Managing coextinction of insects in a changing climate

Final Report

Melinda Moir and Mei Chen Leng

MANAGING COEXTINCTION OF INSECTS IN A CHANGING CLIMATE

Developing management strategies to combat increased coextinction rates of plant-dwelling insects through global climate change

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The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

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ACRONYMS

ANOSIM	Analysis Of Similarities
DEC	Western Australian Department of Environment and Conservation
DRF	Declared Rare Flora
EPBC	Environmental Protection and Biodiversity Conservation [Act]
IUCN	International Union for Conservation of Nature
MCMC	Markov chain Monte Carlo
MDS	Multi-Dimensional Scaling
NCCARF	National Climate Change Adaptation Research Facility
NGO	Non Government Organisation
NSW	New South Wales
SRNP	Stirling Range National Park
TEC	Threaten Ecological Community (also known as an Endangered Ecological Community or EEC in some other Australian states)
TSSC	Western Australian Threaten Species Scientific Committee
WA	Western Australia
WAM	Western Australian Museum

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ABSTRACT

Approximately a quarter of global terrestrial biodiversity is represented by plant-dwelling insects and the potential for thousands of species to be extinguished through widespread disturbances such as a changing climate is high. From a large database of 1,019 insect species on 104 plant species, we identified that 70 species were of immediate conservation concern due to their reliance on threatened plant species. A further 15 insect species were of lesser conservation concern because they rely on several threatened plant species for survival. Of those insects that feed from non-threatened plant species, 178 host-specific species are likely to be at risk in the event that climate change or synergistic factors reduces their host plant's range size. Insect groups that appear most prone to extinction are sessile feeders and highly host-specific groups such as whiteflies, scales, mealybugs. Many weevils are also host specific and at higher risk, possibly as they are dispersal inhibited, such as through brachyptery. More surprisingly, mobile plant louse groups (Psylloidea) were also at high risk. Endophagous insects are predicted to be at high risk, but were under-studied here.

Regions such as gullies and mountains provide refugia for some species. The fluctuations in temperature (less within refugia), and average humidity (higher in refugia) appear particularly important in these habitats. Particular vegetation types are associated with refugial regions, with a recognised Threatened Ecological Community (TEC) of flora species associated with the highest peaks of the Eastern Mastif, and there is evidence of insect species restricted to these peaks. For the majority of plant species that are not restricted to certain areas, their insect assemblages differ significantly between plant populations, particularly across different mountains.

With the assistance of end-users, we have developed an adaptation management framework. The framework assists with conserving plant-dwelling insect species, after they are identified as in need of conservation action. Whilst the primary reason for the development of the framework was to provide adaptation actions in the face of climate change, the framework can be used when insects require conservation action to ameliorate impacts of other threatening processes. Previously published frameworks can be utilized to determine whether an insect is threatened with extinction. Despite the availability of such tools, a survey of end-users still indicted that lack of expertise is the most important factor inhibiting considering plant-dwelling insects.

Land managers currently struggle to determine which insect species inhabit their lands, let alone knowing which are in need of conservation. To assist land managers with these problems, we suggest the employment of dedicated conservation entomologists by the Federal and State governments. Their role would be to bridge the interface between taxonomists, government conservation bodies, land managers and disturbance ecologists. The conservation entomologist's principle tasks would be to identify insects most at risk of extinction, nominate them for listing, and develop management plans to ensure their survival.

EXECUTIVE SUMMARY

Approximately a quarter of global terrestrial biodiversity is represented by plant-dwelling insects and the potential for thousands of species to be extinguished through widespread disturbances, such as a changing climate, is high. Their extinction is termed 'coextinction' as it occurs either through the loss of the host or some change in the population of the host.

Attempting to foresee the impacts of climate change without considering species interactions, exemplified by dependent-host relationships, results in a failure to generate comprehensive predictions or unambiguous suggestions for amelioration. Whilst innovative frameworks are available to assess the potential threat presented by climate change, these are often applicable only when background information is available for the target taxa. In Australia, the vast majority of plant-dwelling insect species do not even have names as yet. Given the numbers of species involved and the lack of knowledge on the majority of plant-dwelling insects, their management can be overwhelming.

This study was commissioned to investigate the threat posed by climate change to plant-dwelling insects, and provide adaptation management options for their conservation. This was achieved in a multifaceted approach. Firstly, we monitored the climate across a series of altitudinal transects with a series of weather data loggers. Secondly, we analysed the host-breadth of insect species from a large database featuring 104 different host plant species. Thirdly, experimental translocations of three co-threatened insect species with their host plants were trialled for the first time in Western Australia. Finally, end-users from industry, non-government organisations, State and Federal government were surveyed to identify barriers in insect conservation and help develop management outcomes that would be most applicable to organisations.

Insect groups that appear most prone to extinction are sessile feeders and highly host-specific groups e.g. whiteflies, scales, mealybugs (Hemiptera: Aleyrodidae, Coccidae, Pseudococcidae). Weevils (Coleoptera: Curculionidae), particularly smaller species from the genera *Apion* and *Cydmaea*, were also host specific and at high risk but these could be dominated by dispersal-limited species such as brachypterous species. Surprisingly, mobile plant louse groups (Hemiptera: Psyllidae and Triozidae) were also at high risk. Internal plant-feeding insects (called endophages) such as gallers and leaf miners are also predicted to be at high risk. Regions such as gullies and mountains provide refugia for some species. The fluctuations in temperature (less within refugia), and humidity (higher in refugia) appear particularly important in these habitats.

With the assistance of end-users, an adaptation management framework was developed to assist with the conservation of plant-dwelling insect species, after they are identified as in need of conservation action. Initially developed to manage climate change, this framework is flexible and can be used when the insect requires conservation action to ameliorate the impacts of other threatening processes. Plant-dwelling insect conservation methods are in their infancy as land managers are struggling to determine which insect species currently reside within their lands, let alone which are in need of conservation action. This is due to a lack of expertise and resources. These issues were found to be the most important factors inhibiting end-users from considering plant-dwelling insects in their management plans. To assist land managers with these concerns, we suggest the employment of dedicated conservation entomologists who would be charged with bridging the interface between taxonomists, government conservation bodies, land managers and disturbance ecologists. Their primary job would be to identify those insects most at risk of extinction, nominate them for listing, and develop management plans to ensure their survival.

INTRODUCTION

The world is evidently facing the sixth mass extinction event, predominantly due to human activities such as land clearing, pollution, introduced species and recently, a changing climate (Bellard *et al.* 2012). Invertebrates are a major component of global diversity and although most groups are understudied, the number of species that we may lose from this component of diversity is likely to be very large (Dunn *et al*. 2009; Cardoso *et al*. 2011). One of the largest groups within the invertebrates is those taxa that are closely dependent upon other species for their survival, for example, herbivorous insects and their host plants (Dunn *et al.* 2009).

Approximately a quarter of global terrestrial biodiversity is represented by plant-dwelling insects (Strong *et al.* 1984), with estimates of the number of insects present in Australia ranging from 205,000 to 400,000 species (Cranston 2010), therefore the potential for thousands of species to be extinguished through widespread disturbances such as a changing climate is high (Moir *et al*. 2011a, 2012a). Their extinction is termed 'coextinction' as it occurs either through the loss of the host or some change in the population of the host (e.g., Koh *et al.* 2004; Moir *et al*. 2010a).

Attempting to foresee the impacts of climate change without considering species interactions, such as exemplified by dependent-host relationships, results in failure to generate comprehensive predictions or unambiguous suggestions for amelioration (Gilman *et al*. 2010). What-is-more, through the process of altering seasonality, temperature and rainfall, climate change may have severely prejudicial effects on species interactions by uncoupling the relationship between host and dependent (Foden *et al.* 2008 in Kingsford and Watson 2011). The flow-on effects for coextinction rates under altered climate change scenarios has not been examined, although rates are high for some groups that feature predominantly dependent taxa, such as Lepidoptera (e.g., Thomas *et al.* 2006; Wilson and Maclean 2011). There is evidence, however, that climate change is causing the loss, or movement, of herbivorous insects across both altitudinal and latitudinal gradients (e.g., Wilson *et al.* 2005; Hickling *et al.* 2006; Raxworthy *et al.* 2008; Chen *et al.* 2009). Most studies relate these changes in plant-dwelling insects to habitat and climate, but not directly to changes in plant host populations (although see Hodkinson 2005; Ashton *et al.* 2009).

Whilst innovative frameworks are available to assess the potential threat climate change presents (e.g., Thomas *et al.* 2011), these are often applicable only when background information is available for the target taxa. In stark contrast, little is known for the majority of the world's insect fauna, with approximately 1 million of the estimated 5-10 million species named (Gaston and Hudson 1994; Cranston 2010; Hamilton *et al*. 2010; but see lower estimates given by Costello *et al*. 2012). Given the numbers of species involved and the lack of knowledge on the majority of plant-dwelling insects, their management can be overwhelming. Perhaps because of the difficulty associated with managing these taxa, insects, and invertebrates in general, are rarely included in systematic conservation plans (Pressey *et al.* 2003). A common misconception of land managers is that conserving the host plant will indirectly conserve all dependent insect species reliant on that plant. Unfortunately, this is not often the case. Managing for the persistence of hosts alone may be insufficient to maintain populations of all their dependent species, just as the conservation of any species may not be assured through maintenance of its habitat alone (e.g., Caughley 1994).

Firstly, dependent species may occur only on particular populations of their hosts. The plant louse *Acizzia veski,* for example, occurs on only one of six surveyed populations of its threatened host, *Acacia veronica* (Taylor and Moir 2009).

Secondly, a disturbance that does not eliminate the host plant may cause the local extinction of the dependent insect. For example, fire may remove all above ground structures of plant for a period of time, which in turn restricts access to a host for the insect (e.g., Werner 2002). Thirdly, a minimal viable population threshold (Benton 2003) of hosts will exist, below which the dependent will be extinguished. In the case of another invertebrate, the tuatara mite, this may have been the reason that translocations were not successful, despite the success for the host tuatara populations (Moir *et al.* 2012a). Given these three factors, plant-dwelling insects are more likely to reach population sizes requiring conservation action and go extinct before their host plants.

The regions that will experience the highest proportion of all global extinctions directly as a result of climate change are predicted to be the world's biodiversity hotspots (*sensu* Myers *et al.* 2000) because these regions contain many species and range restricted, endemic species are especially vulnerable (Thomas *et al*. 2004; Malcolm *et al*. 2006). Modelled effects of climate change on one group of plants, the *Banksia*, indicate that the majority of species will experience population declines, and some extinction, in the next 100 years (Fitzpatrick *et al*. 2008; Yates *et al*. 2010). This is primarily because annual rainfall is predicted to decrease by up to 40% by 2070 in the region of the *Banksia* studies: the south-west of Australia (Whetton 2011). Biodiversity hotspots are also the regions thought to contain the highest richness of plant-dwelling insects precisely because of the high plant host diversity. Fonseca (2009) estimated that the world's biodiversity hotspots contain between 795,971-1,602,423 monophagous plant-dwelling insects in total. Monophagous species are those insects that can only feed on one host plant species. This estimate not only assumes that we know which species are monophagous, but also ignores those insects which can feed on multiple hosts, the oligophagous and polyphagous fauna, which in most studies of plant-dwelling insects, contribute the larger proportions towards the total fauna (e.g., Novotny *et al.* 2002, 2010, 2012; Andrew and Hughes 2004, 2005; Ødegaard *et al*. 2000; Moir *et al.* 2011b).

Although many conservation programs aim to reduce the probabilities of extinction of plants (e.g. Millennium Seed Bank Project, Global Strategy for Plant Conservation), few consider the conservation of species dependent upon those plant species for their survival, such as herbivorous insects (Moir *et al*. 2012a). Typically the only insects that do receive attention in terms of assessing the response to climate change are butterflies (Lepidoptera) because they are charismatic and there usually exists good historical and contemporary datasets (Wilson and Maclean 2011). This present study was commissioned to highlight the threat faced by many different groups of plant-dwelling insects and provide adaptation management options for their survival in the face of climate change. To achieve this, monitoring the climate at different altitudes and locations where co-threatened insects occur with a series of weather loggers was done and analyses of the breadth of the host-range of insects across a suite of plant species were also conducted. In addition, experimental translocations of some of these co-threatened insects onto their translocated host plants at different locations were trialled for the first time in Western Australia. Finally, end-users (land managers from government, non-government organisations, industry and working groups) were surveyed with a questionnaire to identify barriers to insect conservation and help develop outcomes that would be most applicable to stakeholders.

1. OBJECTIVES OF THE RESEARCH

1.1 Deliverables

Utilizing a large dataset of plants and insects from an altitudinal gradient within the biodiversity hotspot of south-west Australia, and collecting environmental data along this gradient, we sought to:

1. Identify species at risk of climate-induced coextinction (and nominate key species for conservation listing),

2. Develop general indicators of the degree to which insect species might be prone to climate change-induced coextinction across Australia,

3. Identify the most cost-effective range of conservation strategies to combat climate change induced coextinction,

4. Trial a Climate Change Adaptation Decision Framework on the ground, that can be readily employed by end users, and

5. Provide recommendations for revising Australian and State Government restoration and translocation policies which explicitly consider coextinction and projected climate change scenarios.

1.2 Timeline

This project commenced in June 2011, with funding from NCCARF commencing in November 2011. The following page shows a timeline of the progress of the project over the period of June 2011 - December 2012 (Table 1).

Table 1: Proposed timeline of activities of the project

		2011	2012
Activity	**Details**	**JASOND**	**JFMAMJJASOND**
Fieldwork	Preparation (buy weather stations, etc) (Moir and Leng)	⇨⇨⇨	
	Fieldwork (set up weather stations, collect data, collect key insect species for DNA work) (Moir and Leng). Prepare translocation proposals for approval by WA DEC	⇨⇨⇨	⇨ ⇨⇨⇨
	Trial climate change adaptation action (translocation) (Moir and Leng)		⇨⇨⇨
Laboratory	Collation of weather data (Leng)	⇨⇨	⇨⇨⇨⇨⇨⇨⇨
	Curation and identification of key insect species most at risk of coextinction (Moir and Leng)	⇨	⇨⇨⇨⇨
	DNA analysis of above insect species (out-sourced)		⇨⇨⇨
Office	Hire research assistant: (Moir)	⇨	
	Data analysis of results (Moir, Vesk, McCarthy and Brennan)		⇨⇨⇨⇨⇨⇨⇨⇨⇨⇨⇨⇨
	Recruit post-graduate students to undertake further analysis of particular insect groups (Moir)		⇨
	Report writing to NCCARF and all identified end-users	⇨	⇨ ⇨ ⇨
	Conference attendance (+ preparation) (Moir)		⇨⇨⇨⇨
Outputs	1. Descriptions of key insects including DNA results (Moir with out-sourced taxonomists)		⇨⇨⇨⇨⇨
	2. Nominate key insects for conservation listing at state, national and international levels (Moir and Leng)		⇨⇨⇨⇨⇨
	3. Complete end-user and communication plans (Moir and Leng)	⇨⇨	
	4. Inform end-users and IUCN of results to date through meetings and email (including meeting with end-users to determine optimal management strategies)(Moir, Leng and Vesk)		⇨⇨ ⇨⇨
	5. Inform end-users and IUCN of final results (Moir and Leng)		⇨⇨
	6. Draft final report to NCCARF (all)		⇨⇨
	7. Scientific paper 1: Which invertebrates are most prone to co-extinction under altered climate scenarios? (all)		⇨⇨⇨⇨⇨
	8. Scientific paper 2: Predictions of losses to Australia's biodiversity through climate change induced co-extinction of plant-dwelling insects (all)		⇨⇨⇨
	9. Scientific paper 3: Cost-effective management strategies for combating loss of plant-dwelling insects through coextinction induced by climate change (all)		⇨⇨⇨⇨
	10. Extension articles in popular media and fact sheets published by end users (various depending on article)		⇨⇨⇨⇨⇨⇨⇨

2. RESEARCH ACTIVITIES AND METHODS

The following section has been broken down into sections that relate to the research activities for the project. The methodology has been explained therein.

2.1 Environmental data collection

Onset® HOBO micro weather stations and data loggers were used to measure temperature (C°), light intensity (lux), relative humidity (RH %), dew point (C°) and rainfall (mm). HOBOware® Pro software was used to set 30 micro weather stations and 100 data 'pendant' loggers to record at one hour intervals. Data loggers only measured temperature and light intensity, whereas micro weather stations recorded temperature (C°), relative humidity (RH %), dew point (C°) and rainfall (mm). Weather stations were placed approximately 50 cm above ground level on metal fence droppers, with rain gauges placed at ground level. Pendants were placed on metal stakes approximately 20 cm above ground level.

Relative humidity, expressed as a percentage value, is the ratio between the water vapour actually present and the water vapour necessary for saturation at a given temperature. In contrast, dew point is a direct measure of the amount of moisture present in the air, and is measured in degrees. It indicates when the air would become saturated and form fog, dew, frost, or clouds (McGraw-Hill, 2005).

Weather transect placement within the Stirling Range National Park (SRNP) was chosen based on aspect, height and position of mountains. Eleven transects were placed on peaks facing north, east, south and west. These transects were a combination of micro weather stations and data loggers which were staggered at altitudes of approximately every 50 m. Micro weather stations were place at the base, middle and summit of the selected peaks with data loggers in between. Data loggers were also placed strategically in six locations within the Stirling Ranges and six locations south of the Stirling Range around Albany, at certain threatened plant populations to record temperature and light intensity. At each placement, altitude, aspect and the position of the site (e.g., gully, ridge, summit, flat, etc.) was recorded.

Data loggers were left to record in the field for six months before data was downloaded. Data was downloaded using an Onset® U-shuttle data transporter and weather data was readout using HOBOware® Pro software.

As the 'pendants' recorded light intensity, and we placed a pendant with a weather station, we noticed that the pendent was less reliable than the weather station at recording temperature in periods of high light intensity. Due to this unreliability, we provide only the results for the weather stations (i.e. temperature). An additional problem of animal attack on the weather station sensors meant that not all stations were functional all of the time. We were able to select 3 months over the 12 months of implementation for which most stations (97 %) were recording, and therefore provide results from February 2012 to April 2012 here. As the aim in recording climatic data for this project was to assess differences with altitude, the shorter period does not impact significantly on the results and interpretation. However, this is evaluated further in the Results, section 4.1 with data from other seasons.

2.1 Plant selection

Plant species were selected based on their phylogeny, availability/accessibility, remnant population size and plant threat status. Target plant genera were *Leucopogon, Lasiopetalum, Thomasia, Hakea, Grevillea, Dryandra (now Banksia), Banksia, Acacia* and *Gastrolobium*. Each of these genera has known associations with families, genera or species of plant-dwelling invertebrates. Threatened plant populations within the SRNP were located with the assistance of scientists from the Western Australian Department of Environment and Conservation (DEC). A total of 104 plant species were selected, for a list of these plant species and the numbers of populations sampled see Appendix 1.

2.2 Insect/plant database

We have utilized an existing large empirical dataset of insect-plant associations to identify those species most at risk of climate change-induced coextinction. The insect dataset contains 26,518 individuals representing >1,019 species from 101 families. These were collected from 3,026 plants, representing 104 plant species (13 plant families) of varying threat status, along an altitudinal/rainfall gradient from Vancouver Peninsular to SRNP, areas managed by Albany City Council and WA DEC, respectively. Collections ranged from an altitude gradient from 10 m above sea level (Vancouver) to 1099 m (Stirling Range), which is relevant to Australian systems as iconic mountains such as the Blue Mountains are of similar height (~1100 m). Such data allow for the detection of subtle changes in insect assemblages on plants caused by changes in environmental conditions with altitude.

2.3 Insect collection

Focus was restricted to predominantly herbivorous invertebrate orders, such as Coleoptera (beetles), Lepidoptera (butterflies and moths), Hemiptera (bugs), Orthoptera (crickets and grasshoppers) and Thysanoptera (thrips), henceforth collectively known as insects. In this study, 28 threatened plant species were chosen. For each threatened plant species, 30 individual plants were sampled for insects (15 sampled by beating, 15 sampled by vacuuming, and all checked afterwards by hand for sessile insects). Spring was chosen as the sampling period as this is the period of greatest insect activity and diversity in this part of southern Australia. Furthermore, the proportion of plant-dwelling fauna that is specialised during this season is similar to the proportion of fauna specialised over an entire year (e.g., Moir *et al.* 2011b).

2.4 Molecular analysis

During insect collecting in the field, specimens were also collected for molecular analysis. Insects collected for DNA purposes were preserved in 100% ethanol and kept at -18°C in a freezer until they could be processed for analysis. Insects considered for molecular analysis included plant-lice in the genus *Trioza*, mealybugs in the genus *Pseudococcus* and leafhoppers in the genus *Austroasca*.

***Trioza* (Hemiptera: Triozidae)**

DNA sequencing was performed in the commercial laboratory, Helix. Sequences were edited using GENEIOUS software (Drummond *et al.* 2011). Alignment was performed with CLUSTAL W (Thompson *et al.* 1994) using default parameters. Four additional sequences from the Psyllidae from the international sequence database GenBank (ncbi.nlm.nih.gov/genbank/) were included in the analysis to provide context to the genetic distances within and among genera. These four sequences were selected because they had the highest pairwise sequence similarity to the *Trioza* specimens, as revealed by the program BLAST (Altschul *et al.* 1997). Three sequences from the

Lepidoptera (*Perimede erransella*, *Napaea eucharila* and *Taxila haquinus*) were also included as reference outgroups.

Prior to phylogenetic analysis, jMODELTEST software (Posada 2008) was used to determine the model of sequence evolution that best fitted the data. Bayesian analysis was the used to construct a phylogenetic tree, incorporating the General Time Reversible model with gamma-distributed rate variation among sites (GTR+G), which was identified as optimal by jMODELTEST. The phylogeny, branch lengths and posterior probabilities were obtained by running two trees simultaneously, each running four simultaneous Markov chain Monte Carlo (MCMC) chains, with the program MRBAYES (Huelsenbeck and Ronquist 2001). The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was run for 1 x 106 generations. A majority rule consensus tree was constructed after discarding the first 2500 ("burn-in") trees. The burn-in value was determined by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded.

***Austroasca* (Hemiptera: Cicadellidae)**

DNA sequencing was performed by the Department of Primary Industries, NSW. DNA was extracted from the hind tibia of adult specimens. The methods are fully detailed in Gopurenko et al. (in press).

***Pseudococcus* (Hemiptera: Pseudococcidae)**

DNA sequencing was conducted by Dr Lyn Cook at the University of Queensland, Brisbane. DNA was extracted from adult females and PCR and sequencing of the small subunit ribosomal RNA gene (18S) was conducted using the protocol described in Cook and Gullan (2004). Voucher specimens from the DNA work are housed in the Australian National Insect Collection (CSIRO, Canberra).

2.5 Host specificity models and data analysis

The host-specificity of each insect species was calculated by using host breadth models. Host breadth models were based on those developed by Vesk *et al.* (2010), with some additional refinement based on the different field locations (Vesk pers. comm. 2012). Put simply we used a Bayesian, zero-inflated Poisson regression to model the abundance conditional upon host use, our focal parameter. We applied a 0.5 binary split to the host-breadths from the model, to give us a definitive single number for host breadth for each insect species. Utilising these host breadths, we averaged the number of monophagous, oligophagous, and polyphagous insect species per plant species. We also determined the proportion of very rare or vagrant species (those species collected in abundances too low to determine their host breadth with any confidence).

We used Analysis-of-Similarities (ANOSIM, Clarke 1993) to assess differences in insect assemblages between plant species. We also used ANOSIM to determine the differences in composition between insect assemblages on different populations of the same plant species (e.g., six populations of the host plant *Acacia veronica*, etc). ANOSIM R-statistics generally range between 0 and 1; a value of 0 indicates that two assemblages are identical whereas a value of 1 indicates that two assemblages are entirely different (see Clarke 1993). Similarity matrices were constructed using the Bray-Curtis measure for the abundance of insect species on each plant individual. Square-root transformation down-weights the importance of abundant species, and increases the contribution from rarer species (Clarke 1993), which was desirable in this study to prevent common species from dominating analyses and overlooking rarer but potentially host-specific insects on each plant species. Non-metric multi-dimensional scaling (MDS) was performed (1,000 restarts) on the Bray-Curtis matrix to produce ordinations. To determine the environmental variables most likely to contribute towards differences in insect assemblages, we used the Bioenv and BVstep (BEST) function after first applying square-root transformation and then normalizing the environmental data. We used the Spearman's rank correlation coefficient (ρ) to analyse the correlations. These analyses were conducted in PRIMER-E version 6.1.11 (PRIMER-E Ltd 2008).

2.6 Insect nominations

For insects native to Western Australia, the process of species conservation nominations must first be accepted at the State-level, Western Australian Threatened Species Scientific Committee (TSSC), before being reviewed federally, as per agreement by the WA State government and Federal government. In contrast, nominations to the International Union for Conservation of Nature (IUCN) are independent and do not need State or Federal approval.

Nominations are brought to the attention of the Western Australian TSSC who meet annually (usually in February) to consider species nominations to list, delist or change categories. Once nominations have undergone consideration, advice is forwarded onto the Minister for the Environment, who makes the final decision. Successful nominations are listed under the *Wildlife Conservation Act 1950* (WA) Successful nominations can also be referred to the Commonwealth Committee for consideration under the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act).

Insect nominations were submitted for the following Stirling Range National Park insects: *Acizza* sp. 70, *Acizza veski*, *Trioza* sp. 30 and *Pseudococcus markharveyi*. Of the insects nominated *Acizza* sp 70, *Acizza veski* and *Trioza* sp 03 have been successfully listed in the Wildlife Conservation Act 1950 under the Wildlife Conservation (Specially Protected Fauna) Notice section (Appendix 2). The nomination for *Pseudococcus markharveyi* will go under review for consideration in 2013. To date, only *Acizzia veski* has been submitted for consideration by the Federal government and internationally by the IUCN.

2.7 Insect translocations

The Western Australian Department of Environment and Conservation have been undertaking translocation trials of 59 critically endangered, and endangered plant species in Western Australia to decrease the immediate threat of extinction by processes such as to Phytophthora dieback caused by *Phytophthora cinnamomi* and wildfire (Barrett *et al.* 2008; Moir *et al.* 2012a, b). The ultimate goal of these translocations is to establish viable self-sustaining populations and to produce seed to establish further populations in Phytophthora free areas. For a previous study, we selected three of the most threatened species found in the montane regions of the SRNP, which also demonstrated rapid growth when translocated and analyzed their insect assemblages both at the native regions and at the translocated site. We did not have a choice with regard to where the translocation site was placed with regard to the native sites, as the translocation of the plant species were established many years previously (see below for details) and plant individuals needed to be of sufficient size to hold the insect cages. From the three plant species we analyzed previously, only *Banksia montana* and *Banksia brownii* had host-specific insect species (Moir *et al.* 2012a, b). The aim of the *ex-situ* translocation of insects onto these plants was to determine whether it was possible to translocate such small insects (~2-3 mm) and whether in the short-term they were able to thrive in the same new location as the host plants were. This positive result would also assist in protecting the insect against global extinction, should the host plants expire in the native areas. For further information, refer to the specific sections, 4.7.2 and 4.7.3.

The *ex-situ* translocation site at Kamballup is approximately 30 km south-west of native sites in the SRNP. It was established in 2003 on private property north of Albany (34°34'S 117°51'E). The site lies on lateritic soils surrounded by revegetated marri (*Corymbia calophylla*) forest. Surrounding this is farmland and other native remnants. No climatic data is available for this area, although as it is south of the Stirling Range and is predominantly marri woodland, it likely receives a higher rainfall than the lowlands of the SRNP and is cooler. For example, Mt Barker, 30 km to the west of Kamballup received 729 mm annually, whereas 50 km to the north-east of the SRNP, Ongerup receives 385 mm annually (Bureau of Meteorology—Australia (BoM) 2011). Before performing this work, we approximated that the latter may be close to the rainfall received in the low-lying regions of the SRNP, but the montane areas where the threatened plants naturally occur would be cooler and wetter (Moir *et al.* 2012b). The montane areas are between 750 – 1070 m in altitude, whereas Kamballup occurs at an altitude of 202 m.

Individuals of the threatened plant species, *Banksia brownii* and *Banksia montana*, were grown from seed or cuttings. They were then transplanted as seedlings to a 2.8 km^2 area of remnant woodland at Kamballup. *Banksia brownii* plant-louse (*Trioza* sp. 30) and *B. montana* mealybug (*Pseudococcus markharveyi*) underwent translocation trials on their respective hosts here.

In situ translocation sites for Vesk's plant-louse are located on the eastern side of the SRNP. These sites have healthy stands of *A. veronica* which is a spindly tree reaching heights of 1.5-7 m and is mainly restricted to watercourses in the Stirling Range, with smaller individuals growing at higher altitudes, and is often associated with marri (*Corymbia calophylla*) woodlands.

Translocation proposals were lodged and approved by the DEC before translocation work commenced. The first translocation of the three insects occurred in spring (October 2012) when collection of these insects was optimal. The plant louse were adult males and females collected by beating and vacuuming their respective host plants (*B. brownii* and *A. veronica*) in the morning and translocated in the afternoon of the same day. In total 38 individuals of *Trioza* sp. 30, and 33 individuals of *Acizzia veski* were translocated. The mealybug was collected by hand from its host plant, *B. montana*, at approximately midday and translocated the next day due to the distance between source and translocation sites. In October 2012, 32 individuals of 1st and 2nd mealybug instars were translocated, while in December 2012 adult females were translocated.

As translocated plants were sourced from the SRNP, the two plant-louse species and one mealybug species were also be obtained from the SRNP. The mealybug was taken from plants on Pyungoorup or Bluff Knoll. The *B. brownii* plant-louse (*Trioza* sp. 30) was taken from the only known population in the SRNP at Mt Hassel. The *A. veronica* plant-louse (*A. veski*) was obtained from it's only known source population at Mt Talyuberlup.

