Quality not quantity; conserving species of low mobility and dispersal capacity in south-western Australian urban remnants

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Abstract: *Urban remnant vegetation is subject to varying degrees of disturbance that may or may not be proportional to the size of the patch. The impact of disturbance within patches on species with low mobility and dispersal capabilities was investigated in a survey targeting nemesiid species of the mygalomorph spider clade in the Perth metropolitan area, south-western Australia. Nemesiid presence was not influenced by patch size, but presence did negatively correlate with higher degrees of invasive grass and rabbit disturbance. Further, patch size was significantly positively correlated with degree of disturbance caused by rabbits. Compared to quadrats, patches were not as effective as sample units in determining the impact of disturbance on nemesiid presence.*

Additional keywords: urbanisation, conservation planning, mygalomorph spider, fragmented landscapes

Introduction

Conservation biology focuses on identifying factors or patterns that pertain to biodiversity persistence and survival (Gilpin and Soulé 1986, Schulze and Mooney 1994); with higher quality environments increasing chances of survival (Thomas *et al.* 2001). Size of suitable habitat is important to support viable populations (Shaffer 1981, Gilpin and Soulé 1986). Measuring quality and size of habitats is especially important for conservation practises as it allows appropriate population or species management to be implemented (Shaffer 1981). Disturbance within patches can be influenced by surrounding land-use, patch size and patch shape (Pickett and White 1985). Maintenance of at least the minimum required size and quality of habitats will increase probability of persistence for viable populations (Shaffer 1981, Gilpin and Soulé 1986). Required habitat of native species within an urban matrix is usually confined to remnant patches, depending on species and degree of specialisation. Urbanisation is a relatively recent process in Australia. Therefore associated threats are novel for native species persisting in urban areas. Identifying factors or patterns important for conservation purposes allows implementation of more informed management practices (Olson *et al.* 2001).

Informed conservation management is especially important in the South-west Australian Global Biodiversity Hotspot (SWA). The biota of SWA is therefore globally significant (Hopper and Gioia 2004, Rix *et al.* 2014), but also threatened (Klausmeyer and Shaw 2009, Wardell-Johnson *et al.* 2011). Though invertebrates were not included in Myers *et al.* (2000) criteria, evidence supports invertebrate biodiversity as also being proportionally high within SWA (Main 2001, Harvey *et al.* 2011). Many clades of invertebrates are locally endemic to the region (Rix *et al.* 2014), likely attributable to shared life history characteristics. A species or clade may be considered a short-range endemic (SRE) if they have a distribution range of less than 10 000 km^2, low fecundity, low dispersal and low mobility. Recently, recognising short-range endemism has allowed rapid synthesis of conservation protocols for a large group of previously unprotected species in SWA (Harvey 2002, EPA 2009, Harvey *et al.* 2011).

Many species of mygalomorph spider are considered SREs. However, taxonomic impediment, taxonomic resolution and insufficient information means SRE status cannot be assigned for the entire mygalomorph clade, hindering conservation outcomes (Mace 2004). Population counts of mygalomorphs may be misleading as to the viability of some populations, due to slow maturation, cryptic mating systems and long lifespans (Main 1987, Abensperg-Traun *et al.* 2000). For example; *Gaius villosus* mature at approximately 5 years for females and 3 years for males (Main 1984). Males die after their mating season. However, some females can live up to 30 years (Main 1987, Abensperg-Traun *et al.* 2000). Persistence despite small population size has occurred after genetic bottlenecks (Main 1987, Abensperg-Traun *et al.* 2000). This implies that limited dispersal and longevity could enable mygalomorphs to persist in small, isolated populations indefinitely. This may also apply to other long-lived SRE taxa such as cossid moths (*Cossidae*) and some Coleoptera (e.g. *Curculionidae*)(Abensperg-Traun *et al.* 2000, Harvey 2002). Unfortunately, being long-lived also increases the likelihood of ghost populations; aging populations that can no longer recruit and are therefore not viable.

Thomas (2000) concluded that species either with high or low mobility, are less impacted by habitat fragmentation than those with intermediate mobility. Mygalomorph spiders are generally sedentary, with the exception of roaming males. Their poor dispersal ability may mean they require less area in which to persist indefinitely (Main 1987, Abensperg-Traun *et al.* 2000). Thus persistence of mygalomorphs in urban areas may be more dependent on the quality rather than absolute size of the remaining habitat. This claim is further substantiated by work on mygalomorph populations persisting in remnant vegetation of less than 20 hectares in 'the wheatbelt', agricultural land near Tammin, WA (Main 1987). As low as twenty *Gaius villosus* matriarchs (females that have reproduced at least once) are thought to be capable of sustaining a viable population indefinitely, if they are in close proximity to one another (Main 1987). More than twenty matriarchs can occur in less than 10 000 m^2 in these wheatbelt populations {Main, 1987 #233}.

The overall aim of this study was to determine the likelihood of persistence of mygalomorph populations in urban remnant vegetation of the SWA. We examined the effects of urbanisation on mygalomorph spiders, using nemesiids as indicator species, in remnant patches of native vegetation of the Perth Metropolitan Area, Swan Coastal Plain. Nemesiidae is a family of mygalomorphs, with ten genera and one hundred and four described species occurring in Australia {W Framenau, 2014 #338}. Nemesiids generally have an open (no lid) and conspicuous burrow. If size of remaining habitat was not a threat, then it becomes important to identify other threatening processes within remaining habitat. In particular:

i) *Does change of surrounding land-use correlate with disturbance variables in urban remnant vegetation patches?* Based on low mobility, we expected surrounding land-use to not correlate strongly with nemesiid presence or with disturbance variables.

ii) *Do disturbance variables correlate with patch size and/or nemesiid species presence?* We expected disturbance variables to negatively correlate with presence of nemesiids and patch size. However, patch size was not expected to correlate with nemesiid presence.

