

Effect of salinity on small, ground-dwelling animals in the Western Australian wheatbelt

N. L. McKenzie^{A,B}, A. H. Burbidge^A and J. K. Rolfe^A

^ADepartment of Conservation and Land Management, PO Box 51, Wanneroo, WA 6065, Australia.

^BCorresponding author; email: normm@calm.wa.gov.au

Abstract. As part of a regional biodiversity survey, in total 304 quadrats, 1 ha each, were positioned to represent the diversity of physical environments across the geographical extent of the Western Australian wheatbelt. Uncleared sites variously affected/unaffected by salinity were chosen, but those showing overt changes caused by other types of disturbance were avoided as far as possible.

Drift fences and pit traps were used to compile lists of the ground-dwelling spiders, scorpions, frogs, reptiles and mammals on the quadrats. For analysis, these data were compiled into a presence–absence matrix of species *v.* quadrat, and quadrats were assigned to various landform and salinity-‘risk’ classes.

There was a negative relationship between the richness of small ground-dwelling animals and increasing salinity. Only lycosid spiders showed a positive relationship. A few vertebrates and spiders, particularly lycosids, are centred on saltflats. Another set of species occupies both the saltflats and the surrounding environments (woodlands) of dissection valley floors and lower slopes, while a much more diverse array of vertebrate and arachnid species is associated with these woodlands if they are not salt-affected. Woodland quadrats that are obviously affected by salinity support a subset of the species on their unaffected counterparts or on ‘natural’ saltflats.

These empirical findings are consistent with predictions that, as soil salinity increases and the valley-floor woodland vegetations die, their faunas also contract. A few saltflat specialists colonise salt-affected sites along with the samphire shrublands.

Introduction

The Western Australian wheatbelt’s landscape comprises isolated remnants of bushland embedded in a mosaic of wheatfields. Clearing has been strongly biased towards the fine-textured, non-salty soils of dissection valley floors and lower slopes, and these are the units that are now most affected by rising ground-water salinity. Salinity is causing extensive vegetation death. Only 26% of the wheatbelt remains as uncleared remnants of native vegetation, and between 3 and 15% of its total land surface is saline (George and Coleman 2001).

Previous data on patterns in the study area’s biodiversity have been geographically localised (e.g. Kitchener 1982; Saunders 1989), confined to a single phylogenetic group (e.g. Hopper 1992; Hopper *et al.* 1997; Main 2000), and/or land class rather than site-based (e.g. Beard 1981). While a number of studies have assessed the effect of increasing soil salinity on wheatbelt vegetation (George *et al.* 1995; Keighery *et al.* 2001; Cramer and Hobbs 2002), nature conservation planning must also take into account its effect

on indigenous animal communities, particularly those small, non-volant species that live at the soil’s surface.

Rising saline water tables affect primary ecosystem processes, imposing a high-order stress on ecosystems (Whisenant 1999). Our dataset is drawn from the results of a regional biodiversity survey (Keighery *et al.* 2001) that aimed to provide the first quantitative benchmark against which future salinity-induced changes in the compositional complexity of the study area’s indigenous plant and animal communities could be measured. In this paper we assess the richness and composition of the Western Australian wheatbelt’s small, ground-dwelling animal assemblages in relation to soil salinity. We focus on arachnids and small, non-volant vertebrates that face the direct physiological effects of environmental salinity at all stages in their life cycles, as well as indirect effects through changed resource availability as plant biomass declines and floristic richness is lost. Empirical observations lead us to predict that, as soil salinity increases and the vegetation dies, this fauna also contracts. Our analysis strategy is deductive rather than

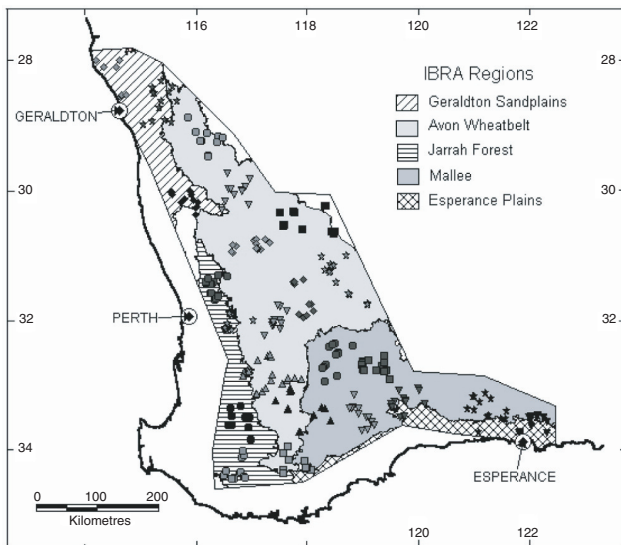


Fig. 1. Wheatbelt study area, showing the 304 quadrats, and relevant IBRA biogeographical region boundaries (Thackway and Cresswell 1995). The different symbols indicate the 12 or 13 quadrats in each of the 24 survey areas.

inductive, and inferential statistics and numerics are used to test consistency among regional replicates of the observed pattern (Oksanen 2001).

Methods

In phytogeographic terms, our 205 000 km² wheatbelt study area comprised the semi-arid parts of the South-western Botanical Province (Beard 1980), and encompassed all or part of five Interim Biogeographical Regionalisation of Australia (IBRA) bioregions (Fig. 1). Its inland boundary was west of the 300-mm rainfall isohyet. Its western boundary was east of the 600-mm isohyet. Along the southern coast, the southern boundary approximated the 550-mm isohyet but avoided near-coastal environments. Overall, 74% of the study area has been cleared for agriculture; it comprises isolated remnants of bushland embedded in a mosaic of croplands.

Its physical environments are detailed by Myers and Hocking (1998), Chin (1986), Mulcahy and Hingston (1961), Schoknecht (2002), Hatton and Ruprecht (2001), Commander *et al.* (2001), George and Coleman (2001) and Bureau of Meteorology (2001). Briefly, the bulk of the study area is an undulating plateau of Tertiary duricrust overlying the Archaean granitic and metamorphic rock strata of the Yilgarn Craton. Under a variety of climates, interacting alluvial and aeolian processes have produced a complex landscape mosaic. The plateau is variously eroded into elluvial and colluvial spillway sand deposits, and dissected to expose valley-slope and -floor units characterised by duplex soils derived from the archaean basement strata. In some areas the valley units are overlain by sands (from alluvial as well as aeolian re-sorting) or reworked as calcareous clays and loams that contain sheet and nodular kankar. Today, the Craton's surface has a semi-arid to subhumid climate influenced by temperate weather systems (mainly winter rainfall). Its surface hydrology is characterised by low gradients, high potential salt loads and high variability in flows.

Detailed descriptions of vegetations are provided by Beard (1981). In south-western parts of the study area, eucalypt open forests and woodlands (dominated by species such as *Eucalyptus marginata* Sm., *E. calophylla* Lindl. and *E. wandoo* Blakely) cover most landscape

units. Elsewhere, woodlands of trees such as *Eucalyptus salubris* F.Muell., *E. salmonophloia* F.Muell., *E. loxophleba* Benth. and/or *E. longicornis* (F.Muell.), and tall mallees such as *E. platypus* Hook., *E. pileata* Blakely and *E. eremophila* (Diels) Maiden dominate the fine-textured, duplex soils of dissection valleys. In contrast, proteaceous and myrtaceous scrubs and heaths dominate the sandy surfaces associated mainly with the Tertiary plateau and derived spillway deposits. Saltflats occur on the dissection valley floors. These support dwarf shrublands of samphire and are surrounded by *Melaleuca* shrublands.

The study area (Fig. 1) was divided into 24 survey areas. In total 12 or 13 quadrats, 1 ha each, were positioned to sample the geomorphic profile of each survey area, and included pseudo-replicates in landform units that were affected by ground-water salinity. In cases where a unit was particularly extensive within a survey area, two sites were sampled. As well, most quadrats were pseudo-replicated in the other survey areas to allow for the internal heterogeneity of the stratification units (hypothesised scalars) and to minimise any analytical circularity introduced by stratification (Taylor and Friend 1984; McKenzie *et al.* 1989, 1991a; Gaston and Blackburn 1999).

