Review

Where have all the spiders gone? The decline of a poorly known invertebrate fauna in the agricultural and arid zones of southern Australia

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Abstract

Earth is currently experiencing the sixth mass extinction of complex multi-cellular life, the first at the hands of a single species. The documented extinctions of iconic (mostly vertebrate and plant) taxa dominate the discourse, while poorly known invertebrate species are disappearing ‘silently’, sometimes without having ever been described. Here, we highlight the decline of elements of the trapdoor spider (Mygalomorphae: Idiopidae) fauna of southern Australia – a taxonomically poorly documented yet diverse assemblage of long-lived fossorial predators. We show that a number of trapdoor spider species may be threatened after a century of intensive land clearing and stocking, and that remaining populations in some areas may be experiencing serious contemporary population declines. So, how do we conserve this fauna? We suggest that baseline systematic studies are crucial, and that follow-up surveys, including integrative citizen science solutions, should be used to assess where remnant populations still exist, and whether they can persist into the future. Detailed population genetic research on a handful of carefully chosen taxa could be broadly informative, and ongoing natural history studies remain invaluable. Although solutions may be limited in the face of ongoing habitat degradation and other threats, urgently quantifying declines has implications not just for spiders but for mitigating against the mass extinction of poorly known invertebrate taxa across the globe.

Key words

Aganippini, Arachnida, Araneae, biodiversity hotspot, south-western Australia.

INTRODUCTION

‘One hundred and fifty nine years [sic, in 1990] of [European] settlement in Western Australia has made a travesty of the natural landscape.’ (Main 1990: 397)

The observations and predictions of Main (1990) on the degradation of the biota of south-western Western Australia (SWWA) make for difficult reading. A biodiversity hotspot (Myers et al. 2000; Rix et al. 2015), SWWA has experienced such destructive degradation since European settlement that a suite of natural ecosystems are now ‘so drastically diminished or have experienced such profound degradation and regime changes that their ecology is fundamentally altered’ (Laurance et al. 2011: 1477). Those fragments that remain face numerous threats (Environmental Protection Authority 2007). The same is true for much of southern Australia, where a mosaic of different ecosystems has experienced widespread land clearing and modification for agriculture, along with historical or contemporary grazing by stock. Unsurprisingly, this degradation has severely affected the region’s biota, with well-documented contemporary extinctions or declines among mammals, birds and plants (e.g. Woinarski et al. 2015). These threatened and often iconic vertebrate and plant taxa have dominated the conservation biology discourse worldwide (Régnier et al. 2015); their declines are usually easily detectable and often generate an emotive public response. It is, however, the invertebrate animals – ‘the little things that run the world’ (Wilson 1987) – that may be affected most. Indeed, the scale of the ongoing decline of poorly known invertebrate faunas may be grossly underestimated by standard assessment practices (Régnier et al. 2015).

Arachnids are rarely the subject of public sympathy, and the widespread fear of these animals is an impediment to their conservation (Yen 1995). Despite this, spiders have featured heavily in the invertebrate conservation literature, none more so than members of the infraorder Mygalomorphae – a worldwide lineage including tarantulas and trapdoor spiders. Mygalomorph spiders (Fig. 1) are mostly fossorial and are renowned for their longevity, habitat specificity and generally poor vagility (Hedin et al. 2013). They have been of
conservation significance in many regions of the world (e.g. Arnedo & Ferrández 2007) and are also widely studied for their utility in systematics research (Cooper et al. 2011; Hedin et al. 2015). Indeed, mygalomorph life histories are often suitable for revealing fine-scale phylogeographic signal; these life history characteristics, in turn, make many species susceptible to threatening processes. The Australian mygalomorph spider fauna is no exception and is replete with a diversity of short-range endemic species (Harvey 2002). Some taxa (e.g. Idiopidae) seem especially vulnerable to threatening processes, and various studies have documented this vulnerability in Australia over several decades (e.g. Main 1987, 1995; Harvey et al. 2015; Mason et al. 2016).

In this essay, we document the potential decline of elements of the trapdoor spider fauna of the agricultural and arid zones of southern Australia (Fig. 2). This geographical region covers a vast area south of the Tropic of Capricorn, characterised by low annual rainfall (i.e. the arid zone) or low summer rainfall (in the temperate Mediterranean-climate regions; Fig. 2). The heavily cleared agricultural lands of south-western and south-eastern Australia occur within these zones (Fig. 2), usually in transitional rainfall habitats. By drawing on multiple lines of evidence and focussing on Idiopidae (Fig. 1) of the Western Australian Wheatbelt (Gibson et al. 2004; Fig. 2), we show that a number of trapdoor spider species may be threatened after a century of intensive land clearing and stocking, and that remaining populations in some areas may be experiencing serious contemporary population declines. We also highlight what data are required to determine if any species may have already been lost. This work is necessarily qualitative in nature – a case study to highlight the challenges faced in documenting the status of poorly known invertebrate taxa, especially those that exhibit: (1) low recruitment and/or long generation times; (2) limited vagility; (3) a high degree of habitat specificity; and (4) are low on the conservation radar. Clearly, most of these same life history characteristics can make populations fundamentally susceptible to habitat disturbance (see Owens & Bennett 2000; Harcourt et al. 2002). In the case of the Wheatbelt’s trapdoor spiders, we have a decades-long perspective for some species for specific localities (e.g. Main 1987); for other regions across southern Australia, there is a need to infer, post hoc, the extent to which populations may have been affected.