Methods

Study site

Perth experiences a Mediterranean climate, with a mean annual rainfall of 740 mm (Australian Bureau of Meteorology, 2011), although this has been trending lower since 1970 (Bates *et al.* 2008). Approximately 80% of rainfall occurs in the winter months with only 4% occurring in summer (Australian Bureau of Meteorology, 2011). The soil of the Spearwood dune system is well-drained and highly leached pale yellow quartz sand, formed in the mid- to late Pleistocene (Kendrick *et al.* 1991). Major soil types were found to correlate with significant change in spider assemblages on the Swan Coastal Plain (Lacey 2012), so sites for this survey were selected to the west of the Bassendean dune system.

Field survey

Comprehensive surveying was required to confidently determine the distribution of nemesiid spider species. Earlier studies used pitfall traps (Harvey *et al.* 1997) that capture specimens not necessarily directly associated with a specific location. Typically, it is only the males that are trapped as they roam to find a mate once sexually mature, and perish shortly thereafter (Main 1984). Due to the potentially high mobility of males, they may be trapped a considerable distance from where they left their burrow. We used a targeted survey approach to determine the number of known locations where nemesiids occur (Olson *et al.* 2007). This was considered the most effective method given the primarily sedentary lifestyle and poor dispersal of mygalomorph species (Harvey *et al.* 2011). Using a targeted approach by locating burrows, enabled more precise information on the distribution of nemesiid species and potential urbanisation threats to be gathered.

A stratified random approach was used whereby a mosaic of habitats was targeted and surveyed, but the transect grid is otherwise random. Sampling was designed by nesting one hundred and thirty-six 100 x 100 meter quadrats divided into ten 100 m transects spaced 10 m apart (Figure 1) within forty-one patches of remnant native vegetation (Figure 2). Randomisation was achieved using the 'Random points' function in the program QGIS v2.8.1 Wein, where each point was the centre of the quadrat. If the point was too close to the boundary, it was shifted in until the quadrat fit within remnant vegetation. Similarly, if points were so close that quadrats overlapped, they were moved apart to the shortest distance to where they would no longer be overlapping. Quadrats were uploaded onto a Garmin handheld GPS and surveyors recorded burrows within 5 m either side of the transect line they were traversing. Due to health and safety risk, surveying was always completed with at least one other person. Quadrats in dense, impenetrable vegetation (e.g. stands of prickly moses; *Acacia pulchella*) were replaced by alternative random sites in the interests of volunteer safety.

Figure 1 here

Figure 2 here

Nemesiid observations

Nemesiid spider (Figure 3a) burrows (Figure 3b) were directly observed, identified, and measured (diameter, diagnostic features; silk lines, number entrances, sand mounds). Burrow locations were recorded using a GPS, accurate to within 5 m. Although other mygalomorph burrows were recorded, statistical analysis was restricted to nemesiids, due to potential for bias arising from the unobserved highly camouflaged burrows in other families. Surveying was also not undertaken during heavy rains. This was because we found that some species of nemesiid pull their burrow opening in on itself during heavy rain. No doubt this enables avoidance of flooding to open-holed burrows but also make burrows more difficult to observe after heavy rain.

Past records from the Western Australian Museum (WAM) indicate a previously uniform distribution of nemesiids throughout the Perth urban area. They have also been recorded throughout the study area since 1922. Museum records were not used for analysis as very few included locations that were specific enough to compare to present distributions. All sites in a bushland survey conducted by WAM during 1996-1997 where mygalomorphs were found contained nemesiids as the dominant group collected (Harvey *et al.* 1997). We concluded that nemesiids were appropriate indicator species for a group subject to taxonomic impediment (Harvey *et al.* 2011). It is apparent that more nemesiid species were observed in this survey than have been recorded by the Museum. As such, analysis was here limited to presence and absence until species can be verified by subsequent study.

Variables

Disturbance factors such as; invasive grass cover, rubbish and rabbit presence were recorded for each quadrat. Invasive grass (Figure 3c, d) was estimated as a proportion of quadrat covered where number of 100 m^2 (n) covered was estimated over the 10000 m^2 quadrat (see equation below).

$$Invasive\ grass = \left(\frac{n(100)}{10000}\right)$$

Rabbit presence was calculated as a proportion (< 1) equal to the number of evidence (n), such as droppings or diggings found per 10 m over 100 m transects (t) and warrens (w) adding 0.5 final score (see equation below).

$$Rabbit\ presence = \left(\frac{n(10)}{t100}\right) + (0.5w)$$

Rubbish was used as a proxy for human activity within patches. Rubbish proportion (< 1) was calculated in a similar fashion, with evidence of active bunkers (b, +0.5) and dumping of industrial waste (i, +0.3) heavily influencing calculations (see equation below).

$$Rubbish\ presence = \left(\frac{n(10)}{t100}\right) + (0.5b) + (0.3i)$$

To account for the possibility of ghost populations in an area of rapid urban expansion (Figure 2), change of surrounding land-use was incorporated over a timeframe of fifty years between 1965 and 2015. Surrounding land-use area was measured by generating shapefile layers (buildings [B], roads [R], parkland [PL] and other remnant vegetation [RV]) within 250 m, 150 m and 50 m buffers. Buffers were measured for both patch and quadrats in the open source program Quantum Geographic Information System (QGIS 2014). The Nearmap plugin was used to determine the proportion of different land-use within each buffer area. The same methodology was performed for surrounding land-use in 1965 using maps available through SLIP (Shared Land Information Platform) Interrogator+.

