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Review

Strategic national approach for improving the conservation management of insects and allied invertebrates in Australia

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Abstract

Despite progress in recent decades, the conservation management of insects and allied invertebrates in Australia is challenging and remains a formidable task against a background of poor taxonomic and biological knowledge, limited resources (funds and scientific expertise) and a relatively low level of community engagement, education and awareness. In this review, we propose a new, strategic national approach for the conservation of insects and allied invertebrates in Australia to complement and build on existing actions and increase awareness with the general public and government. A review of all species listed under relevant State and Territory Acts, national legislation (*EPBC Act*) and on international lists (IUCN Red List) indicated that of the 285 species currently listed under these conservation schedules, 10 (3%) are considered extinct, 204 (72%) threatened (Critically Endangered, Endangered or Vulnerable) and 71 (25%) are classified as other (Threatened, Near Threatened, Rare or Least Concern). Comparison of the geographic ranges of listed species in relation to bioregions (IBRA regions) shows a striking discordance in spatial representation across the Australian landscape, reflecting an *ad hoc* approach to threatened species conservation and the concentration of invertebrate biologists in urban centres of temperate coastal Australia. There is a positive relationship between the number of threatened species and extent of protection according to the National Reserve System within each IBRA region, exemplifying the anomaly in spatial representativeness of listed species. To overcome these shortfalls, we propose a novel educational, regional approach based on selecting, for each of the 89 IBRA

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regions, a relatively small set of 'flagship taxa' (threatened species and/or 'iconic' species of high scientific/social value), which are then promoted and/or nominated for listing by the scientific community. Such species could be adopted by local community groups whereby a community based regional approach would ensure spatial representativeness of insect conservation across the entire Australian continent. This novel approach may ultimately provide a better strategy for the conservation management of habitats and threatened ecological communities, reducing extinction risk of threatened species and addressing key threatening processes. Members of the Australian entomological community are strongly encouraged to nominate candidate taxa as flagship species for wider promotion and/or listing nationally under the *EPBC Act*.

Key words bioregion, community engagement, *EPBC Act*, flagship species, IBRA region, insect conservation, IUCN Red List, key threatening process, legislation, threatened species.

INTRODUCTION

> *The proper conservation and management of Australia's native flora and fauna is a matter of high priority in the face of the increasing threats to their wellbeing ... if only a fraction of the funding devoted to space exploration, to sports sponsorships, or to weapons research is devoted to biodiversity conservation, we would go a long way towards solving the knowledge gaps of our invertebrate fauna.*
>
> *Yen & Butcher, 1997*

Insects and allied invertebrates are the most numerous and di verse organisms in terrestrial and freshwater environments, and they play critical roles in ecosystem health and function (e.g. pollination, herbivory, nutrient cycling, predation/para sitism and food for vertebrates). The need to conserve these or ganisms and the ecological processes that they perform 'the little things that run the world' (Wilson 1987) is now widely recognised internationally (New & Yen 2012; Samways 2005; Wilson 1987).

General concerns over the decline and conservation of in sects in Australia were first raised by Day (1965), Marks (1969) and Marks and Mackerras (1972). These early papers led to three influential publications by Key (1978), New (1984) and Hill and Michaelis (1988), which have done much to advance and promote the field of insect conservation among the wider Australian entomological community during the past three decades (see Braby & Williams 2016; Clarke & Spier Ashcroft 2003; Cranston 2010; Greenslade & New 1991; New & Samways 2014; Raven & Yeates 2007; Sands & New 2002; Yen & Butcher 1997 for reviews). The main drivers behind this accelerated research agenda are three fold: the realisation: (1) that the biodiversity of Australia insects and allied invertebrates is substantial, highly endemic and characterised by numerous ancient lineages, relicts and evolu tionary radiations (Andersen 2016; Austin *et al*. 2003, 2004; Cranston 2010; Raven & Yeates 2007; Taylor 1972); (2) that much of this biodiversity is still undocumented (Hutchings 2017; Yeates *et al*. 2003) and (3) that the extant fauna is under increasing stress and likely to be disappearing rapidly in the face of a multitude of key threatening processes, including hab itat loss for agriculture, invasive species, urbanisation and cli mate change (Cranston 2010; New 2018; New & Samways 2014; Raven & Yeates 2007; Rix *et al*. 2017a,b; Sands 2018) (see also Tables S1, S2).

Despite substantial progress in recognition of insect conser vation as a field of science, with considerable attention towards recognition of short range endemics (Harvey 2002; Harvey *et al*. 2011; New & Sands 2002), status evaluation and recovery of threatened species (Braby 2018; New 2009), protocols for inventory and monitoring programs (Braby & Williams 2016; Kitching *et al*. 2001), and the use of insects as bioindicators in ecological restoration (Andersen 1999; Andersen & Majer 2004; Andersen *et al*. 2004; Barton & Moir 2015; Grimbacher *et al*. 2008; Majer *et al*. 2007; Nakamura *et al*. 2007), challenges to practical insect conservation and management remain formi dable (Cardoso *et al*. 2011; New & Samways 2014; New & Yen 2013; Yen & Butcher 1997). Basically, terrestrial insects and allied invertebrates in Australia are highly impacted by all seven major impediments to invertebrate conservation the pub lic dilemma, political dilemma, scientific dilemma, Linnean shortfall, Wallacean shortfall, Prestonian shortfall and Hutchinsonian shortfall (Cardoso *et al*. 2011). These impedi ments mean that insects and allied invertebrates are often ex cluded from traditional conservation management practices currently employed in Australia.

Two complementary approaches to address these challenges, discussed in an Australian context by New (1984) and Yen and Butcher (1997), are the habitat approach (or 'coarse filter' approach) and the species approach (or 'fine filter' approach). Conservation of a species' habitat is of fundamental importance, and this approach essentially aims to protect ecological (plant) communities or areas for nature conservation (e.g. through National Parks, nature reserves, wildlife sanctuaries, environ mental parks, scientific or special purpose reserves). A limitation with this approach is that defining habitat needs for many terres trial insects and allied invertebrates is difficult because of scale and dependency on factors other than vegetation (e.g. substrate). Moreover, most conservation reserves are set aside for other biodiversity values (e.g. vertebrates and vascular plants), and the assumption that the great majority of insects will be con served automatically, while true to some extent, may not always hold (Moir *et al*. 2014, 2015, 2016). Issues with size, shape, fragmentation and isolation (extent of corridors or smaller patches between reserves) and extent of buffers of habitat patches in order for insects to persist are also often unknown (New 1984). In the Northern Hemisphere, many countries have well documented insect and allied invertebrate faunas and are, therefore, far ahead of Australia in regard to invertebrate conservation; they often have long term datasets that can highlight diversity hotspots (Fox *et al*. 2014; Gillingham *et al*. 2012) and reveal declines or changes in insect species composition, relative abundance or geographic range (Goulson *et al*. 2008; Habel *et al*. 2016; Hallmann *et al*. 2017; Ollerton *et al*. 2014; Parmesan *et al*. 1999). The availability of such comprehensive datasets means that insects can be included in conservation triage decisions (e.g. see Ratcliffe 1977), which is yet to be implemented in Australia because of lack of basic knowledge on insect diversity and status (Walsh *et al*. 2013). A broad scale national inventory is thus required to determine what Australia's insect biodiversity assets are and how they are distributed spatially (diversity hotspots, centres of endemism, evolutionary refugia etc.) to inform reserve design and optimisa tion of resources for conservation management this need is currently being addressed in part by the Commonwealth Bush Blitz nature discovery program [http://www.environment.gov.au/science/abrs/bushblitz].

At the species level, Braby (2018) identified two broad approaches that could be adopted to improve the conservation management of threatened insects and allied invertebrates in Australia: (1) preparation of national Action Plans for higher taxonomic groups to determine which species are at risk of extinction and ought to be considered for nomination and listing and (2) preparation of national Action Plans for 'indicator' species that are symptomatic of key threatening processes and/or threatened ecological communities, habitats and biomes in urgent need of protection, conservation management or eco logical restoration.

A third, complementary approach is to increase public aware ness, advocacy and promotion of species through effective com munication and community participation (Moir *et al*. 2015; New 2018; New & Samways 2014; Sands & New 2013; Yen & New 2013). One possibility of this educational approach is to promote a relatively small set (c. 5 10) of 'flagship' species (threatened species and/or species of high scientific/social value) (Fig. 1) through local communities comprising a diverse array of stakeholders (e.g. scientists, government agencies, non government organisations (NGOs), citizen scientists and Indigenous groups) in different geographical regions so that taxa are represented in each of the various bioregions and ecological communities of the country. Such a community based landscape approach would engender spatial representativeness of insect conservation across the Australian continent.

Here, we explore this educational, regional concept further, which we believe will provide a more strategic framework for the conservation management of insects and allied invertebrates. Essentially, the main components of this approach involve the utilisation of geographical areas at the bioregional scale, which form the basis for the selection of flagship species that inform wider community engagement through nomination and listing (of threatened species) and/or promotion by the scientific com munity and media (of high scientific/social value species) (Fig. 2). We are not advocating that this approach displace any other species level approaches to insect conservation, rather we see the regional flagship species approach through community engagement as an additional strategy for conservation. We also provide an overview of all listed species in each State and Territory under the relevant State/Territory, national and interna tional Acts or lists, and highlight major shortcomings with these conservation schedules.

In providing a platform for the strategic nomination of flagship species of insects and allied invertebrates across the Australian landscape, we include here the Insecta (insects), Entognatha (Collembola, Diplura, Protura), Arachnida (spiders, scorpions, mites and allies), Myriapoda (centipedes, millipedes and allies), some Crustacea (freshwater and terrestrial Amphipoda, Copepoda, Isopoda (woodlice) and Ostracoda (seed shrimps)), and Onychophora (velvet worms). That is, those taxa that may be considered for publication in *Austral Entomology*. Whilst it is recognised that terrestrial Mollusca, Annelida, Nematoda and others have an immense, largely unknown diversity and undocumented ecology, and complementary conservation management issues, these groups are beyond the scope of the Australian Entomological Society Conservation Committee (AESCC).

BIOREGIONS

Bioregional classifications of the Australian landscape (reviewed by Ebach 2012) were developed from the earlier and simpler construct of the Torresian, Eyrean and Bassian subregions (Spencer 1896) and subsequent refinements (e.g. Burbidge 1960). More recently, based on a comprehensive analysis of eco logical communities, the Interim Biogeographic Regionalisation for Australia (IBRA) was developed in 1993 1994 (Thackway & Creswell 1995). With subsequent revisions, this classification now comprises 89 bioregions (Fig. 3a, Table 1) further refined to 419 subregions (IBRA7; Australian Government 2017a). This classification is endorsed by all levels of government as a key planning framework to identify and provide a scientific basis to inform priorities towards the long term protection of Australia's biodiversity through its National Reserve System (Natural Resource Management Ministerial Council (NRMMC) 2010). The National Reserve System aims to develop a 'comprehen sive, adequate and representative' system of protected areas commonly referred to as the 'CAR' system (Australian Government 2017a). This system aims to include examples of regional scale ecosystems in each bioregion ('comprehensive ness'), sufficient areas of each ecosystem within each bioregion to provide ecological viability and to maintain the integrity of populations, species and communities ('adequacy'), and the inclusion of areas at a finer scale, to encompass the variability of habitat within ecosystems ('representativeness') in the National Reserve System (Australian Government 2017a). Following these objectives, the Australian Government aims to protect 17% of the terrestrial environment under its National Reserve System by prioritising under represented bioregions that have less than 10% of their remaining area protected in reserves. Based on the IBRA bioregional classification, a con siderable proportion of the Australian continent remains under represented (Fig. 3c).