As far as possible, co-occurrence patterns in species composition derived from our dataset should reflect those that occurred across the region at the time of European settlement. For this reason, we positioned the quadrats in the least-disturbed examples of each habitat type that we could find, and focused our sampling on taxonomic groups likely to be robust to threatening processes other than salinity—arachnids and small ground-dwelling vertebrates with mean adult bodyweights between 0.005 and 25 g. At the regional scale, known extinctions have been virtually confined to medium-sized mammals (Burbidge and McKenzie 1989), but there is mounting evidence that other taxa such as birds are being extirpated at local scales from small remnants in the fragmented landscape (e.g. Saunders 1989; Saunders *et al.* 1993). Even the sites selected to represent secondarily salt-affected sites were positioned to minimise proximity to wheatfields and avoid evidence of other disturbances such as rubbish disposal, gravel extraction and previous clearing. Thus, our data are strongly biased in terms of the overall health and complexity of the study area's biodiversity.

Landform units in the survey areas on the Yilgarn Craton were numbered from 1 to 12 (see Fig. 2), depending on whether they were low in the landscape (belonging to its dissection profile: from fresh water swamps = 1, thence up valley sides = 7), or spillway sands on or derived from its top (the ironstone duricrust pavements of the 'old Tertiary plateau' = 12). Unit 'Bg' in which 'spillway' sand mantles a clay belonging to the 'dissected valley' profile was assigned to number 8. Quadrats in survey areas on geological basements other than the Yilgarn Craton (those in the Esperance Plains and Geraldton Sandplains bioregions) were positioned using the relevant 1:250 000 maps of surface lithology (e.g. Morgan and Peers 1973), and arbitrarily assigned to our 12-class landform catena according to their soil profile (texture and horizon sequence), position in the relevant landscape's profile and soil origin. Thus, a deep, low-level sandsheet would be assigned to the same number as the lowest of the spillway sand units on the Craton ('Monkopen', = 9). This approximation was considered to be acceptable because data taken from the quadrats themselves were used in subsequent analyses.

Reptiles, frogs and mammals were pit-trapped at each quadrat for 8 nights in both spring and autumn (three drift fences, each comprising 5 pit traps arrayed at regular intervals along a 25-m flywire fence yielding 240 pit-trap nights per quadrat, 120 in each season). The pits were PVC pipe 125 mm diameter and 350 mm deep, had a plastic bottom and included a baffle to hinder escapes. Arachnids were sampled using five 2-L glycol pits left open for one calendar year at each quadrat (1825 pit-trap nights per quadrat). Species were only included in the analysis if they were reliably captured by the sampling

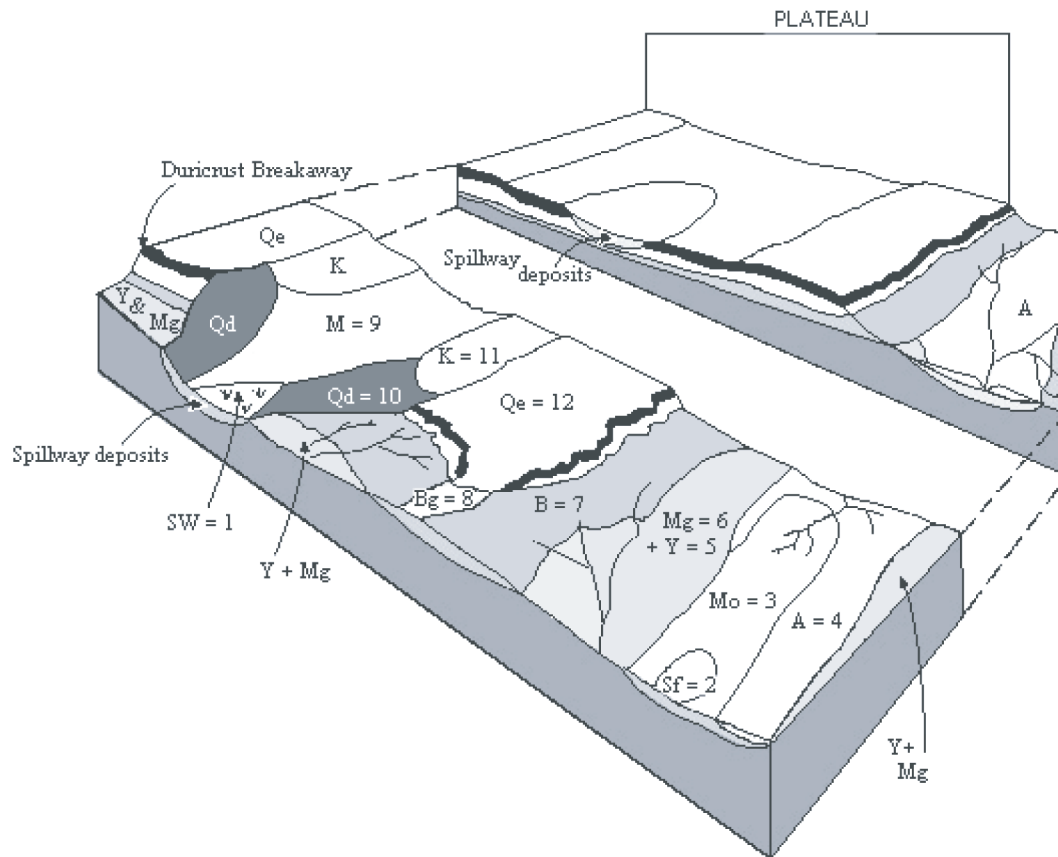


Fig. 2. Wheatbelt landforms, modified from Mulcahy and Hingston (1961). The landscape's 'plateau profile' comprises the duricrusted Tertiary laterite plateau and its derived spillway sands, while the 'dissection profile' comprises finer-textured soils derived from bedrock and pallid-zone clays beneath the duricrust.

methods (see Rolfe and McKenzie 2000); thus, the problems of unreliable 'absence' data in the presence-absence matrix were minimised. In this context, the 10 quadrats in fresh-water swamps (Landform Unit 1, Fig. 2) and three saltflat quadrats are excluded from analyses because of flooding problems. Undescribed species were placed into their taxonomic hierarchy by professional taxonomists familiar with the relevant group in Western Australia (see also Oliver and Beattie 1996).

Eighteen climatic attributes were derived for each quadrat by using ANUCLIM (McMahon *et al.* 1995). These comprised annual and seasonal average and range values for temperature and precipitation. Fifteen soil chemical and texture values for each quadrat were derived from subsamples collected at a depth of 2–10 cm (after removal of surface litter) from 20–30 points, then bulked. These included nitrogen, phosphorus, potassium, pH, electrical conductivity, organic carbon, clay, silt and sand percentages, and magnesium (cf. McKenzie *et al.* 2000a). The soil chemical analyses used are described in Wyrwoll *et al.* (2000). Four landform and two vegetation attributes were also generated, including elevation, soil drainage category, slope, salinity risk, litter/log cover and habitat complexity (modified from Newsome and Catling 1979).

Because heavy-rainfall and/or surface-flow events can flush salt from the soil's upper profile, we could not depend on our chemical assay to provide a reliable measure of ground-water salinity. To minimise this problem, electrical conductivity was also measured from a single soil sample taken lower in the soil profile (at depths of up to 100 cm). In addition, salinity often had discontinuous, uneven or

inconsistent effects within quadrats. For instance, distinct patchiness in vegetation death corresponding to factors such as surface microtopography was observed at some quadrats (see also Cramer and Hobbs 2002; Dirnbock *et al.* 2002). To ensure robust analyses, these additional data and observations were used to assign quadrats into the following four classes of salinity risk (SAL, modified from van Gool and Moore 1999):

- (1) None: salinity will not develop because of any or all of low water tables, high soil permeability, elevated position in the landscape and low salt store in the regolith.
- (2) Partial or low: areas with small variation in local relief and geology where rising water tables may not affect all of the site, or where rising water-tables are not currently saline, and the salt store in the regolith is low. May include lower footslopes and sandy rises on valley floors or near incised stream channels.
- (3) High: salinity already present in limited areas of the quadrat, or saline groundwater is already close to the surface, with a rising trend.
- (4) Saline land: obviously salt-affected areas (entire quadrat is usually salt affected). All saltflat quadrats (Landform Unit 2) are also included in this class and are treated as 'naturally saline', although some of these may have become saline so early in the period of European settlement that they are now indistinguishable from 'naturally' saline sites, and many are now hypersaline in parts.