IDIOPIDAE

The mygalomorph spiders of Australia include over 400 described species in nine families (World Spider Catalog 2015).
Unfortunately, our knowledge of the natural history of most taxa is scant, and it is thus difficult to make reasonable inferences about the conservation status of most groups. However, for the trapdoor spiders of the Idiopidae (Fig. 1), a longer history of research and field work indicates a fauna of recognised conservation significance (Main 1987). Idiopidae in Australia are currently represented by nine valid genera and over 100 described species (World Spider Catalog 2015); at least 100–200 undescribed species are known from museum collections (MGR & MSH unpubl. data). The large tribe Aganippini (Aganippe, Anidiops, Eucyrtops, and Idiosoma; Fig. 1) and members of at least two other genera (Blakistonia and Euoplos) have radiated within the Australian arid and semi-arid zones and are most abundant south of the Tropic of Capricorn. Although the distributions of the vast majority of taxa are not known in detail, molecular and morphological research have shown that the family is replete with short-range endemic species (Harvey 2002) or otherwise more broadly distributed species with strong microhabitat fidelity, with the greatest generic diversity in southern Western Australia. Species for which data are available are long-lived (8 to >40 years; Main 1987, unpubl. data), with long generation times (10+ years), limited vagility, low recruitment, strong site fidelity (Main 1987) and usually deep genetic structuring between populations (MGR unpubl. data). One species (Idiosoma nigrum Main, 1952; Fig. 1d–f) is currently listed as threatened under both Australian State (Western Australian) and Commonwealth legislation.

THE CHALLENGE: DETECTING DECLINES IN A POORLY KNOWN FAUNA

The conservation biology discourse has long been dominated by a focus on vertebrates and plants; under one measure of assessment of conservation status – relative representation on the International Union for the Conservation of Nature (IUCN) Red List – invertebrates remain ‘essentially unevaluated overall’ (Régnier et al. 2015: 1; see also Cardoso et al. 2011, 2012). By definition, a poorly known fauna lacks rigorous empirical or quantitative assessment at the species and population levels, and this, in turn, renders such groups difficult to adjudicate from a conservation perspective. The Australian aganippine Idiopidae are largely undocumented taxonomically, with only 18 of 100–200 species described; museum collections of these taxa are only now being analysed by using both morphological and molecular data. The problem is further amplified in long-lived species with long generation times and low recruitment, in that short-term empirical ecological approaches can fail to detect the symptoms of long-term – and potentially catastrophic – threatening processes. This is especially true of invertebrate faunas, where a lack of iconic species or a dearth of taxonomic documentation can result in an inability to attract conservation funding, thus preventing future quantitative research. For example, the disappearance of small mammals in the Wheatbelt has resulted in this region being classed as a landscape that has already reached a tipping point (Laurance et al. 2011). While this classification seems justified, numerous
endemic invertebrates persist in remnant habitats of the Wheatbelt and continue to contribute critical ecosystem functions.

The question then becomes: Within a realistic timeframe, how do we infer or interpret potential population declines in poorly documented and understudied invertebrate taxa with long generation times? And how do we determine if population declines are occurring in widespread common species or more restricted and potentially threatened rare species? For trapdoor spiders in Australia, we highlight these problems by bringing together three lines of evidence, as follows: (1) previous research on idiopid demographics, natural history, systematics and conservation; (2) personal observations and anecdotes resulting from field work by experienced researchers; and (3) museum and other collection records. As stated above, this is therefore a largely qualitative synthesis, but one which builds on existing information to reveal, and where possible interpret, a complex problem across a vast geographical area. As a case study, we focus on the Wheatbelt of SWWA but extend our observations and conclusions to cover much of southern Australia (Fig. 2).

WHERE HAVE ALL THE SPIDERS GONE?