No direct handling of the insects occurred during the capture, transportation or release phases. Plant-louse specimens were captured by placing a vial over the insects in a beating net or vacuum bag and then transferring specimens into purpose-built transport containers. Mealybugs were transferred using forceps or a piece of leaf. The transport containers had damp florist's foam, into which a 3 cm length of host plant material was wedged, to house between 1-10 individual insects. A maximum of 20 leaves were taken from 20 individual Declared Rare Flora plants (i.e. one per plant for 10 x *B. montana* and 10 x *B. brownii*). A mesh lid was used to close the live capture containers to allow for air flow. Storage for insect transportation occurred in an 'Eski' cooler bag. Transportation of the insects to the translocation site outside the SRNP occurred <35 hrs, whereas transportation of *A. veski* to the two translocation sites within the SRNP occurred within 3 hrs.

At the *ex situ* translocation site outside the SRNP, the host plants were initially vacuumed to remove all invertebrate predators and other herbivores before cages were set up on selected banches. Branches were selected based on their health, length and no evidence of damage. The target insects were transferred onto their host plant into a light mesh cage to protect them during their establishment period (the three month post-release monitoring period). Numbers of individuals were translocated as evenly as possible across 9 *B. brownii* plants (*Trioza* sp. 30) and 11 *B. montana* plants (mealybug). Host plants were selected based on whether they were healthy and had enough branch material to support a 20 x 40 cm mesh cage. Upon release within the cages the insects were observed for 10 minutes to ensure they locate the host plant and did not fall off. The cages are used for protection during the insect's establishment period (the 12 month post-release monitoring period). At the SRNP translocation site for *A. veski*, healthy plants were selected and *A. veski* was released onto these plants without cages.

Monitoring occur a month after translocation to ensure the insects are healthy, and again three months later to assess abundance and survival rates. At the Kamballup site, the land-owner and a DEC Rare Flora Officer were shown the insects and assisted with plant selection and release. Health of the translocated plants will be recorded at each monitoring stage.

2.8 End-user engagement

To canvas as wide a range of land managers as possible, potential end-users from across Australia and representing government (State and Federal), non-government organisations, private industry and working groups were invited to participate in the project. Approximately 50 organizations were originally invited to take part, of which 22 organizations accepted.

A questionnaire (see Appendix 3) was formulated to gain feedback on the awareness, consideration and experiences organisations had of policies for managing associated or dependent invertebrate species (i.e. species that rely upon host species). The aim of the questionnaire was to identify hurdles in insect conservation and help determine outcomes that would be most applicable to organizations. Of the 22 organizations which formed the end-user group for this project, 14 completed the questionnaire (Table 2).

Table 2: Summary of questionnaire responses by end users

Organisation	Response	No comment	Total
Government organizations	7	1	8
Non-government organizations	5	1	6
Private industry	2	6	8
Total	**14**	**8**	**22**

The responses were used to devise an adaptation management framework to assist land managers to incorporate dependent and associated species into their management and conservation polices, particularly in relation to managing species in light of the threat posed by climate change. The management framework was developed by Moir, using end-users responses and consulting with the literature on frameworks for biodiversity in light of climate change (e.g., Thomas *et al.* 2011a, Thomas 2011), and generally (e.g., Moir *et al.* 2012a). It was then distributed to the project's working group (Leng, Vesk, Hughes, Brennan, Coates, Keith, and McCarthy) and end-users for comment. The final framework is presented in **End-user engagement, section 3.8**.

3. RESULTS AND OUTPUTS

This project was conducted in a multifaceted approach to achieve several discrete objectives. The project facilitated the identification of key insect species threatened with extinction through changes in population sizes of their hosts using innovative host breadth models. Depending on the state of knowledge of their taxonomy and ecology, certain insect species were subsequently nominated for conservation listing with State, Federal and/or international bodies.

The impact of climate change was investigated by measuring environmental factors at key sites. Simultaneously we worked alongside end-users to identify factors inhibiting the management of plant-dwelling insects and developed a framework to actively manage those insects that are currently known to be at risk of extinction through climate change and other disturbances. Therefore, the results are presented in several sections. Firstly, the outputs of the project are identified. Secondly, the environmental data from altitudinal transects in the south-west of Australia is presented. Third, we relate this environmental data to a large insect-plant database. Fourth, we elaborate on the ecology and taxonomy of key insect species that require conservation action. Fifth, we expand on two management adaption strategies trialled on three of the key insect species. Sixth, we summarize the responses from our survey of end-users. Finally, we present an adaptation management framework for the conservation of plant-dwelling insects threatened with extinction under a changing climate.

3.1 Environmental data

To determine whether the environmental data from February 2012 to April 2012 that we analyze in detail below was a reliable indicator of changed with altitude across the entire year, we assessed the temperature and humidity from one week in winter (July 2012) and one week in spring (November 2012) and present the results in Appendix 5. These results show that the altitudinal differences are consistent across seasons. As the aim in recording climatic data for this project was to assess differences with altitude, and these differences do not appear to alter across seasons, we contend that the shorter period does not impact significantly on the results and interpretation.

Interestingly, minimum temperate was slightly lower (~3°C) at higher altitudes over the one week period (Figure 1a), but was not significantly different between higher and lower altitudes over the longer period of three months (Figure 1b). In contrast, maximum temperatures demonstrated a more reliable trend with higher altitudes reaching lower temperatures, regardless of the time period (Figures 1a, b). This descrease generally followed published records of environmental lapse rate of 6°C km^{-1} (Barry 1992). The difference between altitudes was more explicit when we examined the differences between minimum and maximum temperatures; variation was on average 9°C at higher altitudes when compared to 16°C at lower altitudes when measured across three months (Figure 1b).

This result is unusal as generally variation in temperature increases with altitude. However, the mountains we examined are small by global comparisons, although preliminary results from different seasons display the same trend (Appendix 5). For biota this would imply having to withstand greater variation in temperature on the sand plains in the SRNP than on the mountains. Surprisingly, even a slight rise in altitude to 400-550 m affords protection from fluctuations by as much as 4°C. In terms of climate change this may indicate that under a future warmer climate temperature fluctuations may become greater at higher altitudes, and the environmental tolerance of the insects will accordingly need to increase, or the insects will need to move to a more suitable climate at higher altitudes, if possible.

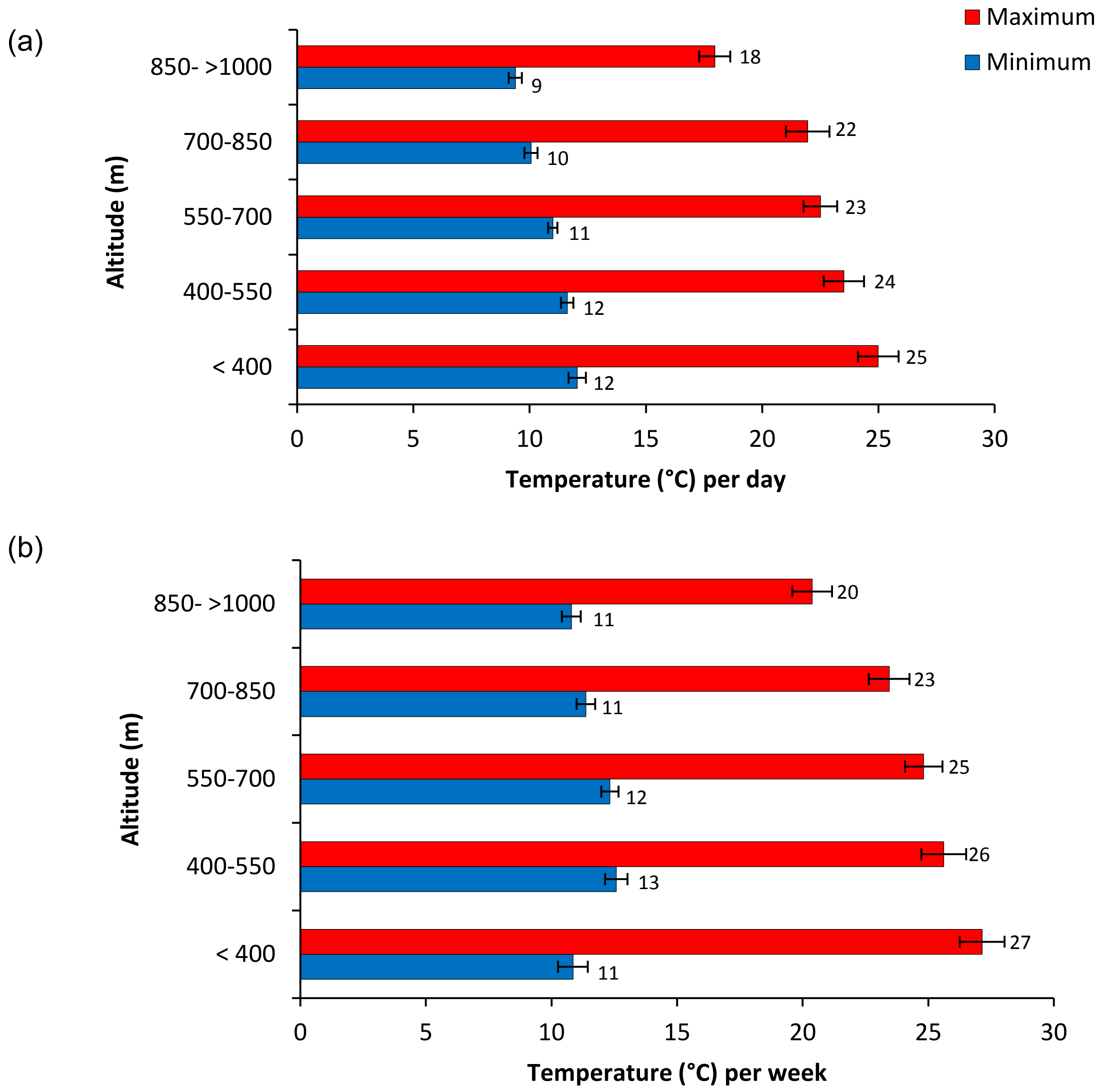


Figure 1: Temperature with maximum and minimum means in the Stirling Range National Park in Western Australia over five altitudinal gradients showing (a) temperatures recorded per day over one week, 04 – 10 Feb 2012, and (b) temperatures recorded per week over three months, February – April 2012

Maximum humidity did not demonstrate significant altitudinal trends, particularly when examined over the three month period (Figures 2a, b). In contrast, minimum humidity was consistently higher at higher altitudes, regardless of the time period (Figures 2a, b). Similar to the results for temperature, the variation between maximum and minimum humidity demonstrated the most interesting differences. At higher altitudes the humidity varied significantly less than at lower altitudes (Figures 2a, b).

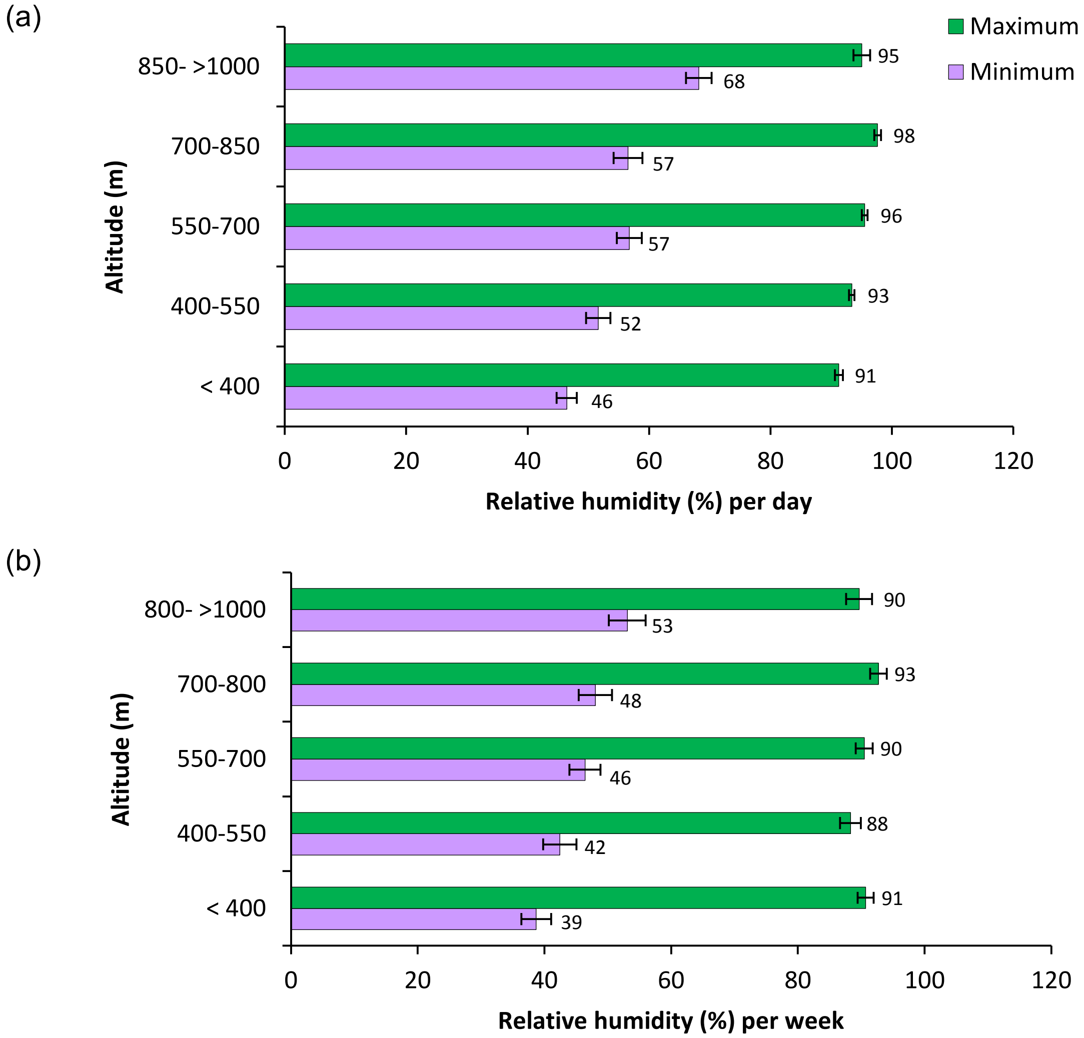


Figure 2: Relative humidity maximum and minimum means in the Stirling Range National Park Western Australia over five altitudinal gradients showing (a) relative humidity recorded per day over one week, 04 – 10 February 2012, and (b) relative humidity recorded per week over three months, February – April 2012

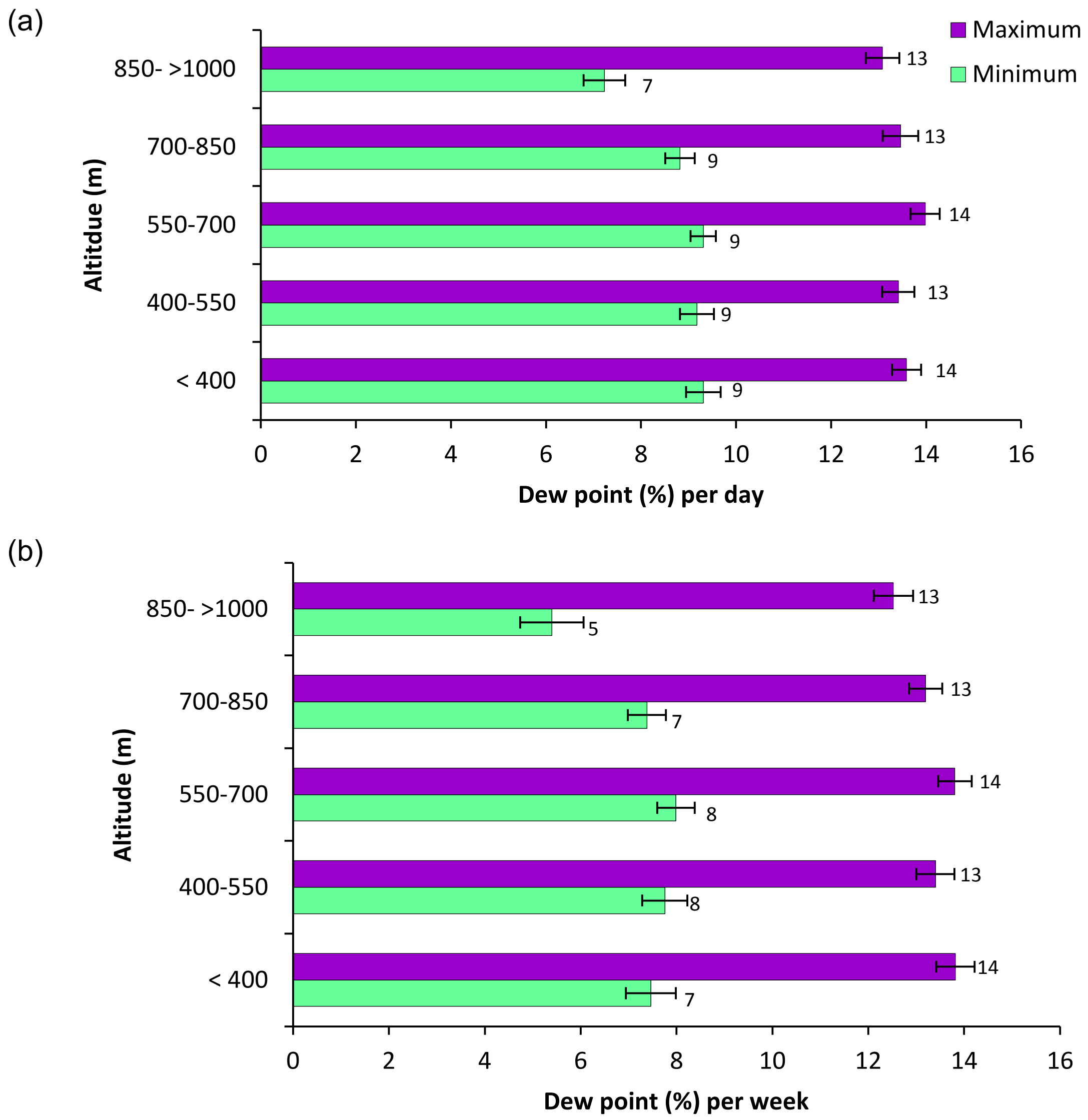


Figure 3: Dew point maximum and minimum means in the Stirling Range National Park Western Australia over five altitudinal gradients showing (a) dew point recorded per day over one week, 04 – 10 February 2012, and (b) dew point recorded per week over three months, February – April 2012

Perhaps more importantly in terms of moisture availability for plant species in particular habitats, dew point was consistently lower at high altitudes (Figures 3a, b). The dew point was linked to the overnight minimum temperature. At lower temperatures overnight at higher elevations, condensation dries the air, and deposits some of the air's moisture on the ground. The added moisture in the form of clouds, fog, mist or dew potentially contributed to the increase in 'rainfall' recorded at higher altitudes.
The SRNP occurs in a temperate Mediterranean climate and thus the majority of rainfall occurs in winter. For the period we present here (summer-autumn) weekly rainfall was highly variable, with large standard error bars common at all altitudes (Figure 4b).

As our calculations are based on averages across a number of rain gauges within each altitude, the variation indicates that rainfall over the SRNP was spatially patchy. Trawling the raw data, the patchiness was present regardless of whether the rainfall

was heavy or light, for example, on the 11th of July 2012 heavy rainfall (~10 mm) was experienced in the northwest of the park, but most other locations experienced moderate showers (2 – 4 mm).
This patchiness is further demonstrated by differences in rainfall over 04 – 10 February 2012 where altitudes 700 – 850 m recorded the highest rainfall (Figures 4a, b).

The highest altitudes over 700 m had higher total rainfall in the recorded three months (Figure 4a), although such a result was not predicted by the low average weekly rainfall (Figure 4b). In three weeks of these three months, altitudes above 700 m received rain when most other altitudes had no rainfall (Figure 4). This ‘rainfall’ at higher altitudes could be attributable either to light showers at high altitudes which evaporate before reaching lower altitudes, or to atmospheric condensation. In support of the second point, the daily average dew point on higher ‘rainfall’ days at higher altitudes was higher than the minimum temperature, suggesting that cloud, mist, or some other condensation from the atmosphere was occurring at these higher altitudes and contributing to the ‘rainfall’ recording. Also in support of the second point, humidity on these days was often at 100%.

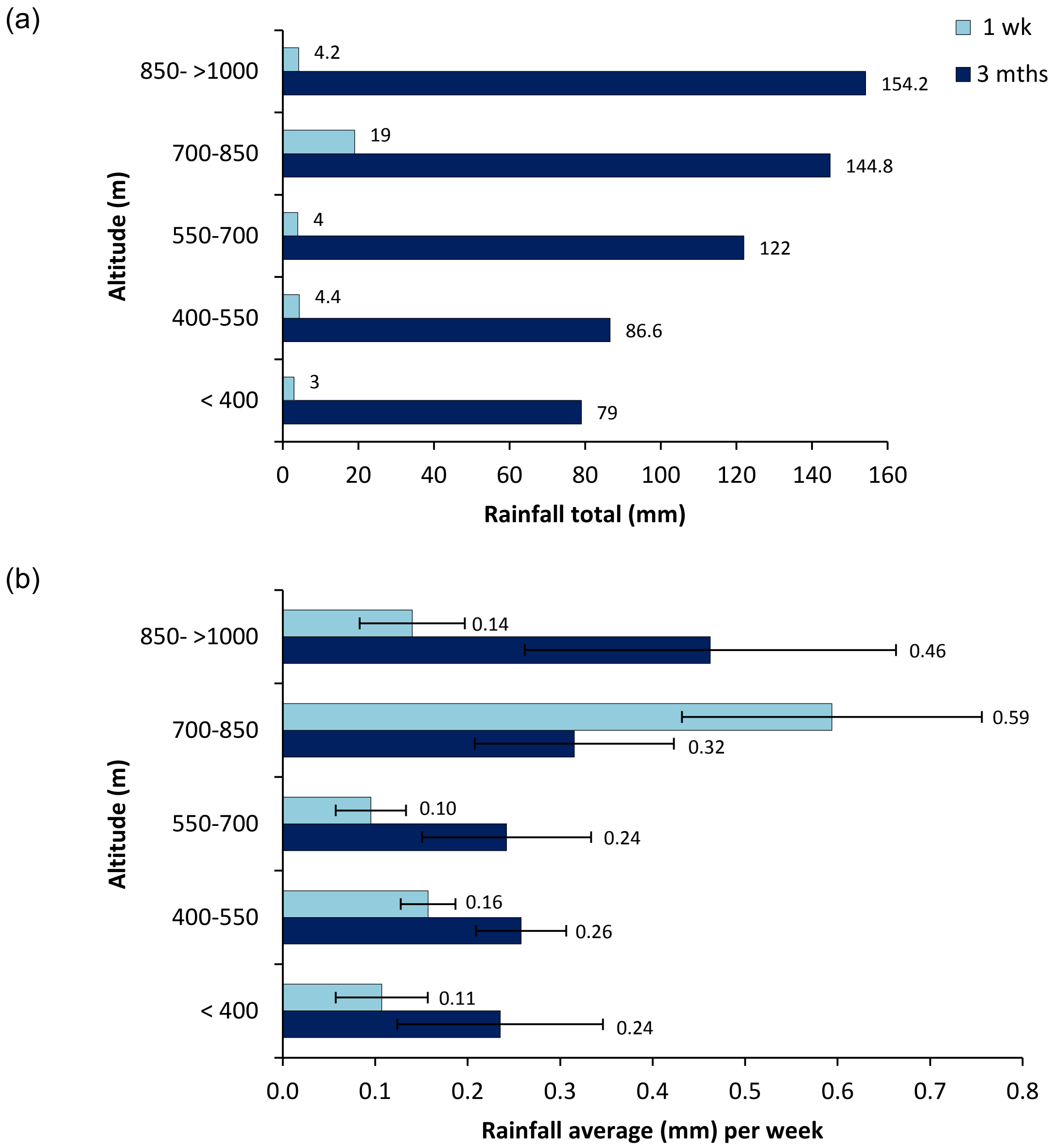


Figure 4: Rainfall recorded in the Stirling Range National Park Western Australia over five altitudinal gradients showing (a) total rainfall recorded over one week, 04 – 10 February 2012 and over three months, February – April 2012, and (b) rainfall per week (± SE, variation is due to difference recorded across multiple weather stations) over the same time periods as in (a)

3.2 Insect assemblage response to climate change

Biotas on mountains are expected to either adapt to the new microclimate, migrate to higher altitudes to escape the hotter and drier conditions experienced with predicted climate change, or move to the cooler side of the mountain (e.g., Chen *et al*. 2009; Berg *et al.* 2010; Hughes 2011). The distribution of herbivorous insects is also limited by the presence of potential host plants. The insect assemblages on selected plant species with populations at different altitudes were examined to determine whether significant differences in their assemblages existed. Differences could give an indication of whether the composition of insect assemblages would alter if plants migrated to higher altitudes. Merrill *et al.* (2008) demonstrated that environmental conditions can set the altitudinal boundary for herbivorous insect species, as can lack of host plants. If the plant host species migrate to an altitude with greater rainfall, for example, then the other environmental variables such as humidity or temperature may not be favourable for the insect herbivore. If the host plant occurs at the summit of the mountains then there will be no where for the plant or insects to migrate to. Alternatively, the host may migrate and still be accessible to the insect herbivore, but there may be a temporal mismatch in their life-cycles due to the differences in environmental variables (DeLucia *et al.* 2012). Therefore, insect assemblages on closely related plant species within the SRNP were also examined to assess the likelihood that insect species will switch host plants in the event of the local extinction of their current focal host plant species, or loss of access to their current host through migration or temporal mismatch. Of the 104 plant species that were sampled in the and around the SRNP, we provide detailed insect assemblage results for 19 below.

3.3 Family Malvaceae

3.3.1 Species: Thomasia sp. "Toolbrunup"

Thomasia sp. "Toolbrunup" is currently undescribed, but is an example of a plant which occurs on mid to higher slopes of the mountains in the SRNP. Four populations were assessed at altitudes of 531 m (Mt Toolbrunup), 641 m (Bluff Knoll), 707 m (Mt Talyuberlup) and 750 m (Mt Trio). All populations had significantly different insect assemblages (*P* < 0.001, R statistic 0.40-0.90, Figure 5). SIMPER analysis indicated that the results are heavily influenced by oligophaous species that are common on Malvaceae plants in the particular region of the different populations of *Thomasia* sp. "Toolbrunup".

For example, the 641 m population on Bluff Knoll is distinguished from the other populations predominantly by an *Aleurocanthus* whitefly (sp. 22) and a *Melaleucoides* plant-bug (sp. 45) found only on Malvaceae species on the Eastern side of the SRNP, but a lack of other species found on other *Thomasia* sp. "Toolbrunup" populations, such as an *Apion* weevil (sp. 188).

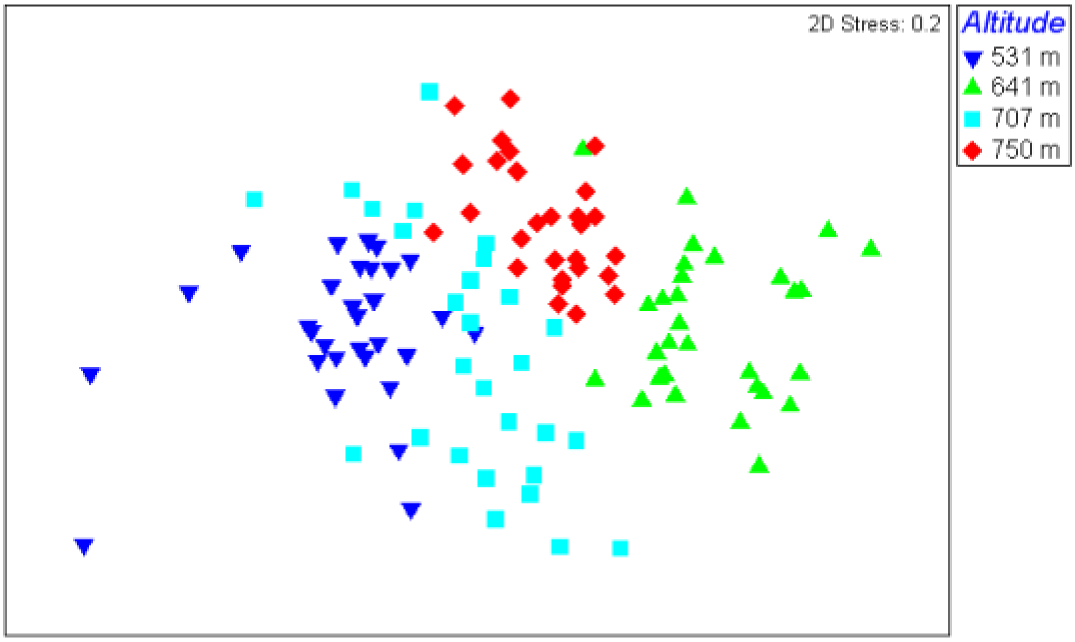


Figure 5: Multidimensional Scaling (MDS) ordination of the insect assemblages on different populations of the host plant *Thomasia sp*. "Toolbrunup"

There is very little difference between 400 to 850 m in altitude in the climatic variables recorded. An analysis of the environmental variables using the procedure 'BEST' (uses all available environmental variables to find the combination of variables that best explains the patterns in biological data, as indicated by the highest rank correlation coefficient; PRIMER-E Ltd 2008) indicates that maximum humidity, plus minimum and maximum temperature are the best explanatory variables for the differences in insect assemblages between populations (rank correlation coefficient ρ = 0.42). Rainfall is possibly not an influential factor on these insect populations as Thomasia sp. "Toolbrunup" is often found in gullies and rock cracks, therefore collecting water as runoff. The maximum and minimum temperature at higher altitudes tended to be cooler than at lower altitudes. If temperatures rise by as little as 2°C (predictions are for a rise of approximately 3°C by 2070; Whetton 2011) then higher altitudes such as 700-850 m will reach similar maximums as currently experienced on the sand plains (< 400 m) and most importantly, this could result in decreased humidity at high altitudes.

If *Thomasia* sp. "Toolbrunup" populations at Bluff Knoll and Mt Toolbrunup migrated to higher altitudes under climate change, the insect assemblages are not expected to change significantly as they should be capable of tracking such movement, particularly as these populations occur in sheltered gullies. However, if these populations migrate to the summit of their mountains, other environmental variables such as wind and solar radiation could change the insect composition.