The analytical approach taken in this paper was based on the assumption that spatial distribution reflects an underlying correlation

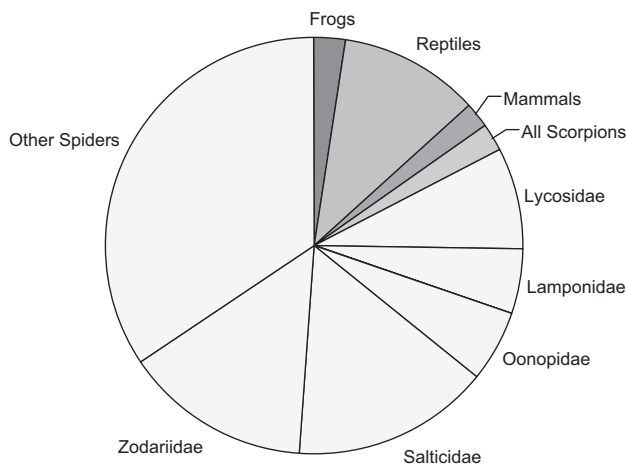


Fig. 3. Total number of species recorded from all 304 quadrats. Spiders are subdivided according to family.

with environmental factors (Austin 1991; Clarke 1993). It is, however, an exploratory survey design, and interpretation is based on deductive rather than inductive logic (Oksanen 2001). No experimental design has been implemented to assess a null hypothesis (Austin and McKenzie 1988), so alternative hypotheses are not excluded. Inferential statistics and numerics are used to test patterns observed in the empirical data.

To explore relationships between species composition and salinity, we focused the compositional analyses on the 13 'naturally' saline quadrats (Landform Unit 2, saltflat) and a subset of the quadrats on the Mortlock and Avon landforms. This Mortlock-Avon subset comprised quadrats that are essentially unaffected by rising saline groundwater (SAL = 1 or 2). By ignoring dissection valley quadrats affected by salinity (SAL = 3 or 4), we hoped to gain a clear separation between species of non-saline environments and those tolerant or adapted to saline conditions. This separation should provide a basis for interpreting the species composition of assemblages on the salt-affected quadrats of the Mortlock and Avon landform units.

We used cluster analysis (from PATN: Belbin 1995) to expose patterns of species composition in the data matrix, after species that occurred at only a single quadrat (singletons) had been excluded. We analysed the presence-absence of species on the quadrats, rather than their relative abundance, because limitations in sampling techniques, aggravated by staff and time limitations, precluded reliable abundance estimates (Austin 1984; McKenzie *et al.* 1991c). The clustering techniques selected were described in McKenzie *et al.* (1991b). Briefly, the Czekanowski association measure (Czekanowski 1932) was used to compare the quadrats according to similarities in their species composition, and the association measure 'Two-step' (Belbin 1980) was used to determine the quantitative relationship between each pair of species as a basis for clustering species that normally co-occurred at the same quadrats. For both measures of association, a modified version of 'unweighted pair group arithmetic averaging' hierarchical clustering strategy was used (UPGMA: Sneath and Sokal 1973; Belbin 1995), with the clustering parameter (Beta) set to -0.1.

The partition structure of the resulting quadrat dendrogram was used as a summary of overall compositional patterns across the study area. Quadrat physical attributes that most closely conformed to this partition structure were assessed for statistical significance using Kruskal-Wallis one-way analysis of variance by ranks (the GSTA module in PATN: Belbin 1995).

Each partition of the species dendrogram was characterised according to the known habitat preferences of its component species throughout their ranges elsewhere in Australia (e.g. How *et al.* 1988;

Harvey *et al.* 2000; McKenzie *et al.* 2000b; Tyler *et al.* 2000). They were treated as independent datasets and analysed separately. The generalised linear interactive modelling package GLIM (NAG 1986; Nicholls 1989) was used to model each species-group's biological patterns in terms of the physical attributes of the quadrats. Forwards stepwise regression models were fitted, with quadrat species richness used as the dependent variable. The significance of the parameters used in the regression equations was calculated by using the Wald Statistic, and is indicated by asterisks: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Results and discussion

In total, 807 species were recorded from the 304 quadrats (Fig. 3). Most were spiders (665 species from more than 31 000 specimens), although reptiles were also numerous (86 species). Mammals were the smallest component, comprising 16 species. Many of the spiders were new to science and appear to have strongly localised patterns of distribution within the study area. These data exclude animals for which the sampling methods were unreliable (e.g. arboreal spiders, mammals with a mean adult bodyweight exceeding 30 g, snakes and large goannas).

Relationship between salinity and species richness

We captured an average of 36 species (s.d. = 9, $n = 227$) on quadrats with no overt salinity (SAL = 1 or 2). While similar richness (34, s.d. = 8.6, $n = 27$) was recorded on quadrats with high salinity risk (SAL = 3), fewer species (27, s.d. = 8.8, $n = 24$) were recorded on entirely salinised quadrats (SAL = 4, but excluding 'natural' saltflats). Saltflats were significantly poorer (21, s.d. = 8.4, $n = 13$). Although only 5 of the 51 spider families trapped were sufficiently species-rich at quadrats to be analysed individually, there was little difference in richness between quadrats with no overt salinity (SAL = 1 or 2) on the two landscape profiles, 'dissection' (Landform Units 3-7, $n = 108$ quadrats, see Fig. 2) and 'plateau' (Landform Units 8-12, $n = 119$) even when taxa were compared separately (Fig. 4).

We saw very few salt-affected areas on uncleared surfaces high in the study area's landscapes. In total, 64 quadrats were affected by salinity (SAL = 3 or 4). All but six of these were on the valley floors and lower slopes of the 'dissection profile' (Landform Units 2-4, see Fig. 2), and only one was sampled on a surface unit belonging to the 'plateau profile' (Table 1). This observation is consistent with hydrological models (George *et al.* 2002). In our dataset therefore, the effect of salinity can be investigated by focusing analysis on the following three landform units: saltflats (Landform Unit 2), 'dissection valley floors' (Landform Unit 3, Mortlock) and 'dissection valley lower slopes' (Landform Unit 4, Avon). Although only 2 of the 27 Avon quadrats were entirely salt-affected, all classes of salinity risk were well represented by our 55 Mortlock quadrats (Table 1).

When we compared the species richness of the Mortlock quadrats in the four salinity-risk classes, we found negative correlations between richness and salinity in all taxa (Fig. 5,

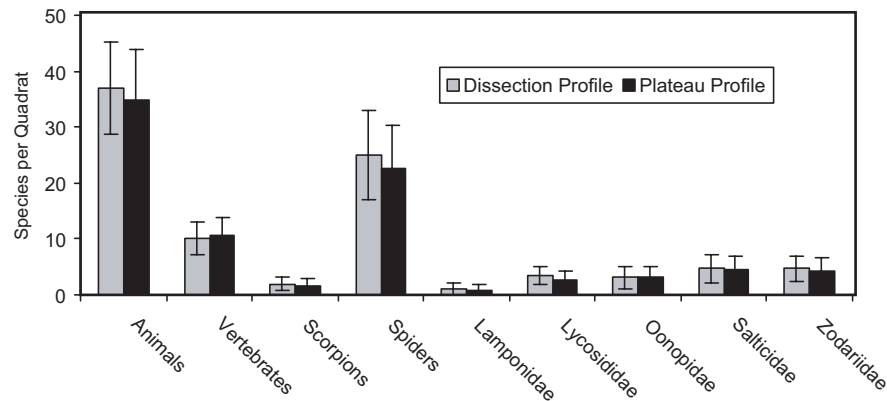


Fig. 4. Average (\pm s.d.) species richness of quadrats with no overt salinity (SAL = 1 or 2).