Most recently, a classification under the Australian Biore gional Atlas (ABA) was derived from a comprehensive

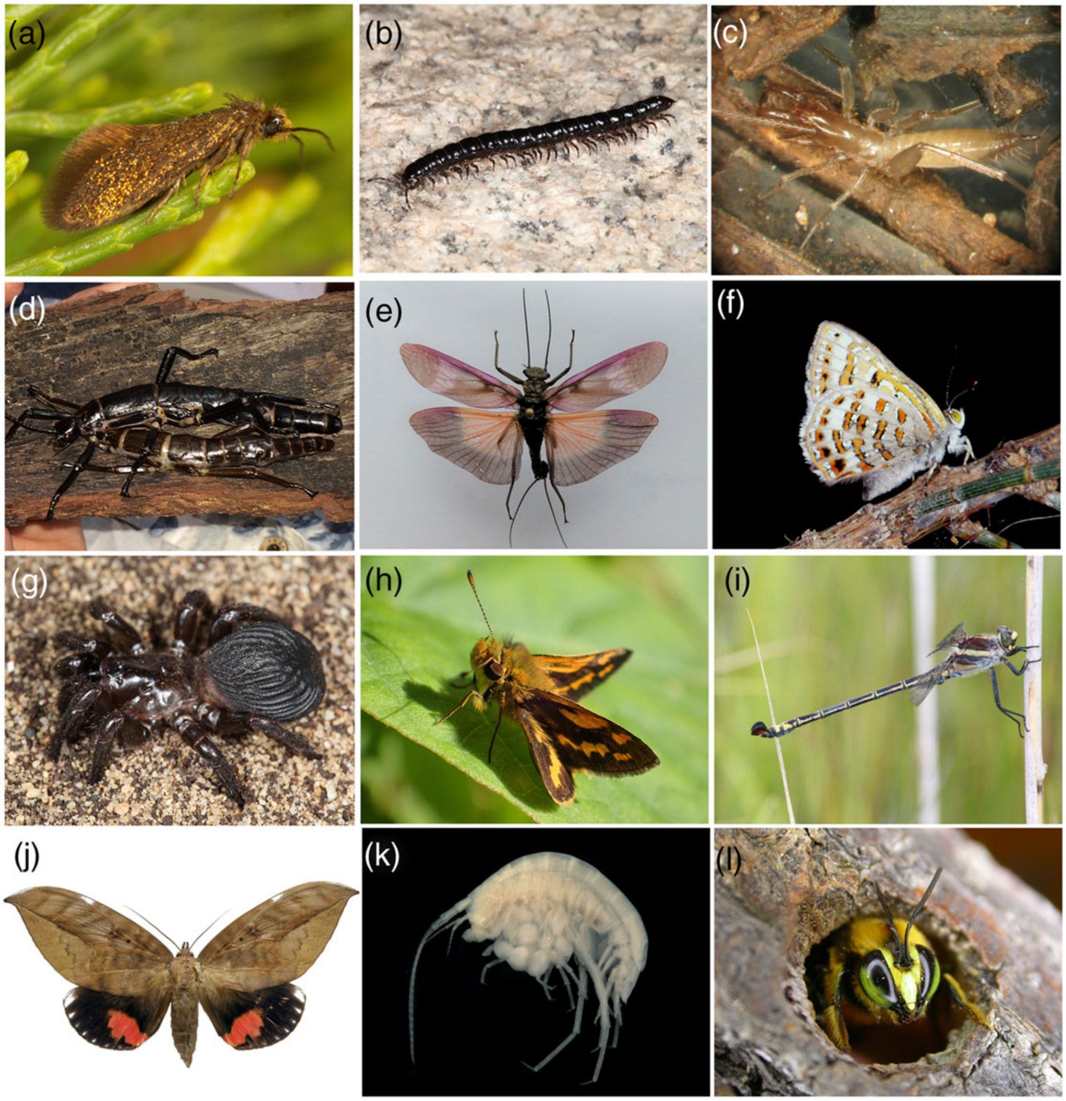

Fig. 1. Examples of insects and allied invertebrates that are under threat and of conservation concern: (a) *Aenigmatinea glatzella* Enigma moth from Kangaroo Island, SA (Image: George Gibbs); (b) an undescribed species of *Antichiropus* millipede from the WA Wheatbelt (Image: Mark Harvey); (c) the schizomid *Draculoides bramstokeri* from Barrow Island, WA (Image: Mark Harvey); (d) *Dryococelus australis* Lord Howe Island Phasmid, NSW (Image: Phil Weinstein); (e) the stonefly *Eusthenia spectabilis* from alpine Tasmania (Image: Shasta Henry); (f) *Hypochrysops piceatus* Bulloak Jewel Butterfly, QLD (Image: Don Sands); (g) the trapdoor spider *Idiosoma nigrum* from the WA wheatbelt, the only *EPBC Act* listed spider (Image: Mark Harvey); (h) *Ocybadistes knightorum* Black Grass dart Butterfly from Sawtell, NSW (Image: Mick Andren); (i) the dragonfly *Petalura litorea* Coastal Petaltail in Bongil NP, NSW (Image: Mick Andren); (j) *Phyllodes imperialis smithersi* Pink Underwing Moth, QLD (Image: Don Sands); (k) *Scutachiltonia axfordi* (female with eggs), monotypic genus endemic to a single aquifer in the Sturt Meadows calcrete near Leonora, WA (Image: Rachael King); (l) *Xylocopa aeratus* Green carpenter bee, Kangaroo Island, SA (Image: Remko Leijs). [Colour figure can be viewed at wileyonlinelibrary.com]

phylogenetic analysis of plant communities. González Orozco *et al*. (2014) defined six phytogeographical regions, reduced to five regions (and 21 subregions) by Ebach *et al*. (2015).

Internationally, Myers *et al*. (2000) proposed a number of global diversity hotspots based principally on floral uniqueness and levels of threat. Myers' original 10 locations include only one Australian example the floral province of the extreme south west. Their original 'hotspots' were subsequently upgraded in a series of further analyses culminating in the 35 recognised by Conservation International (2017). Stimulated by this approach, and overlaying these ABA regions with the IBRA regions, the Australian Government's Threatened Species Scientific Committee (TSSC) in 2003 defined 15 National Biodiversity Hotspots' (Fig. 3b). An aggregate of these local Biodiversity Hotspots occur in south western WA. This aggregate, collectively known as 'Southwest Australia', together with the 'Forests of East Australia', coincide with those recognised internationally by Conservation International as a subset of 35 biodiversity hotspots globally (Conservation International 2017). At a finer scale, and generally at a sub bioregional

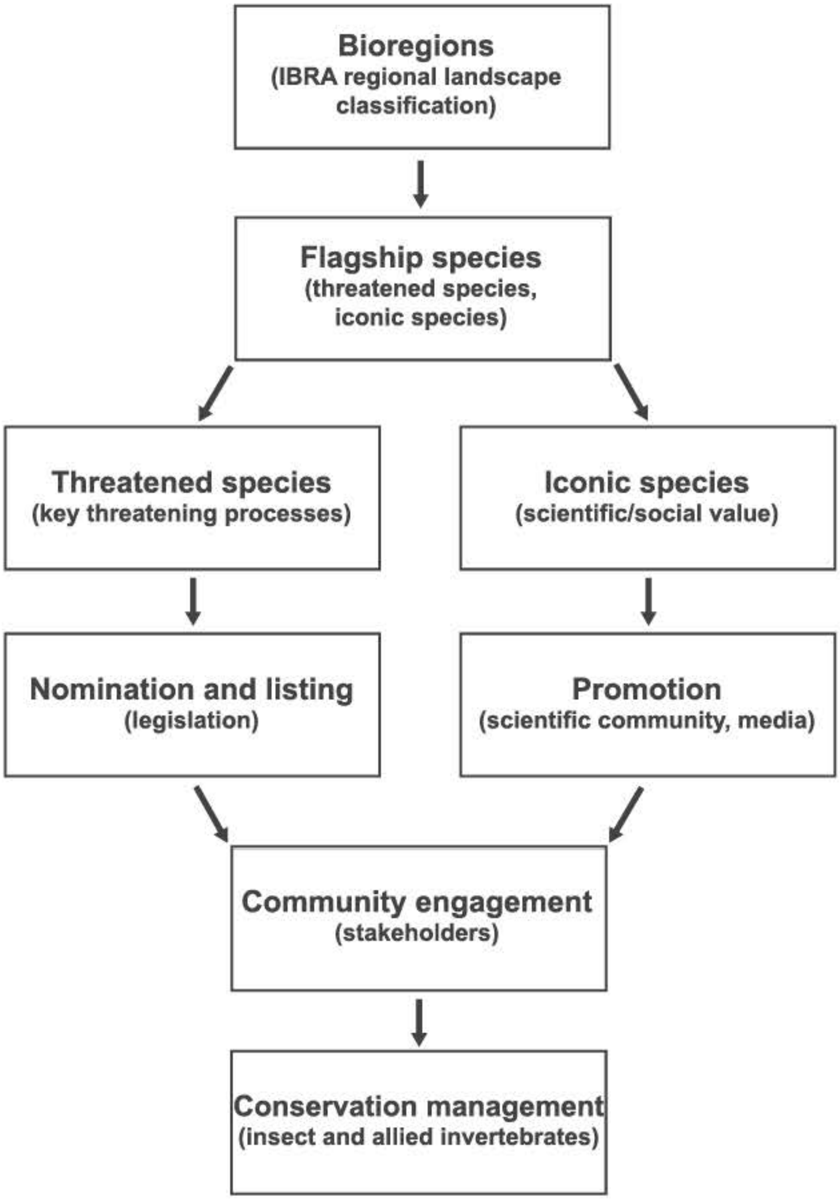

Fig. 2. Strategic framework for the conservation management of Australian insects and allied invertebrates adopted in this paper.

(IBRA) level, the Commonwealth *Environmental Protection and Biodiversity Conservation 1999 Act* (*EPBC Act*) recognises 79 threatened ecological communities within Australia. Of these, 35 are designated as Critically Endangered, 42 Endangered and two Vulnerable (see http://www.environment.gov.au/cgi bin/sprat/public/publicreports.pl). Similarly, various State Acts list threatened ecological communities applicable to each State and largely identifiable within one particular IBRA region some of which are recognised by the *EPBC Act*. For example, in WA, the State Government recognises 69 ecological communities as threatened. Of these, 21 are designated as Critically Endangered, 17 Endangered, 28 Vulnerable and three presumed extinct. Thirty one of these are also listed under the *EPBC Act* (Western Australia Department of Parks and Wildlife 2016).

Here, for the conservation of insect and allied invertebrates, we consider bioregional classifications other than IBRA regions are either too coarse (i.e. too few in number to adequately represent the Australian landscape) or too fine (i.e. too many in number). For example, the 419 IBRA subregions are considered impractical for comprehensive spatial representation, while the listings under State/Territory conservation schedules and the *EPBC Act* of threatened ecological communities may variably be considered too broad or too fine across the landscape for any realistic spatial nomination of representative insect and allied invertebrate species (see Australian Government 2018).

FLAGSHIP SPECIES

'Flagship species' in insect conservation are those taxa that engender substantial public attention and advocacy (Samways 2005). They are often relatively large or highly conspicuous; as such, these species perform a valuable role in biodiversity

