributed to extirpation of this population near Adelaide (New 2011).

Although integrated pest management (IPM) has increasingly taken into account the importance of native predators and parasitoids, inappropriate use of pesticides often results in pest outbreaks, and overspray or spray drift occasionally penetrates into nearby refuges and destroys native arthropods resident in native shrubs (New 2005). Exhaust from vehicles can affect small insects near roadsides, where suppression of attack by Encyrtid parasitoids on scale insects was observed (in 1970s) to result in roadside outbreaks of some Coccidae (GJ Snowball pers. comm.). Vehicle emissions likely to contain napthenates may affect insects breeding near traffic thoroughfares and the efficiency of pollinators including honeybees.

Introduced insects: pests and beneficials

New and Samways (2014) and New (2016) referred to the detrimental impacts on native insects from habitat changes and exotic species. Community concerns continue from the spread of pest species such as the introduced fire ant, *Solenopsis invecta* Buren, and its outbreaks from earlier incursions and new arrivals, threatening terrestrial biodiversity as well as human health. Fire ants are predicted to cause declines of 45% in native birds, 38% in mammals and 69% in reptiles and are capable of occupying over 99% of mainland Australia (NPAQ 2017). On Christmas Island, the impacts of crazy ants *Anoplolepis gracilipes* on native fauna have received wide attention (Csurhes & Hankamer 2012), particularly the effects on indigenous Christmas Island red crab *Gecarcoidea natalis* Pocock and native birds.

Biological control introductions

Procedures in place in Australia for imports and safety testing of exotic agents for classical biological control agents are thorough (Sands 1998; Sands & Papacek 1993; Sands & Van Driesche 2000), and tests conducted before they are released (Van Driesche & Reardon 2004) ensure attacks on native insects are unlikely to occur. Before a potential biological control agent is introduced into quarantine, it is subjected to thorough reviews of the biology and host range in the country of origin, or in any country where it has already been tested. Native species related to the target hosts are always considered for testing (Sands 1997), and once in quarantine, potential biological agents, parasitoids or predators, are examined to ensure they do not carry any ‘unwanted travellers’ (e.g. natural enemies and diseases) before other tests are undertaken and cultures prepared to determine that they only feed and develop on the target host.

Unlike several examples overseas, e.g. in Hawaii (Howarth 1991), there are no recorded examples of detrimental non-target effects resulting from invertebrate biological control agents introduced into Australia. Introduced vertebrates on the other hand, e.g. the cane toad *Rhinellla marina*, have had serious impacts on wildlife without controlling the organisms targeted (Waterhouse & Sands 2001). Cane toads have been observed preying on dung beetles and may pose risks to native species occupying small habitats, and in particular, flightless threatened dung beetles and other ground or subsurface dwelling insect fauna, e.g. carabid beetles including the threatened *Nurus atlas* (Castelnau).

In a few early examples of introductions, where non-target hosts did support development of introduced parasitoids, no cases of detrimental impacts have been recorded. For example, the egg parasitoid *Trissolcus basalis* (Wollaston) introduced into Australia 1936 from Egypt (Waterhouse & Sands 2001) to control green vegetable bug *Nezara viridula* (L.) is known to complete development in eggs of some native bugs, but there is no evidence for parasitoids having a detrimental impact on these non-target hosts (Loch & Walter 1999). In classical biological control projects, parasitoids, e.g. before they are released, must be shown to attack only target pests, and not likely to threaten the survival of beneficial, or non-target hosts. Egg parasitoids known to have broad host ranges, e.g. some *Trichogramma* spp. (Aphelinidae), would not now be considered for introduction.

Potential risks continue from entry to Australia of some biological control agents used overseas, e.g. the generalist predatory coccinellid, *Harmonia axyridis* (Pallas), originally from Asia, was introduced to control agricultural pests in several countries, including New Zealand, but has become invasive with unintentional ecological consequences (Haelewaters *et al*. 2017). Should *H. axyridis* gain entry to Australia, it is likely to displace beneficial coccinellid species and pose risks to the survival or densities of other beneficial arthropods.

Unintentional introductions

The Southeast Asian butterfly, *Acraea terpsicore* (Linnaeus), has become widely established in the Northern Territory and northern Queensland where its larval hosts include *Hybanthus enneaspermus* (L.) F. Muell. (Violaceae) and introduced and native species of Passifloraceae. As this species moves rapidly south (Proserpine in 2017, MF Braby pers. comm.), this exotic butterfly may threaten native plants, particularly those used as food plants by the related native species, *Acraea andromacha* (Fabricius). Australian food plants of *A. terpsicore* (Braby *et al*. 2014) include several *Passiflora* spp. in Qld and deciduous *H. enneaspermus*. The butterfly may have the potential to adapt to Cucurbitaceae of commercial value because of its capacity to exploit these plants in Sri Lanka, but so far, laboratory trials in the NT have demonstrated lack of ability of larvae to feed on cucurbits (Braby *et al*. 2014).

Fungal and microbial pathogens

Myrtle rust *Puccinia psidii* has had a serious effect on palatability of mainly Myrtaceae for insect larvae (Table S1), mostly observed at higher altitudes (>400 m) where the rust has killed plants, or changed the quality of terminal growth by blistering and aggregates of yellow spores (Booth 2011).

Domestic stock and feral animals

Grazing by domestic stock threatens the integrity of native grasses, shrub and plant communities providing habitats and food plants for insects and promotes the introduction of weeds, particularly invasive African grasses. Already affected are protected areas where grazing by stock is permitted in grasslands, woodlands, mountain and coastal heaths. Feral deer (fallow, rusa and red deer in Qld; samba in VIC and ACT) are also serious pests, destroying and damaging native shrubs and trees, feeding on the leaves and terminal growth, pulling shrubs out of the ground and ringbarking a wide range of uncommon insect food and canopy plants. Braysher (2016) refers to the damage by feral animals, including wild pigs, and their destruction of large areas of understorey vegetation, particularly in the national parks of northern Queensland, as are camels, goats, horses and camels in the deserts and rangelands.

THREATS TO INSECT HABITATS AND ECOLOGICAL COMMUNITIES

Threatened ecological communities

The importance of linking conservation of threatened insects to the conservation of insect habitats was emphasised by New (1993) when discussing Lycaenidae but requires more formal inclusion in all conservation assessments. The classification of plant communities and names used for each ecosystem varying from State to State provides difficulties for defining or comparing the habitats occupied by insects and their breeding sites. Different terms for ecosystems include Commonwealth: *Threatened Ecological Communities*, Queensland: *Threatened Regional Ecosystems*, and NSW: *Endangered Ecological Communities*.

Prominent geographical features and their plant communities often require recognition for conservation, e.g. when habitats are geographically separated or become fragmented. Cross-referencing links threatened insects to a particular habitat, the plant community, species of food plant and phenotypic expression (e.g. old growth), geological or soil associations and specific aquatic ecosystems are important steps. Threatened insect species are invariably dependent on the nature of specific food, shelters and habitats, but there is no protection for plant communities on which threatened species are dependent. In some examples, an insect herbivore and its plant community are recognised as threatened, e.g. old growth of Brigalow *Acacia harpophylla* F. Muell. Ex Benth. and *Acacia melvillei* Pedley, habitats and food plants for the Pale Imperial Hairstreak *Jalmenus eubulus* Miskin (Eastwood *et al*. 2008; Sands *et al*. 2016; Braby 2018). There are many other examples (e.g. old-growth *Allocasuarina luehmannii* (R.T. Baker) L.A.S Johnson), where the age of the host plant, e.g. 'old growth', needs protection as a Threatened Ecological Community, in order to protect the endangered bulloak jewel *Hypochrysops piceatus* and its attendant ant (*Anonychomyrma* sp. *itinerans* – group).

The presence of a particular insect species may act as an indicator for rare or threatened plant communities and for other threatened invertebrates including Collembola (Greenslade 2007), land snails adapted to dry rainforests (Stanisic & Ponder 2004) and semi-deciduous monsoon vine thickets on limestone outcrops (Braby *et al*. 2011). Indicator species restricted to lowland subtropical rainforests in eastern Australia include the threatened southern pink underwing moth *Phyllodes imperialis smithersi* Sands (Clarke & Spier-Ashcroft 2003) with only one food plant *Carronia multisepalea* F. Muell. (Sands 2012), the Richmond birdwing butterfly and its rainforest food plant *Pararistolochia praevenosa* (F. Muell.) M.J. Parsons and several carabid beetles *Nurus* spp. adapted to specific habitats, including *Nurus atlas* (Castelnau), *Neolamprologus brevis* (Womersley) (dry inland rainforests, northern NSW) and *Neoleucinodes imperialis* (Sloane) (only at lower Mount Tamborine, Qld).

Protection of hilltops

Hilltops and ridgetops are important landmarks used for congregating and mating by insects from various orders (Alcock & Dodson 2008). Abrupt hilltop summits are preferred over ridgetops by most species, but some congregate on slopes below the summits. Hilltops are especially important for insects that disperse widely when searching for breeding sites. Some species congregate high on branches of trees growing near the summits, while others congregate on low branches or on logs, on the ground or rocks. Hilltopping insects in Australia are particularly well represented by several families, including Diptera: Bombylidae and Tachinidae; Coleoptera, particularly Buprestidae, Cetonidae and Scarabidae; Hymenoptera: Sphecidae, Braconidae and Ichneumonidae; Hemiptera: Pentatomidae; Lepidoptera: Agaristinae, Nymphalidae, Lycaenidae, Hesperiidae, Pieridae and Papilionidae; and Odonata.

Clearing of native vegetation to erect structures, buildings or towers and replacement of native plants by exotic plants on the hilltops or nearby slopes affect hilltops used by these insects. Hilltopping insects avoid burnt vegetation, and most insects only use hilltops when there is native vegetation, or natural rock outcrops. After a fire, it may take at least 5 years for common hilltopping insects to resume their behaviour (DPA Sands, unpublished data).

Pre-development requirements for protecting significant hilltops are already in place in New South Wales and in Victoria, Mt Piper at Broadford 'Butterfly Community No 1', was designated an ecological reserve (FFG 1988), to protect a complex of rare hilltopping lycaenid butterflies and other Lepidoptera (Jelinek *et al*. 1994; Britton *et al*. 1995). NSW State government protection provided a model for the concept of protecting hilltops in all States and Territories, by requiring environmental impact assessments as prerequisites when developmental proposals are being considered.

Water course, wetland and riparian plant communities

Strips of riparian vegetation and creek embankments are important habitats, supporting food plants and decomposing vegetation and often insects of conservation significance. In rural and urban areas, these sites are often disturbed by human activities including erosion and pollution, grazing and soil compaction from cattle and feral animals and replacement of riparian plants by weeds. Creek and stream water courses providing habitats for Odonata, Ephemeroptera, Plecoptera, Trichoptera, some Coleoptera, Lepidoptera and Diptera need to be considered threatened ecological communities when supporting threatened species and protected under appropriate legislation. Drainage and soil backfilling of wetlands are key threatening processes for all insects dependant on permanent high water table wetland adapted flora. As an example, several drain lines through the now protected Billinudgel Nature Reserve in northern NSW, habitat for the threatened Laced or Australian Fritillary butterfly, *Argynnis hyperbius inconstans* Butler, were destroyed by a series of drainage lines that may have lowered the water table and reduced the density of its larval food plant, *Viola betonicifolia* Sm. (see also Lambkin 2017b). Conversely, filling drainage lines can have a positive conservation outcome, e.g. the Nature Glenelg Trust is participating in a program at the Mt Burr Swamp in SA to recover wetlands as habitat and potential translocation of the endangered Ancient Greenling Damselfly, *Hemiphlebia mirabilis* Selys (M Sargent pers. comm.)