Table 1. Number of quadrats sampled in each salinity risk class (SAL) in each landform unit (landform unit names are listed in Fig. 2)

Landform	SAL				Totals
	1	2	3	4	
2 Saltflats	0	0	0	13	13
3 Mortlock	10	12	14	19	55
4 Avon	3	12	10	2	27
5	16	9	0	0	25
6	24	3	0	0	27
7	8	11	3	2	24
8	13	2	0	1	16
9	23	3	0	0	26
10	34	0	0	0	34
11	20	0	0	0	20
12	23	1	0	0	24
Totals	174	53	27	37	

including separate tests on reptiles, frogs, scorpions, salticids, lamponids, zoderiids and oonopids: Kendalls Tau = -0.50 to -0.22 , $P = 0.0001$ – 0.02 , $n = 55$), except wolf spiders (Lycosidae, Tau = 0.37 , $P < 0.0001$, $n = 55$). Lycosids showed a significant positive relationship, even when quadrats on Landform Unit 4 were added (Tau = 0.19 , $P < 0.01$, $n = 82$). Correlation coefficient values for all taxa remained significant, but weaker, when Avon quadrats were added to the analysis. Weaker correlations were not surprising, considering that so few Avon quadrats were entirely salt-affected.

In Australia and elsewhere, many lycosid species are habitat-specific (e.g. Moring and Stewart 1994), with localised distributions confined to particular habitats such as riverine margins, sand dunes and salt lakes (Hudson and Adams 1996). Generally, Main (2001) characterised lycosids as 'adaptive opportunists' that favour open environments, and predicted that the family would increase in lands cleared for agriculture. As with clearing, rising ground-water salinity results in a net loss of vegetation cover and, in the

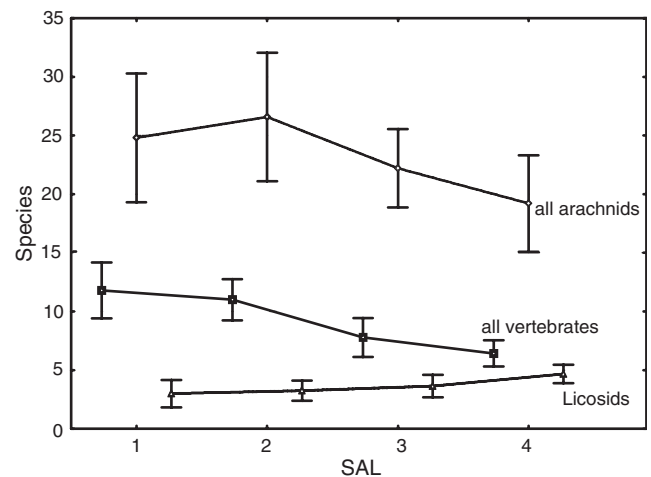


Fig. 5. Average species richness of Mortlock quadrats in each salinity-risk class for various taxa (95% confidence intervals are shown; sample sizes are listed in Table 1).

wheatbelt, our data suggest that these conditions favour lycosids, at least initially.

Relationship between salinity and species composition

Are the species assemblages recorded on salt-affected Mortlock and Avon quadrats (SAL = 3 and 4) subsets of the communities on saltflats and/or on their less salt-affected (SAL = 1 and 2) counterparts? Of the 281 non-singleton species occurring on the 45 obviously salt-affected Mortlock and Avon quadrats (SAL = 3 and 4), only 22 (8%) do not also occur on either their 37 non-salinised (SAL = 1 and 2) counterparts or the 13 saltflat quadrats. The difference is not an artefact of the non-salinised category comprising a larger number of quadrats than its salt-affected counterpart because there were fewer non-salinised Mortlock and Avon quadrats. All 22 were arachnids; 20 with distributions confined to one or two adjacent survey areas in the study area; the other two had wider distributions, but were rare being recorded at only

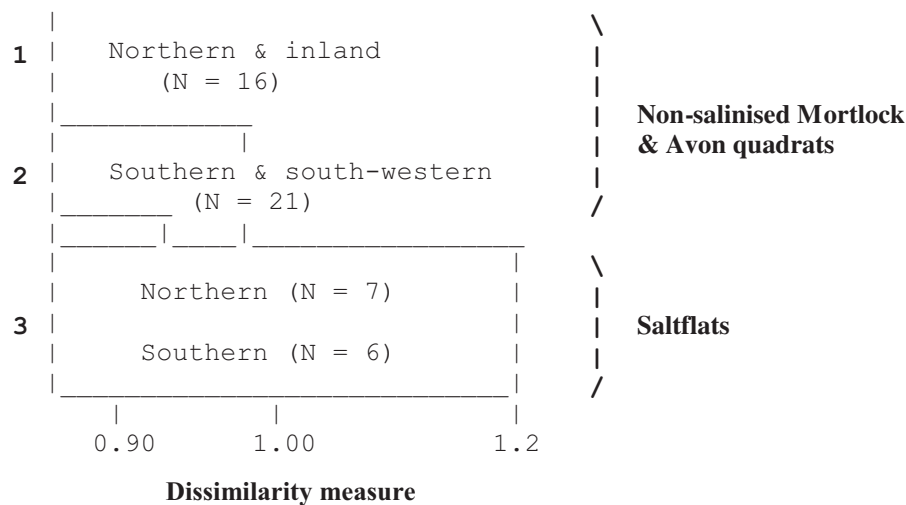


Fig. 6. Partition structure of the dendrogram derived by classifying Mortlock and Avon quadrats (provided they were unaffected by salinity) and quadrats on 'natural' saltflats (Landform Unit 2 in Fig. 2) in terms of their species composition. Dendrogram structure to the 3-group level is displayed (also see Appendix 1).

two locations. Furthermore, only 6 of the 281 species were unique to the 21 entirely salt-affected (SAL = 4) quadrats.

Given the sparsity of the sampling and the localised distributions of many of the spiders, we concluded that the assemblages on the salt-affected sites were subsets of the communities on their naturally saline or less salt-affected counterparts. These obviously salt-affected quadrats do not have a unique fauna of their own. Their composition can be explained in terms of colonisation by saltflat specialists in combination with community collapse induced by a factor such as salinity. So, to gain a clear separation between species of non-saline environments and those tolerant or adapted to saline conditions, subsequent analysis focuses on 'naturally' salty quadrats (13 quadrats on Landform Unit 2, saltflat) and those Mortlock and Avon quadrats that are essentially unaffected by rising saline groundwater (SAL = 1 or 2).

In total, 274 species (25%) in this matrix were recorded from only a single quadrat. Similarly high percentages of singleton species have been reported from a variety of flora studies elsewhere in south-western Australia (e.g. Gibson *et al.* 1994; Wardell-Johnson and Williams 1996). Explanations have ranged from localised species distributions, inefficient sampling methods, the temporal dynamics in species occurrence (ephemeral plants) and high levels of natural rarity. Although the geographical sparsity of our valley woodland and saltflat quadrats would have exaggerated the number of singletons, the study area is within a biodiversity hotspot (Hopper 1992; Mittermeier *et al.* 1999), in which communities are characterised by local species richness, turnover and endemism (Burgman 1988; Hopper *et al.* 1996; Main 1996; Cowling and Lamont 1998; Beard *et al.* 2000; Main 2000).

After the species occurring at only one quadrat were eliminated, the matrix comprised 50 quadrats and 248 species. When these quadrats were classified in terms of similarities in their species composition, saltflat and Mortlock–Avon quadrats formed separate clusters, and geographical patterns related to climatic factors were visible as subclusters (Fig. 6).

Of the 18 substrate and 21 climatic attributes assessed at each quadrat, salinity ('salinity risk', salinity type, tree cover and electrical conductivity), in combination with 'annual average temperature', most clearly separated the first three dendrogram partitions (Fig. 7). Annual average temperatures are highest in the northern and inland parts of the study area. Soil electrical conductivity, tree cover and soil gypsum are closely intercorrelated with salinity risk.