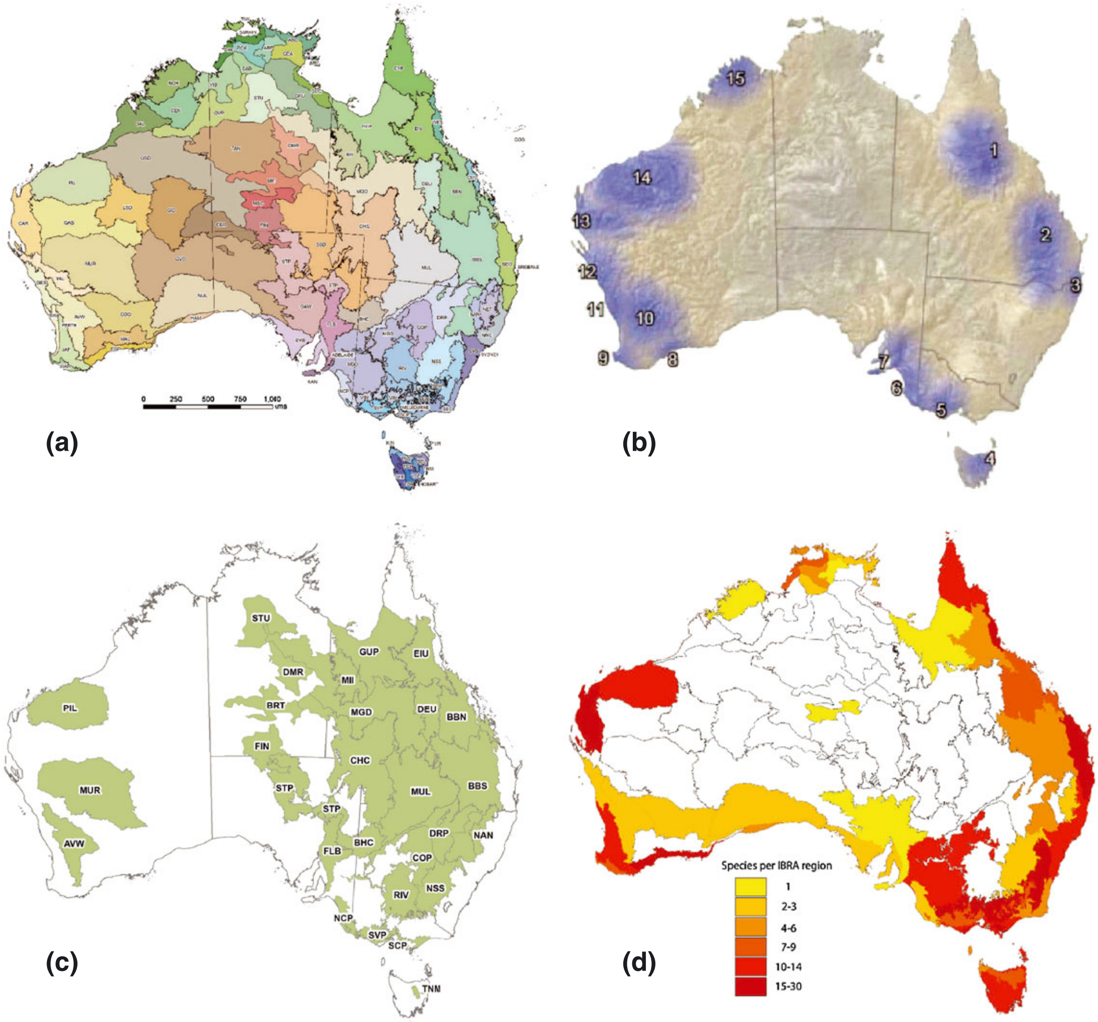

Fig. 3. Maps of Australia depicting: (a) Interim Biogeographic Regionalisation (Version 7, 2012) showing the 89 regions (see Table 1 for acronyms) (© Commonwealth of Australia: https://environment.gov.au/land/nrs/science/ibra); (b) National Biodiversity Hotspots showing the 15 regions: (1, Einasleigh and Desert Uplands (QLD); 2, Brigalow North and South (QLD, NSW); 3, Border Ranges North and South (QLD, NSW); 4, Midlands of Tasmania (TAS); 5, Victorian Volcanic Plain (VIC); 6, South Australia's South East/Victoria's South West (VIC); 7, Mt Lofty/Kangaroo Island (SA); 8, Fitzgerald River Ravensthorpe (WA); 9, Busselton Augusta (WA); 10, Central and Eastern Avon Wheatbelt (WA); 11, Mount Lesueur Eneabba (WA); 12, Geraldton to Shark Bay sand plains (WA); 13, Carnarvon Basin (WA); 14, Hamersley Pilbara (WA); 15, North Kimberley (WA)) (© Commonwealth of Australia: http://www.environment.gov.au/biodiversity/conser vation/hotspots/national biodiversity hotspots); (c) National Reserve System showing IBRA regions that are under represented with less than 10% protection (© Commonwealth of Australia: http://www.environment.gov.au/land/nrs/science/ibra/australias bioregions maps); (d) heat map showing spatial representation of listed insect and allied invertebrates in relation to IBRA regions. [Colour figure can be viewed at wileyonlinelibrary.com]

conservation because of the public interest they generate. In this respect, they act in ways that their myriads of small, hard to recognise and little known relatives simply do not res onate with the general public. Flagship species may include threatened species at risk of extinction or iconic species of im portant scientific or social value. Scientifically, they may be relictual, phylogenetically isolated, ecologically important or distinctive in other, more or less appealing, ways. Socially, they may have aesthetic value, be particularly appealing to the media, of cultural importance, have economic impact or particular tourism values. These categories are not necessarily mutually exclusive a flagship species may be both threatened and iconic (i.e. of scientific and/or social importance). As such, flagship species can be used as 'ambassadors' to raise broader awareness of the biological importance of insects and their conservation needs or to promote threatened ecological com munities or habitats in need of conservation action (Braby 2018; New 2009; Yen & Butcher 1997).

Notable examples of threatened flagship insect species in Australia are primarily Lepidoptera, such as the large saturniid Atlas Moth *Attacus wardi* in northern Australia (Braby 2014; Braby & Nielsen 2011), Papilionidae (e.g. Richmond Birdwing *Ornithoptera richmondia*) (Sands & New 2013) and species of Lycaenidae (blues, e.g. Eltham Copper *Paralucia pyrodiscus lucida*) (New 2011, 2018). There are several other examples (see Threatened Species below), such as the Ancient Greenling

Table 1 Number of listed insects and allied invertebrate species in each Australian IBRA region

Acronym	IBRA Bioregion	State/s	Number of species
ARC	Arnhem Coast	NT	2
ARP	Arnhem Plateau	NT	1
AUA	Australian Alps	NSW, ACT, VIC	8
AVW	Avon Wheatbelt	WA	3
BBN	Brigalow Belt North	QLD	7
BBS	Brigalow Belt South	QLD, NSW	6
BEL	Ben Lomond	TAS	9
BHC	Broken Hill Complex	NSW, SA	0
BRT	Burt Plain	NT	0
CAR	Carnarvon	WA	24
CEA	Central Arnhem	NT	0
CEK	Central Kimberley	WA	0
CER	Central Ranges	WA, NT, SA	0
CHC	Channel Country	NT, QLD, NSW, SA	0
CMC	Central Mackay Coast	QLD	7
COO	Coolgardie	WA	3
COP	Cobar Peneplain	NSW	0
COS	Coral Sea	QLD	0
CYP	Cape York Peninsula	QLD	13
DAB	Daly Basin	NT	2
DAC	Darwin Coastal	NT	9
DAL	Dampierland	WA	0
DEU	Desert Uplands	QLD	0
DMR	Davenport Murchison Ranges	NT	0
DRP	Darling Riverine Plains	QLD, NSW	0
EIU	Einasleigh Uplands	QLD	4
ESP	Esperance Plains	WA	30
EYB	Eyre Yorke Block	SA	2
FIN	Finke	NT, SA	0
FLB	Flinders Lofty Block	SA	1
FUR	Furneaux	TAS	10
GAS	Gascoyne	WA	0
GAW	Gawler	SA	1
GES	Geraldton Sandplains	WA	3
GFU	Gulf Fall and Uplands	NT, QLD	0
GID	Gibson Desert	WA	0
GSD	Great Sandy Desert	WA, NT	0
GUC	Gulf Coastal	NT	0
GUP	Gulf Plains	NT, QLD	1
GVD	Great Victoria Desert	SA, WA	0
HAM	Hampton	SA, WA	5
ITI	Indian Tropical Islands	WA	0
JAF	Jarrah Forest	WA	10
KAN	Kanmantoo	SA	1
KIN	King	TAS	5
LSD	Little Sandy Desert	WA	0
MAC	MacDonnell Ranges	NT	1
MAL	Mallee	WA	0
MDD	Murray Darling Depression	VIC, SA	14
MGD	Mitchell Grass Downs	QLD, NT	0
MII	Mount Isa Inlier	QLD, NT	0
MUL	Mulga Lands	QLD, NSW	0
MUR	Murchison	WA	0
NAN	Nandewar	NSW, QLD	0
NCP	Naracoorte Coastal Plain	SA, VIC	3
NET	New England Tablelands	QLD, NSW	4
NNC	NSW North Coast	NSW	12
NOK	Northern Kimberley	WA	1
NSS	NSW South Western Slopes	NSW	4
NUL	Nullarbor	SA, WA	2
OVP	Ord Victoria Plain	WA, NT	0
PCK	Pine Creek	NT	4
PIL	Pilbara	WA	12

Table 1 (Continued)

Acronym	IBRA Bioregion	State/s	Number of species
PSI	Pacific Subtropical Islands	NSW	4
RIV	Riverina	NSW, VIC	0
SAI	Subantarctic Islands	TAS	0
SCP	South East Coastal Plain	VIC	13
SEC	South East Corner	NSW, VIC	6
SEH	South Eastern Highlands	NSW, ACT, VIC	21
SEQ	South Eastern Queensland	QLD, NSW	19
SSD	Simpson Strzelecki Dunefields	SA, NT, QLD, NSW	0
STP	Stony Plains	SA	0
STU	Sturt Plateau	NT	0
SVP	Southern Volcanic Plain	VIC, SA	9
SWA	Swan Coastal Plain	WA	12
SYB	Sydney Basin	NSW	14
TAN	Tanami	WA, NT	0
TCH	Tasmanian Central Highlands	TAS	13
TIW	Tiwi Cobourg	NT	4
TNM	Tasmanian Northern Midlands	TAS	7
TNS	Tasmanian Northern Slopes	TAS	7
TSE	Tasmanian South East	TAS	14
TSR	Tasmanian Southern Ranges	TAS	14
TWE	Tasmanian West	TAS	10
VIB	Victoria Bonaparte	WA, NT	0
VIM	Victorian Midlands	VIC	20
WAR	Warren	WA	9
WET	Wet Tropics	QLD	27
YAL	Yalgoo	WA	0

Damselfly *Hemiphlebia mirabilis* (Yen *et al*. 1990) and the rediscovered giant Lord Howe Island Stick Insect *Dryococelus australis* (Tulloch & Cleave 2015), but these non Lepidoptera examples are far fewer in numbers.

In addition, there are flagship species that have important scientific value and have received substantial media/public at tention. The Green tree or Weaver Ant *Oecophylla smaragdina* (Hymenoptera: Formicidae) is a keystone species which has developed numerous obligatory ecological interac tions with lycaenid butterflies (Eastwood & Fraser 1999) and forms impressive arboreal nests in northern Australia (Ander sen 2000). The bizarre Cooloola Monster *Cooloola propator* and related monsters (Orthoptera: Cooloolidae) are evolution arily and biologically distinct (Rentz 1980) have garnered sub stantial attention. In addition, the recently discovered Enigma moth *Aenigmatinea glatzella* (Lepidoptera: Aenigmatineidae), a relictual species from Kangaroo Island, SA, that represents an entirely new extant family of homoneurous moths (Kristensen *et al*. 2015) has become increasingly important as a flagship species.

Flagship species with high social value include the spectac ular Leichhardt's Grasshopper *Petasida ephippigera* (Orthop tera: Pyrgomorphidae), which has cultural significance among Indigenous peoples of the Northern Territory (Ander sen *et al*. 2014; Lowe 1995; Wilson *et al*. 2003). The ant *Oecophylla smaragdina* noted above is also significant cultur ally as an important source of food and/or medicine, and the Honey pot Ants (e.g. *Camponotus inflatus*) as a food in cen tral Australia (Rastogi 2011). Some flagship species have achieved their status purely because of the enormous public attention they have received. Males of the giant jewel beetle *Julodimorpha bakewelli* (Coleoptera: Buprestidae) attempting to copulate with beer bottles (Gwynne & Rentz 1983), the striking courtship behaviour of the spectacular peacock spiders *Maratus* spp. (Otto & Hill 2012) and the Kangaroo Island trapdoor spider *Moggridgea rainbowi* that was recently shown to have originated from Africa and spread to the Kangaroo Is land region by trans oceanic dispersal (Harrison *et al*. 2016) all fall into this category. In the case of *Julodimorpha bakewelli*, the paper by Gwynne and Rentz (1983), aptly enti tled 'Beetles on the bottle …', has the highest downloads of any paper published by the Australian Entomological Society, with 19 953 downloads since 2010 soon after it became avail able online, and it won the whimsical IgNobel prize in Biol ogy in 2011.

The prominence of these (and other) flagship species de pends substantially upon the scientific community. Only when information about each species has an established scientific foundation (i.e. documentation in the scientific literature) are they available as 'flagships'. More importantly, however, they only achieve this status when members of the scientific commu nity engage with the media and the general public leading to the wide publicity needed for them to become effective in the promotion of insect and allied invertebrate conservation (and, indeed, science in general). In the examples highlighted above, extensive publicity was only possible because of an established scientific foundation (i.e. published peer reviewed papers) and a willingness of the scientists to raise the profile of these species through the media, online and through public seminars and displays.

NOMINATION, LISTING AND LEGISLATION

The key steps involved in the conservation management of threatened insect and allied invertebrate species to prevent or re duce their risk of extinction in Australia include evaluation of conservation status, formal listing of species under Australian legislation, preparing Action or Recovery Plans, implementation of actions to mitigate threats (ideally through a recovery team) and standardised monitoring in relation to recovery actions (Braby 2018).