Figure 3 here

Statistical analysis

PATN v. 3.0 (Belbin 2013) was used to analyse patches based on the twenty-four surrounding land-use variables as intrinsic in multivariate analysis. We derived groups of patches with similar measures of surrounding land-use proportions using the range standardized values of the 10 measures described earlier (called 'intrinsic variables', following Belbin (2013)) in numerical taxonomic or pattern analysis approaches (Belbin 2013). The key steps were (1) use cluster analysis to identify groups of patches (row groups) that, on the basis of the twenty-four intrinsic variables, are more similar to other members of their groups than to members of other groups, (2) superimpose groups based on the variables (column groups) over the patch groups to identify which variable groups are strongly or weakly represented in different patch groups, and (3) validate the patch groupings by applying different methodologies (MDS ordination and network analysis), to assess congruence between the ordination (for trends), network analysis (for nearest neighbours) and the cluster analysis (for groups). All analyses described below used PATN (Belbin 2013).

The Gower metric was used to determine degree of association between different patches based on surrounding land-use composition to generate groups using unweighted pair group arithmetic averaging (UPGMA) with Beta set at -0.1 (see Belbin 2013). To determine the influence of particular intrinsic variables on patch groupings, we classified the intrinsic variables using the Two-Step association measure with Beta set at -0.1. A two-way table was used to visualise the influence of particular variable groups on the different patch groups, where each cell corresponds to a particular patch score on a particular land-use variable. Shading in the two-way table indicates strength of association between patch and land-use variable. Dark shaded blocks indicate strong associations between groups of patches (sites) and groups of variables, and light or clear blocks indicate weak association.

We presented our original distance matrix visually through semi-strong hybrid multi-dimensional scaling ordination (SSH MDS with dissimilarity cut level at 0.6) (Belbin 2013). MDS ordination seeks to provide, in few dimensions, an accurate representation of the similarity between samples, in this case patches, on the basis of the surrounding land-use variables. Stress (the difference between the input distances and the output distances) determined in how many dimensions the ordination can be reliably assessed. Here, low stress enabled assessment in two dimensions. The Minimum Spanning Tree (MST, Belbin 2013) was used together with SSH MDS to assess congruence between ordination (trends), cluster analysis (groups) and network analysis (nearest neighbour). The three approaches were inspected visually in one diagram. The greater the congruence between them (i.e., all approaches giving similar results), the greater the validity of the derived patterns.

Mygalomorph presence and the disturbance variables; rabbit, weed and rubbish were used as extrinsic factors. Relationships of extrinsic variables to the ordination axes were explored using principal axis correlation (PCC procedure in PATN, Belbin 2013). Significance of the correlation of variables to the axes of the two-dimensional ordination derived from the matrix was assessed using randomization tests (with 1000 permutations) and the MCAO procedure of PATN (Belbin 2013). Vectors of variables correlated significantly with the ordination axes were plotted. Extrinsic factors were superimposed on a two dimensional semi-strong hybrid multidimensional scaling ordination (2D; stress 0.16, SSH MDS; dissimilarity cut off level 0.6) to visualise influence of groups on those factors.

ANOVA were used to determine correlations between disturbance variables and presence of nemesiids for both quadrat and patch scale in the Microsoft Excel plugin StatistiXL 1.8 (Withers and Roberts 2007). As multiple quadrats were in many of the patches surveyed, the factors gathered for each quadrat were averaged for each patch. Quadrat and patch factors were analysed separately and then compared to determine which may be the more useful unit of measurement.

Limitations

The number of burrows located within a quadrat varied markedly depending on species. Species naturally vary in population density and abundance. Using total number of burrows was not logical when species status is not yet verified; this was another reason to limit analysis to presence and absence of all nemesiid species. Vegetation type and structure is likely to have an effect on nemesiid presence (Schut et al. 2014) and visibility. Degree of vegetation heterogeneity, even within quadrats, was too high to account for in this study. Degree of heterogeneity between patches may be similar, as has been found in agricultural landscapes (Thorbek and Topping 2005), and thus not impact on the findings. As noted by Stenhouse (2004), the management of remnant vegetation is difficult to analyse due to the many different authorities responsible for land management in the Perth metropolitan area. We therefore excluded from analysis the potential impact of different management authorities on disturbance variables.

Quadrat data was not useful in analysis of surrounding land-use as groups were too ill-defined. This may be explained by many of the quadrats, in larger patches especially, having high proportions of remnant vegetation within the buffer zone. Sampling bias for nemesiid species in patch scale analysis meant that this could not be used as an extrinsic factor. As such, surrounding land-use analysis was limited to using disturbance variables as extrinsic factors.

Results

Presence of nemesiid burrows was recorded in nineteen of the forty-one patches, and sixty of one-hundred and thirty-five quadrats. Density of adults (as determined by size of burrow) greatly varied between quadrats, from one to 42 burrows. Recruitment was apparent in the smallest patches examined (Figure 2: #4, < 2 ha) with spiderlings and varying age groups present in all but one of the patches (Figure 2: #21) where nemesiids were found. Change of surrounding land-use since 1965 did not correlate with nemesiid presence (Table 1). Hence, patches that were previously surrounded by intact vegetation did not correlate with nemesiid presence, as would be expected if species were occurring as ghost populations.

Change of surrounding land-use affect disturbance and nemesiids

Table 1 here

Intrinsic factors formed distinct groups, and two extrinsic factors were found to be significant: size of patch and rubbish (Figure 4 and 5).

Figure 4here

Figure 5here

Six groups emerged in cluster analysis based on surrounding land use (Figure 4). Groups one and three are characterised by patches that were previously surrounded by remnant vegetation in 1965 that has since been cleared. Group two had higher proportion of parklands as surrounding land-use in 1965 than groups one and three. Groups four, five and six represent patches in long established areas, that is, much of the remnant vegetation was cleared prior to 1965. Group four had a higher proportion of parklands in 2015 than five and six, whereas group six had a higher proportion of parklands in 1965 than groups four and five.