The many small, remnant reserves in the agricultural zones of southern Australia (Fig. 2) typically consist of a denuded series of habitat islands in a sea of cropped or stocked farmland. Weeds are a perennial problem, vertebrate pest species are ubiquitous, bird assemblages are depauperate, and small marsupials are usually absent (McKenzie et al. 2003). In many areas, dryland salinity and plant diseases such as Phytophthora are causing enormous changes to floristics and the structure of vegetation communities, some of which are themselves threatened or home to threatened species (Barrett & Yates 2015; https://www.environment.gov.au/biodiversity/threatened/communities). Other vast tracts of central Australia, while still covered with some primary vegetation, have been denuded by 150 years of stocking with cattle and sheep and the impacts of grazing by rabbits, feral donkeys, camels and goats (Environmental Protection Authority 2007).

What are less obvious in the remnant habitats of southern Australia are the many cryptic invertebrates that survive in these fragments. Indeed, a careful inspection of the ground may reveal burrows belonging to fossorial spider taxa, including highly camouflaged idiopid trapdoors (Fig. 1b,c,e,f,h,i), the latter a once ubiquitous occurrence in many places (e.g. Main 1967). Most of these Idiopidae are members of the diverse tribe Aganippini (Fig. 1). In some of the larger reserve systems, seemingly healthy population clusters of burrows can still be found in suitable habitats. However, surveys in smaller reserves or roadside remnants have shown that these spiders are often increasingly difficult to find. The ‘lone matriarch’ phenomenon, whereby at most one or a very few large burrows with resident older females are active in the absence of any others (with smaller juvenile burrows conspicuously absent), is now a familiar occurrence (for a full description of the matriarch concept in trapdoor spider demographics, see Main 1987). In some places, only defunct (i.e. empty) burrows can be found.

But where have all the spiders gone? What evidence is there of population declines, and does this equate to species actually being (or becoming) threatened? In the Wheatbelt of SWWA and other habitats, one of us (BYM) has documented some of these declines over 65 years, using a combination of demographic and other ecological approaches, combined with taxonomic appraisal and field work across the surrounding landscape. At North Bungulla Nature Reserve (BNR; Fig. 2), trapdoor spiders have been surveyed and their demographic characteristics assessed for over 40 years (Main 1978, 1987, unpubl. data). The results of this work provide evidence for idiopid declines, as well as quantitative life history information implicated in the likely causes of these declines. Indeed, surveys on a private property near BNR with some remnant bush and a variety of other land uses revealed that three of the nine species present in the 1950s may have disappeared by 1980, and of these, most were rare and none were common as in the previous census (Main 1987). Similarly, a pitfall trap survey at nearby Durokoppin Nature Reserve in the late 1980s and early 1990s revealed 10 species in this one reserve; another pitfall trap survey a decade later captured only three species, one of which was not sampled in the first survey (Appendix A in the Supporting Information). Site sampling methods for the two Durokoppin surveys were not precisely replicated, but given the small size of the reserve (1030 ha), these recapture data may be indicative of population declines for some species during the intervening 10 years.

Museum collection records offer another important source of data with which to compare modern distributions. In the case of Idiopidae, these historical collections can be used to track the extinction of populations following land clearing, as shown by Main (1990). In this study, Western Australian Museum records of Idiosoma sigillatum (O. P. Cambridge, 1870) from the Perth region were tracked by location and date of collection. As Perth suburbs expanded throughout the 20th Century, collections (usually public submissions) were made with the advancing front of development; in the aftermath of urbanisation, these records became the so-called ‘phantoms’ of extinct populations. While small populations of I. sigillatum still exist in some reserves in the Perth metropolitan region, and in other remnant woodlands, the species is now locally extinct across the majority of its former range and can be assessed as ‘vulnerable’ by using standard IUCN Red List criteria (Appendix B in the Supporting Information). Clearly, museum collection records provide crucial data necessary to determine which taxa occurred in a particular area, and whether those species still exist.

Some of the strongest evidence for recent declines comes from an accumulation of field work by the authors and other workers over recent decades. While qualitative in nature, these observations are nonetheless informative, given the historical perspective upon which they are founded. One example is Yorkrakine Rock Nature Reserve – a habitat island in the Wheatbelt (Fig. 2). Main (1967) documented the natural history of this woodland remnant and described in detail the populations of four species of trapdoor spiders present at the time of writing.
Two visits to this site and many combined hours of searching by two of us (MGR and MSH) in 2014 revealed just two adult female idiopid specimens – one Aganippe sp. and one Anidiops villosus (Rainbow, 1914) (Fig. 1g, h). No other active burrows were located. Although burrows can sometimes be difficult to locate due to their camouflage (Fig. 1), recruitment has undoubtedly been reduced at Yorkrakine Rock relative to the 1960s. Similar lone matriarchs have been recorded at a number of sites across Australia, including at Lake Broadwater Conservation Park, south-eastern Queensland (2014; 1x Aganippe sp.), and in a small patch of remnant scrub near Chinkapook, western Victoria (2013; 1x Blakistonia sp.; Fig. 2). Both sites are highlighted here as they were surveyed by at least two of the authors for at least five hours, and are surrounded by cleared agricultural lands; in each case, old doors and other defunct burrows were present. While subsequent survey work at Lake Broadwater has revealed a small 9 ha area within the park where a population of two species of Idiopidae can be found, active burrows are yet to be located anywhere else in the reserve, despite follow-up searches. Given the predictions of Main (1987), who calculated that populations of A. villosus were only viable long-term if there were at least 20 matriarchs present (and that populations probably also require habitat-connected satellite populations for occasional recruitment during adverse conditions), the persistence of these species at such localities seems doubtful.