The listing process provides the legal basis on which conser vation measures can be initiated. Advantages of listing include: (1) an explicit recognition that without adequate protection and management a species may be close to extinction; (2) providing a snapshot of the variety of taxa of conservation concern and the number of taxa likely to be at risk of extinction; (3) a justification of funding for further research to clarify the species' distribution, identify critical habitats and key threatening processes, to re evaluate its status more critically, and to develop the recovery ac tions needed; (4) identification of key threatening processes, which may be symptomatic of the ecological community, habitat or biotope to which the species belongs; (5) elevating the species profile among the general public and governments, which may then become a flagship for the conservation of other inverte brates and/or recognition of key threatening processes and (6) placing an onus on developers to ensure that their development proposals will not have an adverse impact on the species (Braby 2018; Braby & Williams 2016; New 2009, 2011; New & Sands 2003; Rodrigues *et al*. 2006; Yen & Butcher 1997). Because for mal listing accords priority for allocation of scarce conservation resources (and may be condition for government support), it must be undertaken responsibly and credibly, with all listed spe cies accepted as worthy of that preference.

In Australia, the listing process may occur at the international, national or State/Territory level. Species nominated at the inter national level are listed under the International Union for the Conservation of Nature (IUCN) Red List categories and criteria for threatened species (Fig. 4), although it should be emphasised that such listings do not carry any legal obligation in terms of for mal action except for international trade in endangered species. The main goal of the IUCN Red List is 'To provide information and analyses on the status, trends and threats to species in order to inform and catalyse action for biodiversity conservation' (IUCN 2017). In other words, the IUCN Red List plays a critical role in initiating and guiding conservation activities of govern ments, NGOs and scientific institutions. The IUCN Red List categories and criteria were developed primarily to establish a rigorous approach to determine risks of extinction and to im prove objectivity and transparency in assessing the conservation status of threatened species (IUCN 2017). As such, they are now widely recognised as the most comprehensive, objective global standard for evaluating the conservation status of all plant and animal species, including insects and allied invertebrates (Lewis & Senior 2011).

At the national level, threatened species may be nominated for listing under the *EPBC Act* (Commonwealth Department of the Environment and Energy 2017). Such nominations may be prepared in one of two ways (New 2009; New & Sands 2003). First, they may be prepared and submitted by any individual the nomination is then reviewed by the TSSC, who will prioritise all nominations for further assessment or not. After an assess ment process that includes opportunity for public comment, the TSSC then advise the Minister of their recommendation on con servation status. Second, where a comprehensive national Action Plan has been prepared that assesses the conservation status of a higher taxonomic group (e.g. Sands & New 2002), species iden tified as being of conservation concern may be fast tracked for

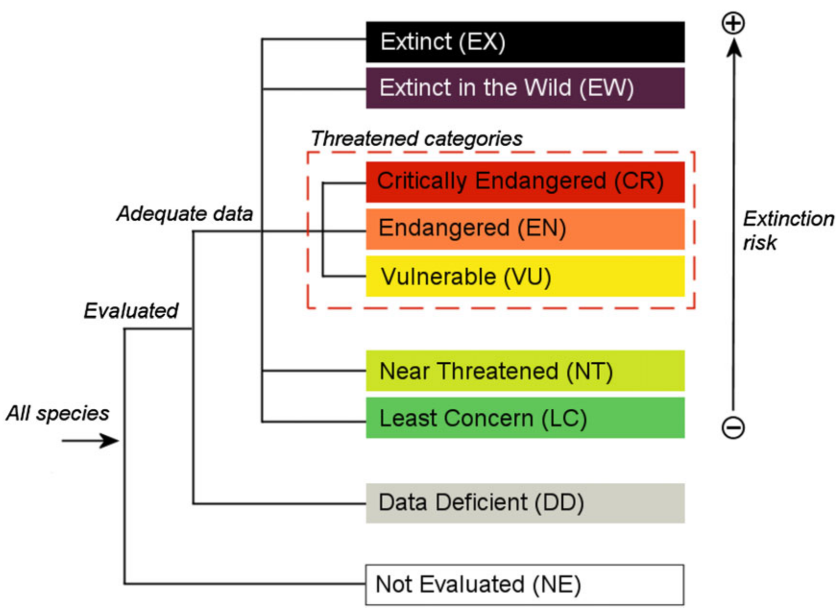

Fig. 4. Structure of the IUCN Red List categories (from IUCN Standards and Petitions Subcommittee 2016). [Colour figure can be viewed at wileyonlinelibrary.com]

recommendation to the Minister for listing. The *EPBC Act* states that all nominations require an assessment period with a statutory timeframe that includes public comment. The Action Plan process does not circumvent that, but it does provide a far more strategic approach than *ad hoc* nominations of individual species and can reduce much of the delay associated with limited resource availability within the TSSC (Braby 2018). The *EPBC Act* closely follows the IUCN Red List categories and criteria (Fig. 4) and currently recognises the following categories for ranking species according to their extinction or extinction risk: 'Extinct' (EX), 'Extinct in the Wild' (EW), 'Critically Endangered' (CR), 'Endangered' (EN) and 'Vulnerable' (VU).

At the State/Territory level, a number of species have been listed under the various local conservation Acts. There is, however, little consistency in the categories and criteria adopted among the Acts, and they rarely follow the classification adopted by the *EPBC Act* and recommended by the IUCN Red List. Moreover, there is a general lack of alignment when the same species are listed on the different schedules (e.g. between Commonwealth and State/Territory Acts) (Curtis *et al*. 2012; New & Yen 2013). For example, the Southern Pink Underwing Moth *Phyllodes imperialis smithersi* is currently listed as Endangered nationally and in NSW (Sands 2012b), but is not listed in QLD. In another context, the Golden Sun moth *Synemon plana* is listed under all three range legislations (ACT, NSW, VIC) and under the *EPBC Act*, but the status given is not consistent. This lack of alignment is currently being approached through a national Common Assessment Method (CAM) and Memorandum of Understanding (MoU) between the Australian States/Territories and the Commonwealth (Braby 2018). The purpose of the MoU is to prevent duplication in time and resources, and apply a standard assessment for all species across Australia. Initiated in October 2015, to date WA, NT, QLD, NSW, ACT, TAS and the Commonwealth are signatories to the MoU and CAM (Commonwealth Department of the Environment and Energy 2017). The MoU should prevent multiple assessments of species at State/Territory and national levels and expedite listing of threatened species. That said, legacy species (i.e. those species already on State/Territory lists, but not on the Commonwealth list) in WA, NT and NSW have been submitted to the Australian Government for consideration under the *EPBC Act* and are, therefore, essentially undergoing a re review. It should be noted that these processes do not necessarily improve the prospects of insects and allied invertebrates being added to threatened species lists, but rather should improve alignment between those already listed on different schedules. An exception will be in SA (should they sign the MoU), where the CAM should allow insect species to be eligible for listing, whereas previously they could not be listed. However, we recommend in the future that all nominations and listing are to be undertaken nationally through the *EPBC Act* and not under State legislation.

Despite these laudable moves and the appointment of a Threatened Species Commissioner, and the roll out of the National Endangered Species Program, very little progress has been made insofar as insects and allied invertebrates are concerned (New & Yen 2013). Apart from some recent progress in butterfly conservation, insects and allied invertebrates in general continue to be considered to be too diverse with many species undescribed (the Linnaean shortfall), too poorly known in terms of their distribution (the Wallacean shortfall), ecology (the Hutchinsonian shortfall) and changes in abundance (the Prestonian shortfall), too small, too hidden and too little publicised (the 'public dilemma'), and receive far too little attention from decision makers (the 'political dilemma') (Cardoso *et al*. 2011). Direct approaches to rectify these deficiencies, especially to overcome the political dilemma, need to be both bottom up, through listing as many species as practical, and top down, through lobbying governments to provide more resources towards insect/invertebrate conservation. To overcome the public dilemma, better promotion, education and awareness of Australian insects and allied invertebrates is required through, for example, extension articles and publications in broad popular journals and magazines, public talks (e.g. schools and natural history clubs), media exposure and programs at zoos and museums (see Community Engagement below). Ultimately though, until invertebrate conservation biologists are employed in an official capacity within each State/Territory government to gauge the extent of threatened insects and allied invertebrates in Australia and proactively work on conservation programs (as recommended by Sands & New 2002), the successful management of threatened species will gain little momentum, and the extinction of untold Australian species must be anticipated.

KEY THREATENING PROCESSES

Threatened species of insects and allied invertebrates are at risk of extinction because their distribution and/or abundance is declining due to many threats, the most impactful of these being referred to as key threatening processes. Their decline is a consequence of five major broad types of human induced environmental change: habitat loss/fragmentation, competitive interactions with exotic or invasive species, pollutants of various sorts, harvesting by humans and climate change (Sih *et al*. 2011). Since European settlement, the Australian landscape has been dramatically altered through land clearing for agriculture, forestry, mining and urbanisation, introduction of alien species and more recently anthropomorphic induced climate change (Gagic *et al*. 2018; New 2018; Sands 2018). The importance of identifying key threatening processes was referred to by Key (1978), Dunn *et al*. (1994) and New (1996), and the criteria for assessment and categories of threat were discussed by Sands (1999) and New and Sands (2003, 2004). Most, if not all key threatening processes affecting terrestrial or freshwater environments have a profound effect on insect and allied invertebrate populations. Land clearing of mature and old growth trees (e.g. brigalow and casuarinas) and removal of logs and fallen timber destroys habitat for seed feeders and wood feeding detritivores, respectively (Sands 2018). Invasive weeds displace native grasses and other native host plants, smother or shade native vegetation, alter fuel loads, modify soil crusts and subsurface structure. Invasive aquatic weeds outcompete native aquatics, hosts of many aquatic weevils and moths (reviewed in Sands 2018). Other threatening process include deliberately lit fires increasingly under the guise of fuel reduction or 'landscape protection' and with increased frequency or through other inappropriate fire regimes can have deleterious effects on under story vegetation and leaf litter invertebrates (Glatz *et al.* 2015; Greenslade 1996). Climate change manifests in physiological changes in metabolism (altered phenologies, disruption to aesti vation and diapause), range extensions to more suitable latitudes or altitudes, extinction of species with narrow environmental ranges or tolerances and poor powers of dispersal (e.g. loss of montane taxa: Rix *et al.* 2017a), sea level rise (affecting coastal lowlands and riparian habitat), extreme weather events (affecting coastal and island habitat), and direct effects of increased carbon dioxide levels (Sands 2018) such as changes in host plant chemistry making plants less edible for herbivorous insects, habitat fragmentation, mismatch between host and dependent phenologies etc. (see fig. 1 in Moir *et al.* 2014). Human food pro duction is a major example of interacting threatening processes, as it combines the effects of land clearing, use of pesticides and other chemical spraying (subject to aerial drift and off target effects), introduced exotics (including biological control intro ductions), and foraging and/or trampling by stock and other feral introductions (camels, deer, goats, horses, buffalo and pigs) (Sands 2018).

Gaining increasing recognition are several 'novel' threats, a prime example of which is light pollution, which has been shown to adversely affect insect populations through three pri mary mechanisms, *viz*: (1) attraction to light sources leading directly to death, or production of aberrant behaviours leading to death via life cycle disruptions (Gaston & Bennie 2014; Firebaugh & Haynes 2016; Hölker *et al.* 2010; Robertson *et al.* 2017); (2) polarisation effect of flat, dark surfaces such as roads and buildings leading to altered behaviour or death (Horváth *et al.* 2014) and (3) fitness reductions through chronic exposure to artificial light at night (Botha *et al.* 2017; McLay *et al.* 2017). Effects of polarised light can act synergistically with effects of non polarised light and is particularly detrimental to aquatic insects as these insects use the polarising effect of the water to recognise the water surface (Egri *et al.* 2017; Robert son *et al.* 2017; Szaz *et al.* 2015). It has been speculated that the advent of LEDs has reduced the overall degree of brightness in major cities but increased the light pollution in areas where development is relatively less (Kyba *et al.* 2017), which would likely equate to areas of higher conservation value. Other novel threats include aquifer draw down and conservation of dis charge mounds springs in the Great Artesian Basin (through mining, rangeland farming, tourism) (Guzik *et al.* 2012), and the issue of coextinction (Colwell *et al.* 2012; Moir *et al.* 2010, 2011, 2012, 2014; Plein *et al.* 2017). Many of these threatening processes are acting synergistically upon one an other to greatly increase the impact upon organisms, particularly insects and allied invertebrates. For example, climate change, fire, plant pathogen induced dieback (*Phytophthora cinnamomi*) and coextinction have acted together to cause an ecological ca tastrophe in threatened montane heath (Barrett & Yates 2015) with dire consequences for associated plant dwelling insects (Moir 2015; Moir *et al.* 2016) of the Stirling Ranges in south western WA.