Disturbance variables affect patch size and nemesiids

There was only one significant result when using patch as a unit of measurement. Thus, rubbish intensity was negatively correlated with patch size ($p = 0.029$, F stat: 5.126). Using quadrats as a unit of measurement, there was a highly significant negative correlation between rubbish and patch size ($p < 0.0001$) (Table 2). However, rubbish had no significant impact on mygalomorph presence or absence (Table 2).

Table 2 here

The presence of rabbits was found to be negatively correlated with presence of mygalomorphs ($p = 0.008$) and positively correlated with size of patch ($p < 0.001$). Invasive grass was significantly negatively correlated with nemesiid presence ($p = 0.004$), but was not significantly correlated with patch size (Table 2).

Discussion

Urbanisation is a relatively recent process in the region with Perth being established in 1829, but with rapid and extensive clearing after the 1950s (Figure 2). Long-term effects of clearing, changing land-use, disturbances and conservation practises may not yet be apparent due to the relatively short time frame. However, attempting to identify threatening processes at early stages is imperative for effective conservation management, especially in terms of mitigating cost both to the environment and to the economy.

Change of surrounding land-use affect disturbance and nemesiids

Correlation between size of patch and surrounding land use groups is reflective of recent developments in urban planning, as smaller patches are more common in more recently established areas. Commonly, patches of remnant vegetation are adjacent to or surrounded by parkland. Rubbish was also more common in more recently established areas. Rubbish, penetrates smaller patches more readily in a form of edge effect. Since rubbish was not found to influence nemesiid presence, this was an inconsequential finding for this study but was included as potentially important in future studies.

Surrounding land-use may be a major driver of disturbance factors. One of the initial reasons change in land-use was incorporated in this study was the speculated high mobility of male mygalomorphs. There have been many incidences where males were collected that had been caught walking against fences and walls, presumably attempting to traverse between patches. If reproductive rates were subsequently reduced due to higher male mortalities since 1965, then ghost populations could have occurred. Although ghost populations were not found in this study, the effects of change in surrounding land use are an important parameter to be incorporated in future studies of mobility relating to threatening processes. This may be especially important for species with medium to high dispersal and/or mobility capabilities that are long-lived, for example Red-tailed and Carnaby Cockatoos (Saunders 1990, Joseph *et al.* 1991) or pollinators (Kremen *et al.* 2007). For more mobile species, visitation or nesting could be mapped within or between patches then compared to cluster analysis of change in land-use variables, for example comparing Figure 2 with Figure 4 and 5. We suggest that distribution mapping, in conjunction with cluster analysis, be implemented in future studies to assess if change of land-use impacts on long lived species.

Disturbance variables affect patch size and nemesiid presence

Disturbance of habitat due to invasive species (rabbits and invasive grass) has a significant impact on nemesiid species. However, patch size does correlate with some disturbance variables (rubbish and rabbits, but not invasive grass) with greater impact being seen in smaller patches than larger patches. Greater disturbance in smaller patches has been noted in other studies in Perth remnants (Stenhouse 2004) and may be attributed to edge effect (Saunders *et al.* 1991). Nevertheless the direct impact of these phenomena on arthropods remains unclear (Bolger *et al.* 2000). Intuitively any impact would be applicable to other mygalomorphs in the Perth metropolitan area.

Invasive grass may be more concerning as a threatening process for all mygalomorph species as it considerably alters ground-level strata. It may seem that high degree of invasive grass may obscure visibility of burrows. However, those that were persisting in areas of high weed invasion tended to be highly visible as they were exhibiting mounding behaviour; a bare, raised area mound of sand that surrounded approximately 20 cm around the burrow entrance. It was concluded that visibility was not compromised and is not considered a limitation.

Invasive grass would impact not only on the foraging behaviour of other mygalomorph species, but the presence of invertebrate species that serve as prey. Invasive grass is cause for concern for not only the choking effect it may have on mygalomorphs and native vegetation (Stenhouse 2004) but also adding to fuel loads during summer die-off, and increasing the likelihood of damaging fire{Anderson, 1982 #339}{Rossiter, 2003 #340}. Invasive weed management through regular herbicide regimes and community involvement is highly recommended.

Rabbit diggings potentially disturb mygalomorph burrows to the point that they are no longer found in areas of rabbit disturbance. During the survey, many burrows of non-nemesiid mygalomorphs were pulled from the ground by rabbit diggings. Though it was primarily rabbits that seemed to be disturbing mygalomorph burrows, this disturbance was also occurring where bandicoots had been re-introduced (Figure 2, #34). Mygalomorphs may be experiencing less disturbance from digging presently (in areas where rabbits are not present) than in the past. Prior to European settlement in 1829, bandicoots and other small mammals were prevalent throughout the region. Therefore, in areas without rabbits, mygalomorphs may be experiencing fewer disturbances from digging than in the past. This lack of disturbance may explain the especially high density of mygalomorphs in some areas with low rabbit presence. Alternatively, a higher abundance of prey species benefiting from human influence in these patches may allow greater numbers of mygalomorph spiders to be supported, as has been seen in golden-orb spiders (Lowe et al. 2014). Mitigating the intensity of rabbits through practises such as fumigation of active warrens is recommended to all organisations in Perth that assist in management of remnant bushland.

Rubbish was not an effective variable to gauge human disturbance, as rubbish was accumulating around the edges of patches, paths and fencing. Quadrat results were more predictive of presence and absence than patch data for disturbance variables. Unsurprisingly, this means patches are not exhibiting uniform processes and should not be analysed as such. Patch is likely at too large a scale and may present false negatives (Type 2 error) when analysed.

Mobility and dispersal capabilities affects conservation

Fahrig (2013) proposed the habitat quantity hypothesis; to challenge the use of habitat patches as natural units of measurement. In support, using quadrats as a unit of measurement was far more insightful into the effects of disturbances; likely due to the low dispersal and mobility of the species. Fragmentation and isolation may have varied effects with species mobility capabilities (Thomas 2000).