In contrast, the populations on Mt Trio and Mt Talyuberlup occur at the summit of their respective mountains and cannot migrate higher, which may instead lead to local extinction. As each plant population housed significantly different insect assemblages, the local extinction of two populations would result in a significant loss of insect diversity on *Thomasia* sp. "Toolbrunup" overall. In the host-breadth analysis, five insect species were host specific to *Thomasia* sp. "Toolbrunup", and all of these species were restricted to single populations of the plant. A further two species occur on both *Thomasia* sp. "Toolbrunup" and another conservation listed plant species within Malvaceae at the same location. For this second group of insects, loss of *Thomasia* sp. "Toolbrunup" through climate change may not at first appear as great a threat given the option of a second host species. However, both plant species are restricted to the same mountain tops (Tayluberlup and Trio) and both species would potentially be extinguished if conditions became hotter and drier.

3.3.2 Species: *Lasiopetalum dielsii*

Lasiopetalum dielsii is an example of a plant that occurs on the higher slopes of mountains in the SRNP. Three populations were assessed at altitudes of 707 m (Mt Talyuberlup), 754 m (Mt Trio) and 920 m (Mt Toolbrunup). All populations had significantly different insect assemblages ($P < 0.001$, R statistic 0.25-0.52, Figure 6). SIMPER analysis indicated that the results are heavily influenced by several, very abundant *Apion* weevil species. These weevils are oligophagous; specific to the genus *Lasiopetalum* (sp. 190), or the family Malvaceae (sp. 128, 189 and 191). They are present on all the populations of *L. dielsii*, although in differing abundances. The exception was one weevil found only at the highest altitude (*Apion* sp. 126).

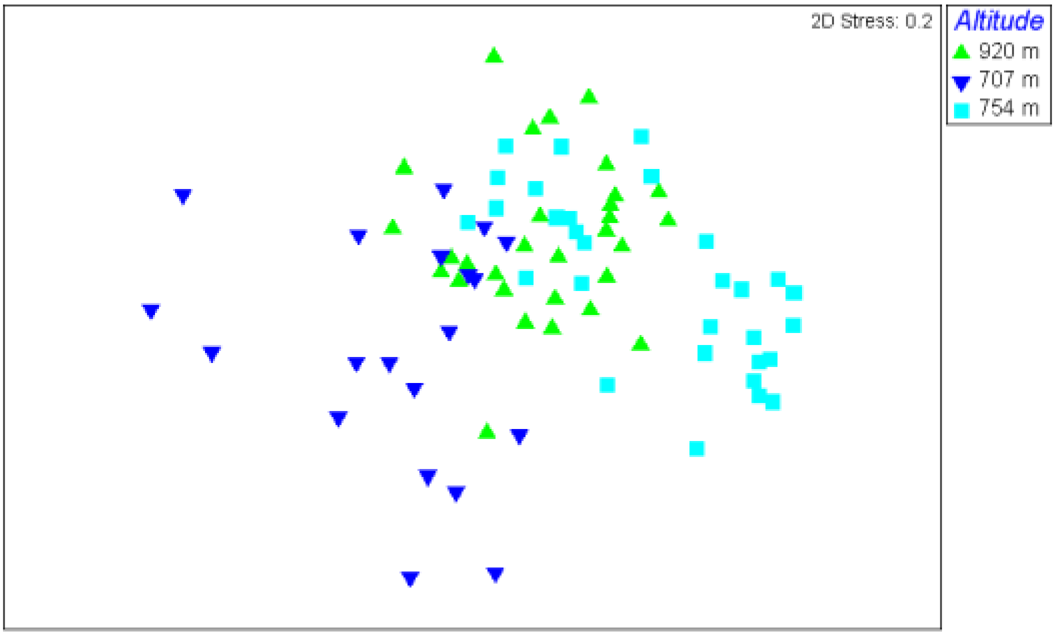


Figure 6: Multidimensional Scaling (MDS) ordination of the insect assemblages on the different populations of the host plant *Lasiopetalum dielsii*

All *L. dielsii* populations assessed occur at the summit of their respective mountains (Mt Trio, Mt Toolbrunup and Mt Talyuberlup). For these populations local extinction is a possibility as they cannot migrate higher under a changing climate. As each plant population hosted significantly different insect assemblages, the local extinction of these three populations would result in a significant loss of insect diversity on *L. dielsii* overall. In the host-breadth analysis, four insect species were host specific to *L. dielsii*; of which two species were restricted to single populations of the plant and two species were found on two populations. A further three species occur on both *L. dielsii* and another conservation listed plant species within Malvaceae (two of these species were found above on *Thomasia* sp. “Toolbrunup” while the other plant host was the conservation listed *Lasiopetalum membranaceum*).

Despite two populations being found at similar altitudes (707 m and 754 m) large differences in the insect community existed (R statistic = 0.52). An analysis of the environmental variables indicates that rainfall and maximum humidity are the best explanatory variables for the differences in insect assemblages between populations (rank correlation coefficient $\rho = 0.38$). Maximum humidity and rainfall are generally higher with altitude (Figures 2 and 4 above); therefore these may be the determining variables for both the distribution of *L. dielsii* and the related insect assemblages. The differences between the insect assemblages on the two *L. dielsii* populations at similar altitudes suggests that the environmental differences were caused by site differences on the mountains. Indeed, the Tayluberlup (707 m) population was ~15 km south-west of the Trio (754 m) population, and although both occurred on their respective summits, the latter was south-facing under a stand of *Eucalyptus* trees, whereas the former was predominantly north-facing without a canopy. These site differences may have caused the observed differences in environmental variables with Trio experiencing slightly higher average rainfall, and almost 2^{o}C lower maximum temperatures.

3.3.3 Family Malvaceae

The trend of significant differences in the insect assemblages between populations of *L. dielsii* and *Thomasia* sp. “Toolbrunup” was repeated for almost every one of the seven species of Malvaceae examined, and comparisons between the species also proved significant. Overall, the environmental variables most influential for insect assemblages on Malvaceae plant species were a combination of maximum humidity and rainfall (rank correlation coefficient $\rho = 0.45$). This suggests that there was a general turnover in insect species with altitudes as maximum humidity and rainfall generally increased with altitude (Figures 2 and 4 above).

However, even species that occurred at the same site had significantly different insect assemblages, such as *Lasiopetalum cordifolium* and *L. membraniflorum* in a gully on the southern side of Bluff Knoll ($P < 0.001$, R statistic 0.51), and *Lysiosepalum involucratum* and *Thomasia foliosa* at the base of Mt Talyuberlup ($P < 0.001$, R statistic 0.37). These insect assemblages can not be responding to the broad environmental variables that we measure at these sites, but to the plant species and their traits, such as leaf structure, chemical properties and nutrient levels. The absence in shared insect herbivores suggests that insects on Malvaceae are unlikely to switch host species if their current host plant is extinguished under a changing climate. This must be determined more conclusively with feeding trials, particularly for the fauna on plant species which are under greater threat (e.g., those species restricted to mountain summits such as *L. dielsii*). The exception to these general findings was *T. foliosa*, which had a more similar insect fauna between two of the three sites examined, although differences remained significant ($P = 0.033$, R statistic 0.23). Common plant species such as *T. foliosa* may be more likely to share insect species across localities than range-restricted species, due to lower degrees of habitat fragmentation (the host plant being the ‘habitat’) in common plant species.

Despite the significant differences between all insect assemblages, plants had variable numbers of host-specific insects (*L. dielsii* 4 insect species, *L. membraniflorum* 1 species, *Thomasia* sp. “Toolbrunup” 5 species, *L. cordifolium* no insects, *Lysiosepalum involucratum* 2 species, *T. foliosa* 10 species). The high number of host-specific insects on the common plant *T. foliosa* supports the theory that common host species support more dependent species (e.g., Altizer *et al.* 2007; Powell 2011), although the common *L. cordifolium* had no host specific insects.

3.4 Family Fabaceae

3.4.1 Species: Acacia veronica

Acacia veronica is an example of a plant that occurs on the lower to mid slopes of mountains in the SRNP, but predominantly in gullies. Six populations were assessed at altitudes of 274 m (Paper Collar Creek), 341 m (Moir Hill), 355 m (Mt Talyuberlup), 386 m (Mt Hassel), 430 m (Mt Trio) and 531 m (Mt Toolbrunup). All populations had significantly different insect assemblages (*P* < 0.003, R statistic 0.14-0.56, Figure 7). The exception was the comparison between assemblages at 341 m and 386 m, where the differences were less significant (*P* = 0.02, R statistic 0.13, Figure 7). SIMPER analysis indicates that the results are heavily influenced by host-specific insect species such as the bugs *Acizzia veski* and *Acizzia* sp. 70, and the beetles *Cydmaea* sp. 125, *Peltoschema* sp. 244 and *Monolepta* sp. 240. These were not found on every population of *A. veronica*, except *Peltoschema* sp. 244, thus separated the host populations in the analysis (for further details see section 4.7 on individual insect species and below). Besides the host-specific insects, some oligophagous species preferred certain populations of *A. veronica*, such as a *Neorupilia* beetle (sp. 71) on Moir Hill (341 m) and a *Storeus* weevil (sp. 44) on Toolbrunup (531 m) and Talyuberlup (355 m). The higher abundance of the monophagous (host-specific) and oligophagous insects on certain *A. veronica* populations were the main reason for the observed differences between assemblages.

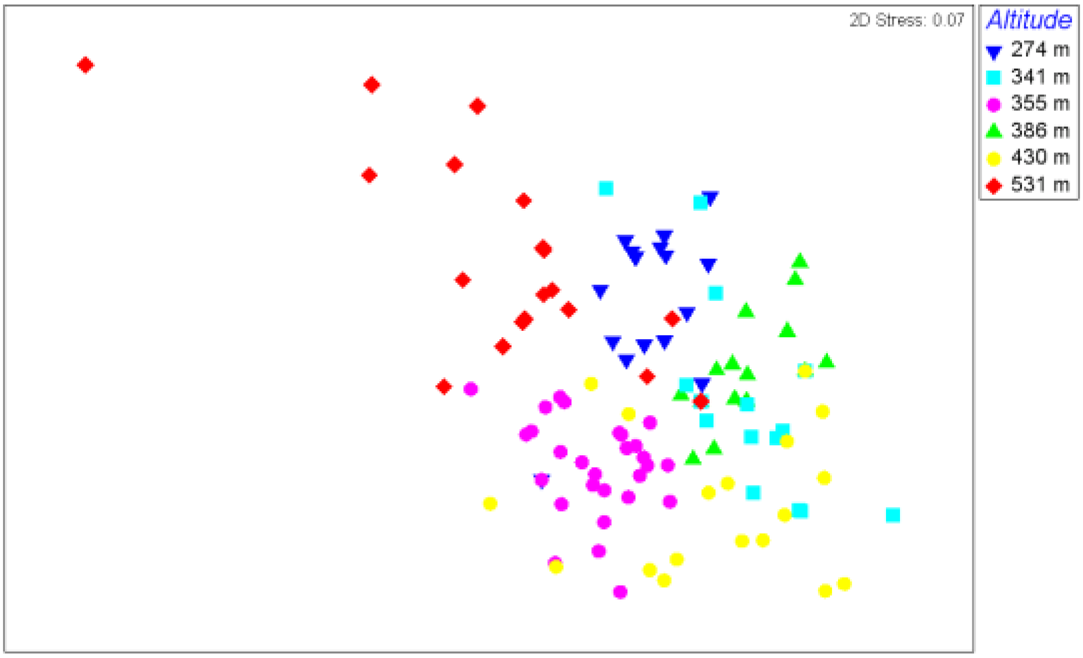


Figure 7: Multidimensional Scaling (MDS) ordination of the insect assemblages on different populations of the host plant *Acacia veronica*

An analysis of the environmental variables indicated that minimum temperature, minimum humidity and dew point are the best explanatory variables for the differences in insect assemblages between populations (rank correlation coefficient ρ = 0.34). Rainfall is possibly not as influential a factor because *Acacia veronica* is often found in gullies thereby collecting water as runoff. Altitude did not appear to contribute to the differences between insect assemblages, which is unsurprising as the plant does not occur at higher altitudes. We note that the correlation coefficient above (ρ = 0.34) is relatively low, suggesting that there are more important factors likely to influence insect assemblages. Such factors are likely to be time since last fire and number of host individuals. Mt Talyuberlup, the population with many individuals, including those with the largest tree stem diameter (a rough indication of time since last fire and age of the stand), produced insect assemblages with the highest number of host-specific insect species.

Host breadth models predicted that five insect species were restricted to *A. veronica*, although four of these insects were found on multiple host populations. The Mt Talyuberlup (355 m) population had three host specific insect species, one of which wasn't found on any other populations (See "*Acizzia veski*", "*Acizzia* sp. 70" and "Curculionidae *Cydmaea* sp. 125" in the section **4.7 Species level insect data** below). The Mt Talyuberlup population also produced the highest R-statistics in pairwise comparisons and therefore its insect assemblage was the most different when compared to other *Acacia veronica* populations. Factors such as time since fire (or plant size as a proxy for time since fire), number of individuals, or extent of occupancy have not been assessed for *Acacia veronica* populations and should be the focus of future work, but is outside the scope for the present study.

3.4.2 Species: Gastrolobium crenulatum

Gastrolobium crenulatum is an example of a plant that occurs over a wide range of altitudes in the SRNP. Three populations were assessed at altitudes of 362 m (The Lookout), 531 m (Mt Toolbrunup) and 720 m (Mt Trio). All populations had significantly different insect assemblages ($P < 0.001$, R statistic 0.52-0.74) (Figure 8). SIMPER analysis indicates that the results are heavily influenced by varying abundances of polyphagous species such as the weevil *Ancyttalia* sp. 89, leafhopper *Anzygina zealandica* (Cicadellidae) and the plant-hopper *Cedusa spinosa* (Derbidae), and insects oligophagous to the family Fabaceae such as the beetle *Neorupilia* sp. 71 and leafhopper *Austrolopa* sp. 02. This is unsurprising as nitrogen-fixing plants generally have higher nutrient content in their leaves and thus attract more generalist insect herbivores, often in very high abundances (e.g., Moir *et al.* 2011b). In fact, the 90 individuals of *G. crenulatum* that were sampled yielded 2014 individual insects representing 121 species (as a comparsion 90 *Banksia solandri* plants yielded 221 individual insects and 76 species). It is therefore difficult to gain insight into the insect assemblages that may be lost if certain host populations are lost using this method for *G. crenulatum*. Host breadth models were more explicit in which insect species were at risk.

Host breadth models predicted that four insect species were restricted to *G. crenulatum*, and three of these species were restricted to single localities of the host plant. The Mt Toolbrunup (531 m) population of *G. crenulatum* had the least number of host specific insects with only one species found here, a Lepidoptera larva or caterpillar (sp. 26). The remaining populations hosted two monophagous insects each (one insect species, the weevil Tychini sp. 145, was found at both Trio and the Lookout). A further two species of insect were only found on this host and another conservation listed *Gastrolobium* species. For example, a thrip (Phlaeothripidae sp. 28) was found on both *G. crentulatum* and the critically endangered *G. lutefolium* at Mt Trio. Both *Gastrolobium* species occur at the summit of this mountain and the thrip may be extinguished in both plant species are lost under a changing climate.

An analysis of the environmental variables indicated that rainfall and minimum humidity are the best explanatory variables for the differences in insect assemblages between populations (rank correlation coefficient $\rho = 0.47$). As minimum humidity is higher at higher altitudes, this suggests that minimum humidity may be influencing the lower altitudinal boundary at which *G. crenulatum* and particular insect herbivores can occur. This requires further investigation. Rainfall may be having an indirect affect on the insect assemblages by increasing the productivity of the host plant at higher altitudes (where there is higher rainfall) and thereby allowing more herbivore species to proliferate on the plant in these locations.

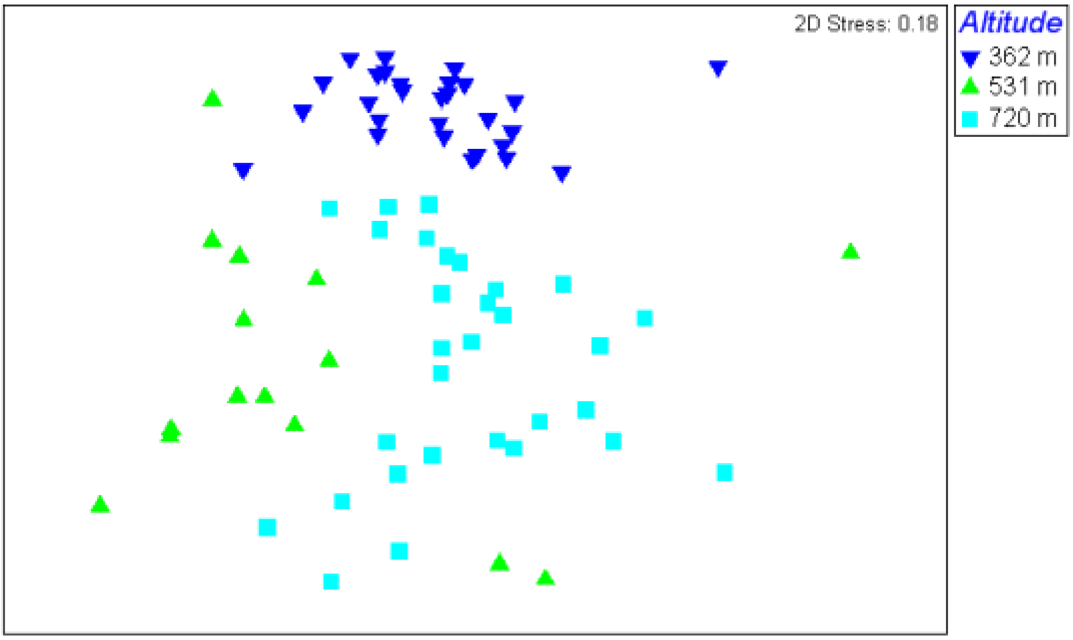


Figure 8: Multidimensional Scaling (MDS) ordination of the insect assemblages on different populations of the host plant *Gastrolobium crenulatum*

3.4.3 Genus Gastrolobium

Eight species of *Gastrolobium* were sampled in total. For five of these species, including *G. crenulatum* as outlined above, we sampled multiple populations. Unlike the trend of significant differences in insect assemblages displayed by the three *G. crenulatum* populations, most of the assemblages on various populations of the *Gastrolobium* species assessed here were similar to at least one other population of *Gastrolobium*. In most cases this was not simply similarity across the same host species at different altitudes and mountains. For example, when we re-examine the results for the three populations of *G. crenulatum* (above), and include all other *Gastrolobium* populations, we find that *G. crenulatum* at 531 m had a similar insect assemblage to *G. leakeanum* at 1039 m (*P* = 0.082, R statistic 0.07), *G. crenulatum* at 362 m had a similar assemblage to *G. rubra* at the same altitude (*P* = 0.052, R statistic 0.19), and *G. crenulatum* at 720 m had a similar assemblage to *G. luteifolium* at the same altitude (*P* = 0.256, R statistic 0.02). These similarities were due to an insect fauna that was dominated by polyphagous and oligophagous species, as described above (section 4.5.2) for *G. crenulatum*.

A lack of specialist insect species was also supported when we examine the four plant species with populations featuring insect assemblages that were significantly different in all comparisons. Generally, over 50% of the differences in insect assemblages between *G. pulchellum* at 910 m and all other plants were caused by the high abundance of the polyphagous plant-hopper *Novotarberus flagellospinosus*, but low abundances of other polyphagous and oligophagous insects. Variation in abundances of these insects was also the main reason *G. vestitum* at 1021 m and *G. rubra* at 531 m differed from all other *Gastrolobium* populations.

Likewise, *G. tetragonophyllum* at 720 m had low abundances of polyphagous and oligophagous insects, but it also had a host specific plant-louse (*Acizzia* sp. 36) and high abundances of a leaf beetle (*Ditropidus* sp. 73), which was most likely feeding on the flowers, as this species was common when sampling plants in flower (Moir pers. obs.). Interestingly, no *Gastrolobium* population that occurred at lower altitudes (< 500 m) had insect assemblages significantly different from every other plant population. This does suggest that climate change may cause the loss of some insect assemblages (especially those at the summits of their respective mountains; *G. vestitum* at 1021 m and *G. tetragonophyllum* at 720 m), but given that the differences were predominantly caused by insect species that were able to feed on other hosts, the loss of these particular *Gastrolobium* populations should not result in the coextinction of insect species.

Despite the non-significant results between most of the insect assemblages, host-breadth analyses indicated that there was a total of 17 host-specific insects on *Gastrolobium* (*G. crenulatum* and *G. leakeanum* 4 insect species each, *G. tetragonophyllum* 3 species, *G. pulchellum* and *G. luteifolium* 2 species each, *G. bilobum* and *G. vestitum* 1 species each, and *G. rubra* no insects). The insects at greatest risk from extinction from climate change are those found on plant species with very few individuals (and therefore already listed as threatened) or those at the summits of mountains. In this case the insects most at threat are the three species found on *G. vestitum* and *G. luteifolium*, plus three of the four species found on *G. leakeanum*.

An analysis of the environmental variables indicates that rainfall and dew point are the best explanatory variables for the differences in insect assemblages between *Gastrolobium* populations (rank correlation coefficient $\rho = 0.20$). This could suggest that there was a general turnover in insect species with altitude (as also indicated by the similarity in insect assemblages on plant species at the same altitude, described above) as rainfall and the difference between minimum and maximum dew point generally increased with altitude (Figures 3 and 4 above). However, this represents only a small proportion of the differences explained. We suggest that other variables such as time since fire and host population size may be important determining factors for the insect assemblages and should be the focus of future work.

3.5 Family Proteaceae

3.5.1 Species: Banksia grandis, Banksia solandri and Banksia oreophila

Banksia grandis, *B. solandri* and *B. oreophila* provide an example of three closely related plants, one of which is very common across all altitudes (*B. grandis*), a second is less common and found on mid to high mountain slopes (*B. oreophila*) and a third species with conservation priority is found from mid to high slopes, in the SRNP (*B. solandri*). We assessed two populations of *B. grandis*, four populations of *B. solandri* and three populations of *B. oreophila* (Figure 9). The insect assemblages on these three plant species were predominantly similar when they occurred at the same site and altitude, with only two out of the six comparions significantly different (*B. oreophila* compared to *B. solandri* at 740 m, $P = 0.008$, R statistic 0.18; *B. grandis* compared to *B. solandri* at 527 m, $P < 0.001$, R statistic 0.22) (Figure 9). This indicates that, unlike other plant families examined, there is evidence that the insect assemblages of these three host species could switch to different host plants if one is extinguished. Further supporting this, there were very few host-specific taxa on each plant species, with none on *B. grandis*, and two insect species on *B. solandri*. There were two host-specific insect species on *B. oreophila*, but these insects occurred only at one population on a mountain where neither *B. grandis* nor *B. solandri* were sampled (at 1039 m, see Figure 9), so the insects could potentially occur on these other plants if they were present. Our results suggest that other *Banksia* species must be present within the same vicinity or, at the very least, on the same mountain, for insects to be able to switch hosts relatively easily.

An analysis of environmental variables indicates that maximum humidity is the best explanatory variable for the differences in insect assemblages between these three

Banksia species and each of their populations (rank correlation coefficient ρ = 0.28). However, maximum humidity explains a small proportion of the differences explained. We suggest that other variables such as time since fire, host population size and the presence of the plant disease dieback (which the genus *Banksia* is highly susceptible to, especially *Banksia solandri*: Barrett *et al*. 2008) may be important determining factors for the insect assemblages and should be the focus of future work.

A decline is predicted with climate change for *Banksia grandis,* and, in high end scenarios, it will go globally extinct (Yates *et al.* 2010). No predictions exist for *B. solandri* and *B. oreophila*, but given that they have restricted distributions and occur on mountain ranges, global extinction is not unrealistic. Furthermore, the genus *Banksia* is predicted to be one of the most severely affected by climate change, with species in the genus relying heavily on rainfall in the southwest and having limited dispersal potential (Fitzpatrick *et al*. 2008; Yates *et al*. 2010). Therefore, whether or not the insect fauna can switch host species may be a moot point if there are no closely related plant species in the vicinity for insects to switch to.

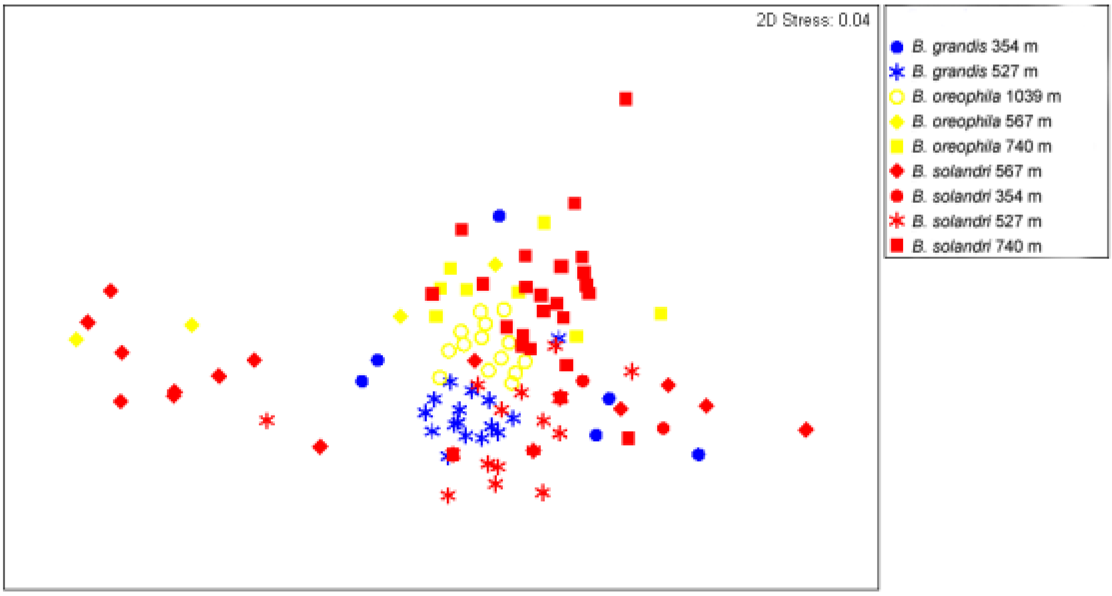


Figure 9: Multidimensional Scaling (MDS) ordination of the insect assemblages on different populations of the plant species *Banksia grandis, B. oreophila* and *B. solandri*

3.6 Species level insect data

Not all species are threatened with extinction from climate change. Particular species will be able to adapt to the new conditions (e.g., through genetic diversity, etc) or be resilient (e.g., if they have the potential to disperse to a more suitable area, they have particular life history traits, etc) (Williams *et al.* 2008). Some of these species are predicted to expand their range (Kocsis and Hufnagel 2011), such as the pine processionary moth (Netherer and Schopf 2010). Our aim was to determine which insect species in the SRNP were highly vulnerable to extinction because they potentially will not be able to adapt or have resilience to climate change.

From the large database of 1,019 insect species across 104 plant species, we identified 70 insect species through host-breadth models (Vesk *et al.* 2010) that were of immediate conservation concern due to their reliance on threatened plant species. A further 15 insect species may be of conservation concern because host-breadth models identified that they rely on several threatened plant species for survival. Of those insects that feed from non-threatened plant species, 178 insect species are likely to be at risk in the event that climate change or synergistic factors reduces their host plant's range size, because these insects are host specific according to host-breadth models. As a proportion of the total insect fauna found then, 8.3 % are of immediate conservation concern and another 17.5 % could become threatened through climate change or other disturbance.

From the 85 insect species that are of immediate conservation concern (those that rely on threatened plant species), the insect groups that appear most prone to extinction are sessile feeders and highly host-specific groups such as whiteflies, scales, and mealybugs (12 species). Although we recognize that there are agricultural pest insect species with these same characteristics, the difference here is that the host itself is restricted in distribution. One of these groups, the Pseudococcidae or mealybugs, is also one of only two hemipteran families to have extinct species listed on the IUCN Red list (IUCN 2012; *Clavicoccus erinaceus* and *Phyllococcus oahuensis*), which further highlights that it is possible for these groups to require conservation management. There is evidence that a changing climate causes the extinction of insects that rely on host species with small ranges, potentially due to a mismatch in the timing between lifecycles of host and dependent insect, and the insect having nowhere to migrate to in the case of host-specific taxa (Pelini *et al.* 2010; Singer and Parmesan 2010; and reviews by Berg *et al.* 2010; Kocsis and Hufnagal 2011; Delucia *et al.* 2012). Insects which are oligophaous (have the ability to feed across several species of plant within the same genus/family) are able to survive a changing climate by migrating to more favourable areas and changing host plant species (e.g., Ashton *et al.* 2009). However, the majority of studies have focused on the generally less host-specific leaf chewer insects, particularly defoliators (Cornellisen 2011), and not those insects which could suffer extinction under a changing climate.

Weevils (Curculioidae) also dominated the potentially threatened fauna (14 species) and may be at higher risk, especially brachypterous species, which are dispersal inhibited. A further 13 species of various other beetle families were host-specific to threatened host plants, with the main group being the leaf beetles (Chrysomelidae: 9 species). More surprisingly, mobile plant louse groups (Psylloidea) were also at high risk, with 9 species from this superfamily found to be host-specific to plant species that are of conservation concern. Endophagous insects are predicted to be at high risk, but were under-studied here due to the sampling methods employed during the collection of the insect-plant database.

Below we provide detailed information for 22 insect species identified as potentially at risk of extinction and identify project outcomes towards their conservation in light of a changing climate. Nineteen of these insect species were selected from modelling analysis that was based upon insect data collected in south-west Australia during 2007 - 2010. Three additional insect species which were recently described are provided as examples from outside the SRNP. Each co-threatened insect example is discussed in detail, highlighting the threats and cause of decline of the insect and it's equally threatened host plant.

3.6.1 Acizza veski (Insecta: Hemiptera: Psyllidae)

Common name: Vesks' plant-louse

Description

This description of *Acizza veski* is adapted from Taylor and Moir (2009); it is a small, winged plant-louse (~3 mm, Figure 10) and the first endemic species of *Acizzia* to be described from WA.

Although the genus *Acizzia* is extremely speciose in Australia (Yen, 2002), only three other species have been recorded from Western Australia; *A. acaciaedecurrentis* (on *A. cyclops*: Van Der Berg 1980)*, A. acaciaebaileyanae* and *A. uncatoides* (Hollis 2004). However, these species of *Acizzia* may be native to eastern Australia, and introduced in Western Australia, as they have been collected in other regions of the world (see Hollis, 2004). There remain numerous undescribed endemic *Acizzia* species present in WA (Moir unpublished data).