Aquifer draw-down of calcretes and mound springs

Threats to stygofauna include changes in water quality of groundwater, changes to water levels or removal of groundwater and compaction of sediment. Groundwater calcrete aquifers in the arid zone harbour a diverse suite of short-range endemic dytiscid diving beetles associated with amphipods, copepods and isopods (Humphreys 2001). Similarly, mound springs, outlets of the Great Artesian Basin, harbour a suite of endemic invertebrates (e.g. snails and crustaceans) (Guzik *et al*. 2012). Both these systems are facing significant risks from lowering of the water table through agriculture and mining (Humphreys 2001, 2017).

Thermal springs and bogomosses

Several thermal springs support at least 10 Orders of unique aquatic and thermally adapted endemic insects, e.g. at ‘Tallaroo’, where the hot springs drain into the Einsleigh River, Queensland (J Marshall pers. comm.), and the Paralana hot springs, Arkaroola, South Australia, may also be habitat for unique invertebrates (C Madden pers. comm.). The hot spring sites and arthropods they support are without conservation designations and require protection under Commonwealth legislation. Similarly, permanently wet or moist bogomosses (= boggomosses) support a range of endemic invertebrates including endangered snails (Stanisic 1996). Thermal springs and bogomosses, and the arthropods they support, require recognition as potentially threatened ecological communities.

Australian offshore islands

Australian island insects are of particular taxonomic and conservation significance. The taxonomy of island populations may differ from those on the Australian mainland, and potential threats are often more severe. Insects of all Australian islands are in need of detailed studies and conservation evaluations. Island ecosystems are prone to invasions of foreign plants and animals that threaten the plant communities on which island endemics are dependent. Long-term protection of ecosystems supporting island fauna and flora has not been a priority for governments, with the exception of Christmas Island, where a large proportion has been designated as national park. An action plan for insect conservation is needed for each island, and threats need to take into account the current tenure, use, management and future plans for designating protected areas. Of the 274 Torres Strait Islands, e.g. only two islands have areas protected as Conservation Parks.

Butterflies of the Australian offshore islands are fairly well documented, e.g. Norfolk Island (Smithers & Peters 1969; Smithers 1970), Lord Howe Island (Peters 1969; Smithers 1971), Christmas Island (Moulds & Lachlan 1987; Wilson & Johnson 2017) and Torres Strait and Bass Strait Islands (Braby 2016; Lambkin 2017a), but the conservation significance of the butterflies has only received preliminary attention (Sands & New 2002, 2008b). Except for Lord Howe Island phasmatid *Dryococelus australis* Montrouzier (Honan 2008), management actions for insects of other orders have not been considered. The insect fauna of the Torres Strait Islands are of particular importance for understanding the biogeographical relationships of the Australian mainland insects (Taylor 1972) and where some species may become temporary residents while others will use the islands as ‘stepping stones’. Threats to insects on Torres Strait Islands are likely to be more severe than for the mainland species, particularly from habitat clearing for planting crops, fires, weed invasions and sea-level rise (Sands & New 2002, 2008b). The proximity of the northern Torres Strait Islands to the Papua New Guinea mainland and the tenure of the insect habitats are major issues affecting the conservation management of many unique insect species (Sands & New 2008b). Native plant communities supporting insects on Norfolk Island are increasingly threatened by invasive woody weeds, in particular, *Schinus terebinthifolius* Radd, a shrub or small tree that has overwhelmed many plants supporting endemic insects, including *Zanthoxylum pinnatum* (J.R. Forst. & G. Forst.) W.R. B. Oliv., an uncommon food plant for an endemic subspecies of the swallowtail butterfly *Papilio amynthor amphiaraus* (Smithers 1970).

Invasion of Christmas Island by the Yellow crazy ant *Anoplolepis gracilipes* F. Smith and its formation of ‘super-colonies’ has had disastrous impacts on the endemic red crab *Gecarcoidea natalis* Pocock (O’Dowd *et al*. 2003). Although not observed attacking the immature butterfly stages of island butterflies (Wilson & Johnson 2017), the ant is likely to have caused disruption to interactions of other invertebrates, and with a reputation for promoting reproduction in coccids by driving off the natural enemies, this ant and coccids have caused the death of native plants on other islands. Several other exotic ants are threats to insects on offshore islands, including the fire ants, *Solenopsis invicta* Buren and *Wasmannia auropunctata* (Roger), big-headed ant, *Pheidole megacephala* (Fabricius), and Argentine ant *Linepithema humile* (Mayr).

CONSERVATION OF INSECT INTERACTIONS

The role of insects as herbivores, predators, pollinators, detritivores, mutualists and food for vertebrates has been largely undervalued in biological conservation programs (Key 1978; New 1991a, 2017; New & Yen 1995). Shreeve and Dennis (2002) referred to insect interactions under the heading of *ecological classification of insects*, when reviewing the implications of their mobility and conservation of their habitats.

Herbivores and host plant specificity

Ecosystem processes and interactions are important for insect conservation and in particular for monophagous or oligophagous species (Samways 2005). Issues relating to the acceptance by insects of food plants includes the age, densities and growth stages needed to oviposit and survive. Many insects require food plants with particular phenotypic expressions, leaf textures and toughness, or nutrients in leaves, all factors important when assessing the conservation requirements of a herbivore, and the suitability of habitats. For age of hosts as an example, the endangered butterfly, bulloak jewel *Hypochrysops piceatus*, occurs in a very limited region of inland southern Queensland and breeds only on old-growth or senescing bulloak trees *Allocasuarina luehmannii* [R.T. Baker] L.A.S Johnson. Moreover, adult butterflies will only oviposit if the food plant trees are occupied by an undescribed species of ant *Anonychomyrma* sp., *itinerans* – group, a species that attends larvae and pupae in the hollow branches, beneath bark (Braby 2000) or in holes at the base of mistletoes attached to bulloak trees (DPA Sands, unpublished data).

Pollinators, seed dispersers and detritivores

Insect pollinators are of considerable conservation significance (Heard 2016; Hogendoorn & Leijs 2017; New 2017), and threats to native bees include habitat loss, fragmentation, air pollution, pesticides and zoodemics of pests and diseases (Heard 2016). Possible threats may occur with loss of pollinators specific for certain plant species, e.g. orchids and other species liable to co-extinctions, and when the pollinators, e.g. fig wasps (Agaonidae) (Fromont *et al*. 2017; New 2017), are adapted to only one species of plant. Further studies are required to determine the extent to which native pollinators and their breeding habitats are threatened and the effect of potential decline in pollination of plant communities, including threatened species.

Insect detritivores and their importance in breaking down dead or senescing vegetation, for nutrient recycling, fuel reduction and as food for other animals, are an increasing priority for ecological research. Important insect detritivores include Oecophoridae (Lepidoptera), with mostly winter-feeding larvae (Zborowski & Edwards 2007), larvae of Cryptocephalinae (Coleoptera), Blattodea, Collembola and land snails, all often forming complexes in moist and dry woodlands.

Adaptation of native insects to introduced host plants

The larvae of some indigenous Lepidoptera have adapted to feed on introduced plants and weeds in disturbed or urban areas, sometimes offsetting the threats from loss of native food plants (New & Sands 2002b; Larsen *et al*. 2008), or declines in abundance where several species would otherwise have become uncommon or extirpated. Several examples include the blue triangle butterfly *Graphium choredon* C. & R. Felder, with larvae adapting to feed on invasive camphor laurel, the swallowtails *Papilio aegeus aegeus* Donovan, *Papilio fuscus capaneus* Westwood and *Papilio anactus* W.S. Macleay on cultivated citrus (Scriber *et al*. 2008) and the evening brown, *Melanitis leda bankia* (Fabricius) on green panic, *Megathyrsus maximus* (Jacq.) B.K. Simon & S.W. Jacobs (see Table S1 for other examples). Larvae of the skipper *Anisynta cynone* (Hewitson) have been found on introduced grasses including rice millet (Douglas & Braby 1992; Field 2013), and larvae of the golden sun moth, *Synemon plana*, were observed to feed on Chilean needle grass *Nasella neesiana* grass (Richter *et al*. 2009), but it is not known if these adaptations alleviate the threats from loss of their native plant hosts.

Insect natural enemies: parasitoids and predators

Natural enemies are important population regulators for native insects, including threatened species. Natural enemies influence the distribution, abundance and fluctuations in the densities of native insects, and their identities and roles need investigation in all insect conservation projects. Impacts from natural enemies have been misinterpreted, especially when low densities cannot be attributable to other forms of natural mortality (e.g. diseases). A range of diseases that attack the immature stages of insects needs to be considered when monitoring populations and preparing management plans.

Native insect predators of insects are mostly generalists, and some species are restricted to preying on certain groups or sizes of prey. The host searching stimulus can be influenced by the plants the host occupies. Such tri-trophic issues may apply to parasitoids when the insect hosts of parasitoids are uncommon or rare, and the plants they feed on are threatened species. The natural enemies commonly observed during conservation studies include the parasitoid families Encyrtidae, Aphelinidae, Braconidae and Ichneumonidae; ant predators: *Iridomyrmex* spp., *Tetramorium* spp., *Oecophylla smaragdina* Smith; some Diptera: Tachinidae and Asilidae; Hemiptera; and spiders (Arachnida).

Mutualism

Insect mutualism was recently referred to by New (2017) when giving examples of insect interactions of conservation concern, and Solodovnikov and Shaw (2017) provided examples of rove beetles living in the fur of small animals and likely to be of conservation interest. Predators and parasites of threatened species are also of conservation significance, e.g. when monophagous, and if they develop on immature stages, or have a narrow range of hosts. Host specificity is well known in myrmecophagous butterflies (Eastwood & Fraser 1999) including several threatened *Acrodipsas* spp. predatory on particular species of ants, and where the ant prey are also likely to be threatened; *Hypochrysops apollo* Miskin larvae are dependent on the ant plants *Mymecodia* spp. as hosts, and its immature stages attended by one species of ant, *Philidris cordatus* (F. Smith) (Braby 2000), has become a conservation issue as the native *P. cordatus* becomes displaced by the introduced ant, *Pheidole megacephala* (F.). Initially thought uneventful (Common & Waterhouse 1972), the introduced ant is now known to disrupt reproduction of the plant, by removing floral parts and developing seeds (G Maynard pers. comm.) (Table S1). Many other examples of the conservation significance of mutualism, include Phthiraptera and Siphonaptera, when parasitic on rare or threatened marsupials, and a species of silverfish *Acrotelsella* (Lepismatidae), said to be an endangered short-range endemic (Smith 2015).