Traditionally, criteria for conservation priorities are based primarily on distribution range. As Runge (2014, 2015) suggests this may be detrimental to mobile species that may be experiencing threatening processes that occur over a large scale. Arguably, protection of ranges could be applicable for some endangered species that receive extensive funding for protection. For most cases though, this is not an economic use of resources to protect most species (Harvey *et al.* 2011). Categorising conservation status based on mobility and dispersion of species and associated threats may be a more effective approach, as has been recently done with 'nomadic' (Runge *et al.* 2015) species. Mobility capabilities would also be useful for distinguishing between local and landscape effects, as they would have varying impacts (Melles *et al.* 2003).

Considering the impact of invasive species demonstrated in this study, threatening processes should be further prioritised in management in SWA. Harvey *et al.* (2007) also concluded that small patches should be conserved for non-passerine bird species and reptiles in Perth, a conclusion likely related to dispersion and mobility capabilities. In the case of mygalomorph spiders, phenology varies between clades (Ferretti *et al.* 2012). Life history events in SWA seem to be triggered by seasonal events of high humidity (perhaps relating to their vulnerability to desiccation; Mason *et al.* 2013).

Significant gradients of rainfall, temperature and vegetation types occur along in SWA hotspot (Sander and Wardell ‑ Johnson 2011). In mygalomorphs, this may allow for greater genetic diversity through both adaptive variation and natural divergence caused by isolation (Moritz 2002, Main 2003). Exceptionally high biodiversity and endemism in SWA are explained by climate stability, landscape age and fire predictability (Mucina and Wardell-Johnson 2011). In conjunction, poor dispersal and poor mobility capabilities, while speculative, may contribute to speciation (Harvey *et al.* 2011), especially in-situ speciation (Rix *et al.* 2014).

Conservation management implications

Habitat clearance is the first and foremost threat to mygalomorphs as they will not be able to readily disperse back into rehabilitated areas from adjoining uncleared land {Yen, 1995 #341}. There has been no record of nemesiid burrows occurring outside uncleared remnant vegetation. Continued habitat clearance occurs at an alarming rate in urban areas of Perth due to urban sprawl. The Perth urban area has more than doubled since the 1970s due to large-scale land clearing (WWF-Australia 2010). Thus 6 812 ha of natural bush, (average 851.5 ha per year) was cleared in the Perth metropolitan area from 2001-2009, (WA Local Government Association's Perth Biodiversity Project). To put this sprawl into perspective, Perth population density (310 people /km^2, is 0.05% that of London (5490 /km^2) and 0.03% that of New York City (10756 /km^2). Urban sprawl is not only a foremost cost to natural environments, but is also a major economic concern as low density living makes public services less effective and more expensive (Nechyba and Walsh 2004).

Clearing is especially problematic for smaller patches, being allocated less value despite being able to retain high biodiversity over time (Stenhouse 2004, Guénard *et al.* 2014). This study has demonstrated the value of small patches for nemesiids, and most likely other mygalomorphs, with viable populations being confirmed from a 10 000 m^2 quadrat, within a 2.7 hectare patch (#4,

Figure 1). It should also be noted that due to landscape effects there may be some species that remain only in small, isolated patches. As many species are yet to be discovered, described and requirements understood (Harvey *et al.* 1997){Yen, 1995 #341}, the clearance of even small, isolated patches could potentially destroy the last remaining population of a species. The high biodiversity consequences of deforestation in this global biodiversity hotspot suggests a need for a ban on further clearing of remnant vegetation within the Perth Metropolitan Area. This would need to be enforced by the EPA and would have wide significance for urban planning in the region.

The current guidelines for short-range endemic sampling (EPA 2009) make it very difficult for status and associated protection for potential species to be assigned. It has been established that there are clades with low dispersal, fecundity and mobility capabilities and that this makes them more vulnerable. It would be appropriate to list them as vulnerable immediately rather than wait for distribution maps of species with low taxonomic resolution. Considering the impact of threatening processes outlined in this study, a conservation status of 'vulnerable' for all mygalomorph species, and other clades considered potential SREs, occurring in Perth is recommended.

Conclusion

Very low dispersal and mobility capabilities seem to allow for ongoing persistence in high quality urban remnant native vegetation patches for mygalomorphs over time. However, management practices to limit the impact caused by rabbits and invasive grass should be prioritised in future management. Protection of clades that exhibit any short-range endemism traits should be implemented immediately and enforcement of no further clearing of remnant bushland in this biodiversity hotspot. We predict that if high quality habitats are maintained, there will be ongoing persistence of mygalomorph populations, even in small patches. If management suggestions are adhered to, there seems no reason mygalomorphs, and other species with poor mobility and dispersal, could not persist indefinitely within urban remnants.

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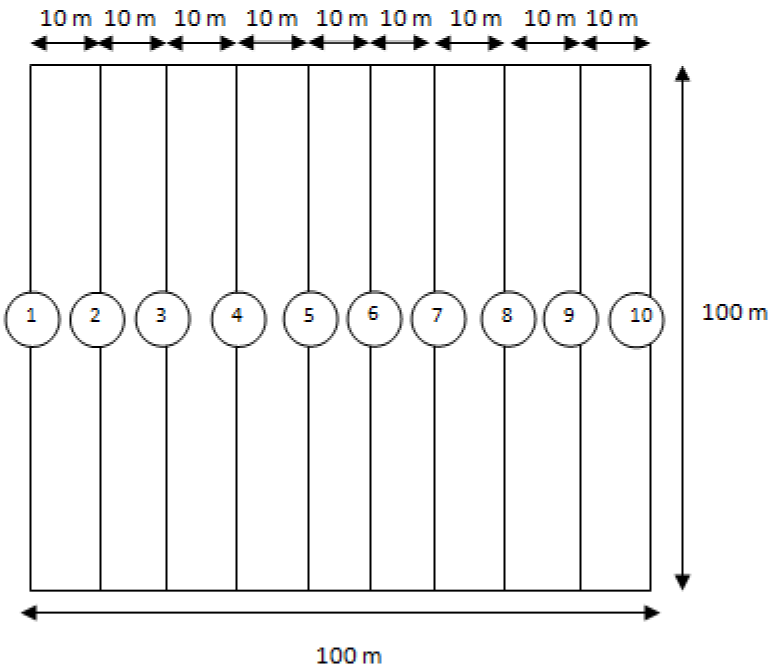