The *EPBC Act* lists 21 key threatening processes. Some of these threats have little relevance to terrestrial insects and allied invertebrates, for example, those relating to marine processes or to other taxa such as amphibians. Without specific mention, most other threats have a profound direct or indirect effect on insects and allied invertebrates. These include land degradation and predation by (numerously listed) vertebrate herbivores and predators, dieback caused by various plant pathogens (e.g. *Phytophthora* and Myrtle rust), introduction of weeds (Gamba grass *Andropogon gayanus* and escaped garden plants), land clearance, loss of corridors and areas of occupation and rapid human induced climate change by emission of greenhouse gases. The remaining few cite invertebrates themselves as key threatening processes, without necessarily referring to insects and allied invertebrates as an affected resource. These threats comprise the reduction in the biodiversity of Australian native fauna and flora due to the Red Imported Fire Ant *Solenopsis invicta* (Threatened Species Scientific Committee 2003); loss of biodiversity and ecosystem integrity following invasion by the Yellow Crazy Ant *Anoplolepis gracilipes* (Threatened Spe cies Scientific Committee 2010) and novel biota and their impact on biodiversity (Threatened Species Scientific Committee 2013).

The *EPBC Act* is by no means comprehensive. Each of the various State and Territory Acts lists a range of key threatening processes, many in common with the *EPBC Act* and with each other. Additional key threatening processes that have direct implications for insects and allied invertebrates (but not neces sarily implicitly stated) includes bushrock removal, native vege tation clearance, eucalypt dieback associated with over abundant psyllids and Bell Miners (in turn the consequence of over clearing and/or invasive weeds), invasion and establishment of exotic plants (grasses, vines, woody perennials and trees) (Sands 2018) and the introduction of exotic insects (e.g. European Honeybee *Apis mellifera* and the Large Earth Bumblebee *Bombus terrestris*). Some Acts also specify the loss of hollow bearing trees, removal of dead wood and dead trees (e.g. NSW *Biodiversity and Conservation Act 2016*). Affecting water courses are the detrimental effects of alteration to natural flow regimes (preventing the passage of aquatic biota as a result of the presence of instream structures), alteration of natural temper ature regimes, increase in sediment deposition and input of toxic substances. Further, degradation of native riparian vegetation of rivers and streams and wetland loss is incurred by dredging, draining, filling and grazing. Inappropriate fire regimes causes disruption to sustainable ecosystem processes and resultant loss of biodiversity (see VIC *Flora and Fauna Guarantee Act 1988*).

Overall, very few key threatening processes appear to be di rected specifically towards insects and allied invertebrates. Two notable exceptions are the loss or degradation (or both) of sites used for hill topping by butterflies (see NSW *Biodiversity and Conservation Act 2016*); and loss of biodiversity in native ant populations and potential ecosystem integrity following in vasion by Argentine Ants *Linepithema humile* (as a potentially threatening processes in the VIC *Flora and Fauna Guarantee Act 1988*). Additionally, the NSW government declared *Apis* *mellifera* and *Bombus terrestris* to be involved with key threatening processes in 2002 and 2004, respectively, under the *Threatened Species Conservation Act 1995* (now superseded by the *Biodiversity Conservation Act 2016*) (Carr 2011; and see https://www.legislation.nsw.gov.au/~/view/act/2016/63).

THREATENED SPECIES

In total, 285 species of insects and allied invertebrates in Australia are currently listed under various State/Territory Acts, the *EPBC Act* and the IUCN Red List (Tables 2 and S3). The majority of species are listed under a single Act or Red List, but at least 34 species have been listed under two or more sched ules. Most of these species are considered threatened because the conservation status categorisation and assessment criteria follow the IUCN Red List, but some listings at the State level do not follow international criteria and terminology. Thus, for example, species in TAS may be listed as 'Rare' or in QLD as 'Least Concern'. Such taxa may not necessarily be threatened but are afforded legal protection under the relevant conservation sched ule. In some States, nominations for listing were historically based prior to rigorous criteria developed by the IUCN, without data on declines in distribution or abundance of breeding populations.

Of the 285 listed species of insects and allied invertebrates, 10 (3%) are considered Extinct (including the categories of Presumed Extinct and Regionally Extinct), 204 (72%) threat ened (14% Critically Endangered, 22% Endangered and 36% Vulnerable) and 71 (25%) as other ('Threatened', Near Threat ened, 'Rare' and Least Concern) (Tables 2 and S3). Currently, 93 (33%) species are listed as threatened internationally under the IUCN Red List, and 36 (13%) are listed as threatened nationally under the *EPBC Act*: only a single species (Lord Howe Island Stick Insect *Dryococelus australis*) is listed under both schedules. At the State/Territory level, 194 (68%) species of insects and allied invertebrates are listed under these Acts. However, the number of taxa listed varies dramatically, from zero in SA to 35 in VIC and 63 in WA. Although SA has a con servation Act that includes the defining of threatened species (under the *National Parks and Wildlife Act 1972*), incredibly and against all scientific practice, it does not consider insects and allied invertebrates to be animals and therefore they are currently not eligible for listing under that legislation.

We provide a brief overview of the taxa listed in each State/Territory, together with a summary of the relevant conser vation Acts, major threats faced and key literature, including Action and Recovery Plans, species profiles and information or fact sheets.

Queensland

Curtis *et al*. (2012) provided a comprehensive overview of the insects and allied invertebrates at risk of extinction in QLD. One species of moth and 17 species of butterflies (including all three subspecies of the New Guinea Birdwing *Ornithoptera priamus*) are currently listed under the *Nature Conservation Act 1992* (*NC Act*) (Table S3). Several of these species listed as Least Concern (e.g. Cairns Birdwing *Ornithoptera euphorion*, and Ulysses Swallowtail *Papilio ulysses joessa*) are protected under the Act, but are not necessarily threatened. These particu lar listings pre date any formal conservation assessment and

Table 2 Summary of the number of listed species of Australian insects and allied invertebrates under various conservation schedules at three different spatial scales (State/Territory, national and international)

Conservation status category	State/Territory (various conservation Acts)	National (*EPBC Act*)	International (IUCN Red List)	State/Territory and National	State/Territory and International	State/Territory, National and International	Total
Extinct	2						2
Presumed Extinct (Wildlife Conservation Act 1950; Threatened Species Protection Act 1995)	4						4
Regionally Extinct (Flora and Fauna Guarantee Act 1988)	4						4
Critically Endangered	15	3	5	8	7	1	39
Endangered	30	2	13	12	5		62
Vulnerable	60	7	32	3	1		103
Threatened (Flora and Fauna Guarantee Act 1988)	4						4
Near Threatened			29				29
Rare (Threatened Species Protection Act 1995)	30						30
Least Concern (Nature Conservation Act 1992)	8						8
Total	158	12	79	23	13	1	285

Thirty-three species have been listed under two schedules (State/Territory and national or State/Territory and international) and one species (*Dryococelus australis*) has been listed internationally, nationally and under State (NSW) legislation. Categories for conservation status mostly follow the IUCN Red List criteria and structure (see Fig. 4), but some State schedules have their own terminology for listed species, *viz*: 'Presumed Extinct' in WA, NSW, TAS; 'Regionally Extinct' and 'Threatened' in VIC; 'Rare' in TAS; 'Least Concern' in QLD. Note where a species is listed under two or more conservation schedules, the higher extinction risk category is used.

were enacted by the Bjelke Petersen government, motivated perhaps to prohibit the collection of specimens from the wild (Quick 1975). Subsequent attempts to 'de list' them, however, have been unsuccessful. However, genuine and continuing threats to butterflies and moths throughout QLD include habitat disturbance, grazing in and insecure tenure for protected areas, clearing of native vegetation, quarrying, clearing of hilltops, inappropriate fire regimes, habitat fragmentation and loss of veg etated corridors, understory invasive weeds and climate change.

Two moths, the Antbed Parrot Moth *Trisyntopa scatophaga* and *Phyllodes imperialis smithersi* are listed as Endangered under the *EPBC Act*. The latter subspecies is not listed under the QLD *NC Act*, even though it is listed in NSW under the *BCA Act 2016*. Two dragonflies, *Acanthaeschna victoria* and *Petalura pulcherrima*, are listed as Vulnerable and Endangered, respectively, and the Mangrove Ant blue Butterfly *Acrodipsas illidgei* is listed as Endangered under the IUCN Red List. *Acrodipsas illidgei* has been a pioneer flagship species for the conservation of mangrove communities from coastal develop ment in south east QLD (Beale 1997; Beale & Zalucki 1995; Samson 1993; Valentine & Johnson 2012).

The threatened Richmond Birdwing *Ornithoptera richmondia* has been widely used as a flagship species for the conservation of subtropical rainforest and has engendered substantial community engagement for several decades (Sands & New 2013) and a Recovery Plan is available (Sands 1999). Experiments with out crossing of this species are being evalu ated by the QLD Department of Environment and Science (I. Gynther pers. comm.) to overcome inbreeding depression known to affect this species (Orr 1994). Many plant nurseries and community groups are propagating and planting the birdwing larval food plant *Pararistolochia praevenosa* to pro vide new breeding sites in gardens and in bushlands (Sands & New 2013). The Ellangowan Nature Refuge at Leyburn, a road side habitat for the Endangered Bulloak Jewel *Hypochrysops piceatus* proposed for butterfly conservation and management, is to be reviewed for improving conservation measures by the QLD Department of Main Roads. A Recovery Plan has been prepared for this species (Lundie Jenkins & Payne 2000).

New South Wales

Fourteen species are currently listed in NSW under the *Biodiver sity Conservation Act 2016* (*BCA Act*). Although new listings under the *BCA Act* are assessed under IUCN Red List criteria, most species were assessed *ad hoc* using older legislation with less rigorous criteria. The listed species include Lepidoptera (6), Coleoptera (4), Odonata (2), Blattodea (1) and Phasmatodea (1) (Table S3). Four of these species are listed nationally under the *EPBC Act* as Critically Endangered (Lord Howe Island Phas mid *Dryococelus australis*, Golden Sun Moth *Synemon plana*, Laced Fritillary *Argynnis hyperbius inconstans*) or Endangered (Pink Underwing Moth *Phyllodes imperialis smithersi*). *Dryococelus australis* and the Black Grass dart *Ocybadistes knightorum* are also listed under the IUCN Red List as Critically Endangered and Endangered, respectively. A further 16 species of insects (all aquatic groups in which part of the life cycle is associated with freshwater) have been listed under the IUCN Red List (1 Critically Endangered, 3 Endangered, 4 Vulnerable, 8 Near Threatened). Dragonflies, with the exception of the two *Petalura* spp. that have a terrestrial larval stage, are listed under the *Fisheries Management Act 1994* in NSW (Hawking & Theischinger 2004). Notable absences from the NSW list include the Richmond Birdwing *Ornithoptera richmondia*, a threatened species which is listed under the *NC Act* in QLD, but neither un der the *BCA Act* nor *EPBC Act*, and the Mangrove Ant blue *Acrodipsas illidgei*, which is listed as Vulnerable under the *NC Act* and Endangered under the IUCN Red List.

Lord Howe Island is a focus for insect conservation, with three species listed (*Dryococelus australis*, Lord Howe Island wood feeding cockroach *Panesthia lata* and Lord Howe Island Leaf Beetle *Menippus darcyi*) (Carlile *et al*. 2018; Honan 2008; Mikheyev *et al*. 2017; Priddel *et al*. 2003) and others potentially threatened (Cassis *et al*. 2003), emphasising the susceptibility of insect assemblages on islands. The Lord Howe Island Ground Weevil *Hybomorphus melanosomus* is the only Presumed Extinct species in NSW. The main threat to the extant species is rodent predators (ship rats), which were accidently introduced to the island in 1918. *Dryococelus australis* has become a significant flagship for the recovery of the island's ecosystems (Tulloch & Cleave 2015). The Lord Howe Island population of this stick insect was extirpated, and there is cur rently a substantial recovery program to breed this species in captivity (from a population discovered nearby on Ball's Pyramid in 2001), with the eventual goal of re introducing the species back on to Lord Howe Island once the rats are eliminated (McGrath *et al*. 2017).