Co-extinction and reciprocal conservation significance

Co-extinction refers to insect mutualism where an insect has obligatory, symbiotic interactions with other threatened fauna or flora. For example, the oecophorid moth, *Trisyntopa scatophaga* (White), was listed (*EPBC Act*) as threatened due to dependence of the moth larvae on excreta from nestlings of the threatened golden shouldered parrot, *Psephotus chrysopterygius* Gould (Turner 1923) in northern Queensland, and on the parrot nests in termite mounds (Zborowski & Edwards 2007). This mutualism involving nesting birds and *T. scatophaga* prompted Edwards *et al*. (2007) to review the identity of a similar moth associated with the hooded parrot *Psephotus dissimilis* Collett in the Northern Territory, and the study resulted in the description of a new species of moth, *Trisyntopa neossophila* Edwards *et al*. 2007, having a reciprocal conservation relationship with the hooded parrot, with its larvae dependent as food on the faecal pellets in nests in termite mounds. These interactions point to the possibility that another species of *Trisyntopa* moth, specific to, and breeding in nests of the paradise parrot *Psephotellus pulcherrimus* (Gould), may have become extinct at the same time as extinction of the paradise parrot (Edwards *et al*. 2007; Olsen 2007). The term *reciprocal conservation* is proposed for taxa predetermined to be liable to co-extinction.

Examples of co-extinction are known for insects and plant partners (e.g. Moir *et al*. 2010, 2011), and when either are threatened species, e.g. when an insect can pollinate the flowers of only one species of threatened plant, and when the plant serves as host to the immature insect stages. For example, several moths of Heliozelidae are known to be specific pollinators of *Boronia* spp. (Rutaceae) (Milla *et al*. 2017). Some threatened *Boronia* spp. have extremely limited distributions, e.g. *Boronia boliviensis* Williams & Hunter (Williams & Hunter 2006; OOE 2016), an example where extinction of an obligatory pollinator would result in extinction of this plant, or vice versa.

CONSERVATION OF INSECTS IN AGRICULTURAL ECOSYSTEMS

Invertebrate conservation, including classical biological control with introduced natural enemies, is important in agricultural ecosystems (New 2005). Whereas introduced biological control agents are either narrowly or entirely host specific, the introduced species persist mostly in weeds or introduced plants. Of predatory insects (New 1991b) attacking pests of grains and legumes, almost all are native species, whereas the parasitoids were mostly introduced as biological control agents (Waterhouse & Sands 2001). For example, of natural enemies of aphids recorded from various crops, all 29 predators were native species, but of the parasitoids, the majority were introduced species. Of seven species of armyworms attacking various crops, 38 parasitoid species were native and eight were introduced, and of natural enemies attacking *Helicoverpa* spp., 21 predators were native, 63 parasitoids were native and eight parasitoids were introduced.

The concept of conservation biological control (Ehler 1998) in Australia depends on conserving native plant communities to maintain populations of biological control agents 'ready and waiting' to move into crops and attack pests before they build up in damaging numbers (Costamagna *et al*. 2015). The importance of retaining native vegetation to provide refuges for beneficials has been undervalued, and in recent studies, Macfadyen *et al*. (2015) and Parry *et al*. (2015) have shown that more beneficial species than pest species occur in native vegetation and that pest species are more often found in exotic weeds and pastures than in native vegetation. Parasitoids from native vegetation were shown to benefit early season colonisation in crops (Bianchi *et al*. 2015). Parry and Schellhorn (2015), Parry *et al*. (2015) and Pedersen (2016) have shown that native plants near farmlands can advance the timing for entry of beneficial insects and their interception of pests, contributing to control before pests can build up in sufficient numbers to cause damage to crops.

By maintaining appropriate species of native plants close to pest-affected crops, or cultivating particular plant species to support breeding colonies of beneficial organisms, an important aspect of invertebrate conservation can reduce costs of managing pests on farmlands, and in the longer term, has the capacity to improve agricultural production, to reduce pesticide applications and the development of pest resistance. Gagic *et al*. (2018) have shown that native woody vegetation with intact ground cover when not grazed supports multiple natural enemy species when native vegetation is in close proximity to the crop and that the proximity of intact native vegetation can reduce the risks of outbreaks in crops.

In each geographical region (Firempong & Zalucki 1990), the beneficial organisms and their arthropod prey, and the food plants of the prey, will vary with location, season and crop. Future prospects for improving conservation biological control on Australian farmlands are considerable but will require compilation for each subregion, information on identities of predators, prey, plant communities supporting them and the plant species carrying the highest diversity of insect beneficials. The distribution of each beneficial species is likely to change under pressures from climate change, influence the distribution and effectiveness or even their survival in each region. Models such as CLIMEX (Sutherst *et al*. 2004; Furlong *et al*. 2017) for predicting such changes need inclusion in future documents prepared on predators and their effectiveness.

The studies by Parry and Schellhorn (2015) focus on maximising benefits from native beneficial organisms, the need to conserve native plant communities that support them, and evaluating the benefits for each bioregion and farming system. This information will be increasingly needed by farmers to complement management of pests, to help reduce or avoid pesticide applications and to minimise the associated costs of farming.

COMMUNITY PARTICIPATION IN INSECT CONSERVATION

Involvement of members of the community in insect conservation, particularly in urban areas (New & Sands 2002b), can achieve practical recovery for threatened species (New 2010), and participate in the success of recovery plans (Boersma *et al*. 2001; Yen & New 2013; Taylor *et al*. 2018). The most popular group is Lepidoptera, and with *icon* or *flagship* species, has produced results when they are seen to breed on cultivated food plants or when adults visit gardens seeking nectar. Collaboration with agencies has been successful in several States and Territories (see Appendix S1), where community members have the information they need to adjust their management such as fires, need to retain senescing trees, rocks, hollow limbs and fallen logs, or become aware of places where weeds, bike riding, walking tracks or other disturbances affect sensitive breeding sites for insects. Maintaining a healthy insect habitat depends on members of the community with knowledge of the local needs for protecting insects, and an understanding how management of insect breeding sites may differ from managing plant communities (see New 2018).

Ecological restoration: integrating bushland and insect habitats

Insect gardening and insect arboretums

Revegetation of disturbed areas using indigenous insect food and habitat plants can increase the abundance of food and nectar plants for rare and threatened insects (Samways 2005). Habitat restoration involves maintaining the range of canopy, shrub, understorey and sub-surface vegetation, including sedges and grasses, as well as nectar-attracting species, and the introduction of logs, branches, rocks and leaf litter as insect shelters. Success has been achieved on privately owned land and increasing efforts have aimed to restore degraded roadside and council-owned land. Community restoration includes providing artificial nesting boxes for native bees (Heard 2016), and shrubs with nectar-rich blossoms to attract Lepidoptera, Coleoptera, Diptera and birds, and planting shrubs, sedges, grasses and vines as food plants for Lepidoptera. Nursery cultivation of food plants, learning how to germinate seeds or grow food plants (e.g. listed by Moss 2002) from cuttings have been valuable contributions from the community. Some sedges once considered difficult to germinate from seed, e.g. *Gahnia* spp., other food plants for Hesperiidae, are now easily grown for gardens or to re-establish species in natural habitats. Community members have contributed to the recovery of several threatened insect species including the Bathurst copper *Paralucia spinifera* Edwards & Common by managing the food plant *Bursaria spinosa* (Nally 2003), and the Richmond birdwing (Sands *et al*. 1997) has benefited from the cultivation of the food plant in sufficient numbers for distribution and planting in gardens and reserves (Sands 2008).

Insect food plants as 'green fire breaks'

Fire retardant insect food plants have been used to create 'green fire breaks', to help reduce the flammability of plants in bush rehabilitation projects, and when planted as hedges near dwellings, to assist capture of embers. Many insect food plants are fire retardant and can be planted to prevent the advancement of wild fires into fire-sensitive plant communities. For example, in 2010, low and dense growth of a mattrush *Lomandra longifolia* Labill. (a food plant for Hesperiidae) at the edge of Coolloola heathlands was observed preventing advancement of a wildfire, despite its rapid advancement as a canopy fire from nearby *Melaleuca quinquenervia* (D Batt pers. comm.). In the Northern Territory, *Capparis umbonata* Lindl. is reported as a fire-resistant plant (Brock 1988), and it is also an important host for larvae of several pierid butterflies (Braby 2011). Green fire breaks to protect insect-attracting gardens may also reduce the flammability of other plants near houses. In urban Brisbane, the sightings of many previously common butterflies and moths have declined seriously over the past 30 years, mostly resulting from loss or disturbance of bushland habitats supporting food plants. For example, at least six species of Lepidoptera have disappeared from their usual haunts on Mt Coot-tha in Brisbane between 1978 and 2002 (DPA Sands, unpublished data), but planting food plants in gardens and bush reserves for the following Lepidoptera has been successful: *Scolopia braunii* (Klotzsch) Sleumer for the rustic, *Cupha prosope* (Fab.), *Pipturus argenteus* Wedd. for Jezebel or White Nymph, *Mynes geoffoyi* Wallace, *Capparis arborea* (F. Muell.) Maiden and *Senna* spp. for pierid butterflies, including the yellow migrant *Catopsilia gorgophone* (Boisduval) and *Clematicissus opaca* (F. Muell.) Jackes & Rossetto, for Joseph's coat moth *Agarista agricola* (Donovan), all species of Lepidoptera that reversed from declines in urban abundance.

Funding support for community groups

While various sources of funds have been available from private and public agencies, one Commonwealth grant in the late 1990s, the *Threatened Species Network Community Grants* (TSN), supported by WWF and Australian Government (Environment Australia), provided the most appropriate method for funding community insect conservation activities and developing recovery plans for threatened species. The community and their projects would benefit considerably if the TSN grants could be reinstated.

Agencies are unlikely to succeed in the rehabilitation of threatened insects without involvement of members of the community, but much is to be gained by their involvement in identifying threats, how to rehabilitate habitats, photography, surveys and monitoring, hosting workshops, updates the distribution of threatened species and help with developing recovery plans. Several examples indicate the potential for community involvement (see Appendix S1).

RECOMMENDATIONS

Many of the issues discussed here can be resolved after comparing the challenges with identification, evaluation and managing the habitat requirements for vertebrates, with those needed for insects, and highlight the importance of insect interactions with other fauna and flora. Several recommendations including threat alleviation may be equally relevant to other fauna and flora and in particular those issues relating to differences between State and Commonwealth evaluation and categories for threatened species, and variation in protected areas management.

Policy

Scientific names

Trinomial/subspecies names are important taxonomic categories in conservation assessments unless a taxon has been formally synonymised in revisions or recognised publications. Accurate lists of insect taxa are readily available from the Australian Faunal Directory (AFD 2017), and authors of taxa need to be added to the scientific names held by conservation agencies. Subspecies and lower rank sub-taxonomic terms, *Biotype*, e.g. and *Evolutionary Significant Units* may be units acceptable for conservation actions (Taylor *et al*. 2018).