Acizzia veski can be distinguished from all other described species of *Acizzia* by the following suite of characters: antenna long, 2.3–2.6 times width of head; genal processes moderate in length, 0.55–0.66 times length of vertex, with broadly rounded apices; both sexes with characteristically mottled wings; male proctiger with thin, reclinate apical node and broadly-rounded lateral (posterior) lobes each with a thin terminal distal appendage; apical segment of aedeagus with an asymmetric bulbous apex with an anterior hook; inner face of parameres with rod-shaped setae; female terminalia short, proctiger broadly rhomboid, and subgenital plate broadly triangular from lateral aspect.

Figure 10: Clockwise from top left, *Acizzia veski*, host plant *Acacia veronica* and habitat at Mt Talyuberlup

Distribution

Acizzia veski is currently known only from one location (Mt Talyuberlup) within the SRNP of WA. *Acizzia veski* is associated with its host plant, *Acacia veronica* Maslin (Fabaceae: Mimosoideae: Acacieae) which has a restricted distribution in the Stirling Range. In this location the host plant population occurs within an area of $1km^2$. Further populations of *A. veski* were not found at nine other population localities of *A. veronica* (Taylor and Moir, 2009). In total, six populations of *A. veronica* were found and sampled, four other previously-recorded populations of *A. veronica* were searched for but were not found, and a remaining seven populations were not searched for or sampled (Hostellers hill, Barnett peak, Wedge hill, Bluff Knoll waterfall, Bakers knob and gullies southwest of Mt Trio, and southeast of Mt Toolbrunup).

Threats and Causes of Decline

Acizzia veski is currently known from only one population of *A. veronica* (in total 10 known populations of *A. veronica* were searched, and seven remain unsampled). The conservation status of *A. veronica* is currently 'Priority 3 (poorly known flora)'. As of February 2012, the conservation status of *A. veski* is listed as vulnerable. Therefore *A. veski* is extremely vulnerable to extinction if its host plant population was further threatened. Key threatening processes most likely include climate change (Barrett *et al.* 2008), inappropriate fire regime and habitat clearing. The latter pertains to the location of this stand of *A. veronica*, which is bisected by a road and popular carpark, and contains some walk trails and picnic area within it. As well as general clearing of the area to widen roads, or create run-off drains, human trampling of young plants may be a threat, as has been shown elsewhere (Rossi *et al.* 2009). Certain processes that may not threaten the host plants still remain a threat to the insect. For example, if a host population was subject to a single fire, the host might survive *in situ* and regenerate eventually from seed; however the insects will go locally extinct as access to their host is temporarily unavailable. Given the distance to the nearest host population, recolonization of the site would be highly unlikely.

Outcomes

- Threatened species nominations were submitted and in February 2012 *Acizzia veski* was listed in WA as a threatened species (Vulnerable). It is currently being considered for federal listing.
- IUCN nominations were submitted in July 2012; however no word has been received to date as to whether the application has been successful.
- In September 2012 an article was published in *Landscope* drawing attention to *Acizzia veski* in the 'Endangered' section of the magazine.
- *Acizzia veski* was translocated *in situ* within the SRNP at two localities onto the host plant *A. veronica* in October 2012 (for more information see section: **4.7 Translocations**).
- The *Acizzia veski* translocation was featured in the newspaper *Albany Advertiser* in September 2012 and again in the Department of Environment and Conservation October 2012 newsletter.
- An extended feature article on the translocations entitled 'Slowing the extinction of insects' has been accepted by *Landscope* and is due for publication in Winter 2013.

Recommendations for Climate Change Adaptation Management

- Identify the extent of occurrence of the single known population and study the ecology of the insect (e.g., how many populations per year, how many eggs are produced per female, etc).
- Survey the remaining *Acacia veronica* populations that have not been sampled to date.

- Increase monitoring of the single natural population.
- Assess the success of reintroduction trials. Consider reintroduction onto other unihabited *Acacia veronica* populations.
- Determine whether the natural site is becoming drier over the years (through weather monitoring and measuring run-off in the catchment) and how this is affecting the health of the host population.
- Determine host recruitment at the natural *A. veski* site and compare to *A. veronica* populations in cooler, wetter sites.
- Other potential actions are outlined in the Decision Protocol (Figure 23).

3.6.2 *Acizza sp. 12 (Insecta: Hemiptera: Psyllidae)*

Common name: Hughes' plant-louse

Description
Acizza sp. 12 is an undescribed species that is currently undergoing taxonomic description. It is a small, winged plant-louse (~3 mm), with clear wings and light yellow speckling colouration towards the apexes, the body is light orange or green in colour.

Distribution
Acizza sp. 12 is associated with its host plant, *Grevillea* sp. 'Stirling Range' (Figure 11). It has not been discovered on any other host species, including numerous *Grevillea* species sampled for this and other projects, nor is it present in any collection viewed by either Moir or taxonomic expert Gary Taylor. This *Grevillea* is associated with sand plain heath vegetation of the SRNP in WA and is a small, flimsy shrub (~1.5 m). Although undescribed, it has been recognised as in need of conservation because of its restricted distribution, and low number of remaining populations. It is listed as a 'Priority 2' flora (three populations known: Barrett pers. comm. 2011).

Figure 11: From left, *Acizza* sp 'Stirling Range' host plant *Grevillea* sp 'Stirling Range' and habitat - sand plain heath

Threats and Causes of Decline
Any threat to the host plant can be seen as a direct threat to *Acizza* sp. 12. However, as the host plant itself is undescribed, it is difficult to infer threats to *Acizza* sp. 12 and raise public awareness of its need for conservation. Due to the host plant's understudied status, key threatening processes are currently unknown, but may include climate change; inappropriate fire regime and Phytophthora dieback disease, which threatens many other plant species within the southwest botanical province (see Barrett *et al*. 2008). Of the two populations of *Grevillea* sp. 'Stirling Range' sampled, only one yielded *Acizza* sp. 12, suggesting that although the host has a 'priority 2' conservation status, the psyllid may be critically endangered.

Outcomes

- Currently undergoing taxonomic description.
- Comparison with *Acizzia hakeae* from New Zealand is vital to determine whether this species is the same or closely related (Gary Taylor pers. comm.. March 2013), and may require molecular work.

Recommendations for Climate Change Adaptation Management

- Identify the extent of occurrence of the single known population and study the ecology of the insect (e.g., how many populations per year, how many eggs are produced per female, etc).
- Survey remaining *Grevillea* sp. ‘Stirling Range’ populations that have not been sampled to date.
- Increase monitoring of the single natural population.
- Consider reintroduction onto other unihabited *Grevillea* sp. ‘Stirling Range’ populations.
- Other potential actions are outlined in the Decision Protocol (Figure 22).

3.6.3 *Acizza sp. 70 (Insecta: Hemiptera: Psyllidae)*

Common name: McCarthys’ plant-louse

Description

Acizzia sp. 70 (Figure 12) is currently undescribed as it has only been recently discovered. It is a small winged plant-louse (~3 mm), with unpatterned clear wings, long black antennae, orange thorax and head with a single dark brown dorsal stripe, the abdomen in predominantly dark brown. As with all species of plant-lice, expert taxonomists are needed to distinguish it from other species. Identification of plant-lice requires genital dissection. Despite being undescribed, this species has been validated by psyllid expert Gary Taylor (University of Adelaide) and is currently subject to taxonomic description.

Figure 12: Clockwise from top left, *Acizzia* sp. 70, host plant *Acacia veronica* and habitat at Mt Talyuberlup

Distribution

Acizzia sp. 70 is currently known only from Mt Talyuberlup and Paper Collar Creek (also known as Papa Colla Creek) within the SRNP of WA. It has not been discovered on any other host species, including numerous *Acacia* species sampled for this and other projects, nor is it present in any collection viewed by either Moir or taxonomic expert Gary Taylor. *Acizzia* sp. 70 relies on its host species, *A. veronica* which is often associated with marri (*Corymbia calophylla*) woodlands. *Acacia veronica* is a small, often spindly tree (1.5–7 m) and is restricted mainly to watercourses, with smaller individuals growing at higher altitudes.

Threats and Causes of Decline

The main threat to *Acizzia* sp. 70 is the loss of its host plant *A. veronica*. *Acacia veronica* is listed by the State Government as 'Priority 3' because of its restricted distribution, and vulnerability to threatening processes. Threats to *A. veronica* populations include inappropriate fire regime, climate change and habitat clearing (i.e. through widening of roads, trampling by visitors) which indirectly threaten *Acizzia* sp. 70.

The distribution of *Acizzia* sp. 70 is severely fragmented due to its very narrow host-breadth association with its host plant *A. veronica. Acizzia* sp. 70 is currently known from only two populations of *A. veronica* (in total 10 known populations of *A. veronica* were searched, and seven remain unsampled). *Acizzia* sp. 70 is therefore extremely vulnerable to extinction if its host plant population was further threatened. In the event of removal of the host population at one locality, and given the distance to the nearest host population (~20 km), recolonization of sites by *Acizzia* sp. 70 would be highly unlikely.

Outcomes

- Threatened species nominations were submitted and in November 2012.
- *Acizzia.*sp. 70 was listed in WA as a threaten species (Vulnerable).
- Currently undergoing taxonomic description.

Recommendations for Climate Change Adaptation Management

- Identify the extent of occurrence of the two known population and study the ecology of the insect (e.g., how many populations per year, how many eggs are produced per female, etc).
- Survey the remaining *Acacia veronica* populations that have not been sampled to date.
- Increase monitoring of the two natural populations.
- Consider reintroduction onto other unihabited *Acacia veronica* populations.
- As suggested for *A. veski* above, determine whether the natural site is becoming drier over the years and how this is affecting the health of the host population, and determine host recruitment to compare to *A. veronica* populations in cooler, wetter sites.
- Other potential actions are outlined in the Decision Protocol (Figure 24).

3.6.4 Trioza sp. 30 (Insecta: Hemiptera: Triozidae)

Common name: *Banksia brownii* plant-louse

Description

Trioza sp. 30 (Figure 13) is an undescribed species that is currently under taxonomic review (by Moir and Gary Taylor, University of Adelaide). It is very small, approximately 3mm in length. Its colour varies from green to orange. Wing venation distinguishes it as a species of *Trioza*. Species placement, however, is determined by dissection of genitalia. As such, taxonomic expert opinion is essential for a correct identification.

Figure 13: Clcokwise from top left, *Banksia brownii* plant-louse (adult), host plant *Banksia brownii* and habitat at Mt Hassel and Vancouver Peninsula

Distribution

Trioza sp. 30 is associated with its host plant *B. brownii* and to date (i.e. 2012) it has been recorded from *B. brownii* populations at Mt Hassel in the Stirling Range, Milbrook Nature Reserve, Waychinnicup National Park, and at Vancouver Peninsula, south of Albany. It has not been discovered on any other host species, including numerous *Banksia* species sampled for this and other projects, nor is it present in any collection viewed by either Moir or taxonomic expert Gary Taylor.

Threats and Causes of Decline

Banksia brownii is a critically endangered species and listed as 'rare or likely to become extinct' under section 14(4) of the *Wildlife Conservation Act 1950* and hence is categorised as a Declared Rare Flora (DRF). As of November 2012 the conservation status of *Trioza* sp. 30 is listed as vulnerable. Given the distance to the nearest host population, recolonization would be highly unlikely. Therefore, any threats to the insects host plant populations are subsequently threats to the insect species. *Banksia brownii* is threatened by Phytophthora dieback disease, inappropriate fire regimes (Barrett *et al.* 2008) and, due to their montane habitat, potentially climate change. As stated previously certain processes that may not threaten the host plants still remain a threat to the insect.

Outcomes

- Threatened species nominations were submitted in January 2012 and in November 2012 *Trioza* sp. 30 was listed in WA as a threatened species (Vulnerable).
- IUCN nominations were also submitted in July 2012; however no word has been received to date as to whether the application has been successful.
- *Trioza* sp. 30 was featured in the newspaper *Albany Advertiser* in September 2012 and again in the Department of Environment and Conservation October 2012 newsletter.
- *Trioza* sp. 30 was translocated *ex situ* at the translocation site onto their host plant *B. brownii* in October 2012 (for more information see section: **4.7 Translocations**).
- Follow up monitoring of translocated *Trioza* sp. 30 was conducted in December 2012. There were no visible signs of *Trioza* sp. 30 on the host plant and success of the translocation will not be known until October 2013.
- An extended translocation article 'Slowing the extinction of insects' has been accepted by *Landscope* and is due for publication in autumn 2013.
- DNA collection occurred in October 2012 as no specimens were found in spring 2011. Sequencing and analysis of different populations of *Trioza* sp. 30 was out-sourced. One gene failed to produce any differences between populations, and a second demonstrated minor differences between three of the four populations analysed. Micro-satellite markers are currently being examined as a possibility to determine differences with the limited number of individuals that are able to be collected (only 30 plants can be sampled per host population and this rarely produced more than 15 plant-louse individuals). This method should also improve the rigour of results. The drawbacks are that it is more expensive and takes much longer to develop.

Recommendations for Climate Change Adaptation Management

- Identify the extent of occurrence of each population of *Trioza* sp. 30. Study the ecology of the insect (e.g., how many populations per year, how many eggs are produced per female, etc).
- Survey the remaining *B. brownii* populations that have not been sampled to date.
- Increase monitoring of all natural populations.
- Assess the success of translocation (introduction) trials. Consider establishing translocation trials on other translocated populations of the host species.
- Determine whether the natural sites are becoming drier over the years (through weather monitoring) and how this is affecting the health of the host population.
- Determine host recruitment and calculate whether the current host populations will be capable of supporting *Trioza* sp. 30 with current losses, or whether host supplementation is required.
- Other potential actions are outlined in the Decision Protocol (Figure 24).

3.6.5 *Pseudococcus markharveyi* (Insecta: Hemiptera: Coccoidea: Pseudococcidae)

Common name: *Bankisa montana* mealybug

Description

Pseudococcus markharveyi (Figure 14) is extremely small (1-3 mm). It has the typical shape of members of the Family, oval, and covered in a film of white 'fluff'. Species placement is determined by slide mounting and taxonomic expert opinion is essential for a correct identification.

This description of *Pseudococcus markharveyi* is from Gullan *et al.* (in press); *Pseudococcus markharveyi* can be distinguished from all other described species of *Pseudococcus* by the following suite of characters, "… adult female is characterized by having drum-like dorsal tubular ducts that often have one or two minute discoidal pores associated with the duct rim, slightly smaller and marginal drum-like ventral tubular ducts, 17 pairs of cerarii.

Figure 14: Clockwise from top left, *Pseudococcus markharveyi* (adult) image taken by Sonja Creese, host pant *Banksia montana* and habitat at Pyungoorup Peak

Distribution

Pseudococcus markharveyi is restricted to old *Banksia montana* plants (Moir *et al.* 2012b). There are four populations of *Banksia montana* remaining in the wild, but only two have been surveyed (Bluff Knoll and Pyungoorup). It has not been discovered on any other host species, including numerous *Banksia* species sampled for this and other projects. However, there is a possibility that it is the same as 2 old specimens collected from *Banksia heliantha* in Fitzgerald River National Park to the east, and we have been searching for adult females from the latter population to compare with molecular analysis since 2011 (see Gullan *et al.* in press). Of the two surveyed *Banksia montana* populations, the mealybug has only been found on one plant in the Bluff Knoll population, but on most individuals on the Pyungoorup population. As such, the mealybug potentially has a geographic range of < 1 km^2.

Threats and Causes of Decline

Banksia montana is critically endangered and listed as 'rare or likely to become extinct' under section 14(4) of the *Wildlife Conservation Act 1950*. Any threats to the insect's host plant populations are subsequently threats to the insect species. *Banksia montana* is threatened by *Phytophthora* dieback disease, inappropriate fire regimes (Barrett *et al.* 2008) and potentially, due to its montane habitat, climate change. Finally, *Pseudococcus markharveyi* is under additional pressure from predators; the mealybug is slow-moving and a favourite prey item of ladybird beetles, particularly *Coccinella transversalis* and the introduced *C. undecimpunctata* (Moir pers. obs.). Both ladybird beetles aregeneralist feeders on invertebrates, but favour aphids, mealybugs and plant-lice.

Outcomes

- Threatened species nomination application was submitted in September 2012 and is currently waiting review in 2013.
- Juvenile *Pseudococcus markharveyi* were translocated *ex situ* at the translocation site onto their host plant *B. montana* in October 2012 (for more information see section: **4.7 Translocations**).
- The *Pseudococcus markharveyi* translocation was featured in the newspaper *Albany Advertiser* in September 2012 and again in the Department of Environment and Conservation October 2012 newsletter.
- An extended translocation article 'Slowing the extinction of insects' has been accepted by *Landscope* and is due for publication in autumn 2013.
- After the initial translocation, follow up monitoring was conducted in December 2012. There were no visible signs of *Pseudococcus markharveyi* on the host plant (we expected to see adult females at this time) and a second attempt at translocation was conducted with adults. The success of the second translocation will not be known until October-December 2013.
- A taxonomic paper describing *Pseudococcus markharveyi* was submitted and is in press (March 2013) with the *Records of the Western Australian Museum*.
- DNA sequencing and analysis was conducted by Dr Lyn Cook at the University of Queensland as part of the taxonomic paper. Key results indicated that the two known populations on the Eastern massif of the SRNP were identical.

Recommendations for Climate Change Adaptation Management

- Identify the extent of occurrence of the natural population and determine whether it occurs on all individuals and within all patches of *B. montana* along the Eastern massif of the SRNP.
- Study the ecology of the insect (e.g., average number of insects per plant, how many populations per year, how many eggs are produced per female, etc).
- Increase monitoring of the natural population.
- Assess the success of translocation (introduction) trials.
- Consider reintroduction of the mealybug onto uninhabitated *B. montana* individuals (as dispersal is particularly limiting for this bug).
- Determine whether the natural site is becoming drier over the years (through weather monitoring) and how this is affecting the health of the host population.
- Determine host recruitment and calculate whether the current host populations will be capable of supporting *P. markharveyi* with current losses, or whether host supplementation is required (currently undertaken at Bluff Knoll but may be required for other host patches).
- Other potential actions are outlined in the Decision Protocol (Figure 24).

3.6.6 Aleyrodidae (Insecta: Hemiptera)

Common name: Whiteflies

Description

Synaleurodicus sp. 19 and *Gomonella* sp. 8.2 are undescribed species that are currently undergoing taxonomic description. As adults, they are minute soft bodied insects that can be mistaken for moths as their wings are covered in a white dust or waxy powder. Taxonomic work relies on the lerp or nymph, which is covered in a hard 'shell'. *Gomonella* sp. 8.2 is unusual in that it is one of the few Aleyrodids to form pit galls (Figure 15; Peter Gillespie pers. comm. 2012).

Figure 15: Examples of whiteflies found on the critically endangered host plant *Banksia pseudoplumosa*, left, *Gomonolla* sp. 8.2 lerp, and right, *Aleurotrachelus dryandrae* lerp, a common whitefly species found on numerous Banksia species, images taken by Peter Gillespie

Distribution

Synaleurodicus sp. 19 was collected in the SRNP on Bluff Knoll in late spring 2007 as lerps on two host plants; *Gastrolobium pulchellum* and *G. leakeanum* (Figure 16). Despite sampling other *G. pulchellum* and *G. leakeanum* populations in the SRNP, there were no additional records of *Synaleurodicus* sp. 19. As all collections of *Synaleurodicus* sp. 19 have been on the Eastern massif of the SRNP, this suggests that the whitefly could be restricted to here. It has not been discovered on any other host species, including numerous *Gastrolobium* species sampled for this and other projects, nor is it present in any collection viewed by taxonomic expert Peter Gillespie.

Figure 16: The only known host plant of *Synaleuroodicus* sp. 19 from left, *Gastrolobium leakeanum* and its habitat on the Eastern massif of SRNP showing Bluff Knoll in the distance

Gomonella sp. 8.2 was collected in the SRNP on Salt River Road in October 2008 on its host plant *Banskia pseudoplumosa* (Figure 17). Despite other *Banksia* species sampled in the vicinity, as well as further afield, *Gomonella* sp 8.2 has not been found elsewhere. In addition, it is not present in any collection viewed by taxonomic expert Peter Gillespie. Interestingly, *Gomonella* sp. 8.2 occurs in sympatry with several other whitefly species on *B. pseudoplumosa*, such as *Aleurotrachelus dryandrae*.

Figure 17: The only known host plant of *Gomonella* sp. 8.2, *Banksia pseudoplumosa* (left) and its habitat at Salt River Road

Threats and Causes of Decline

Gastrolobium pulchellum and *G. leakeanum* are listed as ‘Priority 2’ and *B. pseudoplumosa* is listed as critically endangered and hence a DRF. Threats to these plant populations in the SRNP include inappropriate fire regime, climate change, habitat clearing (i.e. through widening of roads, trampling by visitors) and Phytophthora dieback disease. These threats to the plants indirectly threaten *Synaleurodicus* sp. 19 and *Gomonella* sp. 8.2.

Outcomes

- Both species are currently undergoing taxonomic description.
- Molecular analysis has indicated that both are distinct species from all those analysed in the largest Australian whitefly database held at NSW Department of Primary Industries entomology collection.

Recommendations for Climate Change Adaptation Management

- Identify the extent of occurrence of known populations and study the ecology of the insect (e.g., how many populations per year, how many eggs are produced per female, how many individual lerps per host plant, etc). This is vital, as highlighted by the Decision Protocol for *Gomonella* sp. 8.2 (Figure 27).
- Survey the remaining host populations that have not been sampled to date (i.e. *G. leakeanum*, *G. pulchellum* and *B. pseudoplumosa*).
- Increase monitoring of the natural populations.
- Determine whether the natural site is becoming drier over the years (through weather monitoring) and how this is affecting the health of the host population.
- Assess host recruitment.

- Other potential actions are outlined in the Decision Protocol (Figure 27).

3.6.7 Austroasca species (Insecta: Hemiptera: Cicadellidae)

Common name: Minute green leafhoppers

Description

All species of *Austroasca* found in the SRNP are undescribed and nine species are undergoing taxonomic description. They are small, green leafhoppers (~3 mm), with unpatterned wings (e.g., Figure 18).

Figure 18: *Austroasca* sp. 8 (left) and its host plant *Leucopogan lasiophyllus*

Distribution

Austroasca species were collected from various locations within the SRNP, and one species was collected outside the SRNP. The majority of *Austroasca* species were associated with the sand plain heath vegetation of the SRNP.

Of the estimated 1500+ plant species present in the SRNP, 7 % were represented within our database. We note that Myrtaceae (in particular the genus *Melaleuca*) tend to host many *Austroasca* species (Leng and Moir pers. obs), but this plant family was not a target for this project and hence future work is still required to ascertain *Austroasca* diversity within the SRNP.

Threats and Causes of Decline

Two species of *Austroasca* were restricted to plants of conservation concern; however one plant species has since been delisted although reasons for doing so are unknown to these authors. The other *Austroasca* species is restricted to the critically endangered *Banksia pseudoplumosa*. Of the other plant species that the remaining *Austroasca* species were collected from, two are listed as ‘Priority 2’ (*Banksia aculeata* and *Lasiopetalum membraniflorum*), and one is listed as ‘Priority 4’ (*Leucopogan lasiophyllus*). Predominant threats to the plants in the SRNP include inappropriate fire regime, climate change and *Phytophthora* dieback disease.

The lack of knowledge of the many plant species present in the SRNP also presents a problem. These undescribed plants could be harbouring potential host-specific insect species. The lack of information on these plants can impede their conservation as they tend to be overlooked in management plans and therefore their insect fauna are also overlooked by researchers.

Outcomes

- Preliminary molecular analysis has separated species.
- Targeted survey work in October 2012 located additional specimens of some of the rarer species.
- Currently undergoing taxonomic description.

Recommendations for Climate Change Adaptation Management

- Before recommendations for adaptation strategies can be made, we must determine whether any species are under threat from coextinction, predominantly due to a changing climate. Taxonomic assessment of the leafhoppers is therefore the vital preliminary step.

3.6.8 Curculionidae (Insecta: Coleoptera)

Common name: Weevils

Description

Cydmaea sp. 125 is a very small (~2 mm) winged weevil that is black in colour with fine white markings.

Apion sp. 190 is a very small (~2 mm) winged weevil that is dark red in colour. It has a black body, head and eyes.

Distribution

Cydmaea sp. 125 specimens were collected in spring 2007 and were found on the host plant *A. veronica*. The weevil has been recorded at Mt Trio and, more commonly, at Mt Talyuberlup. A singleton specimen was collected at Mt Toolbrunup on *Gastrolobium vestitum*, but not on any *A. veronica* sampled at this same site.

Apion sp. 190 specimens were collected in spring 2007 and were found feeding on the host plants *Lasiopetalum dielsii* (Figure 19), *L. membraciflorum*, and *L. monticola*. Apion sp. 190 was very common on all populations of *L. dielsii* sampled at Mt Trio, Mt Toolbrunup and Mt Talyuberlup. This implies that *L. dielsii* is their favoured host plant species. Although found on three plant species, all of these plants have conservation status of concern. In addition, the weevil was not found on *L. cordifolium*, the only *Lasiopetalum* sampled that is not of conservation concern.

Figure 19: Clockwise from top left, an *Apion* weevil, *Apion* sp. 190 host plant *Lasiopetalum dielsii* and its habitat at Mt Trio

Threats and Causes of Decline

Cydmaea sp. 125 faces the same problems of decline as other insects on *A. veronica* (see previous sections 4.7.1 *Acizzia veski* and 4.7.3 *Acizzia* sp. 70).

Apion sp. 190 is found at various altitudes on three different species of host plant. However, the favoured host plant *L. deilsii* occurs at the summit of mountains and would most likely be extinguished under a drier and hotter climate. *Lasiopetalum monticola* is also found on mountain slopes but could migrate to higher altitudes. The other host, *L. membraciflorum*, occurs in gullies and could also be extinguished under a drier climate. As the weevil is able to feed on multiple hosts, albeit each of conservation concern, there is the possibility that it has a broader host range which could afford it insurance against local extinction. Feeding trials or sampling of *Lasiopetalum* outside of the SRNP is required to substantiate these possibilities.

Recommendations for Climate Change Adaptation Management

- Before recommendations for adaptation strategies can be made, we must determine whether any species are under threat from coextinction, predominantly due to a changing climate. Taxonomic descriptions of the weevils are therefore the preliminary step.

3.6.9 Chrysomelidae (Insecta: Coleoptera)

Common name: Leaf beetles

Description
Monolepta sp. 240 and *Peltoschema* sp. 244 (Figure 20) are a small winged beetles ranging from 3 - 4 mm in size. The head, legs and body of *Peltoschema* sp. 244 are light yellow in colour, and the elytra are brown with mottled, light yellow, horizontal markings. *Monolepta* sp. 240 is predominantly black with red markings.

Figure 20: *Peltoschema* sp. 244 (inset) and its host plant *Acacia veronica* at Mt Trio

Distribution
Monolepta sp. 240 was found on populations of *Acacia veronica* at Mt Trio (spring 2007) and Moir Hill (spring 2008). *Peltoschema* sp. 244 was found on all populations of *Acacia veronica* during spring 2007 and 2008.

Threats and Causes of Decline
Both beetles are faced with the same problems of decline as other insects dependent on *Acacia veronica* (see previous sections 4.7.1 *Acizzia veski* and 4.7.3 *Acizzia* sp. 70). However, we note that the two populations of the host that *Monolepta* sp. 240 was discovered on are among the smallest in terms of numbers of individuals and extent of occurrence, indicating that this beetle may have good powers of dispersal or be feeding on other unsampled host species.

Recommendations for Climate Change Adaptation Management

- Before recommendations for adaptation strategies can be made, we must determine whether any species are under threat from coextinction, predominantly due to a changing climate. Taxonomic descriptions of the leaf beetles are therefore the preliminary step.

3.6.10 Swaustraltingis isobellae (Insecta: Heteroptera: Tingidae)

Common name: Isobelle's lace bug

Description

The following information for *S. isobellae* is taken from Moir and Guilbert (2012); Body long and slender; head armed with five long and slender spines; antennae long and slender; pronotum narrow, long, flattened and tricarinate; hemelytra long, narrow, not wider than pronotum width, margins curved ventrally to cover sides of abdomen. *Swaustraltingis* differs from other closely related genera by the long, slender antennae, particularly the third antennal segment, presence of five long cephalic tubercles and the long lateral carinae of the pronotum which end anteriorly by forming a loop within the calli.

Distribution

Swaustraltingis isobellae (Figure 21) appears to be restricted along the south coast of south-west Australia from Albany to Walpole. It has not been discovered on any other host species Australia-wide. Its distribution may simultaneously coincide with its host plant's (*Empodisma gracillimum*: Restionaceae) distribution, which extends from Albany westwards and around the coastline to Bunbury. Coastal areas in which *S. isobellae* was found were dominated by coastal heathland comprising peppermint trees (*Agonis flexuosa*) with grass-like ground cover (usually *E. gracillimum*), or tall *Banksia* species with grass-like (including *E. gracillimum*) and reed understoreys (Figure 21).

Threats and Causes of Decline

Swaustraltingis isobellae is flightless and restricted to one host plant species (*E. gracillimum*), which may indicate its potential to become threatened if its habitat is subject to disturbance or climate change which results in the local loss of this host. Together with its tendency to occur in cooler, wetter coastal environments with this host, *S. isobellae* may be at greater risk of coextinction following the protocol set by Moir *et al*. (2011). If *S. isobellae* is represented by only flightless individuals, its poor dispersal ability would predispose it to local extinction with the removal or reduction in population sizes of its host plant.

Figure 21: *Swaustraltingis isobellae* (left) and habitat at Torndirrup National Park

Recommendations for Climate Change Adaptation Management

- Determine the extent of occurrence of *S. isobellae* and study the ecology of the insect in further detail (e.g., how many populations per year, how many eggs are produced per female, etc).
- Survey the remaining *E. gracillimum* populations that have not been sampled to date, particularly at the boundaries of it's distribution, and examine closely related host plant species that the lacebug may be able to feed on.
- Determine whether the climatic zone suitable for *E. gracillimum* is shrinking and any associated loss in *E. gracillimum* populations.