Management actions are currently being undertaken for several species under the NSW Government's 'Saving our Species' and other programs, including monitoring of some pop ulations. Several programs are well established, with high com munity profiles, such as the Giant Dragonfly *Petalura gigantea* and a set of Lepidoptera that have been used as potent flagship species for the conservation of other insects and/or threatened ecological communities. Most notable among these is the Purple or Bathurst Copper *Paralucia spinifera*, an Endangered short range endemic restricted to montane eucalypt grassy woodland on the western slopes of the Blue Mountains and which has had a long history of conservation interest and management (Baker *et al*. 1993; Hill & Michaelis 1988; Kitching & Baker 1990; Mjadwesch & Nally 2008; New 2011; Sands & New 2002) and for which a recovery plan has been prepared (NSW National Parks and Wildlife Service 2001). Ongoing surveys and management actions are being prepared for three other spe cies: Pale Imperial Hairstreak *Jalmenus eubulus*, a threatened species in NSW and QLD where it is restricted to remnant old growth *Acacia* woodland, particularly brigalow (Eastwood *et al*. 2008; Sands *et al*. 2016; Taylor 2014); *Ocybadistes knightorum*, an Endangered short range endemic restricted to coastal grassy open forest in semi saline areas usually adjacent to mangroves (Andren & Cameron 2012, 2014); and *Phyllodes imperialis smithersi*, a subspecies which is restricted to remnant tracts of subtropical rainforest below 600 m (Andren 2017; Sands 2012a,b). Studies are urgently needed to re assess the conservation (and taxonomic) status of *Argynnis hyperbius inconstans*, a butterfly which is restricted to coastal wetlands and which may be extinct, or close to extinction, regionally in NSW and nationally in Australia (Lambkin 2017).

A range of key threatening processes adversely affecting insects and allied invertebrates in NSW is exemplified by *Argynnis hyperbius inconstans*, *Ocybadistes knightorum* and *Phyllodes imperialis smithersi*, namely, habitat loss from coastal development, urbanisation, fragmentation of populations, weed invasion, ecological succession and sea level rise from climate change. Other threats in NSW include underground coal mining depleting upland swamp habitat (*Petalura gigantea*) (Baird & Burgin 2016), predation by Cane Toads *Rhinella marina* (Atlas Rainforest Ground beetle *Nurus atlas*), inappropriate fire regimes (*Paralucia spinifera* and *Ocybadistes knightorum*) and loss of old growth woodland (*Jalmenus eubulus*).

Australian Capital Territory

Threatened species of insects in the ACT are listed under the *Nature Conservation Act 1980* (*NC Act*), which closely follows the IUCN Red List criteria. Currently, two species of insects are listed under this legislation, these being the Golden Sun moth *Synemon plana*, and the Perunga Grasshopper *Perunga ochracea* (Table S3). Critical populations of both species occur within the boundaries of the ACT, and the former has been used as a flagship for the conservation management of threatened tem perate grassland and grassy open woodland habitats (Richter *et al*. 2013a,b). Action Plans (ACT Government 1998, 1999) and information dossiers (Arts, Heritage and Environment 2006a,b) are available for both species.

Victoria

Some threatened insect species in Victoria are listed under the *Flora and Fauna Guarantee Act 1988* (*FFG Act*) and, at the end of 2017, 35 species were listed (Table S3) the list is dom inated by Lepidoptera (21 species, including butterflies (11 spe cies) and Sun moths (five species), with species such as the Eltham Copper *Paralucia pyrodiscus lucida*, Golden Sun moth *Synemon plana*, and several rare myrmecophilous Lycaenidae (*Acrodipsas* spp.), becoming notable and enduring flagships for insect conservation in the state. Six stoneflies (Plecoptera) are listed, marking wider concerns for alpine and montane biota, and single species of Coleoptera, Diptera, Odonata and Trichop tera are also listed. The three species of Hymenoptera include the unusual case of an undescribed ant, known as '*Myrmecia* sp. 17', with the Act enabling listing of such entities under specified con ditions of consensus and voucher specimen deposition. Listing obliges the production of an Action Statement setting out a fuller perspective of threats, conservation needs, remedial actions and responsibility. It may also lead to production of a management plan, but this is optional ('may include') and has rarely eventu ated. Threats largely devolve on habitat losses and change (either to specific sites or more generally), with the trends for some species clearly demonstrating historical losses and that remaining populations occur on small, highly fragmented habitat patches, with increased vulnerability to disturbances, so that currently known populations are remnants from previously far wider distri butions. The Ancient Greenling damselfly *Hemiphlebia mirabilis*, Eltham Copper and Yellow Sedge skipper *Hesperilla flavescens* are examples for which Recovery Plans have been prepared (Crosby 1990; Sant & New 1988; Vaughan 1988).

Unfortunately, Action Statements have not been produced for many of the species, with only 14 species covered by current statements. They include a single Statement covering five species of Sun moths (Douglas 2003) but most documents deal with single taxa only. Action Statements have clearly stated review dates, and some have become long overdue for construc tive revision.

Also under the *FFG Act*, the listing of threatened communi ties included 'Butterfly Community No. 1', designed to draw attention to a unique assemblage of resident and hill topping butterflies at Mt Piper (Broadford), and including several rare species of *Acrodipsas* listed individually under the Act. Consid erable study of that community led to some notable increases in understanding (Britton *et al*. 1995; Jelinek *et al*. 1994; New 2011; New & Britton 1997).

An important innovation in Victoria is the establishment of an Advisory List of Threatened Invertebrates, an informal list of notable species maintained by the Department of Environment, Land, Water and Planning. This has no legal obligations, but includes species suggested or advised as significant or of conser vation need, and the information is useful for planning and indi cates likely candidates for future more formal treatment and listing. Most recently updated in 2009, the 102 insect species (including *FFG Act* listings) include many that are Data Deficient and warrant further investigation.

Tasmania

Threatened insects and allied invertebrates in Tasmania are listed under the *Threatened Species Protection Act 1995* (*TSP Act*), which broadly reflects the IUCN Red List criteria, but with local refinement. The Tasmanian list (Table S3) comprises a wide cross section of taxa and several are thought to be extinct. Others have been delisted as a result of new information from targeted surveys (e.g. the Miena Jewel Beetle *Castiarina insculpta* (Spencer & Richards 2014) and the Pencil Pine moth *Dirce aesiodora*). Specialised habitats support threatened species, notably caves (Doran *et al*. 1997) with an ensemble of adapted pseudoscorpions (Mallick & Driessen 2005), carabid beetles (Driessen *et al*. 2000) and arachnids. Freshwater taxa include geographically restricted caddisflies in a group that exceeds 80% species level endemism.

Currently, 38 species of insects are listed in the schedules under this legislation along with various other invertebrates (Table S3). Threatened Lepidoptera include five butterflies and three moths, mainly coastal and grassland species (Bell 1998; McQuillan 2004; Neyland 1993; Neyland & Bell 2000; Prince 1988, 1993). Coleoptera include stag beetles (Lucanidae: *Hoplogonus* and *Lissotes*) with unusually high levels of specia tion and endemism in Tasmania (Meggs & Munks 2003; Meggs & Taylor 1999; Meggs *et al*. 2003; Munks *et al*. 2004). These are flagship species for the conservation of the remaining old growth forests. The Wielangta stag beetle *Lissotes latidens* featured in the milestone Federal court challenge (Brown v Forestry Tasmania (No 4) [2006] FCA 1729) that exposed the inadequacy of the controversial Regional Forest Agreement as a conservation measure for three forest dependent Endangered species in Tasmania (Bleyer 2007). Edge of range species, rare in Tasmania, include the Green lined ground beetle *Catadromus lacordairei* (Spencer & Richards 2010). Listed Orthoptera are flightless and mainly short range endemic cave crickets (Rhaphidophoridae) (Richards 1974), but Schayer's grasshopper is a monotypic acridid genus endemic to the main island (Key 1991).

The consequences of climate change rank among the most important threats to the Tasmanian fauna. A combination of sea level rise, increasing storm damage and lack of retreat options due to infrastructure threaten some coastal species, notably saltmarsh Lepidoptera such as the geometrids *Amelora acontistica* and *Dasybela achroa* which are both listed as Vulnerable under the *TSPAct* (McQuillan 2004) and the Saltbush Blue *Theclinesthes serpentatus* (Couchman & Couchman 1977). Accelerated warming and drying at high elevations stresses climatically sensitive larval food plants and affects hydrological conditions. Changes in ground water yield are likely to increasingly affect microclimates to the detriment of litter dwelling and cave fauna. Recent increases in the intensity and scale of fires (e.g. the 2016 Lake Mackenzie event) threatened vulnerable habitats, especially at higher elevations. These threats have been exacerbated by the increased flammability of fringing landscapes due to the rapid proliferation of poorly managed exotic eucalypt plantations, a legacy of economic incentives now largely abandoned. Invasive Hymenoptera are a particularly concerning threat in Tasmania, including two species of European wasps *Vespula* spp., the large earth bumblebee *Bombus terrestris* and Argentine ants *Linepithema humile*. The bumblebee occupied the entire state in less than a decade following its introduction in 1992 and political pressure for its introduction to the mainland as a horticultural asset should be resisted. Habitat loss, especially temperate grasslands, organic soils and some rainforests, notably austral conifer forests, continues. Conversion of native habitats to farmland is ongoing (especially to dairy pastures, viticulture and irrigated cropping). Commercial development in national parks and the World Heritage wilderness areas is expanding as tourism numbers are accelerating (8% annual increase in 2017).

South Australia

Threatened species in South Australia are listed under the *National Parks and Wildlife Act 1972* (*NPW Act*), but incorrectly does not consider invertebrates to be animals, and therefore, there are currently no species of insects and allied invertebrates listed under that legislation. This shortcoming is exposed in that three species of insects, listed as Critically Endangered under the IUCN Red List, occur in SA: the katydids *Psacadonotus insulanus* and *Nanodectes bulbicercus*, and Dinosaur Ant *Nothomyrmecia macrops* (Table S3). The representation of listed invertebrates in SA is clearly manifestly inadequate and the *NPW Act* requires revision to take invertebrates into account. In 2014, the SA government rated the Green Carpenter Bee *Xylocopa aeratus* (but incorrectly named as *Xylocopa bombylans*) as Regionally Endangered on Kangaroo Island (it is extinct from mainland SA and VIC) based on the 'best available information' indicating it met one of the five IUCN Red List criteria for Endangered (Gillam & Urban 2014; Glatz *et al*. 2015). Further, an Action Plan for the conservation of the Bitterbush Blue *Theclinesthes albocinctus* from the Northern Adelaide Plains and Kangaroo Island was prepared for the Adelaide and Mount Lofty Ranges Natural Resources Management Board (Glatz *et al*. 2017). In the case of *Xylocopa aeratus*, the purpose of the associated Regional Species Conservation Assessment Project was to produce regional conservation and recovery targets that inform regional recovery plans, rather than identify species to be listed under legislation. In this case, the regional split is legislatively pragmatic and based on existing natural resource management regions.

Western Australia

In WA, threatened taxa are listed under the *Wildlife Conservation Act 1950* and, more recently, the *Biodiversity Conservation Act 2016*. Listing of species follows the IUCN Red List guidelines for the assessment of conservation status. There are 205 invertebrate species listed (including annelids, crustaceans and molluscs): five as Extinct, 118 considered threatened (41 Critically Endangered, 17 Endangered, 60 Vulnerable), and 82 as 'Priority' (Table S3). Priority species are either poorly known and require further input to their conservation status (e.g. geographical surveys, clarification of species boundaries), or they require ongoing monitoring as they are near threatened. The vast majority of invertebrate species (95%) fall into the poorly known category. Of note, most of the listed taxa are arachnids, millipedes, crustaceans and molluscs (172, or 84%), likely due to a combination of available expertise and high proportions of short range endemic taxa within these groups (Harvey 2002).

Western Australia is Australia's largest state and contains a great diversity of habitats and threats. Three regions contain the highest numbers of listed species: the Kimberley (54 species); the Pilbara (51); and the South Coast (48). These regions have been heavily surveyed in the past 20 years because of mining and environmental regulation requirements (Pilbara), proactive community and scientific involvement (South Coast; e.g. Moir *et al*. 2015), and investment in agriculture (Kimberley). This long term survey effort has led to more nominations of insects and allied invertebrates that are primarily restricted to specialised habitats, geology and/or climatic ecotones within these regions.

The main threats to species are habitat loss (e.g. from mining and urbanisation), population fragmentation, inappropriate fire regimes, invasive biota (including diseases) and climate change. Many of these threats are acting synergistically to accelerate population decline towards extinction. For example, the drying climate is changing the fire regime, which is altering habitats in wet refugial zones, such as on mountain tops and within gullies, of many invertebrates within WA (Barrett & Yates 2015; Moir *et al*. 2009, 2016; Rix *et al*. 2017a,b).