There is also evidence for trapdoor spider population declines in the largely uncleared but often heavily stockaded arid zone. A 2014 survey, along a ~1400 km transect following the southern edge of the Nullarbor (Eyre Highway) by two of us (SEH and MSH), revealed just 18 idiopid specimens, despite dedicated field work across hundreds of kilometres over 10 days, including at many sites that provided fertile collecting for three or four genera in the 1950s to 1980s (these <1990 specimens now stored in the BYM collection, Western Australian Museum; Fig. 3; Appendix C in the Supporting Information). At least one genus commonly recorded then (Eucyrtops) was not located in 2014, another (Blakistonia) was unexpectedly sparse (Fig. 4), and sympathy at sites was uncommon; this was surprising, given the ease with which idiopids could be located from the same areas in the 1950s (Fig. 3). Likewise, in arid central Australia, three field trips in 2013 and 2014 by one or more of us (MGR, SEH, MSH and ADA) revealed an almost complete absence of active idiopid burrows; many of these landscapes were severely degraded due to stocking by various introduced herbivores. Taken together, these data provide evidence for a problem that may not simply be restricted to the cleared agricultural zones, but rather to temperate arid and semi-arid southern Australia in general.

WHAT FACTORS ARE IMPLICATED IN POPULATION DECLINES?

Understanding the factors implicated in the decline of a poorly known fauna is by definition difficult and subjective. However, setting out what we know, what we think we know and what we need to ascertain is critical for informing research priorities.

The most significant threatening processes to Australian trapdoor spiders are undoubtedly land clearing, stocking by sheep and cattle and the impacts of other feral grazing animals. Parts of the Wheatbelt and southern South Australia are among the most cleared landscapes in Australia (Bradshaw 2012), the result of destroying ‘a million wild acres a year’ during post-WWI and post-WWII resettlement schemes (Gaynor 2015). Likewise, vast areas of the Australian arid zone have been stocked since the earliest phases of European settlement. Most of the clearing in southern Australia was historical rather than ongoing, and there have been intense efforts to transfer remaining remnants into conservation estates. Nonetheless, it is implicit that land clearing on this scale has major conservation implications for range-restricted or habitat-restricted taxa, as reflected in ‘geographical range’ being a primary consideration in IUCN Red List species assessments (Criterion B), which use ‘extent of occurrence’ and ‘area of occupancy’ data. Stocking was and remains destructive in many areas, and as witnessed by one of us (BYM) in the Wheatbelt, most existing reserves (many of which were gazetted only in the late 20th Century) were previously open to use by stock, largely for shade or water. What appear today to be carefully protected remnants have actually had a long history of disturbance, and it is now clear that trapdoor spider burrows are severely affected (and usually destroyed) by trampling by stock. This problem remains ongoing in the vast unfenced rangelands of the Australian arid zone and is likely implicated in the scarcity of Idiopidae across some of these areas.

Salinity is another threat to inland ecosystems, at all levels. The wholesale changes to vegetation and soil chemistry wrought by an increasingly saline water table affect the entire biota (George et al. 1997). There is no evidence that Idiopidae previously adapted to non-saline environments can persist in newly saline landscapes, although several species are naturally adapted to salt-lake environs in other regions (Main 1982). Dryland salinity is perhaps the most significant threat to the biota of the inland Australian agricultural zone (Keighery 2004) and remains a particular threat to dispersed-limited trapdoor spiders, given that it is so difficult to mitigate. Understanding how idiopid populations are affected and at what salinity threshold individual fitness is reduced are thus important questions for future research.

Despite its central role in the ecology and evolution of the Australian biota, fire (and its potential increase in frequency with progressing climate change) may be another threatening process in the arid and semi-arid zones, especially in small reserves where hot-burn fires may be ‘total instead of patchy’ (Main 1987: 36). Data exist on idiopid post-fire mortality, and in some cases, nearly 50% of adults can die within 3 months after a fire; juveniles are more severely affected with no short-term recruitment (Main 1995). Without recruitment from adjacent unburnt areas, the long-term survival of successively degraded populations may be affected, potentially leading to local population extinction.