Maintaining lists of insect fauna

Commonwealth and State agencies determining the conservation status for threatened taxa need to maintain updated lists of indigenous and newly recorded exotic insects and ensure spellings for species and genera combinations are in accordance with ICZN requirements, and as applied in the Australian Fauna Directory (AFD 2017). Such lists should also be held and updated by the Australian National Insect Collection and State museums. When reviewing conservation status for taxa, in-house decisions (e.g. as currently in Queensland), sometimes inaccurate and contestable, are avoidable with recommendations from expert committees on behalf of States and Commonwealth.

Assessments for conservation status and listing

One Commonwealth agency is recommended to taking responsibility for identifying, assessing and coordinating the listing of threatened invertebrate taxa in Australia and recording the distribution of taxa occurring in bioregions and listed under State, Territory and Commonwealth jurisdictions (as currently under the *EPBC Act*) and to replace inconsistencies in categories and listings made by States. Insect taxa listed by States require review of conservation status and to update categories of threat, using IUCN Red LIst criteria.

Adjustments to threat categories

Categories for listing invertebrates can be adjusted by inclusion of a clause: *the species is a species of an invertebrate*. The category 'Near Threatened' is recommended to be of national environmental significance and to accommodate taxa likely to become threatened without specific actions. Placed here are 'Rehabilitated Taxa' (Sands & New 2002), those which are no longer threatened and eligible to be de-listed. Such Rehabilitated Taxa will need to be monitored to ensure that they do not return to a threatened status.

Species conservation dossiers

Species Conservation Dossiers with a curriculum based on species profiles and ecological data (including natural enemies) are recommended for insect taxa considered for listing. Recovery Plans need to identify actions most feasible for threat abatement. Threats for all taxa need to identify (1) changes in distribution and areas previously occupied, (2) number of breeding populations and areas occupied or (3) estimates of observable individuals at known localities. Monitoring is appropriate for inclusion in management plans, and 'Facts sheets' are recommended for all insect taxa listed under the *EPBC Act* and with information from Species Conservation Dossiers.

Action plans

The following proposed Action Plans are based on some priority insect groups known to be of particular conservation significance (see Braby 2018): (1) Odonata; (2) Diptera: Chironomidae; (3) Coleoptera: Buprestidae, Carabidae, Cetonidae, Cerambicidae and Scarabinae; (4) Hymenoptera: Ichneumonidae, Braconidae, Encytidae, Aphelinidae and Pteromalidae and ants *Anonychomyrma* spp. (*itinerans*-species group), *Camponotis*, *Crematogaster*, *Philidris* and other mutualism genera; (5) Lepidoptera: Agathiphagidae, Micropterigidae, Heliozelidae and Oecophoridae; and (6) Hemiptera: Aradidae and Cicadidae and Thysanura: Lepismatidae (Smith 2015).

Management plans and recovery plans

Listing a species provides a trigger to review threats and seek threat alleviation strategies (New & Sands 2004), before the threatened status changes, or a species becomes extinct. Only about 50% of animals listed by the agency in Queensland have recovery plans included in Species Profiles for each threatened species (Curtis *et al*. 2012), and there is an impression that once a species is listed, threat abatement is unnecessary. Insects listed by the State agency in

Queensland (Curtis *et al*. 2012) included a dragonfly, a damselfly and six butterflies. The few insects listed include two butterflies, the Ulysses (*Papilio ulysses joesa* Butler) and the Cairns birdwing (*Ornithoptera euphorion*) that are not threatened and the reasons for their listing remain obscure! One moth listed nationally (*Phyllodes imperialis smithersi*) was not listed by the State despite a case for listing presented during the 'back on track' reviews for threatened species.

Recovery Plans forming part of Management Plans may be included in dossiers when sufficient information on threats are available, e.g. (1) when threats are amenable to abatement actions, (2) to ensure monitoring will reflect further declines or improvements in population stability and (3) identify further recovery actions. For threatened species, the past distribution and currently known area occupied need evaluation. In addition, the potential for the species to establish in areas south or at higher altitudes, and potential for translocation to suitable areas, needs to be evaluated For each threatened species, modelling distribution with predicted effects from climate changes (e.g. DYMEX) should form part of any recovery plans. All Management or Recovery Plans for insects of conservation concern need to be held by an appropriate agency, preferably the Commonwealth agency, to provide a central place for reference, documentation of threats, and progress and outcomes from recovery actions.

Expert committees and review timetables

Expert committees selected by the Commonwealth agency should include agency representatives from all range States of a listed species, as well as experts with other affiliations. Current anomalies from in-house decisions by agencies can be overcome with the Commonwealth agency responsible for assessments and listing and allow State agencies to focus on conserving and managing habitats for threatened species and finding ways to provide indefinite tenure for habitats of listed species. Scheduled reviews, at least every 3 years, need to consider changes in threats, new information since listing and observed impacts from climate change. Changes in *status* and *delisting* are likely as new information or impacts from threats become more apparent (New & Sands 2003b).

AES to coordinate conservation appraisals

With the appointment of national representatives, the Conservation Committee of the Australian Entomological Society is the most appropriate organisation for coordinating and recommending invertebrate conservation actions under the *EPBC Act* and for making related submissions to the Commonwealth agency. State agencies may wish to participate in assessments for threatened taxa, including preparation and implementation of management plans, but need formal agreements with Commonwealth agencies to protect and secure tenure and to regenerate early succession of certain habitats, when known to be specific for threatened insect species.

Co-extinction

This concept arises from examples of insect mutualism where obligatory interactions between two threatened taxa are recognised by co-listing species of threatened plants and animals. For example, an obligatory pollinator of an orchid (Van der Pijil & Dodson 1966) may be totally dependent on that orchid for its life history and as such should automatically be listed at the same status level as that of the orchid. Where neither species is listed but both are of conservation concern, *reciprocal conservation concern* is applicable to both species.

Practical management

Conservation of insect habitats

Certain habitats and ecological communities dependent on particular landscape features supporting a species or group of species of conservation concern need to be considered eligible for listing as *Threatened Ecological Communities* under the *EPBC Act*. Some hilltops fit this category where facilities such as towers and viewing sites have been constructed on the summits. There are options to avoid destroying such hilltop habitats, e.g. 10 m from an apex or ridgeline. Similarly, roads built along ridgetops often disrupt patrolling and mating by some insects. Intact vegetation on a hilltop or ridgetop should not be deliberately burnt and protected from fire reaching a summit or ridgeline during controlled burns. New South Wales legislation allows for the biodiversity assessment of hilltops before disturbance is allowed. Hilltopping and fire management for invertebrate conservation are topics that require more work, public awareness and political will to ensure that these crucial species in our ecosystems continue to survive in the fragmented landscapes of south-eastern Qld.

Thermal springs and boggomosses and the arthropods they support require conservation assessments, including thermal tolerance evaluations, as potentially threatened species and their ecological communities.

Commonwealth tenure for State-owned protected parks

In the face of threats from activities and industries, a new scheme by the Commonwealth government is needed to manage 'National' parks, perhaps by introducing cooperative agreements or MOUs, to span the interests of State and Commonwealth agencies, with the primary aim to 'permanently protect national parks for conservation of native animals, plants and natural land forms' and to protect certain other categories of land currently protected under State jurisdictions. A long-term option for the States would be to maintain the capacity for managing State-owned parks as Commonwealth national parks, to transfer selected State parks (e.g. those supporting threatened species) to Commonwealth national parks and to re-name those retained by States as 'State Parks'. When eligible, protected areas in all States including national parks and conservation covenants (e.g. Qld Nature Refuges on State-owned road reserves) need to be considered for listing under the *EPBC Act*, when they support EPBC-listed and threatened taxa. By referring to the IUCN (1993) Red List guidelines, such nationally protected areas may be better referred to as *Key Biodiversity Areas*.

Management of invasive weeds

Weeds invading native ecosystems need to be considered equally important as targets for control, as weeds detrimental to agricultural crops or grasslands. When conflicts of interest occur between pastoralists or other industries, methods to reduce the vigour or reproduction (e.g. of seeds or stolons) can be sought, without reducing the benefits to either parties. Most introduced grasses are candidates for classical biological control, and with the potential to find host-specific insect agents, as demonstrated by the USA, controlling infestations of the giant reed *Arundo donax* L. in the Rio Grande Valley (Moran & Goolsby 2009, 2010). Mono-stand thickets of *A. donax* developed so rapidly and became recognised as one of the most serious threats to plant and animal biodiversity in the USA and are already threatening subtropical plant communities edging the Clarence River, New South Wales, and along parts of the Brisbane River, Queensland.

Biological control needs increased recognition by Australian agencies and the community, to reduce the abundance and impacts of exotic plants and invertebrate pests. Despite the many successful examples of biological control programs of weeds in Australia (Julien & Griffiths 1998), obstacles can be attributed to lack of understanding of the precautions taken, the benefits to ecosystems and the flow-on gains for human health (Van Driesche *et al*. 2008). Recent successes overseas in managing invasive grasses with classical biological control (Moran & Goolsby 2009, 2010) indicate that specialist agents could reduce the impacts by exotic grasses on native ecosystems in Australia, enhance the persistence of indigenous plant species and promote conservation of invertebrate biodiversity, without affecting on-farm benefits for pastures.

Management of inappropriate fire regimes

Environmental managers in Australia are mostly unaware of the importance of insects and for conserving insect habitats. For fire management, environmental protection agencies may face a 'policy dilemma' when fuel-reduction fires intended to protect human lives and assets are known to have detrimental impacts on animal biodiversity (Clarke 2008; Woinarski *et al*. 2010; Croft *et al*. 2016). There are also many 'myths' surrounding the needs for survival and reproduction of fire-adapted plants, often said to enhance ecosystem health, plant condition and vigour, and for prescribed burning '... that promotes the health of native habitats' (Anon. 2010). Many mature plants, e.g. most banksias, hakeas and acacias, can appear to *benefit* from being burnt when they re-sprout; seed capsules open or seedlings germinate provincially, but most of these species can reproduce otherwise when stems bearing seed capsules senesce and when capsules open and seeds germinate with sufficient moisture and light. Recent studies in 26 of 30 bioregions in south-eastern Australia indicate no evidence that prescribed burning has reduced the sizes of wildfires (Zylstra 2016) and that dense regrowth following logging has been said to burn at a higher severity than mature forest (Lindenmayer *et al*. 2011).

Micro-mosaic patch burning can be readily applied for managing the fuel loads in flammable plant communities and take into account particular plant communities of habitat, the age and phenotypic expression of food plants needed by the species of insects being managed. Fires should not be deliberately lit in fire-sensitive plant communities, excluded from rainforests or wet woodlands and avoid permanent damage to fire-sensitive plants and animals. Micro-mosaic patch burning, particularly when close to urban or farmland areas, requires retention unburnt of 10–15% of a flammable plant community (Sands & Hosking 2005; New *et al*. 2010b). Such programs should be accompanied by pre-fire inspections and post-fire monitoring of regrowth of plant species, phenotypic growth and forms and recolonisation by invertebrates.