When the 248 species were classified according to their co-occurrences on the same quadrats, four species groups were defined (Fig. 8; Appendix 1). Species Groups 1 and 4 comprised species centred on the non-saline quadrats, Species Group 3 comprised species virtually confined to the saltflat quadrats, and Species Group 2 comprised species that were recorded in both environments. While many species were recorded at too few quadrats to reveal definite patterns, and extrinsic data on the habitat preferences of the spiders and scorpions are scant, several vertebrates in each group were recorded in numerous quadrats and their habitat preferences elsewhere are well known (e.g. How *et al.* 1988; McKenzie and Rolfe 1995; McKenzie *et al.* 2000b; Tyler *et al.* 2000). For instance, *Sminthopsis crassicaudata* and *Ctenophorus salinarum*, which were classified to the saline species group because they were recorded only on the saltflat quadrats, also associate with saltflat environments in adjacent regions, such as the Coolgardie and Carnarvon bioregions. Similarly,

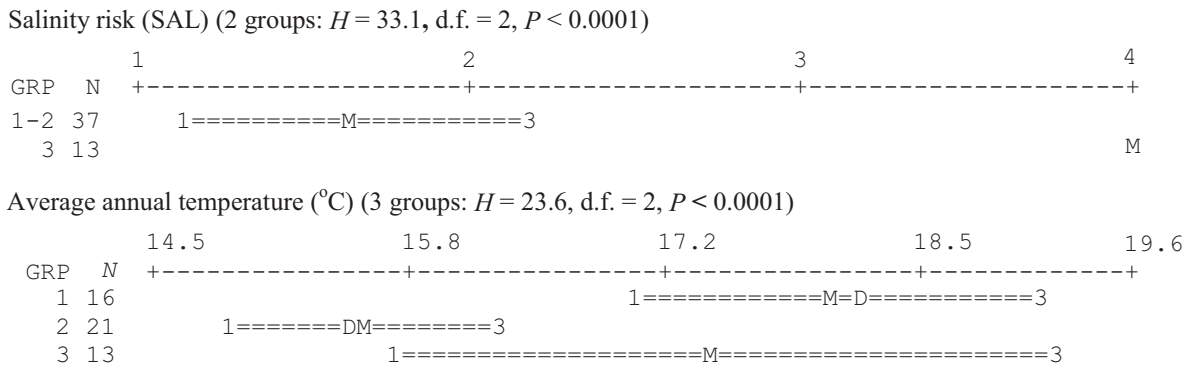


Fig. 7. Physical attributes that separated the quadrat groups defined at the 2- and 3-group levels in the classification structure (Fig. 6). [N = number of quadrats in each classification group (GRP); 1 = = M = = 3 indicates one standard deviation either side of the mean (M); H = Kruskal–Wallis correlation coefficient; d.f. = degrees of freedom; P = probability].

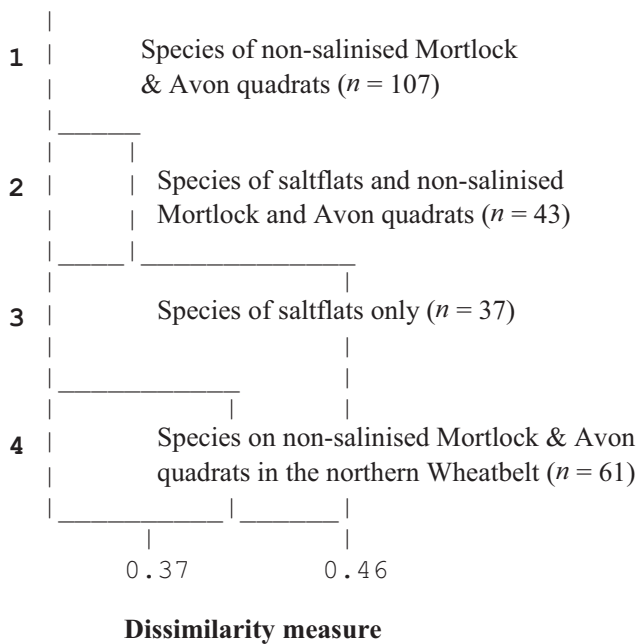


Fig. 8. Species groups derived by classifying the 248 species of spiders, scorpions, frogs, reptiles and mammals according to their co-occurrences at the same quadrats. Dendrogram structure to the 4-group level is displayed and characterised. Species recorded from only a single quadrat are excluded.

Cercartetus concinnus, *Sminthopsis gilberti*, *Morethia obscura*, *Lerista distinguenda*, *Limnodynastes dorsalis*, *Neobatrachus sutor* and *Crinia* spp. were widespread on the non-saline quadrats but absent from saltflat quadrats in our study area as well as elsewhere. While our records of *Mus musculus* and *Menetia greyi* on saline as well as non-saline quadrats are consistent with observations from regions adjacent to our study area, the frog species included in this species group are an artefact of heavy rainfall events that created ephemeral freshwater pools on saltflats during 1999

and 2000 (e.g. *Heleioporus albopunctatus*, *Neobatrachus pelobatoides* and *Pseudophryne guentheri*).

When the four species groups were analysed separately by using the package GLIM, the species richness of each group at any site fitted Poisson error models with logarithmic links (Nicholls 1989; Crawley 1993), and strong relationships between biological patterns and environmental attributes emerged in each case (Table 2). Given that species are clustered into these groups according to their co-occurrence patterns, richness is a reasonable surrogate for gradients in within-group composition. All models involved a combination of climatic and substrate attributes, and included a variable related to salinity (exchangeable Sodium = exNa; salinity risk = SAL) which accounted for a significant amount of scaled deviance. Species Groups 1, 2 and 4 had significant negative relationship with salinity measures, and Species Group 3 had a significant positive relationship. The climatic attributes that emerged as important in the models are similarly consistent with our extrinsic characterisations of the group habitat preferences (Fig. 8).

Overall, 68% of the species were classified to non-salinised Mortlock and Avon units (Species Groups 1 and 4 in Fig. 8), 15% to saltflats (Species Group 3) and 17% to both situations (Species Group 2). Given that the assemblages recorded on salt-affected Mortlock and Avon quadrats (SAL = 3 and 4) were subsets of the assemblages on their non-salinised counterparts and/or saltflats, if salinity is causal in the change we would predict the first and fourth of these species groups to contract as valley woodland sites become salinised, members of Group 2 to persist and Group 3 to colonise.

The analyses exposed strong relationships between compositional patterns and environmental attributes. The environmental relationships that emerged from the analysis were consistent with Australia-wide habitat characterisations of the vertebrates, the taxa for which such data are available. Thus, (1) the relationships might be projected onto future

Table 2. Relationship between biological patterns and environmental attributes

Environmental attribute codes: exMg (me%), exchangeable magnesium; exNa (me%), exchangeable sodium; TwmQ (°C), mean temperature in warmest quarter; PclDQ (mm), precipitation in the coldest quarter; SAL, salinity risk; Tann (°C), mean annual temperature; mxTwmP (°C), maximum temperature in warmest period; C (%), organic carbon; N (%), total nitrogen; Tdir (°C), temperature diurnal range; PdryQ (mm), precipitation in driest quarter; PwmQ (mm), precipitation in warmest quarter; and clay (%). 'Test' lists the quadrat/s to which the fitted model was sensitive, and whether or not the model estimates changed significantly after the quadrat's influence was suppressed: Y, yes; N, no

Species-group (Fig. 8)	Fitted model: Ln(Richness) (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$)	Test
1	$-16.5 + 0.01\text{exMg}^2 - 0.48\text{exNa} + 1.98\text{TwmQ} - 0.05\text{TwmQ}^2 + 0.003\text{PclDQ}$ All***, scaled deviance = 54, d.f. = 44 Scaled deviance of null model = 368, 85.5% explained	LK03, N
2	$1.71 - 0.09\text{exNa} - 0.25\text{SAL} - 0.48\text{Tann} + 0.30\text{mxTwmP}$ exNa**, others****, scaled deviance = 42, d.f. = 45 Scaled deviance of null model = 160, 72% explained	JB08, N
3	$-2.94 - 2.81\text{C} + 36.99\text{N} + 0.10\text{SAL}^2 + 0.02\text{Tdir}^2$ All****, scaled deviance = 41, d.f. = 45 Scaled deviance of null model = 272, 85% explained	PI08, UN12, N
4	$-10.55 - 0.12\text{SAL}^2 + 0.66\text{TwmQ} + 0.002\text{PdryQ}^2 - 0.15\text{PwmQ} + 0.15\text{Clay}$ All****, scaled deviance 54, d.f. = 44 Scaled deviance of null model = 396, 86% explained	ES09, N

landscape scenarios including salinity (Peterson *et al.* 2001), and (2) the relationships are unlikely to be artefacts of the quadrat positioning or of the relatively small size of the study area in relation to the size of the geographical ranges of many of the species (see Blackburn and Gaston 1998).