3.6.11 Ceratocader species (Insecta: Heteroptera: Tingidae)

Common name: Armed lacebugs

The following information for the lacebugs *Ceratocader bridgettae* and *C. coatesi* from southwestern Australia was taken from Moir and Lis (2012).

Description

Ceratocader bridgettae has the costal region of the hemelytra curved up and back upon itself (also termed 'recurved') for almost the entire length. In addition, *C. bridgettae* has 6–8 spines with at least one spine longer than the diameter of the eye.
Ceratocader coatesi has approximately 5 spines per lateral margin of the paranotum, with the anterior spine long, extending forward and surpassing the eyes

Distribution

Ceratocader bridgettae is found in the northern Jarrah (*Eucalyptus marginata*) forest of south-west Australia. This area has a relatively higher rainfall than surrounding northern, eastern and western areas (Orabi *et al.* 2010).
Ceratocader coatesi is found in the most northeastern disjunct population of wet Karri (*Eucalyptus diversicolor*) forest of the Porongurup National Park.

Threats and Causes of Decline

Ceratocader bridgettae and *C. coatesi* are known only from a single locality each. It is highly likely that they are restricted to their specific habitat types represented at these localities. *Ceratocader coatesi* is found in the most northeastern disjunct population of wet Karri (*Eucalyptus diversicolor*) forest (Figure 22), the habitat of which is likely to alter significantly under climate change. Furthermore, it was captured on *Gastrolobium subcordatum*, a plant which is considered in need of conservation (http://florabase.dec.wa.gov.au/browse/profile/20507 and Chandler *et al*. 2002). Therefore, *C. coatesi* may be at risk of extinction through climate change due to both the small range of the host plant, and the habitat type itself. *Ceratocader bridgettae* is not currently known from any plant species, but it's locality in the wet northern jarrah forest suggests that it may similarly be adversely impacted by climate change.

Figure 22: *Ceratocader coatesi* (left) and habitat at Porongurups National Park

Recommendations for Climate Change Adaptation Management

- Identify the extent of occurrence of each of the single known populations of *C. coatesi* and *C. bridgettae* and attempt to uncover more information on the ecology of the insects (e.g., how many populations per year, where do they live, do they feed at night, which host species are preferred, etc).
- Determine whether the native habitats (northern Jarrah forest in the vicinity of Boddington and Karri forest of the Porongurup National Park) is becoming drier and how this is affecting the repsective habitats.

3.7 Translocations

Ex situ conservation in the form of translocations of threatened species is a well-established strategy to maintain or increase genetic diversity and to maintain or establish viable populations (Coates and Aktins 2001; van Winkel 2008; Volis and Blecher 2010). Much recent discussion has focused on the potential role of assisted migration (also termed assisted colonization or managed relocation) in reducing the probability of extinction from climate change (e.g., Hoegh-Guldberg *et al.* 2008; Minteer and Collins 2010). Translocations, incorporating introductions, reintroductions and population supplementation, are common climate change adaptation strategies that we can use to combat extinction risk (also covered by the broad term “planned adaptation”, see Hughes *et al.* 2010, pg 16).

Amongst the numerous threatened plant species within the State of Western Australia, over 50 species are currently undergoing translocation trials, and for some, at least, this should lessen the risk of extinction through a changing climate. Two such plants are the critically endangered feather-leaf *Banksia* (*Banksia brownii*) and the mountain *Banksia* (*Banksia montana*). Individuals of these species are growing at a faster rate within one translocation site (Kamballup) than occurs in their native sites ~ 30 km in the north-east in the SRNP. Below we outline translocation trials of insects on these two plants, and also the translocation in-situ of an insect on native populations of *Acacia veronica* within the SRNP.

3.7.1 Acizzia veski (Vesk’s plant-louse)

Justification

Populations of the insect are expected to decline due to a combination of the following factors: 1. having a very narrow host-breath, 2. host plants being rare and in danger of extinction, 3. host plants have small restricted populations, 4. threats to host plants such as fire and climate change (see section 4.7.1 for a full outline).

It was for these interacting points that the insect was listed by the State government of Western Australia as 'Vulnerable' in February 2012. Thus the translocation would allow these insects to establish in two new areas (on two naturally occurring *A. veronica* populations in the SRNP) to increase their chance of survival. Furthermore, this translocation will present an opportunity to better understand the biology and ecology of these potentially highly co-threatened, but understudied, insects. Through this, it also creates an opportunity to develop suitable methods and protocols to aid in establishing new populations of these highly threatened insects and their equally threatened host specific plants.

Translocation type

Reintroduction (the movement of an organism into part of its native range from which it has disappeared or become extirpated in historic times as a result of human activities or natural catastrophe: DEC policy statement # 29).

Source environment and population

The total number of insects available for translocation was unknown due to the experimental nature of this project. However, nymphs of the plant-lice were not taken and approximately half of all adults found were taken. As we only sampled a small proportion of the host plants at the location (30 plants sampled from >200 individuals), this should not be detrimental to the entire population of *A. veski* at the site. There are no genetic study's for *A. veski* and as only one population is currently known to exist; all individuals were sourced from this one population.

Translocation environment

The translocation sites are at Mt Trio and Mt Hassel within the SRNP, approximately 22 km east of the current existing population (or source population) at Mt Talyuberlup. Both translocation sites occur at similar altitudes to Mt Talyuberlup (Mt Talyuberlup 351 m, Mt Trio 493 m, Mt Hassel 383 m), although aspect of the catchment area differs from the original population site (Mt Talyuberlup is south-facing, Mt Trio is north-facing, Mt Hassel is west facing). Aspect may affect the success of the translocation due to the amount of run-off received by each *A. veronica* population, although given the health of individual plants within the different populations observed over different years (2007, 2008, 2012), we think this unlikely. In any case, weather pendants and stations are place at each site. *Acacia veronica* populations at the translocation sites contain fewer individuals although the exact numbers are not known.

Control of threatening processes at the reintroduction sites

Acizzia veski is currently known from only one population of *A. veronica* (in total ten known populations of *A. veronica* were searched, and another seven remain unsampled). It is likely that *A. veski* could be discovered on some of the unsampled populations of *A. veronica*, but even if this was the case, there would still be very few known populations of the plant-louse. We assume that the plant-louse at some stage occurred on most populations of *A. veronica* and has gone locally extinct from those populations that we searched, possibly due to fire given the relatively young age of the stands that we searched (based on diameter at breast height).

Vesk's plant-louse may therefore be vulnerable to extinction if its host plant population was further threatened. Key threatening processes most likely include climate change (Barrett *et al*. 2008), inappropriate fire regime and habitat clearing. Given the distance to the nearest host population, recolonization of the site would be highly unlikely.

At the source population and translocation populations of *A. veronica*, the threatening process of wildfire is controlled for by prescribed burns by DEC. Trampling; road widening, prescribed burns (which would eliminate immediate access to hosts by the plant-louse and therefore could cause local extinction) and general access to the translocated areas is not currently regulated in light of *A. veronica* or the plant-louse, and could become a problem in the future. By liaising with DEC staff, we aim to reduce the threat posed by these activities in the future if the establishment of *A. veski* is successful.

Competition with native and exotic species
Competition from other insects is unlikely to affect *A. veski* as the source population contained the highest number of invertebrate herbivore species compared to all other *A. veronica* populations surveyed (Moir pers. obs. 2008).

Logistics: Capture, handling, transport and release protocol
Acizzia veski was obtained from its only known source population at Mt Talyuberlup in SRNP. Target collection from their known host plant, via beating (gentle tapping to prevent plant damage), was conducted on two occasions through spring (October 2012). For further details refer to section 3.8 Insect Translocations.

Post-release monitoring and success criteria
Acizzia veski translocations will be assessed in October 2013 when the adults are next active. Thirty *A. veronica* will be sampled at the translocation and source sites to determine the relative abundance per individual plant of the plant-louse. As we assume that this species of *Acizzia* has only one generation per year, success will be determined if there are any adult individuals of *A. veski* recovered in the follow-up sampling as this will have indicated that the original *A. veski* individuals mated and successfully laid eggs. All nymphs and adults will be returned to their host plants at the translocation site to continue towards building a viable population. If no *A. veski* are found then there will be two options, 1. no individuals remain at the site and the translocation was a failure, or 2. they are in too low an abundance. To discount the second option, we plan to sample again in 2014.

3.7.2 Trioza sp. 30 (*Banksia brownii* plant-louse)

Justification
Populations of the insect are expected to decline due to a combination of the following factors: 1. having a very narrow host-breath, 2. host plants being rare and in danger of extinction, 3. host plants have small restricted populations, 4. threats to host plants such as *Phytophthora* dieback, fire and climate change (see section 4.7.2. for a full outline).

Thus the translocation would allow these insects to establish in one new area to increase their chance of survival. Only one translocation is possible because at the time of planning the translocation we were unsure of the genetic variability between the plant-louse populations, but the host has shown populations differences (Coates and McArthur 2010), and host material from SRNP has only been translocated once. In addition, we have not established whether *Trioza* sp. 30 occurs on other native populations of *B. brownii*, as these are relatively difficult to access. We have only recently (October 2012) discovered the plant-louse on two different native populations of *B. brownii*. As noted above for *A. veski*, this translocation will present an opportunity to better understand the biology and ecology of these potentially highly co-threatened, but understudied, insects (note this species is yet to acquire a name and very little is known of its ecology).

Translocation type

This is putatively a reintroduction (the movement of an organism into part of its native range from which it has disappeared or become extirpated in historic times as a result of human activities or natural catastrophe: DEC policy statement # 29). *Banksia brownii* may have once occurred throughout the area and only in recent history retracted to its current fragmented populations (Coates and McArthur 2010). Further, as the plant-louse is found on *B. brownii* stands over 80 km apart, it too may have been as widespread as its host. Plants at the translocation site have been surveyed multiple times (2007, 2012), as have other *Banksia* species at the site, and the plant-louse evidently does not currently occur here (see Moir *et al.* 2012a).

Source environment and population

The number of insects available for translocation is unknown due to the experimental nature of this project. However, nymphs of the plant-lice will not be taken and approximately only half of all adults found will be taken. Molecular analysis of *Trioza* sp. 30 has been conducted, but is preliminary in nature. The results indicate that the Albany and Stirling Range populations demonstrate some genetic differences although small, and are consistent with molecular results for the respective *Banksia brownii* populations (see Coates and McArthur 2010). Therefore we translocated Stirling Range *Trioza* sp. 30 onto translocated Stirling Range *B. brownii* individuals.

Translocation environment

The translocation site is near Kamballup, approximately 40 km south of the SRNP. It is located between four sites where *B. brownii* grows naturally (SRNP, Milbrook Nature Reserve, Waychinnicup National Park and Vancouver Peninsula) within the south-west Australian floristic region of WA. The translocation site was established in 2003 on private property. It lies on lateritic soils surrounded by revegetated marri (*Corymbia calophylla*) forest. Surrounding this is farmland (a mixture of wheat, canola and sheep) and other native remnants. Climate of the area hasn't been recorded, however, the nearest available station (the town Mt Barker, 30 km west of Kamballup) does provide probably meaningful records. Mt Barker receives 729 mm of rain annually (Bureau of Meteorology - Australia (BoM) 2011). Refer to Section 3.8 for further details.

Individuals of *B. brownii* were grown from seed or cuttings. They were then transplanted as seedlings to a 2.8 km^2 area of remnant woodland. The plants are arranged in several monospecific transects of two rows each, numbering approximately 40 plants per transect. This site was selected for the translocation as the genetic material for the host plants originated from the SRNP and also its location between the current *B. brownii* and *Trioza* sp. 30 sites.

Control of threatening processes at the reintroduction sites

The translocated plants are protected from threatening processes such as fire (by firebreaks), mammalian herbivory (exclusion fencing) and dieback (entry protocols such as washing shoes in 70 % methylated spirits). As the translocation site is located on private property, the owner controls access to the plants and other threats such as fire. DEC staff also safeguards the well-being of the plants by monitoring regularly.

Particular threats to the insects at the translocation site were controlled by vacuuming the host plants before insects are translocated to remove all invertebrate predators and herbivore competition. However, based on the samples collected from translocated plants in 2007, there was extremely low abundances of both predators and herbivores (see Moir *et al.* 2012b). The few insect herbivore species that were present were generalist species that were also collected from plants within the same family as *B. brownii* (Moir pers. obs.). We hypothesize that due to the low numbers of prey, predator abundance was also very low. Translocated insects were caged on the plants to help exclude predators. The typical outdoor rearing cages used by entomologists, that are specifically designed to be attached to plants without harming the plants were used. They are made of nylon mesh and slip over a branch like a ‘sleeve’, with a zip along one side. They also have a polyvinyl ‘window’ to observe the insects on the plants. The smallest cage sizes (20 x 40 cm) in green mesh have been selected to ensure no damage to the plant due to the weight of the cage. By caging the insects for 1 year, it will also restrict their movement so they cannot fly or drop from the host plant and die through not locating the host again.

Competition with native and exotic species

The translocation sites, including translocated host plants, have been surveyed for other invertebrate herbivores. No other plant-lice were found on translocated host plants (Moir *et al.* 2012b). Many other invertebrate herbivores occur along with *Trioza* sp. 30 on *B. brownii* in the wild (M. Moir *et al.* unpublished data), suggesting that the plant-louse may be able to successfully compete for resources, without detrimental effects on the host plant.

It is highly unlikely the *B. brownii* plant-louse will colonise other plant species at the translocation site as it is highly host-specific; twenty-one species of *Banksia*, 16 species of other Proteaceae and a further 69 species of other plant have been surveyed in and around the SRNP, and it was not found on any but the one host species (Moir *et al.* 2012b). This sampling included other sister taxa to *B. brownii*, as well as other *Banksia* species occurring naturally within 100 m of *B. brownii* individuals.

Logistics: Capture, handling, transport and release protocol

As translocated plants were sourced from the SRNP it was logical that the plant-louse also be obtained from the SRNP. The plant-louse was taken from the only known population in the SRNP at Mt Hassel. Target collecting on the host plant, *Banksia brownii*, via beating (gentle tapping to prevent plant damage), was conducted in October 2012. There was no direct handling of the insects and a maximum of 50 % of adult plant-louse found were captured. As we only sampled approximately a third of host plants at the location (30 plants sampled from ~90 individuals), this should not be detrimental to the entire population of *Trioza* sp. 30 at the site.

In fact, we sampled this same population in 2007 and 2012, and found that numbers of plant-louse individuals per plant has increased from 0.2 to 1.3 over this period, despite the previous sampling. Transportation of the insects to the translocation site occurred within 24 hrs (the time period was often much shorter <12 hours, depending on how quickly insect collecting on mountains could occur, sorting of samples at the field-base, and subsequently driving the insects to the translocation site). Insects were transferred onto their host plant and a light mesh cage was placed over them for protection during their establishment period (the 12 month post-release monitoring period).

Some of the plants at the translocation site had been grown from cuttings of plants at the source/native site from which insects had been collected. We did not attempt to match up insects captured from wild plants with that of the plant’s off-spring at the translocation site, as this may not always be possible, and may not be an easily replicated method for other insect translocations, for which we hope to provide guidelines. Furthermore, there is no evidence that insects are so host-specific that they require a specific individual of host plant to survive, although there is evidence that the genetics of different populations of host plant are important (Laukkanen *et al.* 2012; Turlure *et al.* 2013) and modelling suggests genotype could be more important than yearly abiotic variations in influencing abundances of herbivores (e.g., Evans *et al.* 2012). Upon release within the cages the insects were observed for 10 minutes to ensure they locate the host plant and did not fall off.

For additonal details refer to section 3.8, Insect Translocations.

Post-release monitoring and success criteria
Monitoring occurred a month after translocation to determine status and no adults were obvious. It is assumed that the adults have mated, laid eggs and died. In April 2013 monitoring will occur to assess abundance and survival rates in case this species has two populations a year (currently unknown). Unfortunately we suspect that the small size of the eggs will preclude their use in assessing translocation success, but we will search for them during this period. Monitoring will also occur in spring 2013 to assess insect abundances and the ultimate success of the trial. Health of the translocated plants will also be recorded at each monitoring stage. Ultimately insects will be released from the cages at the translocation site and their populations, plus that of the host plants, will be monitored every 3-6 months for 3 years.

3.7.3 Pseudococcus markharveyi (*Banksia montana* mealybug)

Justification
Populations of *P. markharveyi* are expected to decline due to a combination of the following factors: 1. having a very narrow host-breath, 2. having low dispersal abilities, 3. host plants being rare and in danger of extinction, 4. host plants having small restricted populations, 5. threats to host plants such as Phytophthora dieback, fire and climate change (see section 4.7.3. for a full outline).

Thus the translocation would allow *P. markharveyi* to establish in one new area to increase their chance of survival (only one *ex-situ* translocation of *B. montana* was available to receive translocated insects). As with the translocations of the plant-lice described previously, this translocation will present an opportunity to better understand the biology and ecology of these mealybugs, and aid in establishing the first management protocols globally for the conservation of these groups of insect.

Translocation type
Introduction (releasing or establishing an organism outside its historically known native range: DEC policy statement # 29). Plants at the translocation site have been thoroughly surveyed and the mealybug evidently does not currently occur here (Moir *et al.* 2012b).

Source environment and population
The number of insects available for translocation is unknown due to the experimental nature of this project. However, when found, the mealybug is in high abundance. To conserve the population in the wild, a maximum of 10 % of any population on any individual plant will be removed. Molecular analysis of *Pseudococcus markharveyi* has been conducted and no differences between populations were detected, so specimens from various sources were mixed.

Translocation environment
The translocation site is the same as that discussed above for *Trioza* sp. 30 (near Kamballup). Please refer to the previous section for details.

Individuals of *B. montana* were grown from seed or cuttings. They were then transplanted as seedlings to a 2.8 km^2 area of remnant woodland. The plants are arranged in several monospecific transects of two rows each, numbering approximately 40 plants per transect. This site was selected for the translocation due to its proximity to the wild population.

Control of threatening processes at the reintroduction sites
As above for *Trioza* sp. 30 (section 4.7.2).

Competition with native and exotic species

The translocation sites, including translocated host plants, have been surveyed for other other invertebrate herbivores. A few individual mealybugs were found on translocated plants but there were of a different family (Coccidae) which originated from surrounding *Banksia* species (Moir *et al.* 2012b). Many other invertebrate herbivores occur on *B. montana* in the wild (Moir *et al.* unpublished data), suggesting that the mealybug is able to successfully compete for resources, without detrimental effects on the host plant.

It is highly unlikely the *B.montana* mealybug will colonise other plant species at the translocation site as it is highly host-specific; twenty-one species of *Banksia*, 16 species of other Proteaceae and a further 69 species of other plants have been surveyed in and around the SRNP, and it was not found on any but the one host species (Moir *et al.* 2012b). This sampling included other sister taxa to *B. montana*, as well as other *Banksia* species occurring naturally within 100 m of *B. montana* individuals.

Logistics: Capture, handling, transport and release protocol

The mealybugs were taken via hand-collecting from plants on Pyungoorup and Bluff Knoll, SRNP, to ensure genetic diversity was maintained. However, only one plant on Bluff Knoll had mealybugs whereas all plants searched at Pyungoorup had the mealybug. There was no direct handling of the insects, as insects were either collected with forceps or by taking the small piece of leaf which the insect was attached to. As the mealybugs are found naturally in high abundance, a maximum of 10 % of mealybug individuals found on any one plant were taken from the wild (collected from 8 plants).
The remaining logistics of translocation was a repeat of that performed for Trioza sp. 30 (section 4.7.2 above). For further details also refer to section 3.8 Insect Translocations.

Post-release monitoring and success criteria

Monitoring occurred a month after translocation to determine status and no adults were evident, although adults were observed on plants at the source/native population at the time. Therefore, the initial trial using 1st and 2nd instar nymphs was deemed a failure, so a further translocation using adults was conducted in December 2012. In April 2013 monitoring will occur to see if this species has two populations a year (currently unknown) and as it is possible to see nymphs on the plant, they will be included in the assessment. Monitoring will also occur in spring 2013 to assess insect abundances (both adults and estimations of the abundances of different instars) and the ultimate success of the trial. Actions further to this will be the same as those listed under *Trioza* sp. 30 above (section 4.7.2)

3.8 End-user engagement

A questionnaire (see Appendix 3) was sent out to 22 end-users to canvas whether their organisation had experience in the management of associated or dependent invertebrate species. In total, 14 organisations responded and collated responses are summarised below.

3.8.1 End-user perspectives

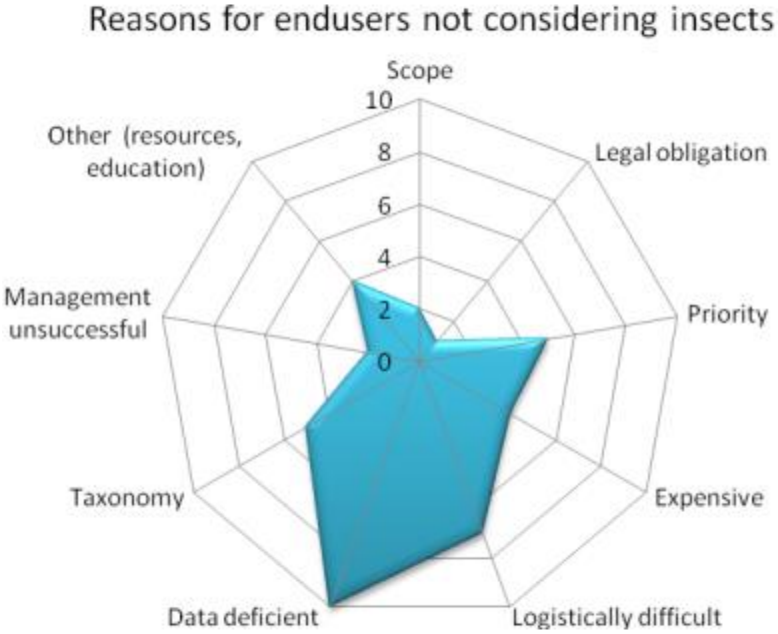
Attitudes towards insects have undoubtedly changed over the past few decades with the end-users surveyed here not questioning why they should consider insects, but instead expressing a desire to include them in management plans. Insects have not been included to date, or have been minimally included, due to end-users encountering multiple obstacles such as deficiencies in funding, data, access to experts (taxonomic and ecological), and education. The surveyed end-users encompassed industry, government, NGOs and working groups, with at least two responses from each sector, and the majority being government (5) and NGOs (5).

End-users believed that the predominant reasons for not incorporating insects into management of their particular landholdings or projects were primarily due to the deficiency of data on insects in their region, including taxonomy, some of the inter-related reasons for insects subsequently being logistically difficult to work with and assess (Figure 23a). Although not explicitly questioned, a few end-users mentioned a lack of funding precluding any work on insects. When asked what would motivate them to consider insects, similar topics rated highly; such as access to data, taxonomists, and entomological experts (Figure 23b). The highest ratings were given to cost-effective management options (i.e. monetary fields, affordable solutions) and insects that were shown to be of functional importance.

The discrepancy between reasons for not including insects (lack of knowledge) and the motivation for end-users to consider insects (value for money, functional importance) can perhaps be explained by the list of options that the end-users were presented with in the first question; “expense” was presented as one of several options available. If “grants and other funding” was presented as an option we would perhaps expect to see higher responses to it, and as it was, end-users needed to specify this under the option of “other reasons”.

The presence of functionally important insects in the end-users land holding and the availability of cost-effective management methods that add value to existing management projects would undoubtedly result in more active insect management. However, many of these areas are inter-related and stem from a lack of entomologists. Few entomologists means that the insect fauna is poorly known, including the functional importance any particular species, and logistically difficult to work with; therefore, any subsequent study on insects is more expensive due to these constraints.

(a)



(b)

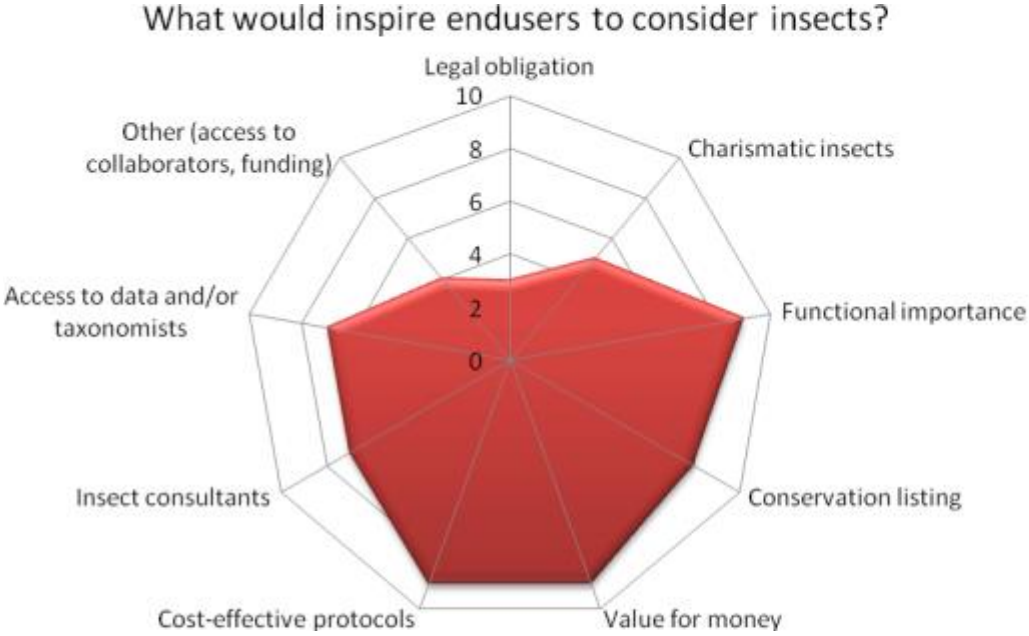


Figure 23: End-users perspective on (a) reasons for end-users not considering insects in management plans and (b) incentives for end-users to consider including insects in management plans

3.8.2 Management Framework

From the feedback obtained from the various organisations an adaptation management framework was constructed (Figure 24). It is envisaged that the few simple additional steps featured in the insect adaptation management framework can be easily incorporated into future end-user management plans. Whilst this framework was initially developed to assist in managing climate change scenarios, it can also be employed to conserve insects that may be under threat due to other processes (e.g. habitat clearing, *Phytophthora* dieback disease, inappropriate fire regimes, etc). Examples of the management framework in use are illustrated in Figures 25, 26 and 27 with several key insect species from this project; *Acizzia veski*, *Trioza* sp. 30 and *Gomonella* sp. 8.2. We discuss each in detail below.

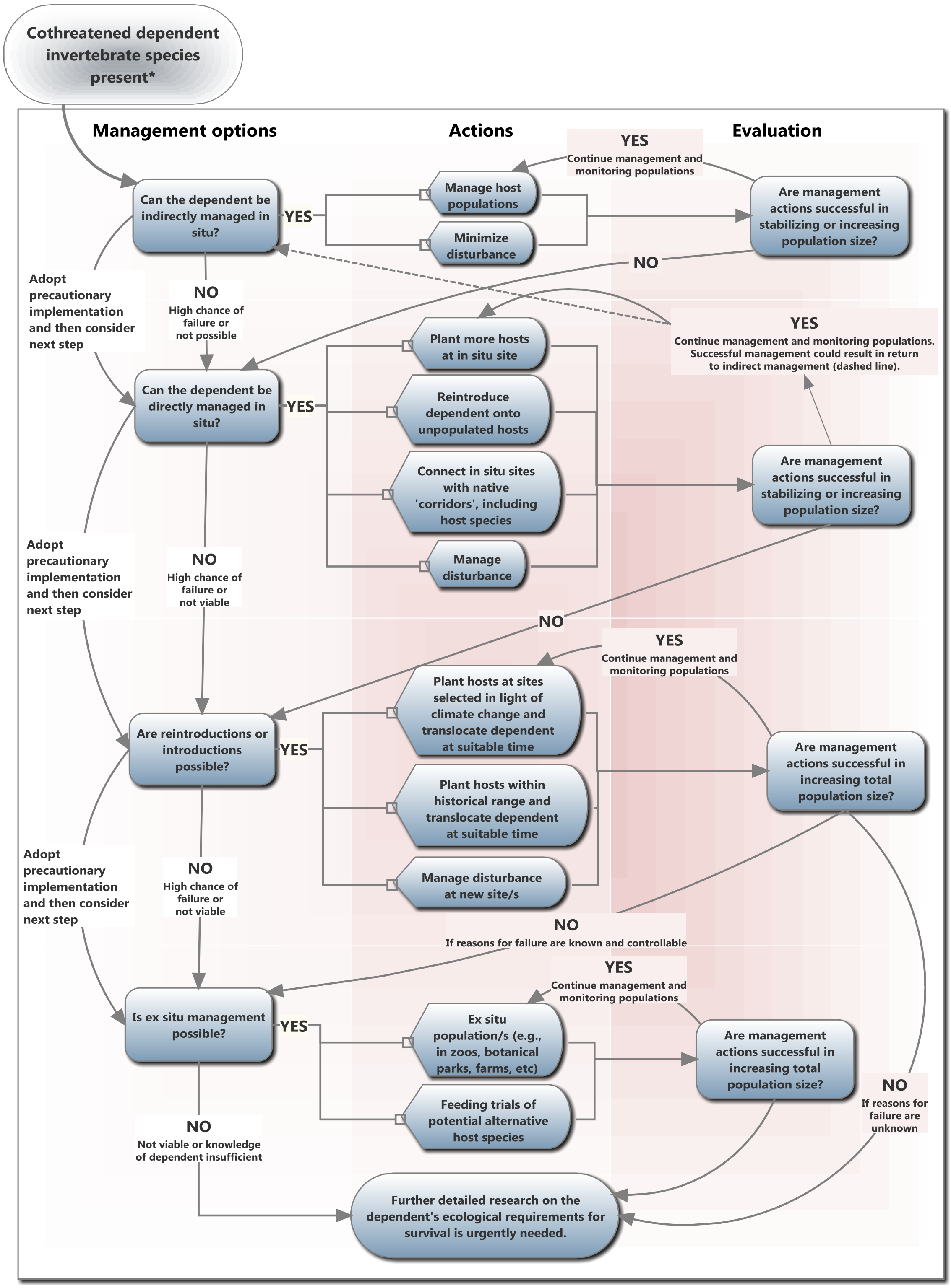


Figure 24: Management framework for threatened plant dwelling invertebrate species

***Acizzia veski* (Vesks' plant-louse)**
As mentioned earlier in section 4.7.1, *A. veski* is found only on *Acacia veronica*, a plant having Priority 3 conservation status. As there are healthy population stands of *A. veronica* present in the SRNP, it is possible to directly manage *A. veski in situ* by adopting a precautionary approach. Because currently *A. veski* is found on only one of 10 known populations of *A. veronica*, direct management has been conducted by protecting the existing *A. veronica* populations against disturbance. In addition, *A. veski* has been subjected to trial reintroductions to two unpopulated *A. veronica* stands in the SRNP.