Insect conservation in agricultural ecosystems

Extending the themes of insect conservation, from protecting threatened insect species and biodiversity to conservation of beneficial arthropods for managing pests on farmlands, is a priority for addressing the counterproductive and broadscale detrimental impacts from tree clearing. However, much research and cost-effective analysis are needed for each bioregion and crop and to identify the major groups and species of beneficial insects, to identify their distributions, hosts, food and plants as habitats and to develop pest management strategies for the benefit of healthy farmlands throughout Australia.

Priority and support

Flagship and 'icon' species for publicity

Already used widely and successfully to popularise fauna conservation, these terms can promote community involvement and publicity or gain financial support for recovery activities (Taylor *et al*. 2018). Excellent television coverage was given by the ABC's 'Morning Show' (25 September 2017) for recovery activities for the 'Giant Atlas Moth', showing involvement of members of the community with school children in Darwin, NT, a project initiated by Michael Braby and his colleagues (Braby 2014).

Commonwealth funding for community participation in insect conservation

Reinstatement of the (Commonwealth) Threatened Species Community Grants Scheme is recommended to support taxonomic studies and recovery activities by community members of incorporated groups and to provide much needed funding for field surveys, newsletters and facts sheets and sometimes for DNA studies. Non-professional entomologists using classical morphological methods for descriptions and determinations often need access to expertise for molecular studies. However, associated costs of these studies are considerable, issues deserving financial assistance from appropriate funding bodies.

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REFERENCES

AFD 2017. *Australian Faunal Directory* ABRS, Canberra. Available from URL: http://www.environment.gov.au/science/abrs/online-resources/citation [Accessed 20 November 2017].

Alcock J & Dodson G. 2008. The diverse mating systems of hilltopping insects. *American Entomologist* Summer **2008**, 80–88.

Andersen AN, Bocciarelli D, Fairman R & Radford IJ. 2014. Conservation status of ants in an iconic region of monsoonal Australia, levels of endemism and responses to fire in the eastern Kimberly. *Journal of Insect Conservation* **18**, 127–146.

Anonymous. 2010. *Managing Fire, A Guide to Brisbane Residents Living in or Near Bushland*. Brisbane City Council Information leaflet, Brisbane.

Anonymous. 2017. Wildlife is already hurting. In: 7 climate facts you need to know. *National Geographic* **231**, 30–39.

Austin AD & Dowton M. 2000. The Hymenoptera: an introduction. In: *Hymenoptera, Evolution, Biodiversity and Biological Control* (eds AD Austin & M Dowton), pp. 3–7. CSIRO, Melbourne.

Beale JP & Zalucki MP. 1995. The status and distribution of *Acrodipsas illidgei* (Waterhouse and Lyell) (Lepidoptera, Lycaenidae) at Redland Bay, south-east Queensland, and a new plant association record. *Journal of the Australian Entomological Society* **34**, 163–168.

Bianchi FJJA, Walters BJ, Hove ALT, Cunningham SA, van der Werf W & Douma JC. 2015. Early-season crop colonisation by parasitoids is associated with remnant native vegetation, but is spatially and temporarily erratic. *Agriculture, Ecosystems & Environment* **207**, 10–16.

Boersma PD, Kareiva P, Fagan P, Clark JA & Hoekstra JM. 2001. How good are endangered species recovery plans? *BioScience* **51**, 643–649.

Booth C. 2011. Myrtle rust, how big a threat to native plants? *Ecos* CSIRO, August 2011.

Bowker MA. 2007. Biological soil crust rehabilitation in theory and practice: an underexploited opportunity. *Restoration Ecology* **15**, 13–23.

Bowman DMJS, Woinarski JCZ, Sands DPA, Wells A & McShane VJ.1990. Slash and burn agriculture in the wet coastal lowlands of Papua New Guinea: response of birds, butterflies and reptiles. *Journal of Biogeography* **17**, 227–239.

Braby MF. 2000. *Butterflies of Australia: Their Identification, Biology and Distribution*. CSIRO Publishing, Collingwood, Melbourne.

Braby MF. 2011. New larval food plant associations for some butterflies and diurnal moths (Lepidoptera) from the Northern Territory and eastern Kimberley, Australia. *The Beagle, Records of the Museums and Art Galleries of the Northern Territory* **27**, 85–105.

Braby MF. 2014. Atlas Moth Conservation Network: a new community group to recover a threatened species in the Northern Territory. *Australian Entomological Society 45th AGM and Scientific Conference. Celebrating the next 50 years of Australian Entomology.* The Australian Entomology Society, Canberra, ACT.

Braby MF. 2016. *The Complete Field Guide to Butterflies of Australia*, Second edn. CSIRO Publishing, Clayton.

Braby MF. 2018. Threatened species conservation of invertebrates in Australia: an overview. *Austral Entomology* **57**, 173–181.

Braby MF & Armstrong JJ. 2018. Observations on the ecology of the silky hairstreak *Pseudalmenus chlorinda* (Blanchard, 1848) (Lepidoptera: Lycaenidae). *The Australian Entomologist* **45** (in press).

Braby MF & Dunford M. 2006. Field observations on the ecology of the golden sun moth, *Synemon plana* Walker (Lepidoptera: Castniidae). *The Australian Entomologist* **33**, 103–110.

Braby MF & Edwards ED. 2006. The butterfly fauna of the Griffith district, a fragmented semi-arid landscape in inland southern New South Wales. *Pacific Conservation Biology* **12**, 140–154.

Braby MF & Williams MR. 2016. Biosystematics and conservation biology, critical scientific disciplines for the management of insect biological diversity. *Austral Entomology* **55**, 1–17.

Braby MF, Willan RC, Woinarski JCZ & Kessner V. 2011. Land snails associated with limestone outcrops in northern Australia – a potential bioindicator group. *Northern Territory Naturalist* **23**, 2–17.

Braby MF, Eastwood R & Murray N. 2012. The subspecies concept in butterflies: has its application in taxonomy and conservation biology outlived its usefulness? *Biological Journal of the Linnaean Society* **106**, 669–716.

Braby MF, Thistleton BM & Neal MJ. 2014. Host plants, biology and distribution of *Acraea terpsicore* (Linnaeus, 1758) (Lepidoptera, Nymphalidae), a new butterfly for northern Australia with potential invasive status. *Austral Entomology* **53**, 288–297.

Braysher M. 2016. *Managing Australia's Pest Animals. A Guide to Strategic Planning and Effective Management*. CSIRO Publishing, Clayton, Australia.

Britton DR, New TR & Jelinek A. 1995. Rare Lepidoptera at Mount Piper, Victoria – the role of a threatened butterfly community in advancing understanding of insect conservation. *Journal of the Lepidopterist's Society* **49**, 97–113.

Brock J. 1988. *Top End Native Plants*. Privately published, John Brock, Darwin.

Burwell C, Nakamura A & Kitching RL. (eds) 2011. Biodiversity, altitude and climate change in an Australian subtropical rainforest. *Memoirs of the Queensland Museum* **55**, Part 2, Brisbane.

Butcher RJ, Clunie PE & Yen AL. 1994. The Victorian Flora and Fauna Guarantee Act. Flagship legislation for invertebrate conservation. *Memoirs of the Queensland Museum* **36**, 13–19.

Butler BDW & Fairfax RJ. 2003. Buffel grass and fire in a Gidgee and Brigalow woodland: a case study from central Queensland. *Ecological Management and Restoration* **4**, 120–125.

Canzano AA, Krockenberger AA, Jones RE & Seymour JE. 2006. Rates of metabolism in diapausing and reproductively active tropical butterflies, *Euploea core* and *Euploea sylvester* (Lepidoptera: Nymphalidae). *Physiological Entomology* **31**, 184–189.

Cardoso P, Erwin TL, Borges PAV & New TR. 2011. The seven impediments in insect conservation and how to overcome them. *Biological Conservation* **144**, 2647–2655.

Clarke MF. 2008. Catering for the needs of fauna in fire management: science or just wishful thinking. *Wildlife Research* **35**, 385–394.

Clarke GM & Spier-Ashcroft F. 2003. *A Review of the Conservation Status of Selected Australian Non-marine Invertebrates*. Environment Australia/National Heritage Trust, Canberra.

Coleman P & Coleman F. 2000. *Local Recovery Plan for the Yellowish Sedge-skipper and Thatching Grass*. Delta Environmental Consulting, Adelaide.

Common IFB. 1990. *Moths of Australia*. Melbourne University Press, Collingwood, Victoria.

Common IFB. 1994. Oecophorine genera of Australia. 1. The *Wingia* group. *Monographs of Australian Lepidoptera* **3**, 1–390 CSIRO Publishing, East Melbourne.

Common IFB & Waterhouse DF. 1972, 1981 (revised ed.). *Butterflies of Australia*. Angus & Robertson, Sydney.

Costamagna AC, Venables WN & Schellhorn NA. 2015. Landscape-scale pest suppression is mediated by timing of predator arrival. *Ecological Applications* **25**, 1114–1130.

Croft P, Hunter JT & Reid N. 2016. Forgotten fauna: habitat attributes of long-unburnt open forests and woodlands dictate a rethink of fire management theory and practice. *Forest Ecology and Management* **366**, 166–174.

Csurhes S & Hankamer C. 2012. Invasive animal risk assessment yellow crazy ant. Queensland Government Report.

Curtis LK, Dennis AJ, McDonald KR, Kyne PM & Debus SJS, eds. 2012. *Queensland's Threatened Animals*. CSIRO Publishing, Melbourne.