Figure 1: Sampling design of mygalomorph targeted survey. Ten transects (1-10, circled), spaced 10 m apart within 100 m x 100 m quadrats. One hundred and thirty-six quadrats were

nested, using a randomising mapping function, throughout 41 remnant vegetation patches within urban areas of Perth, Western Australia.

Site #	Area (ha)	Site name
1	1.5	Hently Loop
2	1.6	Rufus Parkway
3	2.1	Natalie Way
4	2.7	Balcatta Park
5	3.0	Cadogan Street
6	3.2	Goldworthy Ent
7	3.3	Glenbar Road
8	3.6	Amstel Park
9	4.5	Conference Green
10	4.9	Padbury Park
11	5.0	Floreat Park
12	5.1	Paloma Park
13	5.9	Montrose Park
14	6.2	Padstow Street
15	6.7	Hollywood Reserve
16	8.0	Pinnaroo Valley
17	12.3	Coolbellup Reserve
18	13.0	Point Walter Reserve
19	13.6	Gibson Park
20	14.2	Woodvale Reserve West
21	14.3	Highview Park
22	14.5	Sir Fredrick Samson Park
23	15.3	Sheperds Bush Conservation
24	16.4	Yorston Place
25	16.5	Landsdale Park
26	28.1	Bibra Lake Reserve
27	28.2	Shenton Park Bushland
28	28.5	Hepburn Heights Conservation
29	34.1	Marangaroo Conservation
30	36.0	Woodvale Reserve East
31	40.4	Wireless Hill Park
32	48.2	Piney Lakes
33	48.6	Bibra Lake Park
34	49.1	Craigie Bushland
35	82.0	Warwick Open Space
36	101.2	Star Swamp Bushland
37	104.0	Manning Park
38	133.0	Trigg Bushland
39	134.1	Koondoola Bushland
40	358.8	Kings Park
41	426.9	Bold Park

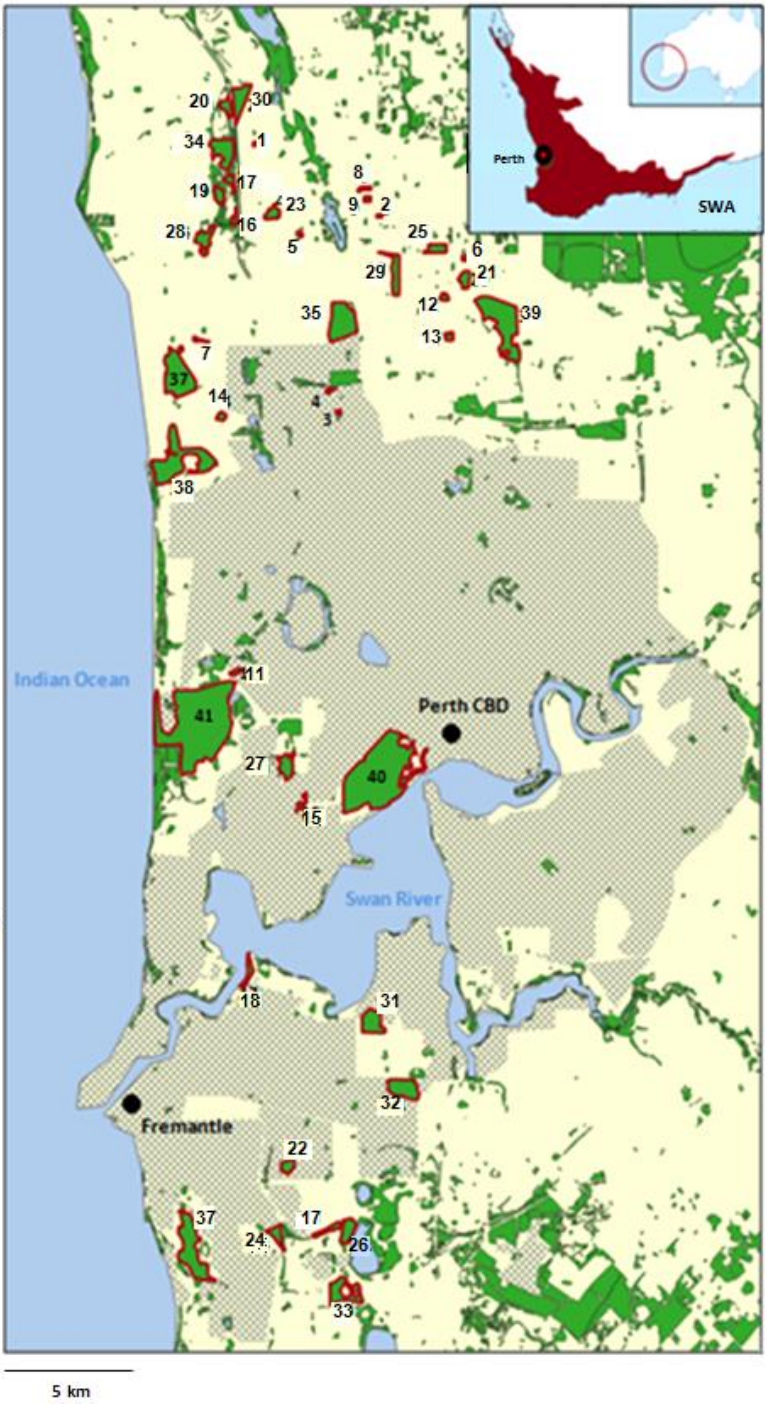

Figure 2: Perth metropolitan urban extent (light yellow), and extent in 1965 (grey hashing), with native remnant vegetation (green) patches surveyed (red border) ordered (Site #) from smallest area (1) to largest area in hectares (41). Cities of Perth and Fremantle are also marked (black dots).