***Trioza* sp. 30 (*Banksia brownii* plant-louse)**
As mentioned earlier in section 4.7.3, is found only on the critically endangered *B. brownii*. *Banksia brownii* has been the subject of translocation trials by DEC for many years due to its critically endangered conservation status. This is advantageous in the management of *Trioza* sp. 30 as it allows for a wider selection of management actions. Due to *B. brownii* translocation efforts, *Trioza* sp. 30 can be managed in multiple ways. Firstly, *Trioza* sp. 30 is managed indirectly through protecting *in situ B. brownii* populations against disturbance (e.g., controlling the spread of dieback disease). Secondly, the plant-louse can be managed directly by planting more *B. brownii* at existing population sites to increase the host population. Finally, by adopting precautionary implementation, *Trioza* sp. 30 is being reintroduced onto translocated *B. brownii* within *B. brownii* and *Trioza* sp. 30's putative historical range, and the new site is being protected from disturbances. The success of these management techniques is currently unassessed for the plant-louse and should be the focus of future work.

***Gomonella* sp. 8.2 (Whitefly sp. 8.2)**
This whitefly species is found only on the critically endangered plant *Banskia pseudoplumosa*. The plant population is currently in decline, and the whitefly is only known from only one population of the host plant. Precautionary management is urgently required because the chance for global extinction in the wild is high. However, no translocation trials of the host plant are currently known to exist therefore translocation of the whitefly is not possible. Reintroduction is not a reliable conservation option as other native populations of *B. pseudoplumosa* are in decline and there are no reports of successful translocation of lerp insects, which are difficult given their attachment to the host plant. The insect is undescribed and the adult unknown, hence translocating adults is not an option. Knowledge on the whitefly's taxonomy and ecology is urgently required, as is translocation trials of *B. pseudoplumosa*, to present any chance for the survival of both host and insect. Immediate conservation action is imperative as most *Banksia* species' populations are predicted to be negatively impacted by climate change (see Fitzpatrick *et al.* 2008), and *B. pseudoplumosa* is already in decline.

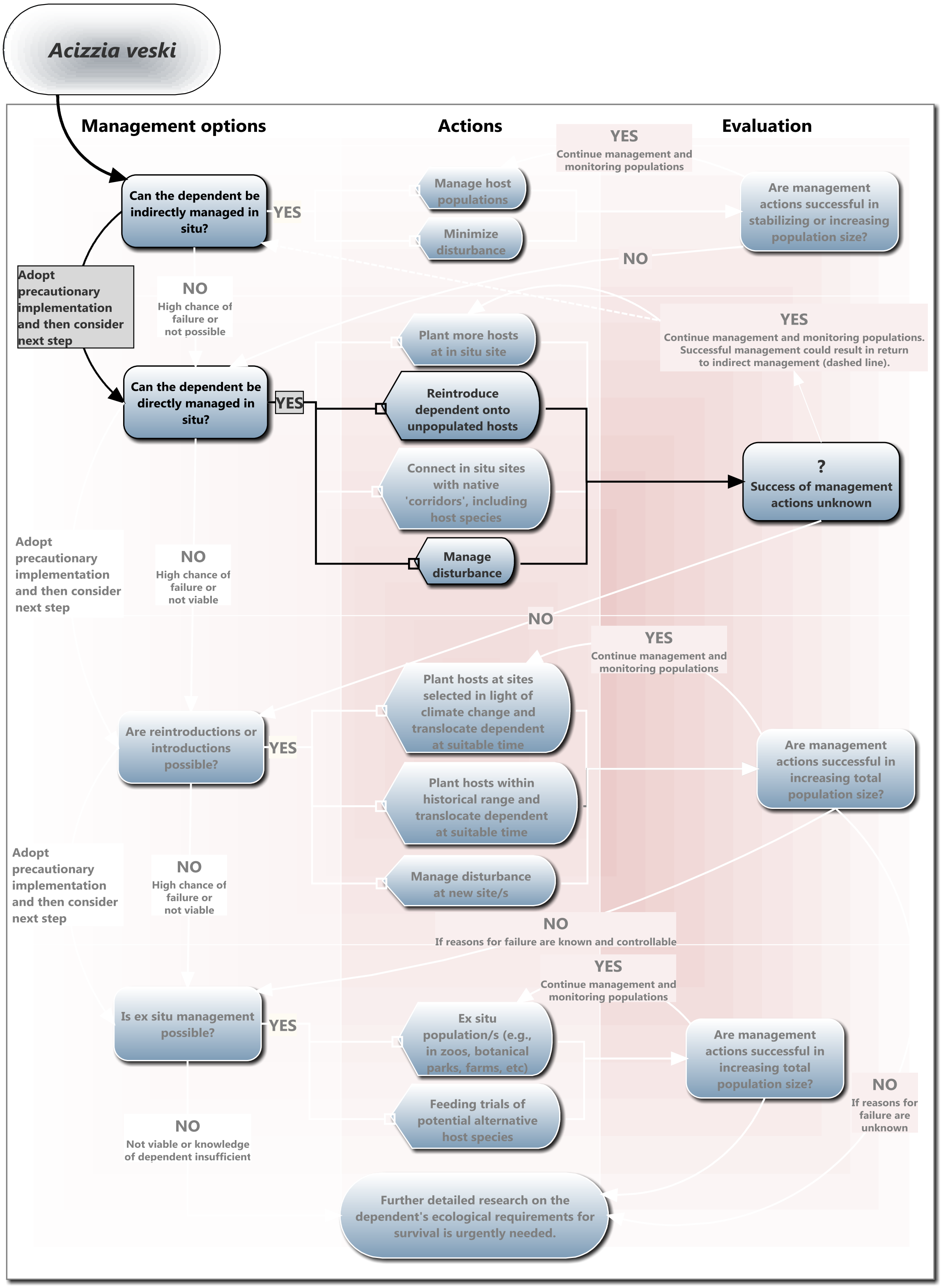


Figure 25: Management framework for *Acizzia veski* (Vesks' plant-louse) on the host plant *Acacia veronica* (Priority 3 conservation status). Highlighted sections denote management actions

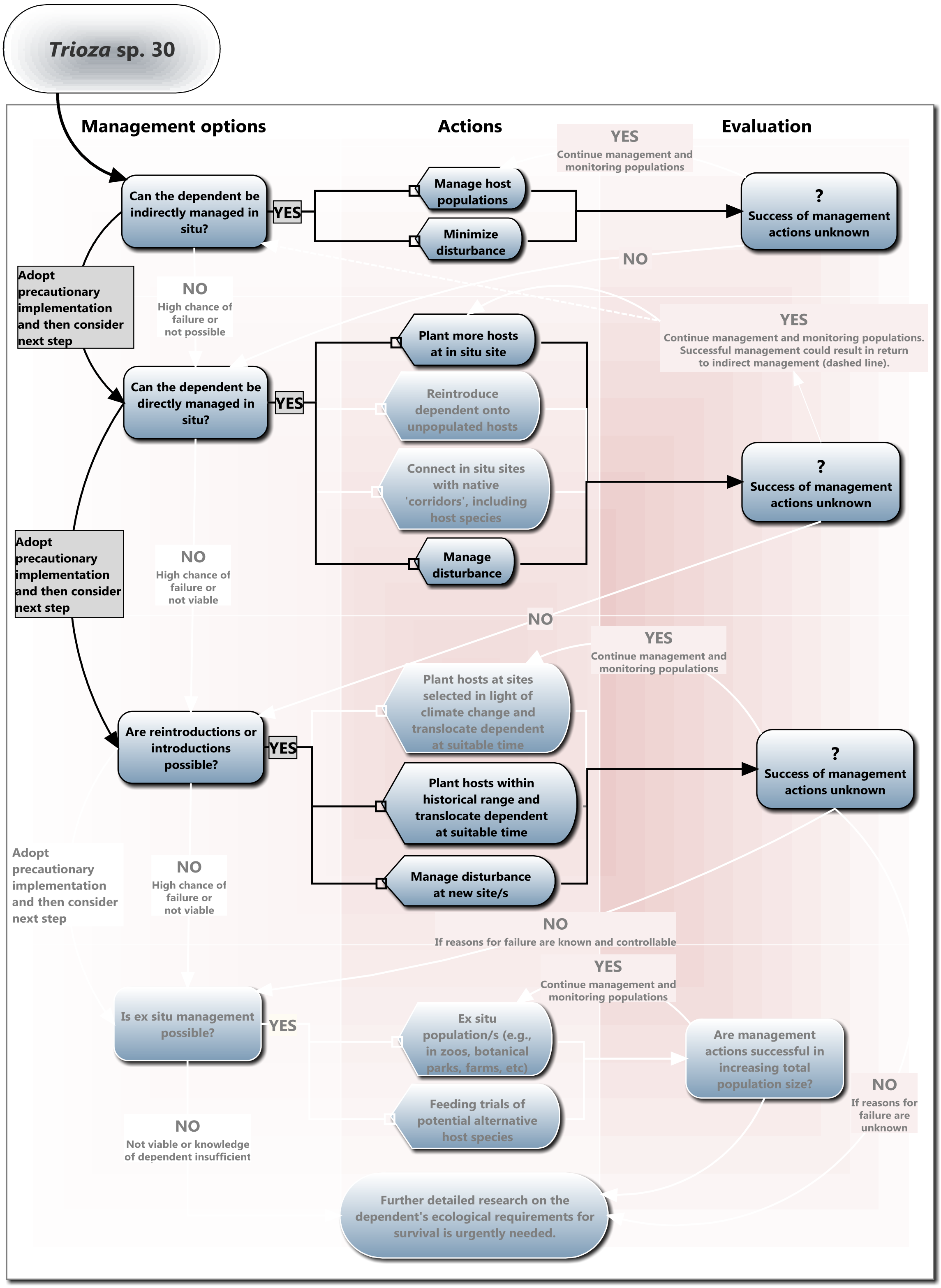


Figure 26: Management framework for *Trioza* sp. 30 (*Banksia brownii* plant-louse) on the critically endangered host plant *Banksia browni*. Highlighted sections denote management actions

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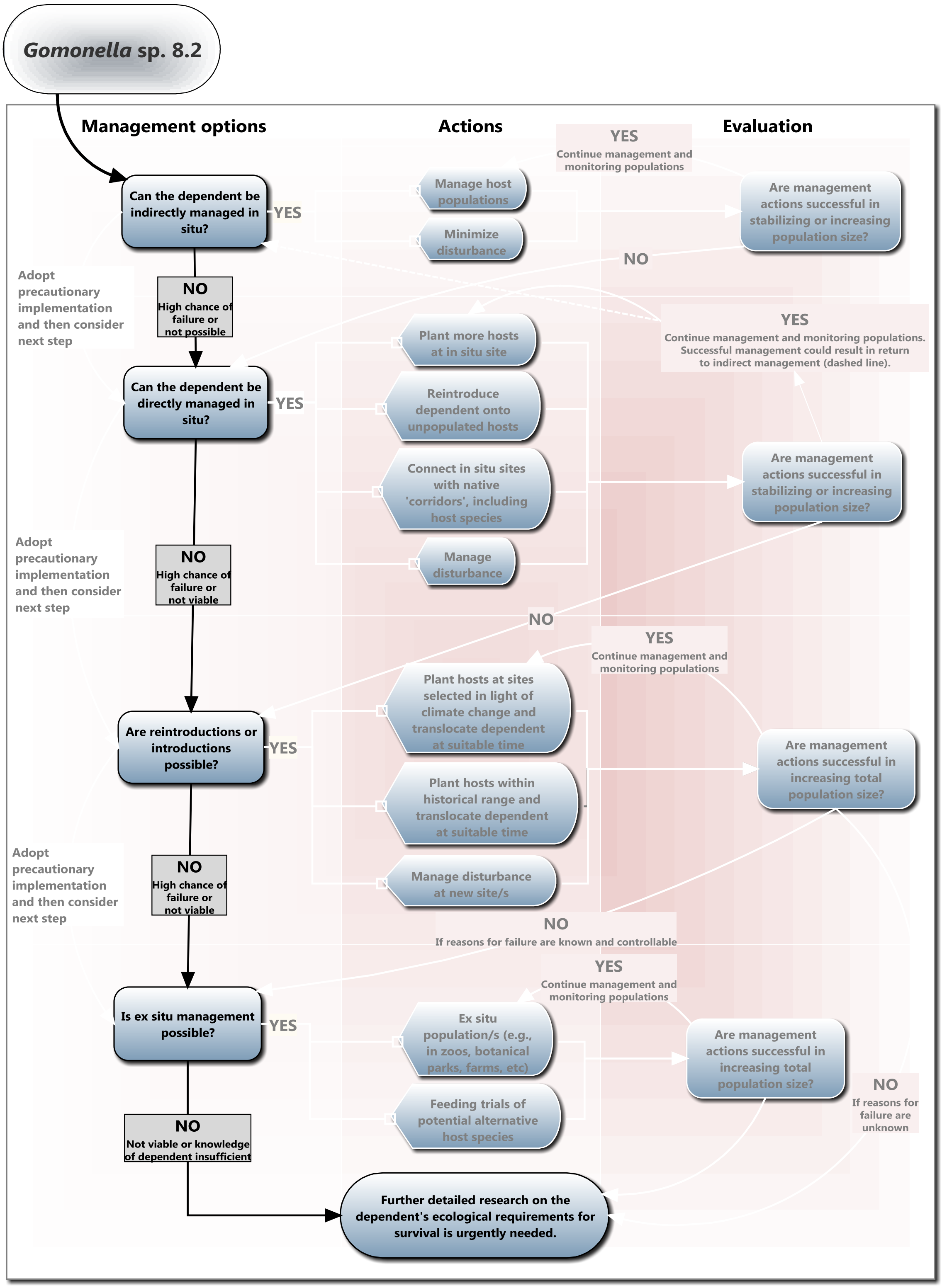

Figure 27: Management framework for *Gomonella* sp. 8.2 (Aleyrodidae whitefly) on the criticially endangered host plant *Banksia pseudoplumosa*. Highlighted sections denote management actions

This project has taken a multifaceted approach to consider the impact on, and management of, plant-dwelling insects as a consequence of a changing climate. We adopted structured decision making (*à la* Possingham 2001; reviewing results regularly

and adapting our field and laboratory investigations in light of these) to develop strategies for end-users to manage the coextinction threat from climate change. Our insect and weather datasets, combined with published literature and expert opinion from our agency partners, was used to assess different combinations of management strategies to minimize the risk of coextinctions in this key component of Australia's terrestrial biodiversity, specifically considering the threat of a changing climate.
Briefly the project has achieved the following:

- measured temperature, humidity and rainfall along multiple altitudinal gradients in the biodiversity hotspot of southwest of Australia, with the primary discovery that climatic variation between minimum and maximum temperature and humidity decreased with altitude in this location,
- correlated the weather data gathered with the insect assemblages on 19 plant species and assessed how climate and insect assemblage changed with altitude on seven of these plants, with the result that the majority of insect assemblages were responding to humidity,
- determined the potential host breadth of 1,019 insect species using novel host breadth models which indicated how many species were host specific to plants at risk of extinction through climate change,
- determined which insect species are most likely at threat of coextinction using the results from the host breadth models, plant threat status and likely insect extinction through climate change, which triggered research into the taxonomy for 22 insect species, and assessment of their management,
- instigated three climate change adaptation strategies (trial reintroductions and introductions) on three key insect species in collaboration with WA DEC,
- publicized the plight of plant-dwelling insects through media (newspaper, radio and magazine) interviews, 4 extension articles, and regular communications with our end-user network of 22 organisations, and
- developed an adaptation management framework designed specifically to assist land managers in deciding on actions to enact to conserve plant-dwelling insects.

This project was conducted in 14 months and as such had time limitations. We are currently in the process of further developing the above achievements, for example, testing the adaptation management framework, following up on management trials, and assessing which correlates increase an insect species' proneness towards coextinction under a changing climate, as is being conducted for plant species (i.e. see Keith *et al*. 2008; Brook *et al*. 2009; Fordham *et al*. 2012).

4 DISCUSSION

4.1 Climate change and insects

4.1.1 Numbers of threatened taxa and host breadth

The majority of insects were not host specific to threatened plant species in the overall database of 1,019 insect species. A total of 8.3 % of all insects were considered of immediate conservation concern because of their host-specificity to range restricted plants. It is possible that the conservation of the insect is of higher priority than the host because there are a number of mechanisms which can lead to the extinction of the insect herbivore before it's host plant is extinguished.

These include mismatch in lifecycles, and different climatic tolerances (we discuss these further in the section below on *Environmental Variables and Insects*). Another mechanism is if the host plant population becomes too small or fragmented to house the insect (see a discussion of this in Moir *et al.* 2010). The host plant population may be reduced or fragmented directly by climate change (e.g., drying wet gullies or mountain tops), or indirectly through disturbances that are synergistically aggravated by climate change, such as wildfire, disease (e.g., *Phytophthora* dieback disease), and explosions of pest species, to name a few.

The 8.3 % of insects that we estimate is threatened does not indicate that coextinction of plant-dwelling insects can be dismissed for several reasons. Firstly, 8.3 % still equates to 85 species, which is a large number, particularly when considering management actions. Secondly, under certain scenarios predicted with climate modelling, even plant species that are currently widespread may face global extinction by 2070 (e.g., *Banksia grandis*: Yates *et al.* 2010), and the 8.3 % of threatened insects estimated in this report does not incorporate monophagous species on wide-spread plants. Fonseca (2009) estimated that the southwest of Australia contains approximately 27,500 species of monophagous insect feeding on the 8,000+ native plant species within this region (i.e. Hopper 2009). Therefore, the loss of even widespread plant species may cause the extinction of insect herbivores. Thirdly, many insect species rely on several related plant species, all of which could go extinct with climate change (see Rezende *et al.* 2007 for a discussion on non-random extinctions of phylogenetic clades). This would result in the loss of these oligophagous insects, in addition to the majority of the monophagous fauna. Thus, based solely on the host breadth, the insects most likely to survive climate change are those species that have a wide host range (i.e. polyphages).

There may be a rescue from extinction for some insect species in the form of host switching or shifting (Moir *et al*. 2010a; Colwell *et al*. 2012). As there are many closely related hosts within the SRNP of the taxa that we analysed (predominantly *Banksia*, *Gastrolobium*, *Grevillea*, *Lasiopetalum*, *Leucopogon* and *Acacia*), host switching should be relatively more common than we observed here and in the southwest in general (Moir *et al*. 2010a). Unfortunately, however, the potential for insects to switch host species was evident only on certain plant species in this study (and for oligophagous insects). Perhaps the insect fauna that were observed to be monophagous have coevolved to such an extent with their current host plant species that they are unable to complete their lifecycles on other hosts. In a historical context, slower extinctions from events such as past climate change may have allowed insects to avoid coextinction through host switching, but current host extinctions occur more rapidly in response to anthropogenic causes (Moir *et al*. 2010a; Colwell *et al*. 2012). This may deny insects time to adapt to new hosts, even if closely related species. Interestingly, host-switching occurs more frequently in feeding trials within the laboratory than is seen in the wild, for example, host range testing of potential biological control insect species often shows that the insect can feed on additional plant species in the proposed introduction area (e.g., McEvoy and Coombs 1999; Kluge and Gordon 2004).

The difference in host-specificity is termed potential versus realised host breadth; realised host breadth is what the insect feeds on in the wild, whereas potential host breadth is the range of plant species that the insect can feed on if given access to these plants (Vesk *et al*. 2010). Although potential new host plants may be available for threatened insect species, even within the insect's current distribution, caution must be taken as the insect must be able to complete all stages of their lifecycle on the new host species for the extinction risk to be alleviated. If feeding trials are conducted as a potential adaptation strategy, the entire insect life-cycle should be assessed for the novel pairing to be considered successful.

Subsequently, a new novel host could be planted in native areas (plant introduction), or translocation areas (plant introduction), or the insect could be introduced onto the new host in the plant's own native range (insect introduction/ assisted migration), as a part of a potential conservation strategy.

4.1.2 Movement rates and dispersal

Recent studies have found that some mountain taxa are moving to higher altitudes at an annual rate of 0.6-8.6 m for plants (Kelly and Goulden 2008; Parolo and Rossi 2008), 1.6 m for Lepidoptera (Chen *et al.* 2009) and 1.9-5.1 m for amphibians and reptiles (Raxworthy *et al*. 2009). A survey by Parmesan and Yohe (2003) across many different taxa found that species are shifting upward by an average of 0.61 m per year, although a more recent study demonstrated significantly higher annual rates of 1.1 m (Chen *et al*. 2011). This may be simply in response to an increase in temperature; for example, a rise of 2.0°C per century with a lapse rate of 1.0°C per 100 m of elevation would result in approximately a 2 m per year migration of temperature zones upward. Migration of taxa depends predominantly both on their ability to disperse and inability to adapt to changes in temperature. A meta-analysis by Parmesan (2006) found that of latitudinal and altitudinal range shifts observed in 1000+ species, taxa with higher dispersal capabilities such as birds, insects and marine invertebrates, were particularly prone to shift their ranges.

Plants, on the other hand, migrate according to how well (or how poorly) they adapt to warmer temperatures (Parolo and Rossi 2008) and how easily they disperse. In terms of dispersal therefore, this implies that insects should generally be able to 'keep up' with the ascending migration by the host plant. There is, however, evidence that parasites and pathogens do not keep up with rapidly migrating host species (such as vertebrate animals) (Philips *et al.* 2010). Similar trends may be seen in insect-plant associations with rapid migration in altitude or latitude as plants may establish but it may take some time for them to develop to a suitable maturity for their associated insects, and time for the insects to find them depending on the distance from inhabitated stands of the host (although see Skou *et al.* 2011). Some sessile insects, such as *Pseudococcus markharveyi* (section 4.6.5) may not be able to locate new host plants that are not connected to the inhabited plant patch. We, therefore, advocate a cautious approach when attempting to generalize the movement of insect herbivores.

Although the upward migration may mean survival for the insect and host plant, migration can bring negative consequences. Such movement usually leads to a reduction in range size of mountaintop species (Forero-Medina *et al*. 2010). Unlike the implications suggested by dispersal rates above, assumptions of insects having good powers of dispersal because they have wings or other obvious mechanisms of movement can often be false. Species that have reduced wings (i.e. are bracyterous) or no wings take significantly longer to disperse even into continuous habitat (e.g., Moir *et al*. 2010b). Furthermore, Wilson and Maclean (2011) note that for insect species currently listed as in need of conservation, most have highly specialized habitat requirements, and such habitat is often highly fragmented. They conclude, therefore, that most such insects will not be able to colonize regions that become climatically favourable, and thus estimates of future distribution sizes should be based on a "no dispersal" scenario. To complicate matters, we have found that insect assemblages on the same plant species can be significantly different on mountains less than 10 km away. This indicates that each plant population must be conserved separately to conserve the entire diversity of insects that rely on that plant species.

Natural migration of insect and plant species to higher altitudes is a moot point when they already occur at the summit. Without human intervention, these communities would most likely be lost to extinction under current climate change predictions, as summit species in other regions have done (e.g., Parmesan 2006). For example, the federally-listed Threatened Ecological Community of montane thicket on the summit of the Eastern Massif of the SRNP (see http://www.environment.gov.au/biodiversity/threatened/communities/east-stirling.html) is threatened by climate change because of lack of suitable migration sites, fragmented habitat and limited capacity of its species to adapt to climatic change (Barrett 2005). Loss of these summit communities will cause consequent coextinctions because, as mentioned above, separate populations of plants have significantly different insect fauna, which would also be extinguished.

4.1.3 Environmental variables and insects

Rainfall, temperature and humidity are predicted to alter significantly in the southwest region of Western Australia with climate change. Specifically it is predicted to become drier in terms of humidity by up to 4 %, approximately 10 % less annual rainfall, and hotter by 2.5°C, by 2070 (CSIRO and Bureau of Meteorology 2007).These changes are not predicted to occur uniformly over the entire year, however. The decrease in humidity is estimated to be the strongest during spring (CSIRO and Bureau of Meteorology 2007), when the majority of insects are active. There will be an estimated 20 % decrease in winter and spring rainfall (according to the 50th percentile outcome of the report by CSIRO and Bureau of Meteorology 2007), which will undoubtedly change the timing of the flowering and growth periods of many of the host plant species in the SRNP, particularly at higher altitudes, as it has done for plant species in better studied regions of the world (there are numerous papers which describe such trends but examples include Fitter and Fitter 2002; Parmesan and Yohe 2003; Wolfe *et al.* 2005). This will most likely cause parallel changes in the insect assemblages on plants (e.g., Altermatt 2010; Illan *et al.* 2012). Extinctions are likely to occur when phenological asynchrony or mismatch between the insect herbivore and the plant host are exacerbated by global warming (see Foden *et al*. 2008 in Kingsford and Watson 2011; Singer and Parmesan 2011).

We found no evidence that a change in altitude *per se* affected the insect assemblages, although environmental variables associated with different altitudes tended to influence the insect assemblage. The environmental variables that consistently featured as influential were humidity and rainfall. Plants that occurred in gullies tended to have insect assemblages that were less influenced by rainfall, presumably as water is not as limiting a factor, being situated in a catchment favoured by additional water inputs from drainage. Generally, the impact of reduced rainfall on plant-dwelling insect species is understudied (Bale *et al*. 2002). All plant species studied, regardless of where they were situated, had insect assemblages that were influenced by humidity in some form.

Our results indicate that the most important climatic variable in this region for the composition of insect assemblages on the majority of plants is humidity. Insect species on plants at higher altitudes may be confined to higher altitudes by favourable (higher) humidity. Montane species may have lower tolerance for dry conditions just as tropical range-restricted species have much lower tolerance than their temperate counterparts (Chown *et al.* 2011; Hoffmann and Sgro 2011). Such climatic tolerances in insects are linked to evolutionary conservative climate responses, thus adaptation to new climatic conditions will not be rapid (Kellermann *et al*. 2012b). Minimum humidity differed significantly at around the 850 m band in our study region, with the montane heath at these altitudes rarely experiencing humidity under 50 %, whereas lowland sand plain heath (< 400 m) did not experience minimum humidity above 50 % (Figure 2b). Future analysis on the environmental tolerances of the key insect species here may find that minimum humidity levels of 50 % are the determinants for survival.

Although humidity and rainfall were the predominant influential factors, temperature cannot be dismissed and remained influential for insect assemblages on two plant species, both of which were found in gullies. Studies on plant-dwelling insects have shown that responses to variations in temperature can be complex. Ashton *et al.* (2009) found that elevational changes in phenology influenced the temperatures experienced by caterpillars, and could affect the selection of host plant species and microhabitat. The caterpillars were actively selecting host plants and microhabitats depending on where they were situated (open versus shaded) due to their differing requirements for thermoregulation at higher altitudes. It is possible that some of the 1000+ species from the SRNP encompassed in this report were actively selecting plant species or individual plants in a similar way, however, our sampling regime and methods were too coarse to assess this. Assuming host plants are available, climatic warming will allow the majority of insect species to extend their ranges to higher altitudes (e.g., 2.5°C may equate to 250 m upward movements according to published studies, see section above on dispersal and movement). This is because species at lower altitudes in some systems may already encounter greater temperature variation, as we have shown in here (Figure 1), and are able to cope with the temperature fluctuations (Bale *et al.* 2002). We recognize that our finding of less temperature and humidity fluctuations at higher altitudes is not a consistent generalisation. For example, tropical systems may display opposite trends with greater climatic fluctuations with increasing altitude.

Thermal safety margins of lowland tropical species have been shown to be small, which places them at higher risk of extinction from climate change (e.g., Deutsch *et al.* 2008; Kellermann *et al*. 2012a). Alternatively alpine and subalpine regions may have large variations in climatic variables such as temperature (e.g., Steinacher and Wagner 2012). It is for this reason that we call for further study across different systems within Australia (section 6 below). Taxa that exist in hot and dry environments have an increased heat tolerance relative to species from wetter areas, and such traits are strongly constrained phylogenetically, meaning that species can not quickly adapt to a changing climate (Kellermann *et al*. 2012a, b). Those with restricted climatic ranges, particularly mountain-top and cold-requiring species, are likely to be more vulnerable to extinction (Bale *et al.* 2002), and require range shifts to survive (Kellermann *et al.* 2012a). Temperatures increasing by less than 1.5°C may increase mortality rates in insect egg and larval stages (Merrill *et al*. 2008). In addition, an increase in temperature of as little as 0.5–1.5°C is anticipated to cause the extinction of some plant species, and a decline in many other species, including many taxa that do not occur on mountains (Hughes 2003; Fitzpatrick *et al.* 2008; Summers *et al.* 2012).

4.1.4 Summary

Insects should generally be able to ‘keep up’ with migration to different altitudes by the host plant, provided the habitat is not overly fragmented. The question becomes whether the insect can tolerate the consequent environmental differences that are then experienced by their particular host plant. The insects most likely to survive climate change are those with both a wide host range and tolerance to a range of environmental conditions (e.g., changed temperature, humidity regimes, etc). Complex interactions that determine the survival of the host plant with climate change, such as life history, disturbance regime and distribution pattern (see Keith *et al*. 2008; Fordham *et al*. 2012) will be exacerbated for the plant-dwelling insects.
This is because the insect’s survival depends on both factors determining the survival of the plant, as well as interactions with factors influencing their own survival. For example, climatic range sets the lower altitudinal limit for the black-veined white butterfly, *Aporia crataegi*, in Spain, whereas lack of host plants set the upper limit (Merrill *et al*. 2008).