D' Antonio CM & Vitousek PM. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecological Systems* **23**, 63–87.
Day MD, Wiley CJ, Playford J & Zalucki MP. 2003. *Lantana: Current Management Status and Future Prospects*. ACIAR Monograph Series, Canberra.
Dingle H, Zalucki MP & Rochester WA. 1999. Season specific directional movement in migratory Australian butterflies. *Australian Journal of Entomology* **38**, 323–329.
Dingle H, Rochester WA & Zalucki MP. 2000. Relationships among climate, latitude and migration: Australian butterflies are not temperate-zone birds. *Oecologia* **124**, 196–207.
Douglas F & Braby MF. 1992. Notes on the distribution and biology of some Hesperiidae and Lycaenidae (Lepidoptera) in Victoria. *Australian Entomological Magazine* **19**, 117–124.
Driessen MM & Greenslade P. 2004. Effect of season, location and fire on Collembola communities in buttongrass moorlands, Tasmania. *Pedobiologia* **48**, 631–642.
Driscoll DA, Lindenmayer DB, Bennett AF *et al*. 2010. Resolving conflicts in fire management using decision theory, asset-protection versus biodiversity conservation. *Conservation Letters* **3**, 215–223.
Eastwood R & Fraser AM. 1999. Associations between lycaenid butterflies and ants in Australia. *Australian Journal of Ecology* **24**, 503–537.
Eastwood R & Hughes JM. 2003. Molecular phylogeny and evolutionary biology of *Acrodipsas* (Lepidoptera; Lycaenidae). *Molecular Phylogenetics and Evolution* **27**, 93–102.
Eastwood R, Braby MF, Schmidt DJ & Hughes JM. 2008. Taxonomy, ecology, genetics and conservation status of the pale Imperial Hairstreak (*Jalmenus eubulus*) (Lepidoptera, Lycaenidae), a threatened butterfly from the Brigalow Belt, Australia. *Invertebrate Systematics* **22**, 407–423.
Edwards ED, Cooney SJN, Olsen PD & Garnett ST. 2007. A new species of *Trisyntopa* Lower (Lepidoptera: Oecophoridae) associated with the nests of the hooded parrot (*Psephotus dissimilis*, Psittacidae) in the Northern Territory. *Australian Journal of Entomology* **46**, 276–280.
Ehler LE. 1998. Theory and practice of biological control. In: *Conservation Biological Control, Past, Present, and Future* (ed Barbosa), pp. 1–8. Academic Press, San Diego.
EPBC. 1999. *Environment Protection and Biodiversity Conservation Act 1999*. Department of the Environment and Energy, Australian Government.
FFG. 1988. *Flora and Fauna Guarantee Act 1988*. Department of Land, Water and Planning, State Government of Victoria.
Field RP. 1999. A new species of *Ogyris* Angas (Lepidoptera: Lycaenidae) from southern arid Australia. *Memoirs of the Museum of Victoria* **57**, 251–259.
Field RP. 2013. *Butterflies*. Identification and life history, Museum Victoria, Melbourne.
Fielder L. 2011. *Weeds of Southern Queensland*, 3rd edn. Weed Society of Queensland Inc., Brisbane.
Firempong S & Zalucki MP. 1990. Host references of populations of *Helicoverpa armigera* (Hübner) (Lepidoptera; Noctuidae) from different geographical locations. *Australian Journal of Zoology* **37**, 665–673.
Francis WD. 1970. *Australian Rain-forest Trees*. Australian Government Publishing Service, Canberra.
Fromont C, DeGabriel JL, Riegler M & Cook JM. 2017. Diversity and specificity of sap-feeding herbivores and their parasitoids on Australian fig trees. *Insect Conservation and Diversity* **10**, 107–119.
Furlong MJ, Zalucki MP, Shabbir A & Adamson DC. 2017. Biological control of diamondback moth in a climate of change. *Mysore Journal of Agricultural Science* **51**, 115–124.
Gagic V, Paull C & Schellhorn NA. 2018. Ecosystem service of biological pest control in Australia: the role of non-crop habitats within landscapes. *Austral Entomology* **57**, 194–206.
Glatz RV, Leijs R & Hogendoorn K. 2015. Biology, distribution and conservation of green carpenter bee (*Xylocopa aeratus*: Apidae) on Kangaroo Island, South Australia. Technical Report, January 2015.
Greenslade P. 1996. Fuel reduction burning: is it causing the extinction of Australia's rare invertebrates? *Habitat April* **1996**, 18–19.
Greenslade P. 2007. The potential of Collembola to act as indicators of landscape stress in Australia. *Australian Journal of Experimental Agriculture* **47**, 424–434.
Greenslade P & Kitching RL. 2011. Potential effects of climate variability on the distribution of Collembola along an altitudinal gradient in Lamington National Park, Queensland Australia. *Memoirs of the Queensland Museum* **55**, 333–347.
Greenslade P & Driessen M. 1999. The effect of fire on epigeic arthropods in buttongrass moorland in Tasmania. In: *The Other 99%. The Conservation and Biodiversity of Invertebrates* (eds W Ponder & D Lunney), pp. 82–89. Transactions of the Royal Zoological Society of New South Wales, Mosman, NSW.
Greer G. 2013. Raiders of our unprotected parks. Life Style, *The Age*, p. 44. (9/11/2013), Melbourne.
Grove SJ & Stork NE 1999. The conservation of saproxylic insects in tropical forests; a research agenda. *Journal of Insect Conservation* **3**, 617–674.
Grove SJ, Meggs JM and Goodwin A. 2002. A review of biodiversity conservation issues relating to coarse woody debris in the wet eucalypt production forests of Tasmania. Technical Report No. 22. Forestry Tasmania, Hobart.
Gunther MJ & New TR. 2003. Exotic pine plantations in Victoria, Australia: a threat to epigaeic beetle (Coleoptera) assemblages? *Journal of Insect Conservation* **7**, 73–84.
Guzik MT, Adams MA, Murphy NP, Cooper SJB, Austin AD. 2012. Desert springs: deep phylogeographic structure in an ancient endemic crustacean (*Phreatomerus latipes*). *PLoS One* **7**, e37642.
Haelewaters D, Zhao SY, Clusella-Trullas S *et al*. 2017. Parasites of *Harmonia axyridis*, current research and perspectives. *BioControl* **62**, 355–371.
Harden GJ, McDonald WJF & Williams JB. 2007. *Rainforest Climbing Plants. A Field Guide to Their Identification*. Gwen Harden Publishing, Nambucca Heads, NSW.
Hayes CD. 1985. The pattern and ecology of *munwag*: traditional Aboriginal fire regimes in North-central Arnhemland. In: *Proceedings of the Ecological Society of Australia*, Vol. 13 (eds MG Ridpath & LK Corbett), pp. 203–214.
Heard T. 2016. *The Australian Native Bee Book*. Sugarbag Bees, West End, Queensland.
Hill CJ. 1997. Conservation corridors and rainforest insects. In: *Forests and Insects* (eds AD Watt, NE Stork & MD Hunter), pp. 381–393. Chapman and Hall, London.
Hogendoorn K & Leijs K. 2017. The diet width of Australian native bees. In: *Abstracts: Australian Entomological Society 48th AGM and Scientific Conference*, (ed Leigh Pilkington), p. 15, 17–20 September 2017, Terrigal NSW.
Holmes DR. 1966. The cruel plant. *Wings and Stings* **2**, 14–15.
Honan P. 2008. Notes on the biology, captive management and conservation status of the Lord Howe Island Stick Insect (*Dryococelus australis*) (Phasmatodea). *Journal of Insect Conservation* **12**, 399–413.
Howarth FG. 1991. Environmental impacts of classical biological control. *Annual Review of Entomology* **36**, 485–509.
Hughes L. 2000. Biological consequences of global warming: is the signal already? *Trees* **15**, 56–61.
Humphreys WF. 2001. Groundwater calcrete aquifers in the Australian arid zone: the context to an unfolding plethora of stygal biodiversity. *Records of the Western Australian Museum* **Supplement No.64**, 63–83.
Humphreys WF. 2017. Towards subterranean fauna conservation in arid Australia – realisation, establishment and consolidation. In: Systematics 2017, p. 82. *Integrating Systematics for Conservation and Ecology.* Proceedings of Joint meeting of the Society of Australian Systematic Biologists, the Australasian Systematic Botany Society, incorporating the Invertebrate Biodiversity and Conservation. Biennial Meeting. University of Adelaide, SA.
IUCN. 1993. *Guidelines for Protected Areas Management Categories*. IUCN Gland, Switzerland.
IUCN. 1996. *Red List of Threatened Animals*. Gland and Cambridge.
Jelinek A, Britton DR & New TR. 1994. Conservation of a threatened butterfly community. *Memoirs of the Queensland Museum* **36**, 115–120.
Johnson SJ & Wilson PR. 2005. A new subspecies of *Hesperilla crypsargyra* (Meyrick) (Lepidoptera, Hesperiidae) from southern Queensland and a new status for *Hesperilla hopsoni*. *The Australian Entomologist* **32**, 163–171.
Julien MH & Griffiths MW. 1998. *Biological Control of Weeds. A World Catalogue of Agents and Their Target Weeds*, 4th edn. CAB International, London.
Kearney M, Porter WP, Williams C, Ritchie S & Hoffmann AA. 2009. Integrating biophysical models and evolutionary theory to predict climatic

impacts on species' ranges: the dengue mosquito *Aedes aegypti* in Australia. *Functional Ecology* **23**, 528–538.

Key KHL. 1978. The conservation status of Australia's insect fauna. Australian National Parks and Wildlife Service, Occasional Paper No. 1, 1–24.

Lambkin TA. 2017a. *Papilio demoleus malayanus* Wallace, 1865 (Lepidoptera: Papilionidae) on Dauan Island, Torres Strait, Queensland and recent confirmation of P. D. Sthenelus Rosthchild, 1895 in the Lesser Sunda Islands. *The Australian Entomologist* **44**, 65–74.

Lambkin TA. 2017b. *Argyreus hyperbius inconstans* Butler, 1873 (Lepidoptera: Nymphalidae: Heliconiinae): a review of its collection history and biology. *Australian Entomologist* **44**, 223–268.

Larsen ML, Scriber JM & Zalucki MP. 2008. Significance of a new oviposition record for *Graphium eurypylus* (L.) (Lepidoptera: Papilionidae) on *Michelia champaca* (Magnoliaceae). *Australian Journal of Entomology* **47**, 58–63.

Legge S, Garnet S, Maute K *et al*. 2015. A landscape-scale applied fire management experiment promotes recovery of a population of the threatened Gouldian finch, *Erythrura gouldiae*, in Australia's tropical savannas. *Plos One* **10**, 1–27.

Leiper G, Glazebrook J, Cox D & Rathie K. 2008 (revised ed.). *Mangroves to Mountains*. Society for Growing Australian Plants. Browns Plains, Queensland.

Lindenmayer DB, Hobbs RJ, Likens GE, Krebs CJ & Banks SC. 2011. Newly discovered landscape traps produce regime shifts in wet forest. *PNAS* **108**, 15887–15891.

Loch AD & Walter GH. 1999. Multiple host use by the egg parasitoid *Trissolcus basalis* (Wollaston) in a soybean agricultural system: biological control and environmental implications. *Agricultural and Forest Entomology* **1**, 271–280.

Lundie-Jenkins G & Payne A. 2000. *Recovery Plan for the Bull Oak Jewel Butterfly (Hypochysops piceatus*) 1999–2003. Queensland Parks and Wildlife Service, Brisbane.

Macfadyen S, Parry H & Schellhorn N. 2015. Native plants that support beneficials in NSW. In: *Pest Suppressive Landscapes*. CSIRO, Brisbane.

Marks EM. 1969. The invertebrates. In: *The Last of Lands. Conservation in Australia* (eds IJ Webb, D Whitlock & G Brereton), pp. 102–114. Jacaranda Press, Milton.

Marks EM & Mackerras IM. 1972. The evolution of a national entomological society in Australia. *Journal of the Australian Entomological Society* **11**, 81–90.

Martin TG, Murphey H, Liedloff A *et al*. 2015. Buffel grass and climate change, a framework for projecting invasive species distributions when data are scarce. *Biological Invasions* **17**, 3197–3210.

Meggs JM & Munks SA. 2003. Distribution, habitat characteristics and conservation requirements of a forest-dependent threatened invertebrate *Lissotes latidens* (Coleoptera: Lucanidae). *Journal of Insect Conservation* **7**, 137–152.

Meyer CE, Brown SS, Knight AI & Brown AL. 2017. First record of *Taenaris catops turdula* Fruhstorfer, 1914 (Lepidoptera: Nymphalidae; Amathusiinae) from Dauan Island, Torres Strait, Queensland. *The Australian Entomologist* **44**, 25–28.