At the biogeographical scale, patterns in species composition of dissection valley floor quadrats conformed with the annual average temperature gradient (Fig. 7). At the local scale, these patterns were predominantly related to soil attributes, particularly those related to salinity. Both were required to explain the observed compositional patterns. Previous studies have shown that scale is important in determining which environmental attributes emerge as significant correlates with compositional patterns (Dale 1983; Whitmore 1984; Bowers 1997). Regional studies have usually linked compositional patterns to both climatic and substrate attributes (Ashton 1976; McKenzie *et al.* 1991b, 2000a), whereas the importance of substrate (soil and topography) have emerged from more geographically restricted studies (Whitmore 1984; Main 1996).

Predictions of the compositional response of valley woodland communities to increasing salinity are not liable to be clear-cut at individual sites for some of the reasons set out by Dirnbock *et al.* (2002), to explain the weak correlation they found between the distribution of vegetation structural types and topographically driven hydrological and erosional processes in the central part of our wheatbelt study area. These included hydrological and geomorphological heterogeneity of the basement strata not being reflected in contemporary surface topography (e.g. McArthur 1993), the subtlety of soil formation and erosional processes in the context of the study area's subdued relief, historical disturbances such as fire (e.g. Beard 1990), and the strongly disjunctive or localised distributions of many species (e.g.

Main 1996). While axes of habitat heterogeneity can be separate or totally coupled and confounded by species responses to the heterogeneity (Bowers 1997; Huston 2002), the question of scaling adds further to the complexity of landscape ecology (Bowers 1997; Mac Nally and Quinn 1997; Huston 2002).

Efforts to protect remaining biodiversity from threatening processes such as rising saline ground water, both on and off reserves, will need to protect samples of these low-level woodland communities across the geographical extent of the various climatic and soil gradients along which they occur in the wheatbelt. Complex systems exhibit properties and behaviour that arise from the interaction of their constituent parts (e.g. Gaston and Blackburn 1999); a significant contraction in the lowland components of the wheatbelt biota caused by a geophysical process such as salinisation is likely to have pervasive consequences on all wheatbelt ecosystems.

Rising saline groundwater is likely to further reduce the 26% of the study area that remains uncleared. Its effect has been, and will continue to be, profound on woodland communities confined to, or centred on, fine-textured valley lower slopes and floors. Uncleared valley woodland remnants need to be assessed against hydrological models to identify the priority areas of land for protecting biodiversity from salinity.

Conclusion

There is a negative relationship between the richness of small ground-dwelling animals and increasing salinity. Only lycosid spiders showed a positive relationship. A few wheatbelt vertebrates and spiders, particularly lycosids, are centred on saltflat habitats. Another set of wheatbelt species occupies both the saltflat and surrounding non-saline environments of dissection valley floors and lower slopes,

while a much more diverse array of vertebrate and arachnid species is associated with these valley-floor and lower-slope environments if they are not salt-affected. In the study area, these non-salty surfaces support woodland vegetations, but are now largely cleared (Keighery *et al.* 2001). As soil salinity increases and remaining woodland remnants die, their faunas should contract. A few saltflat specialists are expected to colonise the salt-affected sites along with the samphire shrublands.

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Appendix 1. Data from quadrats on Mortlock and Avon landforms (provided they were unaffected by salinity) and from quadrats on ‘natural’ salt pans (landform unit 2 in Fig. 2)

Quadrat codes are printed vertically. Species that were recorded from only one quadrat are removed. Quadrats and species have been re-ordered and clustered according to their similarities (see Figs 6 and 8). Species codes: M mammal, R reptile, A frog, S spider, SC scorpion). Numbers indicate an undescribed genus or species. Quadrat locations are listed in Appendix 2

	Quadrat group number (from Fig. 6)		
	1	2	3
	BMWWBBKDMQKYWEM	DSDGLNPNGGGJJNNYSUSU	BMMKWMMDSEHLG
	EOUUEELNNULOHHSL	UTUPKRIRPPPPBBRROTNTN	EOLLUNOUTSYKP
	0101011000000000	001000010100000000001	1010001000000
	5290832619416796	990324804289186731352	1421891586235
Species Group 1			
S <i>Missulena</i> sp. 3	*	*	
S Araneidae gen.?? sp. 1	**	*	
S <i>Clynotis</i> sp. 3	* *		
S Amaurobiidae gen. 2 sp. 1	* *	*	*
S <i>Lycidas</i> sp. 4	*	* * *	*
S Desidae gen. 1 sp. 1	*	**	
S <i>Enoplognatha</i> sp.	* *	*	*
S <i>Storena formosa</i> Thorell, 1870	*		*
R <i>Egernia multiscutata</i> Mitchell & Behrndt, 1949		*	*
S Theridiidae gen. 4 sp. 6		* *	
S Liocranidae gen.?? sp. 5		*	*
S <i>Lycosa</i> sp. 15			**
S <i>Lycosa</i> sp. 9		* *	**
A <i>Myobatrachus gouldii</i> (Gray, 1841)		*	*
S Amaurobiidae gen. 3 sp. 12	* *		
S <i>Micropholcomma?</i> sp. 1	*	*	
S Desidae type?? sp. 1		**	
S <i>Phoroncidia</i> sp. 4		**	
S <i>Hadrotarsus</i> sp. C		* *	
S <i>Gamasomorpha</i> sp. 7		*	* *
S Salticidae gen. 17 sp. 1		*	*
S <i>Gmogola</i> sp. 3	* *	*	
S Theridiidae gen. 6 sp. 1		*	*
R <i>Ctenotus fallens</i> Storr, 1974			*
S Desidae gen. 1 sp. 3			**
A <i>Heleioporus barycragus</i> Lee, 1967			**
S Theridiidae gen.?? sp.			**
S Amaurobiidae gen. 3 sp. 2	***	*	
S <i>Opopaea</i> sp. 6	**		
S <i>Lamponina elongata</i> Platnick, 2000	*		*
S <i>Habronestes</i> sp. 10	*		*
S <i>Lamponina</i> sp. 3	* *		
S <i>Zebraplatys</i> sp. 1	*		
R <i>Delma fraseri</i> Gray, 1831	*	* *	*
S <i>Cavasteron</i> sp. 1	*	*	*
S <i>Clynotis</i> sp. 2	* *	* *	
S <i>Opopaea</i> sp. 7	* *	*	*
SC <i>Lychas</i> sp. 4	*		*
S <i>Margaromma</i> sp. 1	*	*	
S Amaurobiidae gen. 3 sp. 6	*	** * *	*
SC <i>Urodacus</i> sp. 11	*	* *	
S <i>Laestrygones</i> sp. 1	*	*	
S <i>Artoria</i> sp. 17	*	*	
S <i>Hadrotarsus</i> sp. 2	*	*	
S <i>Corasoides</i> sp. 1	*	* *	*
A <i>Heleioporus psammophilus</i> (Lee & Main, 1954)	*		*
R <i>Amphibolurus norrisi</i> Witten & Coventry, 1984	*	*	
S <i>Steatoda</i> sp. B	*	*	*
S Lycosidae gen. 2 sp. 2	* *	*	
S <i>Artoria</i> sp. 6	*		*
S <i>Neostorena</i> sp. 3	*	*	*
R <i>Hemiergis peronii</i> (Fitzinger, 1826)		* ** *	***
M <i>Tarsipes rostratus</i> Gervais & Verraux, 1842		* ** *	*
A <i>Limnodynastes dorsalis</i> (Gray, 1841)	* *	** * ** ** *	*
A <i>Neobatrachus albipes</i> Roberts et al. 1991	* *	*	** **
S <i>Prionosternum scutatum</i> Dunn, 1951		*	**

Appendix 1. (continued)