We suggest that the altitudinal range of 700-900m is where the signal of future climate change may be most apparent, with this region an obvious transition zone in plant species in the SRNP, and this altitudinal band displays the most significant transition between climatic variables studied here. The results presented in this report are applicable to other Australian systems as many mountains, such as the Blue Mountains, are of similar height (1,100 m). Only a small proportion of mountains in Australia rise above 1,500 m (37 % of mountains across Qld, NSW, ACT, Vic and WA: see Appendix 4). Insect assemblages may give varying results with higher altitude in these mountain ranges, particularly within different climatic systems. Some of these regions, especially alpine and tropical mountains, are predicted to be the most vulnerable to climate change (Hughes 2003, 2011), and studying changes in insect assemblages in these systems should be the focus of future research.

4.2 Translocations

Translocation and *ex situ* conservation (see definitions as outlined in Moir *et al.* 2012a) of threatened host species may increase probabilities of persistence of dependent species, but in most cases the dependents cannot recolonise the hosts independently in any reasonable time and require human intervention to move them onto the translocated hosts (Moir *et al*. 2012a). Dependent species with simple life cycles and high host-specificity are good candidates for conservation via movement with their hosts (Moir *et al*. 2012a), although success may be dependent upon monitoring and prerelease actions undertaken to maximize the probability of successful translocation of the dependent species (New 1994). The *ex situ* translocation site at Kamballup is a good initial test of insect translocations because it is well connected historically to the source populations, but is currently surrounded by human-dominated landscapes that might be a barrier if the translocated species has unacceptable effects (Hunter 2007). The latter would limit the spread of the translocated insects.

Thus, the next step in the translocation trials undertaken through this project is to assess the number of progeny of the translocated insects in April 2013 (for those insects with two generations per year) and October 2013 (for both insect species with multiple and single generations per year). Further supplementation of individuals may be required, or given a population crash at the translocation site, further research into potential inhibitory factors such as differences in climate and the associated physiological requirements of the insects themselves (New 2008), may need to be investigated. An example of this was provided by the current study, in which the translocated *Banksia montana* mealybug population crashed, indicating that nymphs are physiologically less robust than adults, and a second attempt has been made with adults. Such additional knowledge will be included into the management framework. Incorporating knowledge as it is acquired will assist in determining the most appropriate way forward in conserving these particular threatened taxa, and more generally provide examples for differing management requirements of plant-dwelling insects.

Given the immediate threats to these host plants in the wild, from multiple threatening processes — climate change being just one (see Barrett *et al*. 2008) — and the fact that populations of host-specific insects may decline faster than that of their hosts (e.g., Taylor and Moir 2009; Moir *et al*. 2010a), conservation actions to assist in the insects' survival are required urgently (Moir *et al*. 2012b).

Using our dataset we have already provided a framework in assessing those species most at risk of coextinction (Moir *et al*. 2011a). An earlier study by us (Moir *et al*. 2012a) also provided the first step in the development of an adaptive management strategy that guides a structured process of learning by doing (e.g., Keith *et al*. 2011) to improve translocation outcomes for dependent invertebrate fauna as well as their threatened plant hosts. translocation).

5 GAPS AND FUTURE RESEARCH

Plant-dwelling insect conservation methods are in their infancy. In fact, most land managers are struggling to understand which insect species currently reside within their lease-hold or lands, let alone which are in need of conservation actions. This problem is not restricted to land managers; even specialist entomologists struggle to identify which insect species could be threatened and then have the time or capacity to highlight their plight in the form of conservation nominations. This is evident by the very low numbers of insect species listed on conservation schedules: 10 insects from a total of 446 listed fauna on the Australian Federal list; 6 insects listed from 240 Western Australian State Government listed fauna (see Appendix 2); and 38 Australian insect species listed as threaten by the IUCN (IUCN 2012). The situation is exacerbated by two factors; 1. Insect taxonomists are currently overworked, a situation which is deteriorating as specialists retire and are not replaced, and 2. the funds available to work on insects, including ecological and taxonomic research, are meagre (Cranston 2010). As highlighted by our broad end-user group of 22 governmental, non-governmental, and industry organisations, both funds and resources (particularly trained entomologists) are lacking and this prevents the management and conservation of insects.

To assist land managers with this problem, we suggest the employment of dedicated conservation entomologists within each state and territory (perhaps funded jointly by State and Federal governments but located in the relevant state government's environmental conservation department), who would be charged with bridging the interface between taxonomists, government conservation bodies, land managers and disturbance ecologists. Their primary job would be to identify those insects most at risk of extinction, nominate them for state and federal listing (the latter under the Environmental Protection and Biodiversity Conservation Act 1999, the legislation for state listings depend on the particular state), and develop management plans to secure their survival. To date, zoologists or ecologists who find themselves in this role are often preoccupied (frequently due to political and social pressures) with the more public-friendly vertebrates, particularly mammals and birds, and occasionally charismatic invertebrates, such as trapdoor spiders and butterflies. The vast majority of plant-dwelling invertebrates, such as beetles, bugs, grasshoppers, thrips, moths, wasps, flies, and domatia mites, are largely overlooked or left for specialist taxonomists to promote their cause. We also suggest that this body of conservation entomologists form a working group that meets regularly to discuss cases and provide a formal active front for Australian insect conservation. One method to assess the success of conservation entomologists would be to evaluate listings on threatened species lists, and assess when the lists begin to realistically reflect the contribution insects make toward biodiversity (approximately 25 % of terrestrial species are plant-dwelling insects, while invertebrates contribute over 99 % of the world's biodiversity; Ponder and Lunney 1999).

A limitation with our study was that in assessing variation in the insect assemblages on plant species, we predominantly adopted different mountains to represent different altitudes; therefore, host plant populations often occurred on different mountains. Initially we believed this to be the best experimental design for two reasons. Firstly, mountains were relatively close together (~10 km), and as many plant-dwelling insect species are winged and have good powers of dispersal, we assumed that colonisation of different populations of the same host plant species would not be a limiting factor. Previous studies have shown that herbivorous insects are more widespread across mountains than other guilds, even when associated with rare habitat (e.g., Niemelä and Baur 1998).

Also, a study of the beetles of Argentinean Mountains showed that species were specific to different vegetation types rather than specific mountains (Werenkraut and Ruggiero 2013).

Secondly, a plant population on any one mountain was often continuous across altitudes and therefore sub-sampling within this one population would result in pseudo-replicated samples. However, surprisingly, insect assemblages on mountains tended to be significantly different from one mountain to another, regardless of the altitude, and despite the small distances between mountains. Significantly different insect fauna on different mountains has been shown by other studies previously, but predominantly for flightless insects (e.g., Bruhl 1997; Yeates *et al.* 2002). The majority of our herbivorous insect species were capable of flight. The differences between assemblages were particularly evident when assessing populations on different mountains but at similar altitudes. For future studies assessing possible climatic impacts on plant-dwelling insects in Australia, we recommend assessing herbivorous insect assemblages across multiple altitudes within any one plant population, and include replicates on different mountains if possible. It is also essential that the insects are identified to species-level where possible, as this information can elicit additional information such as pest from native species, wide-spread from rare species.

Because of the dire predictions of changes in climate over the next 60 years or so, some areas of future research, beyond the basic taxonomy and ecology of the large majority of Australia's plant-dwelling fauna, are urgently required. Firstly, we need to understand how plant-dwelling insect assemblages and climatic conditions vary with altitude in other systems such as tropical and alpine ranges in eastern Australia, and arid ranges, such as are found in central Australia. Do insect herbivores, for example, simply track their host plant's range, or are they limited by climatic, spatial, or other factors?

This would allow us to develop generalisations of where the most extinctions of plant-dwelling invertebrates are likely to occur under a changing climate. Secondly, the impact of synergistic disturbances (e.g., disease, fire, invasive species, etc) on plant and plant-dwelling fauna communities requires research, as climate change alone may not cause many extinctions, however, secondary disturbances exacerbated by climate change could extinguish a large proportion of the biota in a given region. Third, replication and extended monitoring of insect translocation trials is required to determine the success of translocations in the conservation of insect species. Future trials with insects having different feeding modes (such as chewers and burrowers) would also be useful to extend the management framework to different types of insects.

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APPENDIX 1 – PLANT SPECIES LIST

Order	Family	Genus	Species	Conservation Status (Letters indicate WA Gov., asterisk indicate Federal Gov ***CR, **E, *V)	No. sites present	No. of plants sampled
Fagales	Casuarinaceae	*Allocasuarina*	*humilis*		1	14
	Cyperaceae	*Lepidosperma*	'Bluff Knoll robust'		1	14
	Dilleniaceae	*Hibbertia*	*gracilipes*		1	14
Ericales	Ericaceae	*Andersonia*	*axilliflora*	R**	1	30
Ericales	Ericaceae	*Andersonia*	*echinocephala*	P3	3	42
Ericales	Ericaceae	*Astroloma*	*epacridis*		1	14
Ericales	Ericaceae	*Astroloma*	*pallidum*		1	14
Ericales	Ericaceae	*Leucopogon*	*atherolepis*		3	42
Ericales	Ericaceae	*Leucopogon*	*australis*		3	42
Ericales	Ericaceae	*Leucopogon*	*cucullatus*		1	14
Ericales	Ericaceae	*Leucopogon*	*gibbosus*		1	14
Ericales	Ericaceae	*Leucopogon*	*gnaphaloides*	R**	2	45
Ericales	Ericaceae	*Leucopogon*	*lasiophyllus*	P2	3	90
Ericales	Ericaceae	*Leucopogon*	*oppositifolius*		1	14
Ericales	Ericaceae	*Leucopogon*	*interstans*		1	14
Ericales	Ericaceae	*Leucopogon*	sp. 'short style'		1	30
Ericales	Ericaceae	*Leucopogon*	*tamariscinus*		1	30
Ericales	Ericaceae	*Dielsiodoxa*	*tamariscina*	P2	1	14
Ericales	Ericaceae	*Sphenotoma*	sp 'Stirling'	P3	2	28
Fabales	Fabaceae	*Acacia*	*acuminata*		1	14
Fabales	Fabaceae	*Acacia*	*baxteri*		1	14
Fabales	Fabaceae	*Acacia*	*browniana var. intermedia*		1	14
Fabales	Fabaceae	*Acacia*	*celastrifolia*		1	14
Fabales	Fabaceae	*Acacia*	*drummondi*		3	42
Fabales	Fabaceae	*Acacia*	*ferocior*		1	14
Fabales	Fabaceae	*Acacia*	*pulchella*		1	14
Fabales	Fabaceae	*Acacia*	*subcaerulea*		1	14

Order	**Family**	**Genus**	**Species**	**Conservation Status (Letters indicate WA Gov., asterisk indicate Federal Gov ***CR, **E, *V)**	**No. sites present**	**No. of plants sampled**
Fabales	Fabaceae	*Acacia*	*veronica*	P3	6	180
Myrtales	Myrtaceae	*Beaufortia*	*anisandra*		1	14
Myrtales	Myrtaceae	*Calothamnus*	*montanus*		1	14
Myrtales	Myrtaceae	*Calothamnus*	*preissii*		1	14
Myrtales	Myrtaceae	*Darwinia*	*wittwerorum*	R**	1	14
Myrtales	Myrtaceae	*Eucalyptus*	*talyuberlup*		1	14
Myrtales	Myrtaceae	*Kunzea*	*montana*		2	28
Myrtales	Myrtaceae	*Kunzea*	*recurva*		1	14
Myrtales	Myrtaceae	*Leptospermum*	*erubescens*		1	14
Myrtales	Myrtaceae	*Melaleuca*	*blaerifolia*		1	14
Fabales	Fabaceae	*Aotus*	*genistoides*		1	14
Fabales	Fabaceae	*Bossiaea*	*linophylla*		1	14
Fabales	Fabaceae	*Bossiaea*	*ornata*		1	14
Fabales	Fabaceae	*Daviesia*	*incrassata* subsp. *incrassata*		1	14
Fabales	Fabaceae	*Daviesia*	*trigonophylla*		1	14
Fabales	Fabaceae	*Eutaxia*	*parvifolia*		1	14
Fabales	Fabaceae	*Gastrolobium*	*bilobum*		1	14
Fabales	Fabaceae	*Gastrolobium*	*crenulatum*	P2	3	90
Fabales	Fabaceae	*Gastrolobium*	*leakeanum*	P2	2	60
Fabales	Fabaceae	*Gastrolobium*	*luteifolium*	R***	2	60
Fabales	Fabaceae	*Gastrolobium*	*pulchellum*	P2	2	28
Fabales	Fabaceae	*Gastrolobium*	*rubrum*		3	42
Fabales	Fabaceae	*Gastrolobium*	*tetragonophyllum*		2	28
Fabales	Fabaceae	*Gastrolobium*	*vestitum*	R	1	30
Fabales	Fabaceae	*Gompholobium*	*scabrum*		1	14
Fabales	Fabaceae	*Jacksonia*	*grevilleoides*		1	14
Fabales	Fabaceae	*Latrobea*	*elliptica*	P2	1	14
Fabales	Fabaceae	*Latrobea*	*hirtella*		1	14
Fabales	Fabaceae	*Mirbelia*	*dilatata*		2	28

Order	**Family**	**Genus**	**Species**	**Conservation Status (Letters indicate WA Gov., asterisk indicate Federal Gov ***CR, **E, *V)**	**No. sites present**	**No. of plants sampled**
Apiales	Pittosporaceae	*Billardiera*	*drummondi*		1	14
Apiales	Pittosporaceae	*Billardiera*	*fusiformis*		1	14
Proteales	Proteaceae	*Banksia*	*aculeata*	P2	1	30
Proteales	Proteaceae	*Banksia*	*brownii*	R**	5	135
Proteales	Proteaceae	*Banksia*	*caleyi*		1	14
Proteales	Proteaceae	*Banksia*	*grandis*		3	42
Proteales	Proteaceae	*Banksia*	*lemanniana*		1	14
Proteales	Proteaceae	*Banksia*	*littoralis*		1	14
Proteales	Proteaceae	*Banksia*	*oreophila*		3	42
Proteales	Proteaceae	*Banksia*	*solandri*	P4	3	90
Proteales	Proteaceae	*Banksia*	*sphaerocarpa* var. *sphaerocarpa*		2	28
Proteales	Proteaceae	*Banksia*	*anatona*	R**	1	30
Proteales	Proteaceae	*Banksia*	*biterax*		1	14
Proteales	Proteaceae	*Banksia*	*drummondii* subsp. *drummondii*		1	14
Proteales	Proteaceae	*Banksia*	*falcata*		1	14
Proteales	Proteaceae	*Banksia*	*foliolata*	P4	2	60
Proteales	Proteaceae	*Banksia*	*formosa*		3	42
Proteales	Proteaceae	*Banksia*	*hirta*	P3	2	60
Proteales	Proteaceae	*Banksia*	*montana*	R**	2	22
Proteales	Proteaceae	*Banksia*	*plumosa* subsp. *denticulata*		1	14
Proteales	Proteaceae	*Banksia*	*polycephala*		1	14
Proteales	Proteaceae	*Banksia*	*pseudoplumosa*	R**	1	30
Proteales	Proteaceae	*Banksia*	*sessilis* var. *sessilis*		3	42
Proteales	Proteaceae	*Grevillea*	*anethifolia*		1	14
Proteales	Proteaceae	*Grevillea*	*depauperata*		3	42
Proteales	Proteaceae	*Grevillea*	*fasiculata*		1	14
Proteales	Proteaceae	*Grevillea*	sp. 'Stirling'	P2	2	60
Proteales	Proteaceae	*Grevillea*	*teretifolia*		2	28
Proteales	Proteaceae	*Hakea*	*ambigua*		1	14

Order	**Family**	**Genus**	**Species**	**Conservation Status (Letters indicate WA Gov., asterisk indicate Federal Gov ***CR, **E, *V)**	**No. sites present**	**No. of plants sampled**
Proteales	Proteaceae	*Hakea*	*baxteri*		1	14
Proteales	Proteaceae	*Hakea*	*corymbosa*		2	28
Proteales	Proteaceae	*Hakea*	*florida*		3	42
Proteales	Proteaceae	*Hakea*	*trifurcata*		2	28
Proteales	Proteaceae	*Hakea*	*undulata*		1	14
Proteales	Proteaceae	*Hakea*	*varia*		2	28
Proteales	Proteaceae	*Petrophile*	*heterophylla*		1	14
Proteales	Proteaceae	*Petrophile*	*serruriae*		1	14
	Restionaceae	*Anarthria*	*prolifera*		1	14
Rosales	Rhamnaceae	*Trymalium*	*odoratissimum* subsp. *trifidum*		1	14
Rosales	Rhamnaceae	*Trymalium*	*ledifolium* var. *rosmarinifolium*		1	14
Malvales	Malvaceae	*Lasiopetalum*	*cordifolium*		1	14
Malvales	Malvaceae	*Lasiopetalum*	*dielsii*	P2	4	120
Malvales	Malvaceae	*Lasiopetalum*	*membraniflorum*	P2	1	30
Malvales	Malvaceae	*Lasiopetalum*	*monticola*	P3	1	30
Malvales	Malvaceae	*Lysiosepalum*	*involucratum*		1	14
Malvales	Malvaceae	*Thomasia*	*foliosa*		3	42
Malvales	Malvaceae	*Thomasia*	sp. 'Toolbrunup'	P3	4	120
	Elaeocarpaceae	*Tremandra*	*stelligera*		1	14
Asparagales	Xanthorrhoeaceae	*Xanthorrhoea*	*platyphylla*		1	14
				Total	105 species	3086 individuals
				Total threatened	27	1542
				Total non-threatened	78	1544

APPENDIX 2 – WESTERN AUSTRALIAN GOVERNMENT, WILDLIFE CONSERVATION

(SPECIALLY PROTECTED FAUNA) NOTICE 2012

6 November 2012 GOVERNMENT GAZETTE, WA
5295

CONSERVATION

CO301*

Wildlife Conservation Act 1950

Wildlife Conservation (Specially Protected Fauna) Notice 2012(2)

Made by the Minister for the Environment under section 14(4) of the Act.

1. Citation

This notice may be cited as the *Wildlife Conservation (Specially Protected Fauna) Notice 2012(2)*.

2. Interpretation

In this notice —

“taxon” includes any taxon that is described by a family name or a genus name or any other name or description.

Note: The plural form of “taxon” is “taxa”.

3. Declaration of specially protected fauna

For the purposes of the Act, all taxa of the fauna —

(a) specified in Schedule 1, being fauna that is rare or likely to become extinct, are declared to be fauna that is in need of special protection;

(b) specified in Schedule 2, being fauna that is presumed to be extinct, are declared to be fauna that is in need of special protection;

(c) specified in Schedule 3, being birds that are subject to an agreement between the government of Australia and the governments of Japan, China and the Republic of Korea relating to the protection of migratory birds, are declared to be fauna that is in need of special protection; and

(d) specified in Schedule 4, are declared to be fauna that is in need of special protection, otherwise than for the reasons mentioned in paragraphs (a), (b) and (c).

4. Revocation

The *Wildlife Conservation (Specially Protected Fauna) Notice 2012* is revoked.

Schedule 1 — Fauna that is rare or is likely to become extinct

[cl. 3(a)]

Division 1 — Mammals

	Scientific Name	**Common name**
1.	*Balaenoptera borealis*	Sei Whale
2.	*Balaenoptera musculus*	Blue Whale
3.	*Balaenoptera physalus*	Fin Whale
4.	*Bettongia lesueur lesueur*	Burrowing Bettong or Boodie(Shark Bay islands)
5.	*Bettongia lesueur* ssp. (WAM M10733)	Burrowing Bettong or Boodie (Barrow Island)
6.	*Bettongia penicillata ogilbyi*	Brush-tailed bettong or Woylie
7.	*Conilurus penicillatus penicillatus*	Pakooma or Brush-tailed rabbit-rat
8.	*Dasycercus cristicauda*	Mulgara or Minyi-minyi
9.	*Dasyurus geoffroii*	Chuditch or Western Quoll
10.	*Dasyurus hallucatus*	Northern Quoll
11.	*Eubalaena australis*	Southern Right Whale
12.	*Isoodon auratus auratus*	Golden Bandicoot or Wintarru (mainland)
13.	*Isoodon auratus barrowensis*	Barrow Island Golden Bandicoot
14.	*Lagorchestes conspicillatus conspicillatus*	Barrow Island Spectacled Hare-wallaby
15.	*Lagorchestes hirsutus bernieri*	Bernier and Dorre Island Rufous Hare wallaby or Mala
16.	*Lagorchestes hirsutus* ssp. (NTM U2430)	Rufous Hare-wallaby or Mala (Tanami Desert)
17.	*Lagostrophus fasciatus fasciatus*	Banded Hare-wallaby or Mernine
18.	*Leporillus conditor*	Greater Stick-nest Rat or Wopilkara
19.	*Macropus robustus isabellinus*	Barrow Island Euro
20.	*Macrotis lagotis*	Dalgyte or Bilby or Ninu
21.	*Mesembriomys gouldii gouldii*	Djintamoonga or Black-footed tree-rat
22.	*Mesembriomys macrurus*	Golden-backed tree-rat
23.	*Megaptera novaeangliae*	Humpback Whale
24.	*Myrmecobius fasciatus*	Numbat or Walpurti
25.	*Notoryctes caurinus*	Kakarratul or Northern Marsupial Mole
26.	*Notoryctes typhlops*	Itjaritjari or Southern Marsupial Mole
27.	*Parantechinus apicalis*	Dibbler
28.	*Perameles bougainville bougainville*	Western Barred Bandicoot or Marl
29.	*Petrogale lateralis hacketti*	Recherche Rock-wallaby
30.	*Petrogale lateralis lateralis*	Black-footed Rock-wallaby or Warru
31.	*Petrogale lateralis* ssp. (ANWC CM15314)	McDonnell Range Rock-wallaby
32.	*Petrogale lateralis* ssp. (WAM M15135)	West Kimberley Rock-wallaby
33.	*Phascogale calura*	Red-tailed Phascogale or Keengoor
34.	*Phascogale tapoatafa* ssp. (WAM M434)	Brush-tailed Phascogale
35.	*Potorous gilbertii*	Gilbert’s Potoroo
36.	*Pseudocheirus occidentalis*	Western Ringtail Possum or Nguara
37.	*Pseudomys australis*	Plains Rat or Palyoora
38.	*Pseudomys fieldi*	Shark Bay Mouse or Djoongari
39.	*Pseudomys shortridgei*	Heath Rat or Dayang
40.	*Rhinonicteris aurantius*	Orange Leaf-nosed Bat

41.	*Setonix brachyurus*	Quokka
42.	*Sminthopsis butleri*	Butler’s Dunnart
43.	*Sminthopsis psammophila*	Sandhill Dunnart
44.	*Zyzomys pedunculatus*	Central Rock-rat or Antina

Division 2 — Birds

	Scientific name	**Common name**
45.	*Anous tenuirostris melanops*	Lesser Noddy
46.	*Atrichornis clamosus*	Noisy Scrub-bird or Tjimiluk
47.	*Botaurus poiciloptilus*	Australasian Bittern
48.	*Calamanthus campestris dorrie*	Dorre Island Rufous Fieldwren
49.	*Calamanthus campestris hartogi*	Dirk Hartog Island Rufous Fieldwren
50.	*Calidris canutus piersmai*	Red Knot (New Siberian Islands)
51.	*Calidris canutus rogersi*	Red Knot (north-eastern Siberia)
52.	*Calidris ferruginea*	Curlew Sandpiper
53.	*Calidris tenuirostris*	Great Knot
54.	*Calyptorhynchus banksii naso*	Forest Red-tailed Black Cockatoo
55.	*Calyptorhynchus baudinii*	Baudin’s Cockatoo
56.	*Calyptorhynchus latirostris*	Carnaby’s Cockatoo
57.	*Catharacta lonnbergi lonnbergi*	Subantarctic Skua
58.	*Cereopsis novaehollandiae grisea*	Recherche Cape Barren Goose
59.	*Charadrius leschenaultia leschenaultia*	Greater Sand Plover (Mongolian)
60.	*Charadrius mongolus*	Lesser Sand Plover
61.	*Dasyornis longirostris*	Western Bristlebird
62.	*Diomedea amsterdamensis*	Amsterdam Albatross
63.	*Diomedea dabbenena*	Tristan Albatross
64.	*Diomedea epomophora*	Southern Royal Albatross
65.	*Diomedea exulans*	Wandering Albatross
66.	*Diomedea gibsoni*	Gibson’s Albatross
67.	*Diomedea sanfordi*	Northern Royal Albatross
68.	*Erythrotriorchis radiatus*	Red Goshawk
69.	*Falco hypoleucos*	Grey Falcon
70.	*Geophaps smithii blaauwi*	Partridge Pigeon (western)
71.	*Leipoa ocellata*	Malleefowl
72.	*Limosa lapponica baueri*	Bar-tailed Godwit (western Alaskan)
73.	Limosa lapponica menzbieri	Bar-talied Godwit (northern Siberian)
74.	*Malurus coronatus coronatus*	Purple-crowned Fairy-wren (western)
75.	*Malurus lamberti bernieri*	Shark Bay Variegated Fairy-wren
76.	*Malurus leucopterus edouardi*	Barrow Island Black and White Fairy-wren
77.	*Malurus leucopterus leucopterus*	Dirk Hartog Island Black and White Fairy-wren
78.	*Numenius madagascariensis*	Eastern Curlew
79.	*Pezoporus flaviventris*	Western Ground Parrot
80.	*Pezoporus occidentalis*	Night Parrot
81.	*Phoebetria fusca*	Sooty Albatross
82.	*Procellaria aequinoctialis*	White-chinned Petrel
83	*Psophodes nigrogularis nigrogularis*	Western Whipbird (Western Heath)
84.	*Puffinus huttoni*	Hutton’s Shearwater
85.	*Rostratula benghalensis australis*	Australian Painted Snipe

86.	*Sterna nereis nereis*	Fairy Tern
87.	*Stipiturus malachurus hartogi*	Dirk Hartog Island Southern Emu-wren
88.	*Thalassarche carteri*	Indian Yellow-nosed Albatross
89.	*Thalassarche cauta*	Shy Albatross
90.	*Thalassarche chlororhynchos*	Atlantic Yellow-nosed Albatross
91.	*Thalassarche chrysostoma*	Grey-headed Albatross
92.	*Thalassarche impavida*	Campbell Albatross
93.	*Thalassarche melanophris*	Black Browed Albatross
94.	*Thalassarche salvini*	Salvin’s Albatross

	Scientific name	**Common name**
95.	*Thalassarche steadi*	White-capped Albatross
96.	*Turnix varia scintillans*	Abrolhos Painted Button-quail

Division 3 — Reptiles

	Scientific name	**Common name**
97.	*Aprasia rostrata rostrata*	Hermite Island Worm Lizard
98.	*Aipysurus apraefrontalis*	Short-nosed Sea Snake
99.	*Aipysurus foliosquama*	Leaf-scaled Sea Snake
100.	*Caretta caretta*	Loggerhead Turtle
101.	*Chelonia mydas*	Green Turtle
102.	*Ctenophorus yinnietharra*	Yinnietharra Rock-dragon
103.	*Ctenotus angusticeps*	Airlie Island Ctenotus
104.	*Ctenotus lancelini*	Lancelin Island Skink
105.	*Ctenotus zastictus*	Hamelin Ctenotus
106.	*Cyclodomorphus branchialis*	
107.	*Dermochelys coriacea*	Leathery Turtle or Luth
108.	*Egernia stokesii aethiops*	Baudin Island Spiny-tailed Skink
109.	*Egernia stokesii badia*	Western Spiny-tailed Skink
110.	*Eretmochelys imbricata*	Hawksbill Turtle
111.	*Lepidochelys olivacea*	Olive Ridley Turtle
112.	*Lerista nevinae*	
113.	*Lerista praefrontalis*	Buccaneer Burrowing Skink
114.	*Liasis olivaceus barroni*	Pilbara Olive Python
115.	*Liopholis kintorei*	Giant Desert Skink
116.	*Liopholis pulchra longicauda*	
117.	*Natator depressus*	Flatback Turtle
118.	*Pogona minor minima*	
119.	*Pseudemydura umbrina*	Western Swamp Tortoise
120.	*Pseudonaja affinis exilis*	Rottnest Island Dugite
121.	*Pseudonaja affinis tanneri*	Pygmy Dugite
122.	*Tiliqua rugosa konowi*	Rottnest Island Bobtail

Division 4 — Frogs

	Scientific name	**Common name**
123.	*Geocrinia alba*	White-bellied Frog
124.	*Geocrinia vitellina*	Orange-bellied Frog
125.	*Spicospina flammocaerulea*	Sunset Frog

Division 5 — Fish

	Scientific name	**Common name**

126.	*Carcharias taurus*	Grey Nurse Shark
127.	*Carcharodon carcharias*	Great White Shark
128.	*Galaxias truttaceus hesperius*	Western Trout Minnow
129.	*Galaxiella munda*	Mud Minnow
130.	*Milyeringa veritas*	Blind Gudgeon
131.	*Nannatherina balstoni*	Balston’s Pygmy Perch
132.	*Ophisternon candidum*	Blind Cave Eel
133.	*Pristis zijsron*	Green Sawfish

Division 6 — Snails

	Scientific name	**Common name**
134.	*Amplirhagada astuta*	
135.	*Austroassiminea letha*	Cape Leeuwin Freshwater Snail
136.	*Carinotrachia carsoniana*	
137.	*Cristilabrum bubulum*	
138.	*Cristilabrum buryillum*	
139.	*Cristilabrum grossum*	
140.	*Cristilabrum isolatum*	
141.	*Cristilabrum monodon*	
142.	*Cristilabrum primum*	
143.	*Cristilabrum rectum*	
144.	*Cristilabrum simplex*	
145.	*Cristilabrum solitudum*	
146.	*Cristilabrum spectaculum*	
147.	*Mouldingia occidentalis*	
148.	*Mouldingia orientalis*	
149.	*Ningbingia australis australis*	
150.	*Ningbingia australis elongata*	
151.	*Ningbingia bulla*	
152.	*Ningbingia dentiens*	
153.	*Ningbingia laurina*	
154.	*Ningbingia octava*	
155.	*Ningbingia res*	
156.	*Ordtrachia elegans*	
157.	*Turgenitubulus christenseni*	
158.	*Turgenitubulus costus*	
159.	*Turgenitubulus depressus*	
160.	*Turgenitubulus foramenus*	
161.	*Turgenitubulus opiranus*	
162.	*Turgenitubulus pagodula*	
163.	*Turgenitubulus tanmurrana*	
164.	Undescribed Rhytidid species (WAM 2295-69)	
165.	*Westraltrachia alterna*	
166.	*Westraltrachia inopinata*	
167.	*Westraltrachia turbinate*	Stirling Range Rhytidid Snail