Other potential threats are less clear or may have indirect effects, and they are listed below in no particular order. Firstly, the effects of drought (and increased drought frequency), agricultural herbicides and pesticides on trapdoor spiders are little known, although the latter may be worthy of urgent
assessment, given their widespread use in fields adjacent to conservation estates. For species with small population sizes, there are a series of threats that relate to the genetic viability of populations, including low standing genetic variation (Frankham 1996; Lynch & Lande 1998), inbreeding depression (e.g. Charlesworth & Charlesworth 1987) and over longer periods of time, the overriding influence of genetic drift over selection. This ‘genetic load’ can have the cumulative effect of lowering the fitness of populations (Kirkpatrick & Jarne 2000). Fortunately, techniques in the field of conservation genetics are now available to explore these threats, and this could be a fruitful area of research.

Finally, introduced pest species may be a threat across all landscapes, but especially within small reserves. Weeds and aggressive introduced grasses seem to choke out burrows in previously favourable areas, further reducing habitat. Rabbits have localised effects on soil stability and integrity, and it has been reported that plagues of mice become omnivorous when they run out of other food resources (M. Cowan pers. comm.); clearly, this may be detrimental to local trapdoor spiders, both by direct

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**Fig. 3.** Maps of southern Western Australia and southern South Australia, showing collection records of Idiopidae from the Eyre Highway section of the Nullarbor Plain (Fig. 2) from the 1950s (top), from the 1960s–1980s (middle) and from 2014 (bottom). The Interim Biogeographic Regionalisation of Australia (IBRA) Nullarbor bioregion is highlighted. Different genera are denoted by differently coloured circles; open circles from 2014 denote negative records. The number of collecting days represented by the mapped collections is shown to indicate relative survey effort; the less than symbol in panel 2 (middle) denotes a range of collecting dates for some records. Note the numerous collection records from the 1950s and the relative paucity of specimens and genera (and the low levels of sympatry) recorded at sites in 2014 (especially in south-eastern South Australia). See text for details.
predation and predation by mice on the spiders’ invertebrate prey. It is unknown what effect foxes and feral cats might also be having on idiopid populations, but anecdotal evidence suggests that foxes dig up spiders from their burrows (N. Moore & H. Cannon pers. comm.); a detailed scat or gut content analysis would help clarify this. We also postulate that seasonal predation by foxes and/or cats on wandering male spiders (i.e. sex-biased predation), or on recent recruits that have shallow burrows, may be an overlooked but potentially significant factor in the long-term decline of populations. Demographic work has shown that for a reasonably healthy population of *A. villosus* (Fig. 1g,h) with 15–24 matriarchs, at most, only three male spiders ‘run’ (i.e. emerge and search for female spiders during appropriate conditions) in any one season (Main 1987). Should anything happen to this small male cohort over successive seasons, or if the number of available male spiders decreases further, recruitment may be affected. This is especially so when both sexes mature at around 8 years of age, and female spiders only reproduce at most once every two years thereafter (Main 1987). It is well documented that foxes and cats have both extraordinarily broad diets and occur in high densities in remnant habitats (Read & Bowen 2001); what effect they are having on long-term population demographics if they hunt nocturnally wandering mygalomorph spiders is at present unknown.

**QUANTIFYING DECLINES AND FUTURE RESEARCH**

Adequately quantifying trapdoor spider declines is essential to determining the nature and scale of the conservation problems facing different taxa and to addressing conservation priorities (where they exist) in constructive and proactive ways. Some of the most powerful approaches to understanding population dynamics are molecular, and fine-scale genetic studies on gene flow, recruitment and paternity are required, if only to provide some guiding case studies with which to inform broader management. To date, many phylogenetic studies on mygalomorph spiders have focused on deep genetic breaks, often correlating with species boundaries or at least independently evolving lineages with long histories of isolation (e.g. Satler et al. 2013). Finer scale genetic and geospatial studies among subpopulations are needed to test for gene flow (dispersal capacity), genetic variation (standing genetic variation and inbreeding) and/or recent extinction (e.g. Bond et al. 2006). These data will inform recolonisation potential and the potential for assisted reintroduction of conspecific juveniles (e.g. into habitats where a species has recently become extinct) and help clarify if male spiders can move genes between seemingly isolated habitat patches, possibly salvaging the reproductive potential of lone matriarchs. Similarly, recent developments in next-generation sequencing technology open up the potential to assess selection in non-model organisms, which could likewise inform conservation actions (Allendorf et al. 2010). For all genetic studies, the need to not over-collect from small populations is important (Minteer et al. 2014), and thus exemplar taxa should be chosen carefully for their ability to withstand representative sampling. Alternatively, silk-sampling or non-lethal tissue sampling procedures need to be developed (e.g. Smith et al. 2015).