Milla L., Young DA, Jones TM, Kallies A & Hilton DJ. 2017. Exploring the possible co-evolution of *Boronia* (Rutaceae) and their pollinator moths (Heliozelidae, Lepidoptera), pp 66. In: Systematics 2017 – *Integrating Systematics for Conservation and Ecology.* Proceedings of the Australasian Systematic Botany Society & Society of Australian Systematic Biologists Conference and the Invertebrate Biodiversity and Conservation Biennial Meeting. 27–29 November 2017, Adelaide.

Moir ML, Vesk PA, Brennan KEC, Keith DA, Hughes L & McCarthy MA. 2010. Current constraints and future directions in estimating coextinction. *Conservation Biology* **24**, 682–690.

Moir ML, Vesk PA, Brennan KEC, Keith DA, McCarthy MA & Hughes L. 2011. Identifying and managing cothreatened invertebrates through assessment of coextinction risk. *Conservation Biology* **25**, 787–796.

Moran PJ & Goolsby JA. 2009. Biology of the galling wasp *Tetramesa romana*, a biological control agent of giant reed. *Biological Control* **49**, 169–179.

Moran PJ & Goolsby JA. 2010. Biology of the armored Scale *Rhizaspidiotus donacis* (Hemiptera, Diaspididae), a candidate agent for biological control of giant reed. *Environmental Entomology* **103**, 252–263.

Morcombe M. 1974. *Australia's National Parks*. Lansdowne Melbourne.

Moss JT. 2002. *Butterfly Host Plants of South-east Queensland and Northern New South Wales*. Butterfly and Other Invertebrates Club, Runcorn, Brisbane.

Moulds MS & Lachlan RB. 1987. The butterflies (Lepidoptera) of Christmas Island, Indian Ocean. *Australian Entomological Magazine* **14**, 57–66.

Nally SC. 2003. Community involvement in the conservation of the endangered purple copper butterfly, *Paralucia spinifera* Edwards & Common (Lepidoptera: Lycaenidae). In: *Invertebrate Biodiversity and Conservation. Special Issue* (eds AD Austin, DA Mackay & SJB Cooper), pp. 217–224. Records of the South Australian Museum, Monograph Series, Adelaide.

Nelson K & Sullivan TA (eds) 1992. New Federal Endangered Species Act for Australia, pp 8–9, Species. Newsletter of the Species Survival Commission IUCN – The World Conservation Union. No. 19, December 1992.

New TR. 1991a. The "doctors dilemma", or ideals, attitudes and compromise in insect conservation. *Journal of the Australian Entomological Society* **30**, 97–108.

New TR. 1991b. *Insects as Predators*. New South Wales University Press, Kensington.

New TR, ed. 1993. *Conservation Biology of Lycaenidae (Butterflies)*. IUCN, Gland, Switzerland.

New TR. 2005. *Invertebrate Conservation and Agricultural Ecosystems*. Cambridge University Press, Cambridge.

New TR. 2008. Legislative inconsistencies and species conservation status: understanding or confusion? The case of *Riekoperla darlingtoni* (Plecoptera) in Australia. *Journal of Insect Conservation* **12**, 1–2.

New TR. 2010. Butterfly conservation in Australia, the importance of community participation. *Journal of Insect Conservation* **14**, 305–311.

New TR. 2011. *Butterfly Conservation in South-eastern Australia, Progress and Prospects*. Springer, Dordrecht.

New TR. 2014. *Insects, Fire and Conservation*. Springer, Dordrecht.

New TR. 2016. *Alien Species and Insect Conservation*. Springer, Dordrecht.

New TR. 2017. *Mutualisms and Insect Conservation*. Springer, Dordrecht.

New TR. 2018. Promoting and developing insect conservation in Australia's urban environments. *Austral Entomology* **57**, 182–193.

New TR & Samways MJ. 2014. Insect conservation in the southern temperate zones: an overview. *Austral Entomology* **53**, 26–31.

New TR & Sands DPA. 2002a. Narrow-range endemicity and conservation status, interpretations for Australian butterflies. *Invertebrate Systematics* **16**, 665–670.

New TR & Sands DPA. 2002b. Conservation concerns for butterflies in urban areas of Australia. *Journal of Insect Conservation* **6**, 207–215.

New TR & Sands DPA. 2003a. Coordinated invertebrate surveys in Australia's National Parks, an important tool in refining invertebrate conservation management. *Records of the South Australian Museum Monograph* **Series No.7**, 203–207.

New TR & Sands DPA. 2003b. The listing and de-listing of invertebrate species for conservation in Australia. *Journal of Insect Conservation* **7**, 199–205.

New TR & Sands DPA. 2004. Management of threatened insect species in Australia, with particular reference to butterflies. *Australian Journal of Entomology* **43**, 258–270.

New TR & Yen AL. 1995. Ecological importance and invertebrate conservation. *ORYX* **29**, 187–191.

New TR, Van Praagh BD & Yen AL. 2010a. Fire and the management of habitat quality in an Australian lycaenid butterfly, *Paralucia pyrodiscus lucida* Crosby, the Eltham copper. *Metamorphosis* **11**, 154–163.

New TR, Yen AL, Sands DPA *et al*. 2010b. Planned fires and invertebrate conservation in south east Australia. *Journal of Insect Conservation* **14**, 567–544.

Noss RF. 1966. Protected areas, how much is enough? Chapter 6. In: *National Parks and Protected Areas, Their Role in Environmental Protection* (ed RG Wright), p. 470. Blackwell, Cambridge.

NPAQ 2017. Governments urged to eradicate fire ants to save ecosystem. *Bulletin of the National Parks Association of Queensland*, Issue 56, 15 May 2017. Brisbane.

O'Dowd DJ, Green PT & Lake PS. 2003. Invasion meltdown on an oceanic island. *Ecological Letters* **6**, 812–817.

Olsen P. 2007. *Glimpses of Paradise. The Quest for the Beautiful Parakeet*. National library of Australia, Canberra.

OOE. 2016. *Office of Environment*. Government, New South Wales.

Orr AG. 1994. Inbreeding depression in Australian butterflies: some implications for conservation. *Memoirs of the Queensland Museum* **36**, 179–184.

Parmesan C, Ryrholm N, Stefanescu C *et al*. 1999. Polewards shifts in geographical ranges of butterfly species associated with regional warming. *Nature* **399**, 579–583.

Parry H & Schellhorn N. 2015. *Grain Pests & Beneficials, Where Do They Come from? Pest Suppressive Landscapes*. CSIRO, Brisbane.

Parry H, Macfadyen S, Hopkinson JE *et al*. 2015. Plant composition modulates arthropod pest and predator abundance, evidence for culling exotics and planting natives. *Basic and Applied Ecology* **16**, 531–543.

Pedersen D. 2016. Growing bottom line. Economic boom as new trees flourish. *The Land* (No. 4875), September 29, 2016, p. 8.

Peters JV. 1969. The butterflies of Lord Howe Island. *Proceedings of the Royal Society of New South Wales* **1967–1968**, 63–64.

Pleasants JM, Zalucki MP, Oberhauser K *et al*. 2017. Interpreting measures of the size of the monarch butterfly population: pitfalls and prospects. *PLoS ONE* **12**, e0181245. https://doi.org/10.1371/journal.pone.0181245.

Raven PH & Yeates DK. 2007. Australian biodiversity, threats for the present, opportunities for the future. *Australian Journal of Entomology* **46**, 117–187.

Richter A, Sands DPA & Yen LA. 2009. (Abstract) Introduced invasive plants and rare insect species in Australia. *Proceedings of the International Congress on Biological Invasions*. Fuzhou, China 2–6 November 2009.

Robinson N. 2017. Science grounded in conservation. In: *Science for Saving Species*, p. 16. Canberra, Threatened Species Recovery Hub, Natural Environment Science Program.

Roitman M, Gardner MG, New TR, Nguyen Thuy TT, Roycroft EJ, Sunnucks P, Yen AL & Harrison KA. 2017. Assessing the scope for genetic rescue of an endangered butterfly: the case of the Eltham copper. Insect conservation and diversity. *The Royal Entomological Society, London*, pp 1–16.

Rossiter N, Setterfield SA, Douglas MM & Hutley LB. 2003. Testing the grass-fire cycle: alien grass invasion in the tropical savannas of northern Australia. *Diversity and Distributions* **9**, 169–176.

Russell TL, Kay B & Skilleter GA. 2009. Environmental effects of mosquito insecticides on saltmarsh invertebrate fauna. *Aquatic Biology* **6**, 77–90.

Russell-Smith J & Yates CP. 2007. Australian savanna fire regimes: context, scale, patchiness. *Fire Ecology* **3**, 48–63.

Saccheri I, Kuussaari M, Kankare M, Vikman P, Fortellus W & Iikka H. 1998. Inbreeding and extinction in a butterfly metapopulation. *Nature* **3921**, 491–494.

Samson PR. 1993. Illidge's ant-blue, *Acrodipsas illidgei* (Waterhouse and Lyell). In: *Conservation Biology of Lycaenidae (Butterflies)* (ed TR New), pp. 163–165. IUCN, Switzerland.

Samways MJ. 2005. *Insect Diversity Conservation*. UK, Cambridge.

Sands DPA. 1997. The 'safety' of biological control agents, assessing their impact on beneficial and other non-target hosts. *Memoirs of the Museum of Victoria* **56**, 611–616.

Sands DPA 1998. Guidelines for testing host specificity of agents for biological control of arthropod pests. In: *Proceedings of the 6th AAERC*. 29 Sept.–2 Oct. 1998, (eds Zalucki M.P., Drew R.A.I & White G.G.), pp. 556–560, Brisbane.

Sands DPA. 1999. Conservation and recovery of the Richmond birdwing butterfly, *Ornithoptera richmondia* and its lowland food plant, *Pararistolochia praevenosa*. In: Rainforest Recovery for the New Millennium (ed. BR Boyes), *Proceedings of the World Wide Fund for Nature 1998 South-East Rainforest Recovery Conference*, pp.124–132, WWF, Sydney.

Sands DPA. 2008. Conserving the Richmond birdwing butterfly over two decades. Where to next? *Ecological Management & Restoration* **9**, 4–16.

Sands DPA. 2012. Southern pink underwing moth *Phyllodes imperialis* H. Druce. In: *Queensland's Threatened Animals* (eds LK Curtis, AJ Dennis, K McDonald, PM Kyne & SJS Debus), pp. 38–39. CSIRO Publishing, Melbourne.

Sands DPA & Van Driesche R. 2000. Evaluating host specificity of agents for biological control of arthropods, rationale, methodology and interpretation. In: *Proceedings, Host Specificity Testing of Exotic Arthropod Biological Control Agents, the Biological Basis for Improvement in Safety*, July 4–14 1999, International Symposium on Biological Control of Weeds (eds RG Van Driesche, TA Heard, AS McClay & R Reardon), pp. 69–83X, Bozeman, USA Forest Service Bulletin, FHTET-99-1, Morgantown, West Virginia, USA.