Northern Territory

Threatened species of insects in the NT are listed under the *Territory Parks and Wildlife Conservation Act 2000* (*TPWC Act*), which closely follows the IUCN Red List criteria for conservation status evaluation. Currently, four species of insects are listed (Table S3). Two of these species (Desert Sand skipper *Croitana aestiva* and Gove Crow Butterfly *Euploea alcathoe enastri*) have recently been revised 'down' from Endangered to Near Threatened under NT legislation, although they are listed as Endangered nationally under the *EPBC Act*. National recovery plans have been prepared for both these butterflies (Braby 2007; Palmer 2010), with new information published more recently (Braby 2010; Palmer & Braby 2012), and information dossiers are available for all four taxa (Braby & Woinarski 2006; Braby *et al*. 2012a,b; Palmer *et al*. 2012). A more recent conservation assessment of the two other listed species (Dodd's Azure *Ogyris iphis doddi* and Atlas Moth *Attacus wardi*) suggests both are Vulnerable under IUCN Red List criteria (Braby & Nielsen 2011; Braby *et al*. 2018). Most research on threatened insects in the NT has focused on status evaluation by understanding their spatial distribution, critical habitat requirements and identification of key threatening processes. There has been little attempt to implement management actions to mitigate threats, or to monitor the effectiveness of management. Both the Atlas Moth and Gove Crow Butterfly are large, spectacular species that have received varying levels of community engagement, from NGOs and Indigenous Rangers/Traditional Owners, respectively (Braby 2010, 2014), and have potential as flagship taxa for the conservation management of coastal and near coastal monsoon forest habitats.

In addition, five species of odonates are currently listed as threatened (Vulnerable) under the IUCN Red List, although these do not appear on national or NT schedules (Table S3). These species have aquatic larvae and highly restricted distributions. The assessment of criteria for IUCN listing is far more precautionary than that applied under Australian and/or Territory legislation. Thus, for three species endemic to Kakadu National Park, mining is listed as a threat despite it not occurring anywhere near the relevant populations, and there is no evidence that the other threat listed (tourism) is actually affecting the relevant species (Andersen *et al*. 2014). The remaining two species (Melville Island Threadtail *Nososticta taracumbi* and Forestwatcher *Huonia melvillensis*) are mainly restricted to the Tiwi Islands traditional private land outside the National Reserve System. The identified threats (particularly habitat loss on Melville Island) may well be relevant so that their conservation security cannot be assured.

COMMUNITY ENGAGEMENT

The critical importance of community engagement has been recognised in Australia's *Biodiversity Conservation Strategy 2010 to 2030*, which states as its first priority "Engaging all Australians in biodiversity conservation" (Natural Resource Management Ministerial Council 2010). This recognises the essential role of the Australian Commonwealth Government in the management of biodiversity conservation internationally (as party to various international treaties and bilateral agreements, for example, the United Nations *Convention on Biological Diversity*) and nationally (e.g. management of National Parks and those included in various World Heritage designations, administration of the *EPBC Act*, implementation of the *Australia's Biodiversity Conservation Strategy 2010 2030* and the Natural Resources Management Boards through the National Landcare program). The strategy also recognises the role of State and Territory Governments to implement a suite of State and Territory Acts and local government to manage local and regional planning for ecologically sustainable development.

The scientific community is paramount to communicate information on biodiversity and best practice and are involved in education and communication with policymakers, the research community, the private sector and the general community. The private sector includes farming, forestry, agriculture, mining, tourism, developers and Indigenous communities. Farming properties account for 60% of the Australian landscape (Natural Resource Management Ministerial Council 2010), and farmers are integral to managing natural habitat and maintaining wildlife corridors, indeed they benefit enormously from biodiversity conservation knowingly or otherwise (Gagic *et al*. 2018). The mining industry as well is increasingly adopting protective actions and contributing to funding for habitat and/or species conservation. For examples, Chevron implemented stringent biosecurity measures to maintain the conservation integrity of Barrow Island, Alcoa sponsored long term monitoring and research into the invertebrates of the Jarrah forest in WA (Majer *et al*. 2007), and BHP Billiton has co funded the Australian Biological Resources Study Bush Blitz species discovery program (taxonomic outputs reviewed in Taylor 2017a,b). Indeed, one such example of multi actor partnerships, comprising as many as four participants is *Arid Recovery* in mid northern South Australia, an alliance among BHP Billiton, South Australian Department for Environment and Heritage, The University of Adelaide and the community group, Friends of Arid Recovery (Natural Resource Management Ministerial Council 2010).

Such 'multi actor' partnerships are likely to be long lasting, encompass numerous types of insects and allied invertebrates and be more effective in conservation management as the stakeholders or 'actors' are often diverse and complementary (e.g. scientists, land managers, farmers, public, mining industries including environmental consultants and Indigenous communities (Moir *et al*. 2015; New 2011)). It is likely that similar partnerships can be devised in many parts of Australia. Indigenous communities are profoundly important to Australian conservation management, with Indigenous tenure comprising some 20% of the Australian land area, including some of the most ecologically intact regions in Australia such as the Great Victoria Desert. It is anticipated that nominations of insects and allied invertebrates will come from Indigenous Protected Areas (IPAs) supported by ranger groups engaged in customary land management due to their intimate local ecological knowledge and the high social and cultural value (foods and seasonal indicators) of some invertebrates. Nominations from IPAs could be greatly enhanced with the documentation and scientific identification of cryptic host specific traditional foods (Commonwealth of Australia 2017) and would be especially beneficial to act as flagship species for the many regions across the Australian landscape that are currently so poorly represented. NGOs include a multitude of 'grass roots' community Landcare groups (e.g. Landcare Australia, Greening Australia and Land for Wildlife programs, Australian Wildlife Conservancy, Trees for Life, 'Friends of …' parks, reserves and localities and schools) (e.g. New 2018 for community groups in urban areas). It is noted that there is often a high level of personal investment through inclusion of voluntary local community groups in conservation management. At the fundamental level, it is the general public, from communities and families to the individual, each with vital roles in education, 'connecting' with the natural environment and instilling an appreciation of the roles, and even existence(!), of the multitude of insects and allied invertebrates that underpins ecological interactions and maintains biodiversity. Incorporation of teaching about 'bugs' is already penetrating school curricula at all levels and, here again, professional scientists can readily engage with this process as visitors, advisors, parents and grandparents.

Community engagement and science communication are inextricably linked. Only with an appreciation of the role of insects and allied invertebrates in ecosystem function is direct and ongoing community engagement in their conservation possible. Iconic, mediagenic, high profile species can of course act as focal points for engagement. This is particularly true for species with a high visual impact and those with fascinating life histories. Such species and science communicators of the ilk of Sir David Attenborough (television) and Robyn Williams AM (radio) have arguably done more for engaging the community in conservation generally, and insect/invertebrate conservation in particular, than any other modality. For children and adults alike, fascination as a point of engagement is invaluable, but for a sustainable community contribution to conservation management, a deeper understanding of the critical role of insects and allied invertebrates in ecosystem functioning and biodiversity conservation is essential. Strategies for achieving such longer term community engagement are under valued, and there is an urgent need for research into community engagement in conservation management.

In the past, the main platforms for science communicators were radio, television, books and popular magazines to reach an audience broad enough to educate the general public in traditional natural history. However, these outlets may not have had the immediacy to mobilise or unite, unlike the communicative nature of current social media. On platforms such as Facebook, Instagram, Twitter and YouTube providers release content in real time, which is then liked or disliked, shared, commented on, reviewed and replied to. This process of public engagement helps build and sustain trust among stakeholders while increasing the perceived and actual relevance of science to society (National Academies of Science, Engineering and Medicine 2017). As the AESCC intends to identify flagship species of high scientific and social value, we would do well to access society's opinion. Each platform also offers dozens of inbuilt statistic summaries. Facebook professional pages summarise and graph not only the number of followers but their gender and age demographics, country of origin and language group. The impact of different posts can be compared between reach (views) and engagement (likes). Together, this contributes to a mass of useful information to help understand the audience of insects and allied invertebrate conservation and facilitates the dissemination of positive outcomes.

Given the amount of information generated by social media platforms, published findings from the impact of social media on conservation outcomes is largely absent. This is likely owing to lack of study time and not a lack of impact *per se* (Ballard *et al.* 2017). However, a survey of 44 citizen science projects at three natural history museums revealed that ongoing monitoring projects, such as BioBlitz, had measurable impacts in the greatest number of categories: research outcomes, community education, policy and actual site and species management (Ballard *et al.* 2017). Social media has been shown to offer invaluable resources to support the development and retention of the long term relationships that enable those projects. Enhanced storytelling and event broadcasting increases engagement and social networking encourages a sense of social inclusion post project (Rowlatt 2012; Russell 2016). The importance of social media to conservation might be more clearly measured by the hundreds of thousands of followers supporting the innumerable Conservation Facebook pages, from Greenpeace USA, New Zealand, Polski, Norge and the World Wildlife Fund to Shark Savers Malaysia, Boreal Songbird Initiative and the Pollinator Partnership. The metrics embedded in these pages represent the next frontier for statistical analysis of the impact of social media on conservation outcomes.

DISCUSSION

The goal of this review has been to provide a more strategic framework, using a species based landscape approach through community participation, for the conservation management of insects and allied invertebrates in Australia, than has previously been attempted. The key elements of this framework are the use of areas at the bioregional scale, which form the basis for the selection of flagship species coupled with wider community engagement through formal nomination and listing and promotion by the scientific community (Fig. 2).

A compendium of all threatened species was collated from species listed in each of the State/Territory Acts, the *EPBC Act* and the IUCN Red List (Table S3). These listed species were assigned to IBRA regions (Fig. 3a) by aligning distribution data from the Atlas of Living Australia (Atlas of Living Australia 2018). Where a species occurred across multiple States/Territories, but was only listed from one particular State/Territory, only the point data for the listed State/Territory was used. When the geographic distributions of these species

(Tables 1 and S3) are plotted spatially in relation to the 89 IBRA regions, it is clear that there is a striking discordance between where threatened species have been listed and their overall spatial representation across bioregions (Fig. 3d). The majority of species have been listed from the mesic areas of the continent, with particularly high concentrations in the coastal areas of eastern Australia (from Cape York Peninsula, QLD, through NSW to eastern Gippsland, VIC), southern VIC, TAS, south western WA, and central western WA (Carnarvon and Pilbara IBRA regions). Very few species have been listed from arid areas (one species in each of the MacDonnell Ranges and Gawler IBRA regions). Thirty six (40%) IBRA regions have no listed species, nearly all of which are located in semi arid or arid areas of the continent.

Moreover, of the 53 (60%) IBRA regions in which listed species are represented, the number of species listed is highly skewed, with six regions (Carnarvon, Esperance Plains, South Eastern Highlands, South Eastern Queensland, Victorian Midlands, Wet Tropics) having more than 18 species (Fig. 5). Despite some congruence with recognised biodiversity hotspots, it is not well documented that all of these six regions harbour high concentrations of threatened species because of higher levels of extinction risk *per se*. Rather, the mismatch between spatial representation of listed species and bioregions reflects an historical approach to insect conservation and the concentration of entomological expertise in urban centres located in the southern half of the continent. Nor does it explain why the Esperance Plains IBRA region, for example, with high levels of plant diversity coupled with high loss of habitat (and consequential potential loss of associated insects and allied invertebrates) (Fonesca 2009) has a high number of listed species, but other adjacent regions (IBRA regions of Geraldton Sandplains, Jarrah Forest, Swan Coastal Plain, Warren etc.) that comprise the south western WA biodiversity hotspot (see Myers *et al.* 2000) do not. The 36 IBRA regions for which no species have been listed (Table 1 and Fig. 3d) have no representation simply because of data deficiency and lack of conservation attention and advocacy. Clearly, the nomination and listing of species has been anything but stra

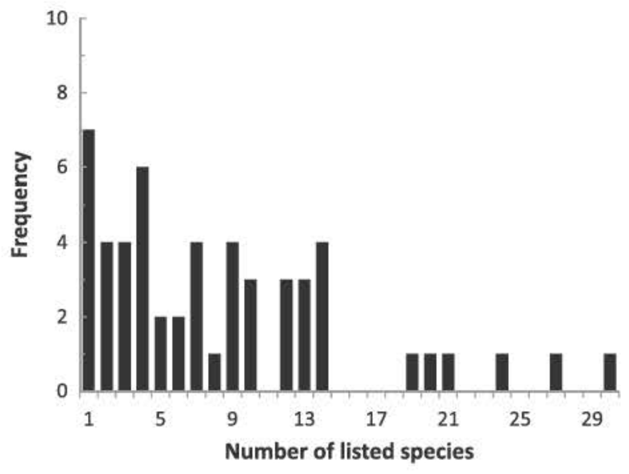

Fig. 5. Frequency distribution of the number of listed species within each IBRA region. (See National Reserve System IBRA region protection level, © Commonwealth of Australia: https://environment.gov.au/land/nrs/science/ibra). Note 36 regions have no listed species.