Ecosystem niche modelling (Elith & Leathwick 2009) and the application of IUCN Red List assessments are two other tools useful for assessing taxa of conservation concern at different spatial scales. For example, undertaking IUCN assessments for a randomly selected taxon set provides a statistically sound and relatively unbiased method for determining the level of threat and/or the potential severity of the conservation problem facing a particular lineage or fauna (Saíz et al. 2015). However, importantly, these approaches first require knowledge of what the species are – the latter usually unavailable due to numerous impediments. This taxonomic issue is a critical one for Idiopidae (and other invertebrates; see Braby & Williams 2016), and another important early step in addressing trapdoor spider conservation across Australia is to facilitate taxonomic study of the fauna, the so-called ‘Wallacean shortfall’ (Cardoso et al. 2011). We now know that the Australian idiopid fauna is far more diverse than previously thought and species more difficult.
to delimit accurately without a combined molecular and morphological approach. When it is known what species occur where, and therefore what species occurred in which remnant reserves more specifically, a foundation will exist for determining their conservation status and likely survival (or otherwise) in those same locations (e.g. Paquin et al. 2008). Current systematic research on Australian idioptid by the authors indicates that the majority of the Australian fauna remains undescribed. However, once taxonomic revisions and/or more rapid molecular species delimitation datasets are published, this shortfall can be addressed at an IUCN Red List assessment level (as for *I. sigillatum;* see Appendix B in the Supporting Information). For other families of trapdoor spiders, there is much to be done. Thereafter, the foundations will be in place not only for modelling, statistical and other quantitative ecological approaches but also for informing follow-up survey work over longer timeframes. Indeed, we envisage citizen science as playing a key role in future conservation efforts; e.g. online public submissions of geo-referenced burrow photos could be used to pinpoint new localities or track population fluctuations over time.

Online platforms such as the Atlas of Living Australia’s ‘BioCollect’ [http://www.ala.org.au/biocollect/] or iNaturalist [http://www.inaturalist.org/] could be used to this end. The sheer size of the Australian landscape means that concerted members of the public can play a vital part in this endeavour, and integrative solutions for enhancing their involvement need to be found. For example, the unlikely case of the ‘horrid ground weaver’ (*Notothophantes horridus* Merrett & Stevens, 1995) in the UK highlighted the potential value of a citizen science solution to an acute arachnid conservation problem (IUCN 2015).

Finally, demographic work at North Bungulla Nature Reserve and elsewhere has highlighted just how useful fundamental life history studies can be, especially those that are long-running and therefore powerful in having a historical perspective. Unfortunately, natural history is an endangered field of scientific endeavour (Tewksbury et al. 2014), but if there is to be any chance of ameliorating declines and mitigating against a mass extinction, then better data must be obtained on the natural history characteristics of these animals. For example, understanding how many mature male spiders emerge each year and when they disperse and mate could help enormously in determining if they routinely fall prey to feral predators or in facilitating any (admittedly drastic) assisted reproduction attempts in those most endangered populations with the lowest recruitment. For other populations, simply knowing their microhabitat preferences is crucial to effectively manage those microhabitats for posterity.

It should be noted that all of these research priorities will be most useful in the context of similar studies on trapdoor spiders elsewhere in Australia, e.g. in the arid Pilbara bioregion of northwestern Australia (Castalanelli et al. 2014; JAH unpubl. data). Indeed, comparative studies will allow us to determine whether population declines in southern Australia are unique or whether mygalomorph spider faunas are also threatened elsewhere in the world (e.g. Yanez & Floater 2000). Most importantly, determining which threats are the most urgent to manage (and why) has implications not just for spiders but also for mitigating against the mass extinction of poorly known invertebrate taxa across the globe.

We hope that this paper stimulates interest in the conservation of Australian mygalomorph spiders, a vigorous debate as to how populations can be preserved for future generations, and urgent research into their systematics, population genetics and natural history.

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REFERENCES

Allendorf FW, Hohenlohe PA & Luikart G. 2010. Genomics and the future of conservation genetics. *Nature Reviews Genetics* 11, 697–709.

Amedo MA & Ferrándiz MA. 2007. Mitochondrial markers reveal deep population subdivision in the European protected spider *Macrothele culpaeana* (Walckenaer, 1805) (Araneae, Hexathelidae). *Conservation Genetics* 8, 1147–1162.

Barrett S & Yates CJ. 2015. Risks to a mountain summit ecosystem with endemic biota in southwestern Australia. *Austral Ecology* 40, 423–432.

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

Bradsjav CJA. 2012. Little left to lose: deforestation and forest degradation in Australia since European colonization. *Journal of Plant Ecology* 5, 109–120.