Figure 3: a) Nemesiid mygalomorph spider, 55 mm in body length. b) Nemesiid mygalomorph spider burrow, 22 mm in diameter. c) Habitat with low weed invasion; understorey predominantly native species. d) Habitat with high weed invasion; predominantly veldt grass.

Table 1: Twenty-four land-use variables used as intrinsic factors in PATN (Belbin 2013) analysis. Code used in Figure 3, is described by Year, Land-use and Buffer size. Minimum, maximum, mean and standard error (SE) of proportions surrounding patches are listed for each variable.

Code	Year	Land-use	Buffer size	Minimum	Maximum	Mean		SE
2015.B.50	2015	Building	50	0	0.58	0.23	±	0.06
2015.B.150	2015	Building	150	0	0.65	0.28	±	0.06
2015.B.250	2015	Building	250	0.06	0.74	0.43	±	0.07
2015.R.50	2015	Road	50	0.04	0.91	0.30	±	0.06
2015.R.150	2015	Road	150	0.05	0.41	0.14	±	0.04
2015.R.250	2015	Road	250	0.08	0.37	0.25	±	0.04
2015.PL.50	2015	Parkland	50	0	0.69	0.19	±	0.06
2015.PL.150	2015	Parkland	150	0	0.45	0.13	±	0.05
2015.PL.250	2015	Parkland	250	0	0.52	0.17	±	0.06
2015.RV.50	2015	Remnant vegetation	50	0	0.61	0.05	±	0.06
2015.RV.150	2015	Remnant vegetation	150	0	0.67	0.07	±	0.06
2015.RV.250	2015	Remnant vegetation	250	0	0.34	0.07	±	0.05
1965.B.50	1965	Building	50	0	0.33	0.03	±	0.04
1965.B.150	1965	Building	150	0	0.48	0.05	±	0.05
1965.B.250	1965	Building	250	0	0.48	0.05	±	0.05
1965.R.50	1965	Road	50	0	0.47	0.07	±	0.05
1965.R.150	1965	Road	150	0	0.48	0.04	±	0.05
1965.R.250	1965	Road	250	0	0.26	0.04	±	0.04
1965.PL.50	1965	Parkland	50	0	1	0.09	±	0.08
1965.PL.150	1965	Parkland	150	0	1	0.08	±	0.05
1965.PL.250	1965	Parkland	250	0	1	0.08	±	0.04
1965.RV.50	1965	Remnant vegetation	50	0	1	0.72	±	0.10
1965.RV.150	1965	Remnant vegetation	150	0	1	0.75	±	0.10
1965.RV.250	1965	Remnant vegetation	250	0	1	0.79	±	0.09