	Quadrat group number (from Fig. 6)		
	1	2	3
	BMWWBBKDMQKYWEM	DSDGLNPNGGGJJNNYSUSU	BMMKWMMMDSEHLG
	EOUUEELNNULOHSL	UTUPKRIRPPPPBBRRONTN	EOLLUNOUTSYKP
	0101011000000000	001000010100000000001	1010001000000
	5290832619416796	990324804289186731352	1421891586235
A <i>Litoria cyclorhyncha</i> (Boulenger, 1882)		***	*
S <i>Venatrix arenaris</i> (Hogg, 1905)		*	*
S <i>Neostorena</i> sp. 24		*	*
S <i>Hetaerica harveyi</i> Raven & Baehr, 2000		*	*
S Amphinectidae gen. ?? sp. 10			**
S Desidae gen. 3 sp. 2			* **
S <i>Baiami volucripes</i> (Simon, 1908)		*	* **
R <i>Christinus marmoratus</i> (Gray, 1845)		*	* **
S <i>Artoria</i> sp. 1		*	* **
A <i>Heleioporus eyrei</i> (Gray, 1845)		*	* **
A <i>Litoria adelaidensis</i> (Gray, 1841)		*	* **
A <i>Crinia georgiana</i> Tschudi, 1838		*	* **
A <i>Crinia pseudinsignifera</i> (Main, 1957)		*	* **
S <i>Lychas</i> sp. 5		*	* **
S <i>Habronestes</i> sp. 13		*	* **
S Amphinectidae Gen. ?? sp. 8		*	*
S <i>Longepi woodman</i> Platnick, 2000		*	* **
A <i>Crinia glauerti</i> (Loveridge, 1933)			* **
S <i>Lampona</i> sp. 5			*
S <i>Venatrix pullastra</i> (Simon, 1909)			**
S <i>Nostera</i> sp. 8			*
S Desidae gen. 2 sp. 1			*
M <i>Sminthopsis griseoventer</i> Kitchener et al. 1984			* **
S Amphinectidae gen. ?? sp. 7		*	*
S <i>Lampona</i> sp. 2		*	*
S <i>Pseudolampona boree</i> Platnick, 2000		*	*
S <i>Habronestes</i> sp. 14		*	*
S <i>Gmogola</i> sp. U	*	*	*
R <i>Ctenotus impar</i> Storr, 1969		**	*
S <i>Lycosa</i> sp. 8		**	*
S <i>Gmogola</i> sp. B	*	*	**
S <i>Storosa</i> sp. 1	*	*	*
S Liocranidae gen. ?? sp. 7		*	*
S <i>Sondra</i> sp. 1		*	**
M <i>Cercartetus concinnus</i> (Gould, 1845)		****	****
R <i>Morethia obscura</i> Storr, 1973	*	****	****
R <i>Lerista distinguenda</i> (Werner, 1910)	*	**	*****
S <i>Urodacus</i> sp. 6	*	**	****
S <i>Gamasomorpha</i> sp. 8		*	****
R <i>Hemiergis initialis</i> (Werner, 1910)		**	**
S <i>Neostorena</i> sp. 2		**	*
R <i>Crenadactylus ocellatus</i> (Gray, 1845)		**	*
S <i>Nico</i> sp. 1		*	**
S <i>Cercophonium</i> sp.	*	**	*
S <i>Artoria</i> sp. 4		*	**
R <i>Ctenotus schomburgkii</i> (Peters, 1863)	**	*	*****
M <i>Sminthopsis gilberti</i> Kitchener et al. 1984		*	*****
R <i>Pogona minor</i> (Sternfeld, 1919)	*	*	****
S <i>Clynotis</i> sp. 1		*	****
S <i>Maratus vespertilio</i> (Simon, 1901)	*	*	** ** *
S <i>Lycidas michaelsoni</i> (Simon, 1909)		**	*
Species Group 2			
R <i>Cryptoblepharus plagioccephalus</i> (Cocteau, 1836)	**	** **	* *****
R <i>Diplodactylus granariensis</i> Storr, 1979	*	* **	** ** * **
S <i>Habronestes</i> sp. 3	*	***	** ** *
S Salticidae gen. 2 sp. 1		*** *	*** ** **
A <i>Heleioporus albopunctatus</i> Gray, 1841		*** *	* ****
A <i>Neobatrachus pelobatoides</i> (Werner, 1914)	*	* ** *	*****
A <i>Pseudophryne guentheri</i> Boulenger, 1882	*	*****	* *****

Appendix 1. (continued)

Quadrat group number (from Fig. 6)

	1	2	3
	BMWWBBKDMQKYWWEM	DSDGLNPNGGGGJJNNYSUSU	BMMKWMMDSEHLG
	EOUUEELNNULOHHSL	UTUPKRIRPPPPBBRROTNTN	EOLLUNOUTSYKP
	0101011000000000	001000010100000000001	1010001000000
	5290832619416796	990324804289186731352	1421891586235
S <i>Lycidas</i> sp. 3	* * * *	* * *	*
S <i>Lycosa</i> sp. 17	** * * * *	* * *	** *
S <i>Habronestes</i> sp. 23	* * * *	* * *	* * *
R <i>Oedura reticulata</i> Bustard, 1969	* * * *	* * *	* * *
S <i>Arctoria</i> sp. 3	* * *	* * *	* * *
S <i>Nicodamus mainae</i> Harvey, 1995	* * *	* * *	* *
S <i>Nostera</i> sp. 1	* * *	* * *	* * *
S <i>Gamasomorpha</i> sp. 9	** * * *	* * *	* * *
S <i>Lycidas chrysomelas</i> (Simon, 1909)	* * * *	** * * *	* * *
S <i>Habronestes</i> sp. 5	* * * *	* * *	* * *
SC <i>Urodacus</i> sp. 7	* * * *	* * *	* * *
S <i>Habronestes</i> sp. 2	* * *	* * *	* * *
S <i>Liocranidae</i> gen. ?? sp. 12	* * *	* * *	* * *
S <i>Lycidas</i> sp. 5	* * *	* * *	* * *
S <i>Textracella</i> sp. 1	* * *	* * *	* * *
S <i>Phoroncidia</i> sp. 6	* * *	* * *	* * *
S <i>Lampona cylindrata</i> (L. Koch, 1866)	* * *	* * *	* * *
S <i>Habronestes</i> sp. 9	* * * *	* * * *	* * * *
S <i>Neostorena</i> sp. 1	* * * *	* * * *	* * * *
S <i>Habronestes</i> sp. 4	* * * *	* * * *	* * * *
S <i>Lycidas</i> sp. 2A	* * * *	* * * *	* * * *
S <i>Lycosa</i> sp. 10	* * * *	* * * *	* * * *
S <i>Lycosa leuckartii</i> (Thorell, 1870)	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
M <i>Mus musculus</i> Linnaeus, 1758	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
R <i>Menetia greyii</i> Gray, 1845	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
S <i>Myrmopopaea</i> sp.	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
S <i>Latrodectus hasseltii</i> Thorell, 1870	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
S <i>Steatoda</i> sp. 1	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
S <i>Opopaea</i> sp. 1	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
S <i>Lycidas</i> sp. 1	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
A <i>Neobatrachus kunapalari</i> Mahony & Roberts, 1986	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
SC <i>Isometroides</i> sp.	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
SCL <i>ychas</i> sp. 2	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
S <i>Euryopsis</i> sp. 9	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
S <i>Grymeus</i> sp. 9	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
S <i>Salticidae</i> gen. 1 sp. 1	* * * * * * * * * *	* * * * * * * * * *	* * * * * * * * * *
Species Group 3			
S <i>Amaurobiidae</i> gen. 3 sp. 1	* * *	* * *	* * *
S <i>Notsodipus quobba</i> Platnick, 2000	* * *	* * *	* * *
S <i>Segestriidae</i> gen. 1 sp. 2	* * *	* * *	* * *
S <i>Opopaea</i> sp. 4	* * *	* * *	* * *
S <i>Euryopsis</i> sp. 6	* * *	* * *	* * *
R <i>Lerista connivens</i> Storr, 1972	* * *	* * *	* * *
SC <i>Urodacus</i> sp. 10	* * *	* * *	* * *
S <i>Lycosa</i> sp. 21	* * *	* * *	* * *
S <i>Lycosa</i> sp. 22	* * *	* * *	* * *
R <i>Ctenotus leonhardii</i> (Sternfeld, 1919)	* * *	* * *	* * *
S <i>Habronestes</i> sp. 17	* * *	* * *	* * *
M <i>Pseudomys hermannsburgensis</i> (Waite, 1896)	* * *	* * *	* * *
R <i>Diplodactylus squarrosus</i> Kluge, 1962	* * *	* * *	* * *
S <i>Lycosa</i> sp. 2	* * *	* * *	* * *
SC <i>Urodacus</i> sp. 1	* * *	* * *	* * *
S <i>Lycosa</i> sp. 27	* * *	* * *	* * *
R <i>Ctenophorus salinarum</i> (Storr, 1966)	* * *	* * *	* * *
S <i>Theridiidae</i> gen. 5 sp. 3	* * *	* * *	* * *
M <i>Sminthopsis crassicaudata</i> (Gould, 1844)	* * *	* * *	* * *
S <i>Corasoides?</i> sp. 4	* * *	* * *	* * *
S <i>Lycosa</i> sp. 20	* * *	* * *	* * *
S <i>Lycidas</i> sp. 19	* * *	* * *	* * *
S <i>Lycosa</i> sp. 14	* * *	* * *	* * *