Bond JE, Beamer DA, Lamb T & Hedin M. 2006. Combining genetic and geospatial analyses to infer population extinction in mygalomorph spiders endemic to the Los Angeles region. *Animal Conservation* 9, 145–157.

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

Cardoso P, Borges PAV, Triantis KA, Ferrándiz MA & Martín JL. 2012. The underrepresentation and misrepresentation of invertebrates in the IUCN Red List. *Biological Conservation* 149, 147–148.

Castalanelli MA, Teale R, Rix MG, Kennington WJ & Harvey MS. 2014. Barcoding of mygalomorph spiders (Araneae: Mygalomorphae) in the Pilbara bioregion of Western Australia reveals a highly diverse biota. *Invertebrate Systematics* 28, 375–385.

Charlesworth D & Charlesworth B. 1987. Inbreeding depression and its evolutionary consequences. *Annual Review of Ecology and Systematics* 18, 237–268.

Cooper SJB, Harvey MS, Saint KM & Main BY. 2011. Deep phylogeographic structuring of populations of the trapdoor spider *Moggridgea tingle* (Migidae) from southwestern Australia: evidence for long-term refugia within refugia. *Molecular Ecology* 20, 3219–3236.

Elith J & Leathwick JR. 2009. Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution and Systematics* 40, 677–697.

Environmental Protection Authority. 2007. State of the environment report: Western Australia 2007 — 5.0 biodiversity. Department of Environment and Conservation, Perth. [Accessed Jan 2016.] Available from URL: [http://www.epa.wa.gov.au/AbouttheEPA/EOE/2007/Pages/default.aspx](http://www.epa.wa.gov.au/AbouttheEPA/EOE/2007/Pages/default.aspx)

Frankham R. 1996. Relationship of genetic variation to population size in wildlife. *Conservation Biology* 10, 1500–1508.

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Gaynor A. 2015. How to eat a wilderness: the past and future of the wheatbelt. Griffith Review 47, 169–180.

George RJ, McFarlane DJ & Nilsen RA. 1997. Salinity threatens the viability of agriculture and ecosystems in Western Australia. Hydrogeology 5, 6–21.

Gibson N, Keighery GJ, Lyons MN & Webb A. 2004. Terrestrial flora and vegetation of the Western Australian wheatbelt. Records of the Western Australian Museum Supplement 67, 139–189.

Harcourt AH, Coppeto SA & Parks SA. 2002. Rarity, specialization and extinction in primates. Journal of Biogeography 29, 445–456.

Harvey MS. 2002. Short-range endemism among the Australian fauna: some examples from non-marine environments. Invertebrate Systematics 16, 553–570.

Harvey MS, Main BY, Rix MG & Cooper SJB. 2015. Refugia within refugia: in situ speciation and conservation of threatened Bertmaulius (Araneae: Migidae), a new genus of relicual trapdoor spiders endemic to the mesic zone of south-western Australia. Invertebrate Systematics 29, 511–553.

Hedin M, Carlson D & Coyle F. 2015. Sky island diversification meets the multispecies coalescent – divergence in the spruce-fir moss spider (Microhexura montivaga, Araneae, Mygalomorphae) on the highest peaks of southern Appalachia. Molecular Ecology 24, 3467–3484.

Hedin M, Starrett J & Hayashi C. 2013. Crossing the uncrossable: novel trans-valley biogeographic patterns revealed in the genetic history of low-dispersal mygalomorph spiders (Antrodiaetidae, Antrodiaetus) from California. Molecular Ecology 22, 508–526.

International Union for Conservation of Nature. 2015. Critically endangered spider saved from planning development. [Accessed May 2016.] Available from URL: http://www.iucn.org/news_homepage/all_news_by_theme/species_news?721467/Critically-Endangered-spider-saved-from-planning-development

Keighery GJ. 2004. State salinity strategy biological survey of the Western Australian wheatbelt: background. Records of the Western Australian Museum Supplement 67, 1–6.

Kirkpatrick M & Jame P. 2000. The effects of a bottleneck on inbreeding depression and the genetic load. American Naturalist 155, 154–167.

Laurence WF, Dell B, Turton SM et al. 2011. The ten Australian ecosystems most vulnerable to tipping points. Biological Conservation 144, 1472–1480.

Lynch M & Lande R. 1998. The critical effective size for a genetically secure population. Animal Conservation 1, 70–72.

Main BY. 1967. Between Wodil and Tor: Jacaranda Press, Melbourne.

Main BY. 1978. Biology of the arid-adapted Australian trapdoor spider Aptopus villosus (Rainbow). Bulletin of the British Arachnological Society 4, 161–175.