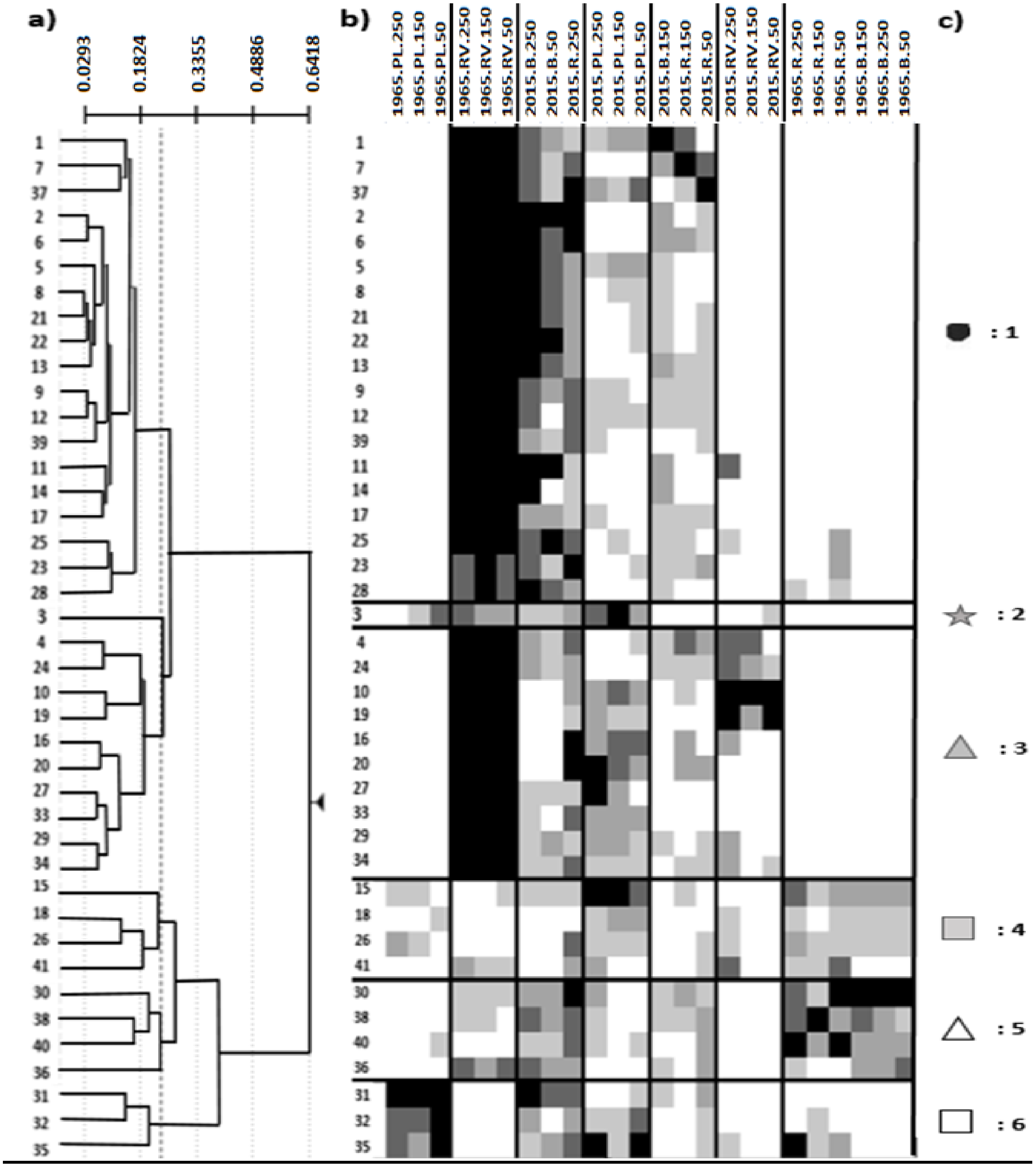

Figure 4: (a) Dendrogram showing line along which groups are formed as dark dashed line that corresponds to groups shown in two-way table. (b) Two-way table showing 6 groupings of 41 patches during 2015 and 1965 using proportion of land-use variables (R: Road, PL: Parkland, B: Buildings and RV: Remnant Vegetation) at buffers of 250, 150 and 50 m. Dark shaded blocks indicate strong associations between groups of patches and groups of variables, and light or clear indicate weak association. Codes for land-use variables columns in (b) correspond to Table 1. Gower (rows), Two-step (columns), UPGMA. Group symbols and numbers (c) correspond to Figure 4 and numbers in text whereas patch numbers (1-41) correspond to patches shown in Figure 1.

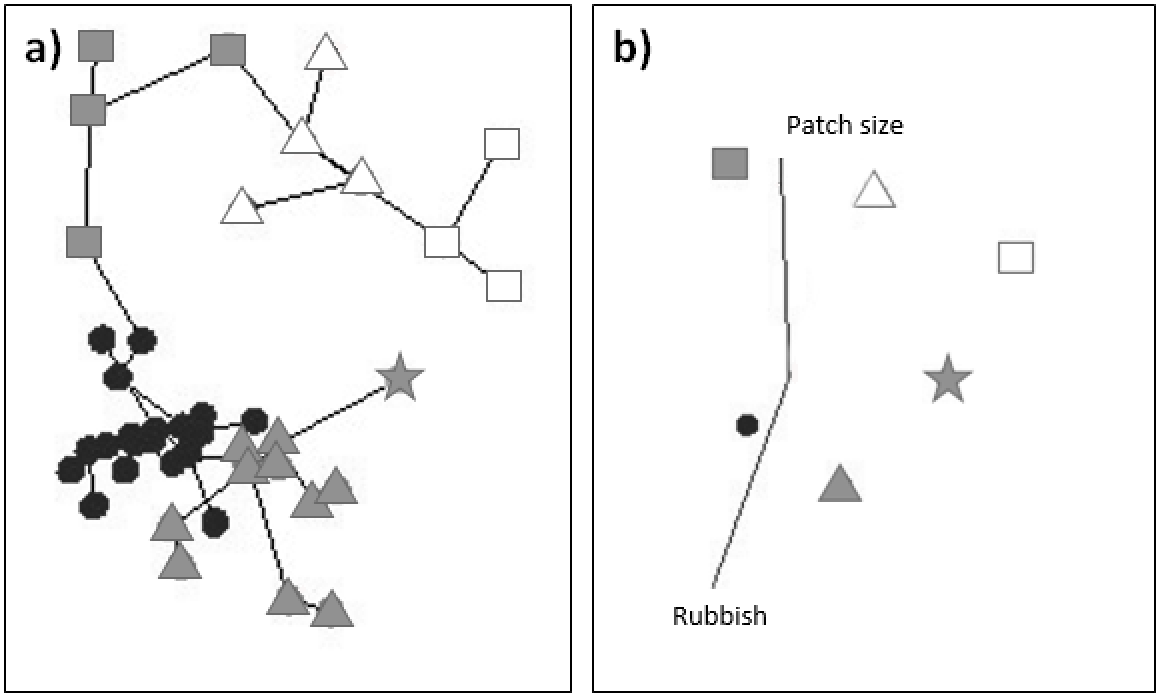

Figure 5: a) Two dimensional ordination (SSH MDS, Stress = 0.1596, Cut-off value: 0.6, 1000 random starts) of 41 patches of remnant urban bushland, based on 24 surrounding land-use variables. Groupings derived through cluster analysis (Fig. 4) are also shown. b) Centroids with Monte-Carlos Attributes in Ordination extrinsic variables rubbish and patch size statistically significantly correlated with ordination axes.

Table 2: ANOVA output from StatistXL Microsoft Excel plugin package. Analysis at quadrat level to determine any significant relationships between disturbance variables (Grass, rabbits and litter) and whether this correlates presences/absences of nemesiids (PR_AB) with patch remnant vegetation (PRV) as a covariate in urban extent of Swan Coastal Plain, Western Australia. * indicates significant p-values.

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Prob.
RABBIT	PRV	1.782	1	1.782	27.692	0.000*
	PR_AB	0.641	2	0.321	4.982	0.008*
GRASS	PRV	0.011	1	0.011	0.100	0.752
	PR_AB	1.323	2	0.661	5.794	0.004*
LITTER	PRV	1.469	1	1.469	51.402	0.000*
	PR_AB	0.051	2	0.026	0.894	0.411