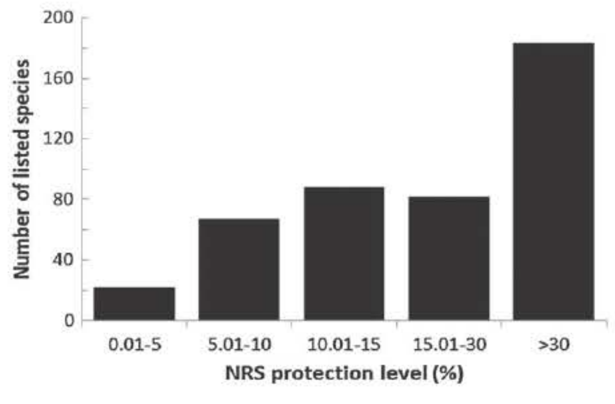

Fig. 6. Relationship between the number of listed species and the level of protection according to the National Reserve System (NRS) within each IBRA region. Data for listed species are based on Table 1 and that for the NRS are based on the protection level of bioregions map prepared by the Commonwealth of Australia (http://www.environment.gov.au/land/nrs/science/ibra/australias bioregions maps).

Table 3 Examples of 12 flagship species that could be promoted, or nominated for listing under the *EPBC Act* to strategically improve conservation management of insects and allied invertebrates within Australian IBRA regions.

Flagship species	IBRA region (state/territory)	Threats	Conservations status	Scientific and/or social value	Community engagement	Reference
Aenigmatinea glatzella (Enigma Moth)	KAN (SA)	Highly restricted range	Not listed	Endemic to Kangaroo Island, SA New monotypic family; first discovery of a new extant family of homoneurous moths since the 1970s	Initial surveys funded by State Government Ongoing surveys to clarify distribution and abundance	Kristensen *et al* (2015)
Badisis ambulans (Ant Mimic Pitcher Plant Fly)	WAR (WA)	Host plant listed as Vulnerable under IUCN Red List	Not listed	Restricted to southwest WA Co-dependent on the vulnerable host-plant, Albany Pitcher Plant, *Cephalotus follicularis*	None	Lymbery *et al* (2016)
Cooloola propator (Cooloola Monster)	SEQ (QLD)	Not threatened	Not listed	Enigmatic orthopteroid family Cooloolidae Discovered in 1980 in the Great Sandy Desert National Park, QLD Lives in sandy soil near streams under casuarinas	None	Rentz (1980)
Euschemon rafflesia (Regent Skipper)	CMC, WET (QLD), SEQ (QLD, NSW), NNC (NSW)	Not threatened	Not listed	Occurs in scattered localities in eastern Australia Monotypic subfamily endemic to Australia Only butterfly with a frenulum and a retinaculum	None	Braby (2000), Warren *et al* (2009)
Nemotyla oribates (Tasmanian Cushion Plant Moth)	TSR (TAS)	Climate change	Not listed	Restricted to cushion plants (Epacridaceae) in alpine Tasmania	None	Nielsen *et al* (1992)
Nothomyrmecia macrops (Dinosaur Ant)	EYR (SA)	Habitat fragmentation of old growth woodland (most populations on farmland and roadsides)	Listed as Critically Endangered (under IUCN Red List) Deemed ineligible for listing under *EPBC Act* (full geographic range not determined)	Enigmatic 'primitive' ant	One population has been fenced and protected by land owner	Threatened Species Scientific Committee (2002)
Panesthia lata (Lord Howe Island Cockroach)	PSI (NSW)	Invasive species (Ship Rat) and habitat fragmentation	Listed as Endangered (under *NSW Biodiversity Conservation Act 2016*)	Endemic to Lord Howe Island	Rodent eradication program, population monitoring, translocation and revegetation	Carlile *et al* (2018)
Petalura ingentissima (Giant Petaltail)	WET (QLD)	Not threatened	Not listed	Restricted range in rainforests of northeast QLD World's largest dragonfly Indicator value of freshwater streams	None	Davies (1998)
Petasida ephippigera (Leichhardt's Grasshopper)	ARP, GFU, VIB (NT)	Possibly by inappropriate fire regimes	Not listed Previously listed in NT (under *Territory Parks and Wildlife Conservation Act 2000*)	Cultural significance among Indigenous people	Some monitoring by Indigenous rangers at Keep River and Kakadu National Parks	Lowe (1995), Wilson *et al* (2003), Andersen *et al* (2014)

Phalacrognathus muelleri (Mueller's Stag Beetle)	WET (QLD)	Not threatened	Not listed	Restricted range in rainforests of northeast QLD A spectacular stag beetle, emblem of the Entomological Society of Queensland	None	Wood *et al* (1996)
Phreatomerus latipes sensu stricto (Lake Eyre GAB Mound Springs phreatoicid Isopod)	STP (SA)	Water extraction of the Great Artesian Basin by mining and pastoral activities	Not listed	Type locality extinct; taxon likely to be extinct Exhibits deep genetic diversity Likely multiple short range endemic cryptic species restricted to certain mound springs	State Government program to cap and fence mound springs	Guzik *et al* (2012)
Xylocopa aeratus (Green Carpenter Bee)	KAN (SA)	Inappropriate fire regimes and fragmentation through land clearing	Listed as Regionally Extinct in VIC (under *Flora and Fauna Guarantee Act 1988*) Rated (not listed) as Regionally Endangered in SA	Indicator of old growth heathland Disjunct distribution: occurs in scattered areas along the east coast of Australia and on Kangaroo Island, SA	Initial surveys funded by State Government Installation of artificial nesting sites; lobbying land managers to alter fire regimes	Gillam and Urban (2014), Glatz *et al* (2015)

tegic. In many cases, it has been simply '*ad hoc*', from the inter ests and zeal of individual specialists familiar with the taxa and the areas in which they occur. Lack of wider expertise sometimes renders obtaining responsible independent reviews of such nom inations very difficult.

The anomaly in spatial representativeness of listed species is even more striking when the relationship between the number of species and the level of protection according to the National Reserve System within each IBRA region is examined (Fig. 6). A substantial portion of Australia is under represented in the na tional estate (<10% protection), particularly in the semi arid and arid zones (Fig. 3c). These non mesic areas coincide with IBRA regions that have comparatively few listed species (Figs 3d and 6) in fact, with the exceptions of parts of the Great Sandy, Tanami, Gibson and Great Victoria Deserts, Figure 3d is almost the inverse of Figure 3c. Clearly, focussing attention on threat ened species and key threatening processes in regions with poor representation of insects and allied invertebrates should be a priority because it may provide a strategy to increase the extent of protection of the National Reserve System in these areas.

Another point to consider is the relationship between national biodiversity hotspots identified by the Commonwealth Govern ment for conservation (Fig. 3b) and the occurrence of listed in sects and allied invertebrates (Fig. 3d). The analysis for the Australian landscape for national biodiversity hotspots was initiated through the Australian Government TSSC after consul tation with experts in biodiversity and representatives from conservation groups, museums and states and territories based on perceived endemicity of plants and animals (Australian Government 2017b). Although the map of listed species is not an accurate portrayal of invertebrate biodiversity, there is little congruence between national biodiversity hotspots (Fig. 3b) and apparent concentrations of listed insects and allied inverte brates (Fig. 3d). Five national biodiversity hotspots (Einasleigh and Desert Uplands, QLD; South Australia's South East/ Victoria's South West; Mt Lofty/Kangaroo Island, SA; Central and Eastern Avon Wheatbelt, WA; Geraldton to Shark Bay sand plains, WA: Fig. 3b) are poorly represented with low numbers of threatened insects and allied invertebrates (Fig. 3d). Conversely, IBRA regions with seemingly high numbers of listed species (Darwin Coastal, Cape York Peninsula, Wet Tropics, Sydney Basin, South Eastern Highlands, Victorian Midlands, Murray Darling Depression Fig. 3d, Table 1) are not considered biodi versity hotspots (Fig. 3b). Clearly, threatened insects and allied invertebrates could provide valuable information for setting conservation priorities nationally in future, despite the inherent bias in the data and the *ad hoc* approach to listing species.

Future directions

So where to from here? The AESCC aims to promote the conser vation management of insects and allied invertebrates by nomi nating and promoting flagship species throughout Australia. The strategy presented here adopts a education landscape ap proach that ensures spatial representativeness of threatened and/or iconic species across all bioregions. We envisage this ap proach may provide better conservation management of habitats, ecological communities and key threatening processes within each IBRA region, in addition to reducing extinction risk of threatened species. Knowledge of the true extent of threats to our insect fauna is highly fragmentary. We thus emphasise the wellbeing of a few selected taxa known or suggested to be under threat and declining. This limitation does not diminish the impor tance of conserving wider insect diversity and measures to pre vent numerous other species many of them localised endemics from becoming more obviously threatened. In that context, we view many of the selected ecologically specialised taxa as 'umbrella species' for the wider diversity in the biotopes in which they are conserved. However, the focal species ap proach, despite shortcomings, is tangible to managers, the wider population, and political agencies, and provides clear pathways for constructive action.

What criteria then should be used in selecting insect and allied invertebrate flagship species for conservation? With a wealth of choice in iconic and threatened species, it is essential to formulate practical and achievable criteria for the selection of insect species that are ideally placed to engage local communities in conserva tion activities. Flagship species should be selected for visual im pact, ecological importance, scientific and/or social value and, above all, resonance with the general public. Then, sufficiently intriguing information and practical conservation management measures should be made available to facilitate engagement. Ad ditionally, they need to be promoted as representatives of a much broader biodiversity leading directly to the conservation manage ment of habitat and ecological communities. Lastly, it is impor tant to consider that if a species declines despite a large input into its conservation, this may be demotivating and could lead to deflation of the overall community effort. Therefore, notwith standing their role in habitat conservation, flagship species should be selected to have a reasonable chance of recovery through conservation actions by local communities.

In Table 3, we provide some examples of flagship species that are either at risk of extinction and/or are of high scientific or social value. These examples represent a broad range of biore gions (IBRA regions), threatening processes and values, and il lustrate the task required. Our vision is to encourage AES members to nominate additional taxa for consideration by pre paring a species dossier that includes a set of 10 key attributes (Table 4), with the view of reviewing all submissions in 2020. Calls for nominations will be posted on the AES website (see https://www.austentsoc.org.au/AES/) and relevant social media sites and promoted through various activities of the AESCC (conferences, outreach to other societies and local community groups). Taxa will then be prioritised (according to spatial representation in bioregions, degree of risk of extinction, threats, scientific/social value, and extent of community engagement) and then nominated for listing nationally under the *EPBC Act* and/or promoted through the society and media. Ultimately, the key drivers for success will be education, promotion, advocacy and public outreach by entomologists to the wider community and the adoption of flagship species by a national network of lo cal community groups to facilitate better conservation manage ment of habitat and ecological communities across the Australian bioregional landscape.

Table 4 Species dossier detailing required information for 10 key attributes for the nomination of flagship species of Australian insects and allied invertebrates to the Australian Entomological Society Conservation Committee

Attribute	Required Information
Taxonomy	(a) scientific name, author, date, synonymies; (b) higher classification (Order: Family); (c) common name (provide one if not available)
Description	(a) brief description providing diagnostic features for identification; (b) similar species; (c) image of species
Conservation status	under which conservation schedule or Act, if known or evaluated
Distribution	(a) IBRA region; (b) spatial map; (c) breeding habitat or ecological community; (d) land tenure; (e) occupancy (sites/areas occupied)
Biology	life history, seasonality, life cycle
Ecology	ecological interactions (food plants, hosts, predators)
Key threatening processes	(a) threats; (b) evidence of decline
Scientific and/or social value	e.g. relictual, phylogenetically distinct, keystone species, aesthetic, mediagenic, cultural, entomophagy, biophilia, economic, ecotourism
Community engagement	(a) identify stakeholders; (b) management plan; (c) recovery team
References	cite all relevant information

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SUPPORTING INFORMATION

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

Table S1 Estimated number of threatened species for all biota (after Chapman 2009).

Table S2 Estimated number of invertebrates (after Chapman 2009) considered under the auspices of the Australian Entomological Society Conservation Committee (AESCC).

Table S3 Australian insects and allied invertebrates that have been listed under various conservation schedules, including State/Territory Acts, the *EPBC Act* and the IUCN Red List, and their occurrence in IBRA regions.