Main BY. 1982. Adaptations to arid habitats by mygalomorph spiders. In: Evolution of the Flora and Fauna of Arid Australia (eds WR Barker & PJM Greenslade), pp. 273–283. Peacock Publications in association with Australian Systematic Botany Society and ANZAAS, South Australian Division, Frewville, South Australia.

Main BY. 1987. Persistence of invertebrates in small areas: case studies of trapdoor spiders in Western Australia. In: Nature Conservation: The Role of Remnants of Native Vegetation (eds DA Saunders, GW Arnold, AA Burridge & AJM Hopkins), pp. 29–39. Surrey Beatty and Sons Pty Limited in association with CSIRO and CALM, Chipping Norton.

Main BY. 1990. Restoration of biological scenarios: the role of museum collections. Proceedings of the Ecological Society of Australia 16, 397–409.

Main BY. 1995. Survival of trapdoor spiders during and after fire. CALMSScience Supplement 4, 207–216.

Mason LD, Wardell-Johnson DW & Main BY. 2016. Quality not quantity: conserving species of low mobility and dispersal capacity in southwestern Australian urban remnants. Pacific Conservation Biology 22, 37–47.

McKenzie NJ, May JE & McKenna S, eds. 2003. Bioregional Summary of the 2002 Biodiversity Audit for Western Australia. Department of Conservation and Land Management, Perth.

Minteer BA, Collins JP, Love KE & Puschendorf R. 2014. Avoiding (re)xtraction. Science 344, 260–261.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB & Kent J. 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Owens IPF & Bennett PM. 2000. Ecological basis of extinction risk in birds: habitat loss versus human persecution and introduced predators. Proceedings of the National Academy of Sciences of the United States of America 97, 144–148.

Paquin P, Dupérré N, Cokendolpher JC, White K & Hedlin MD. 2008. The fundamental importance of taxonomy in conservation biology: the case of the eyeless Cicurina bandida (Araneae: Dictynidae) of central Texas, including new synonyms and the description of the male of the species. Invertebrate Systematics 22, 139–149.

Read J & Bowen Z. 2001. Population dynamics, diet and aspects of the biology of feral cats and foxes in arid South Australia. Wildlife Research 28, 195–203.

Régnier C, Achaí G, Lambert A, Cowie RH, Bouchez P & Fontaine B. 2015. Mass extinction in poorly known taxa. Proceedings of the National Academy of Sciences of the United States of America 112, 7761–7766.

Rix MG, Edwards DL, Byrne M, Harvey MS, Joseph L & Roberts JD. 2015. Biogeography and speciation of terrestrial fauna in the south-western Australian biodiversity hotspot. Biological Reviews 90, 762–793.

Saiz JC, Lozano FD, Gómez MM & Baudet AB. 2015. Application of the Red List Index for conservation assessment of Spanish vascular plants. Conservation Biology 29, 910–919.

Satler JD, Carstens BC & Hedin M. 2013. Multilocus species delimitation in a complex of morphologically conserved trapdoor spiders (Mygalomorphae, Antrodiaetidae, Allatypus). Systematic Biology 62, 805–823.

Smith VR, Vink CJ, Cruickshank RH & Paterson AM. 2015. Beetling: a method for capturing trapdoor spiders (Idiopidae) using tethered beetles. Arachnology 16, 294–297.

Tewksbury JJ, Anderson JGT, Bakker JD et al. 2014. Natural history’s place in science and society. Bioscience 64, 300–310.

Wilson EO. 1987. The little things that run the world (the importance and conservation of invertebrates). Conservation Biology 1, 344–346.

Woinarski JCZ, Burridge AA & Harrison PL. 2015. Ongoing unraveling of a mass extinction in poorly known taxa. National Academy of Sciences of the United States of America 112, 4531–4540.

World Spider Catalog. 2015. Natural History Museum, Bern. [Accessed Oct 2015.] Available from URL: http://wsc.nmbe.ch

Yanez M & Floater F. 2000. Spatial distribution and habitat preference of the endangered tarantula, Brachypelma klaasi (Araneae: Theraphosidae) in Mexico. Biodiversity and Conservation 9, 795–810.

Yen AL. 1995. Australian spiders: an opportunity for conservation. Records of the Western Australian Museum Supplement 52, 39–47.

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**SUPPORTING INFORMATION**

Additional Supporting Information may be found in the online version of this article at the publisher’s web site:

**Appendix A** Collection records of pitfall-trapped Idiopidae from Durokoppin Nature Reserve from 1987–1991 and from 1997–1998. See text for details.

**Appendix B** IUCN Red List assessment for Idiosoma sigillatum (O.P.-Cambridge, 1870). See text for details.

**Appendix C** Collection records of Idiopidae from the Nullarbor Plain (Eyre Highway section) from 1950–1990 (B.Y.M.) and from 2014 (M.S.H., S.E.H.). See Figures 3–4 and text for details.