Sands DPA & Hosking CJ. 2005. *Ecologically Sustainable Fire Management, an Advisory Code for Brisbane's Western Suburbs*, pp. 38. Moggill Creek Catchment Group, The Hut Environmental and Community Association and Pullen Pullen Catchments Group, Brisbane.

Sands DPA & New TR. 2002. *The Action Plan for Australian Butterflies*, p. 378. Environment Australia, Canberra and CD.

Sands DPA & New TR. 2003. Coordinated invertebrate surveys in Australia's national parks: an important tool in refining invertebrate conservation management. *Records of the South Australian Museum, Monograph Series* **7**, 203–207.

Sands DPA & New TR. 2008a. Irregular diapause, apparency and evaluating conservation status, anomalies from the Australian butterflies. *Journal of Insect Conservation* **12**, 81–85.

Sands DPA & New TR. 2008b. Conservation status and needs of butterflies (Lepidoptera) on the Torres Strait Islands. *Journal of Insect Conservation* **12**, 325–332.

Sands DPA & New TR. 2013. *Conservation of the Richmond Birdwing Butterfly in Australia*. Springer Dondrecht.

Sands DPA & Papacek D. 1993. Specificity requirements of exotic agents for biological control of arthropod pests. In: *Pest Control and Sustainable Agriculture* (eds SA Corey, DJ Dall & WM Milne), p. 495. CSIRO, Melbourne.

Sands DPA & Sands MC. 2017. Description of *Anisynta cynone anomala* ssp. n. (Lepidoptera: Hesperiidae) from the Northern Tablelands of New South Wales, with a discussion on its variation, sympatry with, and similarity to *A. tillyardi* Waterhouse and Lyell. *The Australian Entomologist* **44**, 89–102.

Sands DPA, Scott SE & Moffatt R. 1997. The threatened Richmond birdwing butterfly *Ornithoptera richmondia* (Gray): a community conservation project. *Memoirs of the Museum of Victoria* **56**, 449–453.

Sands DPA, Grimshaw P & Raghu S. 2015. Invasive flammable exotic grasses: increasing detrimental impacts on Australia's invertebrate biodiversity. In: Entomology Up North & to Asia Beyond, *The Australian Entomological Society 46th AGM and Scientific Conference*, p. 77. Cairns 27–30 September 2015.

Sands DPA, Grimshaw P & Sands MC. 2016. *Acacia melvillei* Pedley (Mimosaceae), a newly-recorded larval food plant for *Jalmenus eubulus* Miskin (Lepidoptera: Lycaenidae). *The Australian Entomologist* **44**, 89–102.

Satterfield SA, Rossiter-Rachor NA, Douglas MM *et al*. 2013. Adding fuel to the fire: the impacts of non-native grass invasion on fire management at a regional scale. *PLOS ONE* **8**, 1–10.

Schwarz MP & Hogendoorn K. 1999. Biodiversity and conservation of Australian bees. In: *The Other 99%. The Conservation and Biodiversity of Invertebrates* (eds W Ponder & D Lunney), pp. 388–393. Transactions of the Royal Zoological Society of New South Wales, Mossman.

Scriber JM, Larsen ML, Allen GR, Walker PW & Zalucki MP. 2008. Interactions between Papilionidae and ancient Australian Angiosperms; evolutionary specialization or ecological monophagy. *Entomologia Experimentalis et Applicata* **128**, 230–239.

Shreeve T & Dennis R. 2002. Ecological classification of butterflies: implications for conservation and mobility at the landscape scale. In: *Butterfly Conservation's 4th International Symposium*, 5–8 September 2002 (eds A Pullin & M Warren), p. 17. Lancaster University, UK.

Smith GB. 2015. A new Australian species of *Acrotelsella* (Zygentoma: Lepismatidae): could it be an endangered short range endemic? *Soil Organisms* **87**, 169–181.

Smithers CN. 1970. *Norfolk Island Butterflies*. Australian Entomological Press, Sydney.

Smithers CN. 1971. A note on Lord Howe Island butterflies. *Journal of the Australian Entomological Society* **10**, 299–300.

Smithers CN & Peters JV. 1969. The butterflies of Norfolk, Philip and Nepean Islands. *Australian Zoologist* **15**, 185–187.

Solodovnikov A & Shaw JJ. 2017. The remarkable rove beetle genus Myotyphlus: its cryptic diversity and significance for exploring mutualism among insects and mammals. *Austral Entomology* **56**, 311–321.

Stanisic J. 1996. New land snails from boggomoss environments in the Dawson Valley, southeastern Queensland (Eupulmonata: Charopidae and Camaenidae). *Memoirs of the Queensland Museum* **39**, 343–354.

Stanisic J & Ponder WF. 2004. Forest snails in eastern Australia – one aspect of the other 99%. In: *Conservation of Australia's Forest Fauna* (ed P Lunney), pp. 127–149. Royal Zoological Society of New South Wales, Mosman, NSW xiv +. 1073 pp.

Straatman R. 1962. Notes on certain Lepidoptera ovipositing on plants which are toxic to their larvae. *Journal of the Lepidopterists Society* **16**, 99–103.

Sutherst RW. 2003. Prediction of species geographical ranges. Guest Editorial. *Journal of Biogeography* **30**, 1–12.

Sutherst RW, Jones RJ & Schnitzerling HJ. 1982. Tropical legumes of the genus *Stylosanthes* immobilise and kill cattle ticks. *Nature* **295**, 320–321.

Sutherst RW, Maywald GF & Bourne AS. 2004. *CLIMEX Version 2, Users Guide*. Hearne Scientific Software Inc., Melbourne.

Sutherst RW, Maywald GF & Bourne AS. 2007. Including species interactions in risk assessments for global change. *Global Change Biology* **13**, 1843–1858.

Taylor RW. 1972. Biogeography of insects of New Guinea and Cape York Peninsula. In: *Bridge and Barrier: The Natural and Cultural History of Torres Strait* (ed D Walker), pp. 231–230. Australian National University, Canberra.

Taylor RW. 1983. Descriptive taxonomy: past, present and future. In: *Australian Systematic Entomology: A Bicentenary Perspective* (eds E Highley & RW Taylor), pp. 93–134. CSIRO, Melbourne, Australia.

Taylor GS, Braby MF, Moir ML *et al*. 2018. Strategic national approach for improving the conservation management of insects and allied invertebrates in Australia. *Austral Entomology* **57**, 124–149.

Torre-Bueno JR. De La1978. *A Glossary of Entomology.* New York Entomological Society, New York. 336 + 36 pp.

Tothill JC & Hacker JB. 1983. *The Grasses of Southern Queensland*. University of Queensland, Brisbane.

Tran C. 2009. Managing fire for biodiversity outcomes: the role of Southeast Queensland Fire and Biodiversity Consortium. *NPA News, National Parks Association of Queensland* **79**, 6–7.

Turner AJ. 1923. A lepidopterous scavenger living in parrots' nests. *Transaction of the Royal Zoological Society of London* **I & II**, 170–175.

Valentine PS. 2009. Protected areas, necessary but not sufficient. In: *Proceedings of the Australian Protected Area Congress 2008* (eds I Garven & S Monk), pp. 55–57. Australian Protected Area Congress 2008, 24-28 November 2008, Twin Waters, Qld, Australia.

Van der Pijil L & Dodson CH. 1966. *Orchid Flowers – Their Pollination and Evolution*. University of Miami, Coral Gables, Florida.

Van Driesche R & Reardon R, eds. 2004. *Assessing Host Ranges for Parasitoids and Predators Used for Classical Biological Control: A Guide To Best Practice*. Forest Health Technology Enterprise Team, US Forest Service & USDA, Morningtown, West Virginia.

Van Driesche R, Hoddle M & Centre T. 2008. *Control of Pests and Weeds by Natural Enemies. An Introduction to Biological Control*. Blackwell, Malden, MA.

Van Driesche RG, Carruthers RI, Center T *et al*. 2010. Classical biological control for the protection of natural ecosystems. *Biological Control* **54**, S2–S33.

Van Klinken RD, Panetta DF, Ross B & Wilson C. 2004a. A pain in the grass, what's the diagnosis? In: *Weed Management, Balancing People, Planet, Profit. Proceedings of the Fourteenth Australian Weeds Conference*, 6–9 September 2004 (eds. B.M. Sindel & S.B. Johnson), Pp. 480–483. Weed Society of New South Wales, Charles Sturt University, Wagga Wagga, New South Wales, Australia.

Van Klinken R, Panetta DF, Ross B & Wilson C. 2004b. *Learning from the Past to Predict the Future, an Historical analysis of grass invasions northern Australia*. *Biological Invasions*, Springer, Dondrecht.

Van Klinken RD, Panetta FD & Coutts SR. 2013. Are high-impact species predictable? An analysis of naturalised grasses in Northern Australia. *PLOS ONE* **8**, 1–11.

Walker B & Weston EJ. 1990. Pasture development in Queensland – a success story. *Tropical Grasslands* **24**, 257–268.

Waterhouse DF & Sands DPA. 2001. *Classical Biological Control of Arthropods in Australia*. ACIAR Monograph No 77, p. 559. Canberra, ACIAR.

Williams JB & Hunter JT. 2006. *Boronia boliviensis* (Rutaceae series Erianthae), a new rare granite outcrop endemic from north-eastern New South Wales. *Telopea* **11**, 260–264.

Williams WJ, Eldridge DJ & Alchin BM. 2008. Grazing and drought reduce cyanobacterial soil crusts in an Australian woodland. *Journal of Arid Environmets* **72**, 1064–1075.

Williams AAE, Williams MR, Edwards ED & Coppen RAM. 2016. The sun-moths (Lepidoptera, Castniidae) of Western Australia, an inventory of extent of occurrence, larval food plants, habitat, behaviour, seasonality and conservation status. *Records of the Western Australian Museum* **31**, 90–162.

Wilson PR & Johnson IR. 2017. Five new butterfly life histories (Lepidoptera) from Christmas Island. *Australian Entomologist* **44**, 181–195.

Woinarski JCZ, Armstrong M, Brennan K *et al*. 2010. Monitoring indicates rapid and severe decline of native small mammals in Kakadu National Park, northern Australia. *Wildlife Research* **37**, 116–126.

Yen AL & New TR. 2013. Scientists, agencies and community working together: a key need for invertebrate conservation in Victoria. *The Victorian Naturalist* **130**, 165–173.

York A. 1999. Long-term effects of frequent low-intensity burning on the abundance of litter-dwelling invertebrates in coastal blackbutt forests of south eastern Australia. *Journal of Insect Conservation* **3**, 191–199.

Zalucki MP, Day MD & Playford J. 2007. Will biological control of *Lantana camara* ever succeed? Patterns, processes and prospects. *Biological Control* **42**, 251–261.

Zborowski P & Edwards E. 2007. *A Guide to the Australian Moths*. CSIRO Melbourne.

Zylstra P. 2016. New modelling on bushfires shows how they really burn through an area. *The Conversation*, August 22, 2016.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

Table S1 Unpublished observations by the author and others.
Appendix S1 Examples of community engagement in insect conservation in Australia.