Appendix 1. (continued)

	Quadrat group number (from Fig. 6)		
	1	2	3
	BMWWBBKDMQKYWWM	DSDGLNPNGGGGJJNNYSUSU	BMMKWMMDSEHLG
	EOUUEELNNULOHSL	UTUPKRIRPPPPBBRRONTN	EOLLUNOUTSYKP
	0101011000000000	001000010100000000001	1010001000000
	5290832619416796	990324804289186731352	1421891586235
S Salticidae gen. 5 sp. 1	* *		**** *
S Desidae gen. 2 sp. 2			* *
S <i>Opisthoncus</i> sp. 3			* *
S <i>Artoria</i> sp. 2		*	* *
S <i>Lycosa</i> sp. 4			**
S <i>Artoria</i> sp. 10			**
S Theridiidae gen. 2 sp. 1			* **
S <i>Grymeus</i> sp. 8			* *
S Salticidae gen. 10 sp. 1A			* *
S <i>Opisthoncus</i> sp. 2A			* *
S Theridiidae gen. 1 sp. 3			* *
S <i>Lycosa</i> sp. 3		*	***
S <i>Lycosa</i> sp. 7			* *
S <i>Lycidas</i> sp. 8			* *
Species Group 4			
S Amaurobiidae gen. 3 sp. 11	* *		
S <i>Asadipus phaleratus</i> (Simon, 1909)	* * *		
R <i>Lialis burtoni</i> Gray, 1835	* *		
S <i>Lycosa</i> sp. 1	* * *		
S Desidae gen. 1 sp. 10	*	*	
S Salticidae gen. 13 sp. 1	*	*	
R <i>Ctenotus mimetes</i> Storr, 1969	****		*
S <i>Lycosa forresti</i> McKay, 1973	****		
R <i>Morethia butleri</i> (Storr, 1963)	**** *		
SCUrodacus sp. 8	* ***		
S <i>Wandella barbarella</i> Gray, 1994	** *		
R <i>Lerista gerrardii</i> (Gray, 1864)	***		
S <i>Asteron</i> complex sp. 2	**		
S <i>Neostorena</i> sp. 4	**		
S <i>Matiida</i> sp. 1	* * *	* *	*
SCLychas sp. 3	* * *	* *	*
S <i>Lycosa</i> sp. 6	** * *	* *	*
R <i>Diplodactylus pulcher</i> (Steindachner 1870)	** * *		
S <i>Teyl</i> sp. 3	** * *		
R <i>Gehyra variegata</i> (Dumeril & Bibron 1836)	** ***** *		
M <i>Sminthopsis dolichura</i> Kitchener et al. 1984	***** ** **		*
S <i>Kerasteron</i> sp. 1	***** **		** *
S <i>Australutica</i> sp. 1	***** * *****		**
R <i>Lerista muelleri</i> (Fischer, 1881)	* * * * *		
S <i>Grayenulla australensis</i> Zabka, 1992	* *** * * *		
A <i>Neobatrachus sutor</i> Main, 1957	** * **		*
S <i>Hadrotarsus</i> sp. 3	* * * *	*	*
S <i>Opopaea</i> sp. 5	* * **		
S Amaurobiidae gen. 3 sp. 16	* * *	*	*
R <i>Diplodactylus maini</i> Kluge, 1962	* *	*	
S <i>Breda jovialis</i> (L. Koch, 1879)	*	*	*
S <i>Habronestes</i> sp. 6	* * *	*	*
S Salticidae gen. 1 sp. 3	*	*	
S Salticidae gen. 9 sp. 1	*		*
S Theridiidae gen. 3 sp. 1	*	*	*
S <i>Australutica quaerens</i> Jocqué, 1995	*	*	
S Segestriidae gen. 2 sp.	*	*	
S Amphinectidae gen. ?? sp. 9	* * *	*	*
S <i>Micropholcomma?</i> sp. 2	*		* *
R <i>Delma australis</i> Kluge, 1974	*	*	
S <i>Lycidas</i> sp. 17	*	*	
S Desidae gen. 1 sp. 4	* *		
S <i>Neostorena</i> sp. 11	* *		
S <i>Lampona dwellingup</i> Platnick, 2000	* *		

Appendix 1. (continued)

	Quadrat group number (from Fig. 6)		
	1	2	3
	BMWWBBKDMQKYWWEM	DSDGLNPNGGGGJNNYSUSU	BMMKWMMDSEHLG
	EOUUEELNNULOHSL	UTUPKRIRPPPPBBRROTNTN	EOLLUNOUTSYKP
	0101011000000000	001000010100000000001	1010001000000
	5290832619416796	990324804289186731352	1421891586235
S Oonopidae gen. ?? sp. 1	* *		
S Lycosa sp. 29	*		*
S Opopaea sp. 2	*		*
S Amaurobiidae gen. 4 sp. 3	*	*	
S Lycidas sp. 26	* *		
R Ctenotus uber Storr, 1969	**		
S Habronestes sp. 7	* *		
S Gamasomorpha sp. 3	* *		
S Lamponina scutata (Strand, 1913)	*		*
S Neostorena sp. 5	**		*
S Lamponata daviesae Platnick, 2000	** * * *		
S Grymeus sp. 6	** *	*	
S Euryopsis sp. 7	* * *		*
S Euryopsis sp. 8	* *		*
R Lerista macropisthopus (Werner, 1903)	* ***		
S Salticidae gen. 1 sp. 2	* ***		
S Steatoda sp. 3	* *	*	*

Appendix 2. Geographical locations of quadrats

Quadrat	Latitude (S)	Longitude (E)	Quadrat	Latitude (S)	Longitude (E)
BE05	30°39'39"	118°28'37"	ML12	28°37'14"	115°21'31"
BE08	30°31'49"	117°34'44"	MN01	31°44'29"	119°05'02"
BE11	30°20'01"	117°29'43"	MN09	31°07'29"	118°25'05"
BE13	30°20'55"	117°45'28"	MO04	29°13'52"	116°04'06"
DN06	30°03'44"	115°55'11"	MO11	29°11'21"	116°27'09"
DU05	33°21'29"	117°38'40"	MO12	29°11'21"	116°28'27"
DU09	33°27'08"	118°06'57"	NR04	32°48'39"	116°53'23"
DU10	33°20'10"	118°15'34"	NR06	33°03'10"	117°14'27"
ES06	33°28'11"	122°00'50"	NR07	33°08'46"	117°03'13"
ES09	33°29'05"	122°14'27"	NR10	32°45'12"	116°56'43"
GP03	33°15'28"	121°05'47"	PI08	33°29'32"	119°05'28"
GP04	33°09'31"	121°00'03"	QU09	32°05'00"	117°22'05"
GP05	33°09'45"	120°58'10"	ST01	34°18'30"	117°34'09"
GP08	33°23'09"	121°34'56"	ST05	34°18'01"	118°04'03"
GP09	33°31'02"	121°33'33"	ST08	34°15'50"	117°57'49"
GP12	33°28'31"	121°14'10"	ST09	34°10'04"	117°57'01"
HY02	32°45'59"	119°24'39"	UN03	34°06'19"	116°49'35"
JB01	31°34'41"	116°15'49"	UN12	34°25'14"	116°40'06"
JB08	31°24'00"	116°19'04"	WH06	30°45'28"	117°05'24"
KL01	31°54'38"	117°50'15"	WH07	30°49'11"	117°04'57"
KL04	31°51'23"	118°06'14"	WU08	29°56'09"	116°53'10"
KL12	31°22'38"	117°56'01"	WU09	29°49'54"	116°57'21"
LK02	33°12'11"	119°42'55"	WU10	30°00'30"	116°49'18"
LK03	33°14'29"	119°45'42"	YO01	31°59'35"	117°01'25"
ML06	28°28'38"	115°30'20"	YO03	32°05'38"	116°34'05"