Division 7 — Arachnids

	Scientific name	**Common name**
168.	*Bamazomus subsolanus*	Eastern Cape Range Bamazomus
169.	*Bamazomus vespertinus*	Western Cape Range Bamazomus

170.	*Draculoides bramstokeri*	Barrow Island Draculoides
171.	*Draculoides brooksi*	Northern Cape Range Draculoides
172.	*Draculoides julianneae*	Western Cape Range Draculoides
173.	*Draculoides mesozeirus*	Middle Robe Draculoides
174.	*Idiosoma nigrum*	Shield-backed Trapdoor Spider
175.	*Indohya damocles*	Cameron’s Cave Pseudoscorpion
176.	*Kwonkan eboracum*	Yorkrakine Trapdoor Spider
177.	*Moggridgea* sp. *(*BY Main 1990/24, 25)	Stirling Range Trapdoor Spider
178.	*Moggridgea tingle*	Tingle Trapdoor Spider
179.	*Paradraculoides anachoretus*	Mesa A Paradraculoides
180.	*Paradraculoides bythius*	Mesa B/C Paradraculoides
	Scientific name	**Common name**
181.	*Paradraculoides gnophicola*	Mesa G Paradraculoides
182.	*Paradraculoides kryptus*	Mesa K Paradraculoides
183.	*Tartarus mullamullangensis*	Mullamullalang Cave Spider
184.	*Tartarus murdochensis*	Murdoch Sink Cave spider
185.	*Tartarus nurinensis*	Nurina Cave Spider
186.	*Tartarus thampannensis*	Thampanna Cave Spider
187.	*Teyl* sp. (BY Main 1953/2683,1984/13)	Minnivale Trapdoor Spider
188.	*Troglodiplura lowryi*	Nullarbor Cave Trapdoor Spider
189.	*Zephyrarchaea mainae*	Main’s Assassin Spider

Division 8 — Crustaceans

	Scientific name	**Common name**
190.	*Abebaioscia troglodytes*	Pannikin Plain Cave Isopod
191.	*Bogidomma australis*	Barrow Island Bogidomma
192.	*Bunderia misophaga*	
193.	*Cherax tenuimanus*	Margaret River Marron
194.	*Danielopolina kornickeri*	
195.	*Engaewa pseudoreducta*	Margaret River Burrowing Crayfish
196.	*Engaewa reducta*	Dunsborough Burrowing Crayfish
197.	*Engaewa walpolea*	Walpole Burrowing Crayfish
198.	*Hurleya* sp. (WAM 642-97)	Crystal Cave Crangonyctoid
199.	*Lasionectes exleyi*	Cape Range Lasionectes
200.	*Liagoceradocus branchialis*	Cape Range Liagoceradocus
201.	*Liagoceradocus subthalassicus*	Barrow Island Liagoceradocus
202.	*Nedsia fragilis*	
203.	*Nedsia humphreysi*	
204.	*Nedsia hurlberti*	
205.	*Nedsia macrosculptilis*	
206.	*Nedsia sculptilis*	
207.	*Nedsia straskraba*	
208.	*Nedsia urifimbriata*	
209.	*Speleophria bunderae*	
210.	*Stygiocaris lancifera*	Lance-Beaked Cave Shrimp
211.	*Stygiocylopia australis*	

Division 9 — Polychaetes

	Scientific name	**Common name**
212.	*Prionospio thalanji*	

Division 10 — Millipedes

	Scientific name	**Common name**
213.	*Atelomastix anancita*	
214.	*Atelomastix brenanni*	
215.	*Atelomastix culleni*	
216.	*Atelomastix danksi*	Toolbrunup Atelomastix Millipede
217.	*Atelomastix dendritica*	Recherche Atelomastix Millipede
218.	*Atelomastix flavognatha*	
219.	*Atelomastix grandis*	
220.	*Atelomastix julianneae*	
	Scientific name	**Common name**
221.	*Atelomastix lengae*	
222.	*Atelomastix longbottomi*	
223.	*Atelomastix melindae*	
224.	*Atelomastix poustiei*	Wedge Hill Atelomastix Millipede
225.	*Atelomastix priona*	
226.	*Atelomastix sarahae*	
227.	*Atelomastix tigrina*	Striped Atelomastix Millipede
228.	*Atelomastix tumula*	Bluff Knoll Atelomastix Millipede
229.	*Cynotelopus notabilis*	Western Australian Pill Millipede
230.	*Epicyliosoma sarahae*	Sarah’s Pill Millipede
231.	*Speleostrophus nesiotes*	Barrow Island Millipede
232.	*Stygiochiropus isolates*	
233.	*Stygiochiropus peculiaris*	Cameron’s Cave Millipede
234.	*Stygiochiropus sympatricus*	

Division 11 — Insects

	Scientific Name	**Common name**
235.	*Acizzia* sp. 70	McCarthy’s plant-louse
236.	*Acizzia veski*	Vesk’s plant-louse
237.	*Leioproctus douglasiellus*	
238.	*Neopasiphae simplicior*	
239.	*Ogyris subterrestris petrina*	Arid Bronze Azure Butterfly
240.	*Trioza* sp. 30	*Banksia brownii* plant-louse

Schedule 2 — Fauna presumed to be extinct

[cl. 3(b)]

Division 1 — Mammals

	Scientific Name	**Common name**
1	*Bettongia pusilla*	Dwarf Nullarbor Bettong
2.	*Chaeropus ecaudatus*	Pig-footed Bandicoot or Kantjilpa
3.	*Lagorchestes asomatus*	Central Hare-wallaby or Kuluwarri
4.	*Leporillus apicalis*	Lesser Stick-nest Rat
5.	*Macrotis leucura*	Lesser Bilby or Tjunpi

6.	*Notomys amplus*	Short-tailed Hopping Mouse or Yoontoo
7.	*Notomys longicaudatus*	Long-tailed Hopping-mouse
8.	*Notomys macrotis*	Big-eared Hopping-mouse
9.	*Onychogalea lunata*	Crescent Nailtail Wallaby or Tjawalpa
10.	*Perameles eremiana*	Desert Bandicoot or Walilya
11.	*Potorous platyops*	Broad-faced Potoroo

Division 2 — Birds

	Scientific name	**Common name**
12.	*Dasyornis broadbenti litoralis*	Rufous Bristlebird
13.	*Rallus pectoralis clelandi*	Lewin's Rail

Division 3 — Snails

	Scientific name	**Common name**
14.	*Bothriembryon praecelsus*	
15.	*Bothriembryon whitleyi*	
16.	*Helicarion castanea*	
17.	*Occirhenea georgiana*	

Division 4 — Insects

	Scientific name	**Common name**
18.	*Hesperocolletes douglasi*	a Short-tongued Native Bee

Schedule 3 — Migratory birds protected under an international agreement

[cl. 3(c)]

	Scientific Name	**Common name**
1	*Acrocephalus orientalis*	Great Reed-Warbler, Oriental Reed-Warbler
2.	*Actitis hypoleucos*	Common Sandpiper
3.	*Anas clypeata*	Northern Shoveler
4.	*Anas querquedula*	Garganey
5.	*Anous stolidus*	Common Noddy
6.	*Apus pacificus*	Fork-tailed Swift
7.	*Ardea ibis*	Cattle Egret
8.	*Ardea modesta*	Great Egret, White Egret
9.	*Ardenna carneipes*	Flesh-footed Shearwater
10.	*Ardenna grisea*	Sooty Shearwater
11.	*Ardenna tenuirostris*	Short-tailed Shearwater
12.	*Arenaria interpres*	Ruddy Turnstone
13.	*Calidris acuminata*	Sharp-tailed Sandpiper
14.	*Calidris alba*	Sanderling
15.	*Calidris alpina*	Dunlin
16.	*Calidris bairdii*	Baird's Sandpiper
17.	*Calidris canutus*	Red Knot, Knot
18.	*Calidris ferruginea*	Curlew Sandpiper

19.	*Calidris mauri*	Western Sandpiper
20.	*Calidris melanotos*	Pectoral Sandpiper
21.	*Calidris minuta*	Little Stint
22.	*Calidris ruficollis*	Red-necked Stint
23.	*Calidris subminuta*	Long-toed Stint
24.	*Calidris tenuirostris*	Great Knot
25.	*Calonectris leucomelas*	Streaked Shearwater
26.	*Catharacta maccormicki*	South Polar Skua
27.	*Charadrius asiaticus*	Caspian Plover
28.	*Charadrius dubius*	Little Ringed Plover
29.	*Charadrius hiaticula*	Ringed Plover
30.	*Charadrius leschenaultia*	Greater Sand Plover, Large Sand Plover
31.	*Charadrius mongolus*	Lesser Sand Plover
32.	*Charadrius veredus*	Oriental Plover
33.	*Chlidonias leucopterus*	White-winged Black Tern, White-winged Tern
34.	*Chlidonias niger*	Black Tern
35.	*Crex crex*	Corncrake
36.	*Cuculus saturatus*	Oriental Cuckoo
	Scientific Name	**Common name**
37.	*Diomedea exulans*	Wandering Albatross
38.	*Egretta sacra*	Eastern Reef Egret
39.	*Fregata andrewsi*	Christmas Island Frigatebird,
40.	*Fregata ariel*	Andrew’s Frigatebird, Lesser Frigatebird
41.	*Fregata minor*	Great Frigatebird
42.	*Gallinago hardwickii*	Latham’s Snipe, Japanese Snipe
43.	*Gallinago megala*	Swinhoe’s Snipe
44.	*Gallinago stenura*	Pin-tailed Snipe
45.	*Glareola maldivarum*	Oriental Pratincole
46.	*Grus antigone*	Sarus Crane
47.	*Haliaeetus leucogaster*	White-bellied Sea-Eagle
48.	*Heteroscelus brevipes*	Grey-tailed Tattler
49.	*Heteroscelus incanus*	Wandering Tattler
50.	*Hirundapus caudacutus*	White-throated Needletail
51.	*Hirundo daurica*	Red-rumped Swallow
52.	*Hirundo rustica*	Barn Swallow
53.	*Hirundo striolata*	Greater Striated Swallow
54.	*Hydrophasianus chirurgus*	Pheasant-tailed Jacana
55.	*Ixobrychus sinensis*	Yellow Bittern
56.	*Limicola falcinellus*	Broad-billed Sandpiper
57.	*Limnodromus semipalmatus*	Asian Dowitcher
58.	*Limosa lapponica*	Bar-tailed Godwit
59.	*Limosa limosa*	Black-tailed Godwit
60.	Merops ornatus	Rainbow Bee-eater
61	*Motacilla alba*	White Wagtail
62.	*Motacilla cinerea*	Grey Wagtail
63.	*Motacilla citreola*	Citrine Wagtail
64.	*Motacilla flava*	Yellow Wagtail
65.	*Numenius arquata*	Eurasian Curlew
66.	*Numenius madagascariensis*	Eastern Curlew
67.	*Numenius minutus*	Little Curlew, Little Whimbrel
68.	*Numenius phaeopus*	Whimbrel
69.	*Oceanites oceanicus*	Wilson’s Storm-Petrel
70.	*Oceanodroma leucorhoa*	Leach’s Storm-Petrel
71.	*Onychoprion anaethetus*	Bridled Tern

72.	*Phaethon lepturus*	White-tailed Tropicbird
73.	*Phalaropus fulicaria*	Grey Phalarope
74.	*Phalaropus lobatus*	Red-necked Phalarope
75.	*Philomachus pugnax*	Ruff (Reeve)
76.	*Phylloscopus borealis*	Arctic Warbler
77.	*Plegadis falcinellus*	Glossy Ibis
78.	*Pluvialis dominica*	American Golden Plover
79.	*Pluvialis fulva*	Pacific Golden Plover
80.	*Pluvialis squatarola*	Grey Plover
81.	*Pterodroma solandri*	Providence Petrel
82.	*Puffinus pacificus*	Wedge-tailed Shearwater
83.	*Rallina fasciata*	Red-legged Crake
84.	*Rostratula australis*	Painted Snipe
85.	*Stercorarius longicaudus*	Long-tailed Jaeger, Long-tailed Skua
86.	*Stercorarius parasiticus*	Arctic Jaeger, Arctic Skua
87.	*Stercorarius pomarinus*	Pomarine Jaeger, Pomarine Skua
88.	*Sterna bengalensis*	Lesser Crested Tern
89.	*Sterna caspia*	Caspian Tern
90.	*Sterna dougallii*	Roseate Tern

	Scientific Name	**Common name**
91.	*Sterna hirundo*	Common Tern
92.	*Sterna sumatrana*	Black-naped Tern
93.	*Sternula albifrons*	Little Tern
94.	*Sula dactylatra*	Masked Booby
95.	*Sula leucogaster*	Brown Booby
96.	*Sula sula*	Red-footed Booby
97.	*Tringa glareola*	Wood Sandpiper
98.	*Tringa nebularia*	Common Greenshank, Greenshank
99.	*Tringa stagnatilis*	Marsh Sandpiper, Little Greenshank
100.	*Tringa totanus*	Common Redshank, Redshank
101.	*Tryngites subruficollis*	Buff-breasted Sandpiper
102.	*Xenus cinereus*	Terek Sandpiper

Schedule 4 — Other specially protected fauna

[cl. 3(d)]

Division 1 — Mammals

	Scientific Name	**Common name**
1.	*Arctocephalus forsteri*	New Zealand Fur-seal
2.	*Dugong dugon*	Dugong
3.	*Neophoca cinerea*	Australian Sealion

Division 2 — Birds

	Scientific name	**Common name**
4.	*Cacatua leadbeateri*	Pink or Major Mitchell’s Cockatoo
5.	*Cacatua pastinator pastinator*	Muir’s Corella
6.	*Falco peregrinus*	Peregrine Falcon
7.	*Northiella haematogaster narethae*	Naretha Blue Bonnet
8.	*Tadorna radjah*	Burdekin Duck or Radjah Shelduck

Division 3 — Reptiles

	Scientific name	Common name
9.	*Aspidites ramsayi*	Woma or Ramsay's Python
10.	*Crocodylus johnstoni*	Australian Freshwater Crocodile
11.	*Crocodylus porosus*	Saltwater Crocodile
12.	*Morelia spilota imbricata*	Carpet Python

BILL MARMION MLA, Minister for Environment; Water.

APPENDIX 3 – END-USER QUESTIONNAIRE

MANAGING INSECTS THAT ARE ASSOCIATED OR DEPENDENT ON HOST SPECIES

This questionnaire aims to determine your organizations experience and policies regarding managing associated or dependent invertebrate species. These are invertebrate species that rely upon a host species, such as insect herbivores on plants. The answers you provide are strictly confidential and the information obtained will assist us to recognize what outcomes would be most useful to your organization towards addressing dependent/associated species management and conservation in Australia, particularly in light of climate change. Your personal details will not be disclosed to any other third party without your consent unless required to do so by law. We value your input and ask that if you have any queries or are able to provide further information that you please email us. ***Melinda Moir*** *(*mmoir@unimelb.edu.au*)* ***& Frances Leng*** (leng.frances@gmail.com); *NCCARF Terrestrial Biodiversity project TB1106)*

1. Does your organization work with threatened plant species?

☐ No (go to Qu. 3)

☐ Yes

2. In what role does your organization work with threatened plants (e.g., in restoration, translocations for conservation, etc): ____
____
____
____
____

3. Has your organization considered, or currently manages, invertebrates associated with different plant species?

☐ No (go to Qu. 6)

☐ Yes

4. What has been the objective/s of your organization in working with dependent invertebrates? Please tick all relevant applications:

☐ Managing invasive or pest species

☐ Managing other exotic/introduced species

☐ Restoring native species to degraded lands

☐ Maintaining ecosystem function (e.g., pollination, herbivory)

☐ Managing rare taxa in light of climate change

☐ Conservation of rare taxa through further research and monitoring

☐ Conservation of rare taxa through translocations

☐ Other, please list: ____

5. What associated invertebrate groups has your organization considered or currently works with (please tick all relevant groups):

☐ Pollinators (e.g., bees, some crickets, etc)

☐ Herbivorous beetles (including weevils)

☐ Herbivorous true bugs (including scales, leafhoppers, plant-lice, cicadas, etc)

☐ Butterflies

☐ Moths

☐ Thrips

☐ Gall-forming insects (e.g., some flies and wasps, etc)

☐ Grasshoppers, crickets and stick insects

☐ Other, including non-insect groups (e.g., domatia mites, root nematodes, etc), please list ____

6. What inhibits your organization from considering or managing associated insects, please tick one or more of the following:

☐ Not within the scope of the organization’s role

☐ Not currently undertaking any restoration or other type of conservation work

☐ No legal obligation (e.g., as set by ERA standards, current policies and procedures, etc)

☐ Not as high a priority compared to other groups (such as plants, birds, mammals, etc)

☐ Expensive

☐ Logistically difficult (overwhelming number of species to consider, collecting techniques that require entomological expertise, laboratory facilities to sort and curate specimens unavailable, etc)

☐ Data deficient (information on insects possible under threat or requiring management unavailable)

☐ Taxonomy difficult (obtaining identifications difficult and/or most species undescribed)

☐ Management actions assessed as unlikely to be successful

☐ Other (please explain) ____

7. If the barrier was "expensive" please provide further details of

What was the action considered? ____

When was this work costed?____

What was the most expensive component?____________________________________

8. Would your organization be interested in working with associated insects if a management framework was supplied?

☐ No

☐ Yes

9. Other than a management framework, what would inspire your organization to work with associated insects? Please tick all that are relevant.

☐ N/A. Cannot foresee such work as this is outside the scope of the organization's role

☐ Legislation or other legal requirements to do so

☐ Conservation listing of threatened dependent/associated invertebrates in your organization's region

☐ Cost-effective protocols and methods to assess which taxa to target in your organization's region

☐ Access to dependent/associated invertebrate consultants who can conduct the work required

☐ Access to data and/or taxonomists for the taxa in a particular region

☐ Charismatic dependent/associated species from your region that receive public attention

☐ Recognition of the functional importance of dependent/associated species

☐ Value for money (conserving/managing more species for little added resources)

☐ Other (please explain) ____

10. Can you provide any further details which you think may be relevant (e.g., your organization’s work on dependent/associated species such as management plans for particular associated insects, scoping studies, research on associated insects, etc).

☐ No

☐ Yes. Please provide contact details and/or attach relevant documents in an email

____

11. Would you be happy to be contacted for follow-up information regarding your answers above?

☐ No

☐ Yes

Thank you for your time and input into this NCCARF funded project.

APPENDIX 4 – HIGH MOUNTAINS IN AUSTRALIA

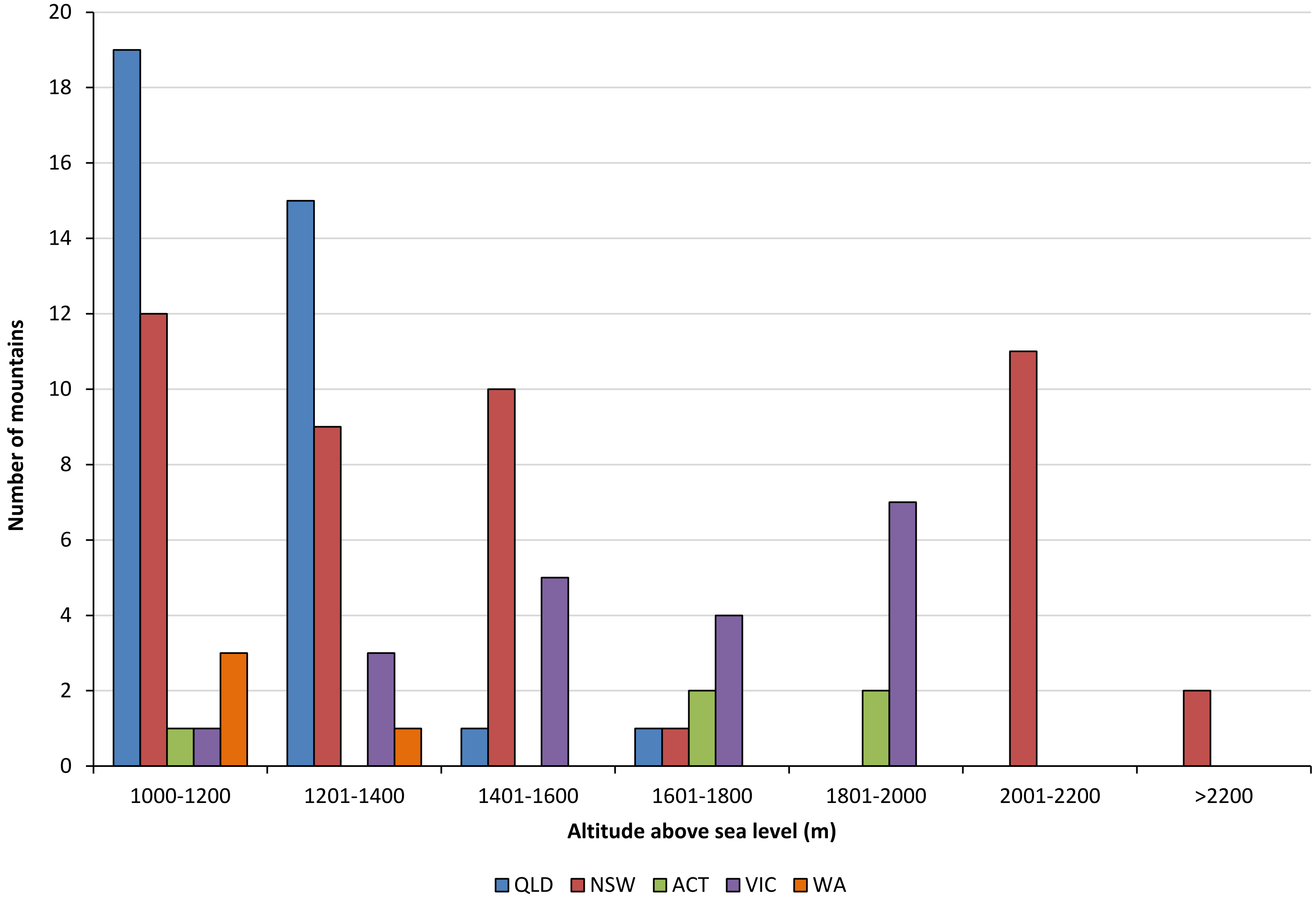


Figure 28: Number of mountains 1000 m or more in altitude above sea level across selected Australian states

APPENDIX 5 – SEASONAL DIFFERENCES IN CLIMATIC VARIABLES

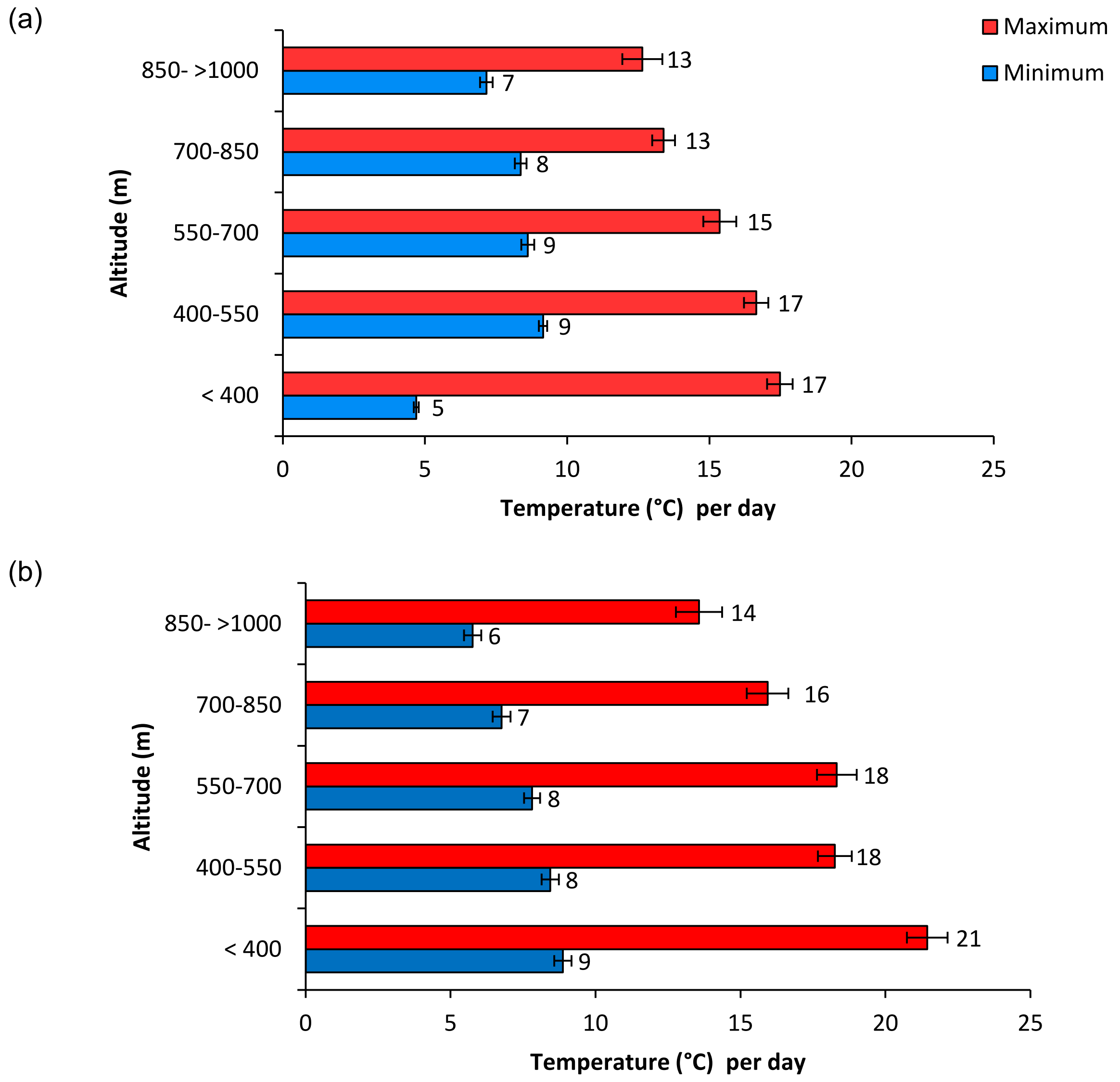


Figure 29: Temperature with maximum and minimum means in the Stirling Range National Park Western Australia over five altitudinal gradients for the time periods of (a) 1-7 July 2012(winter) and (b) 1-7 Nov 2012 (spring)

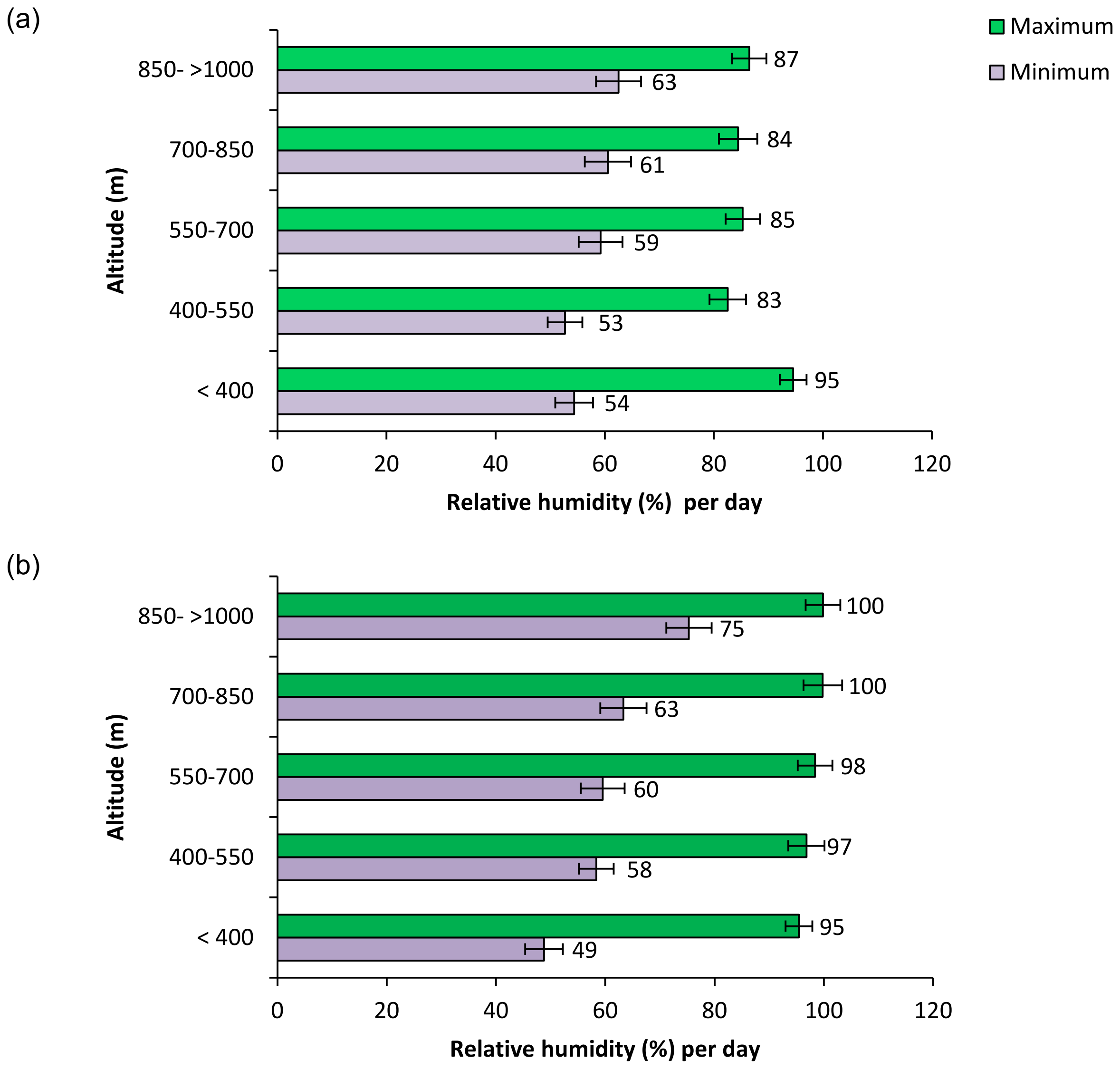
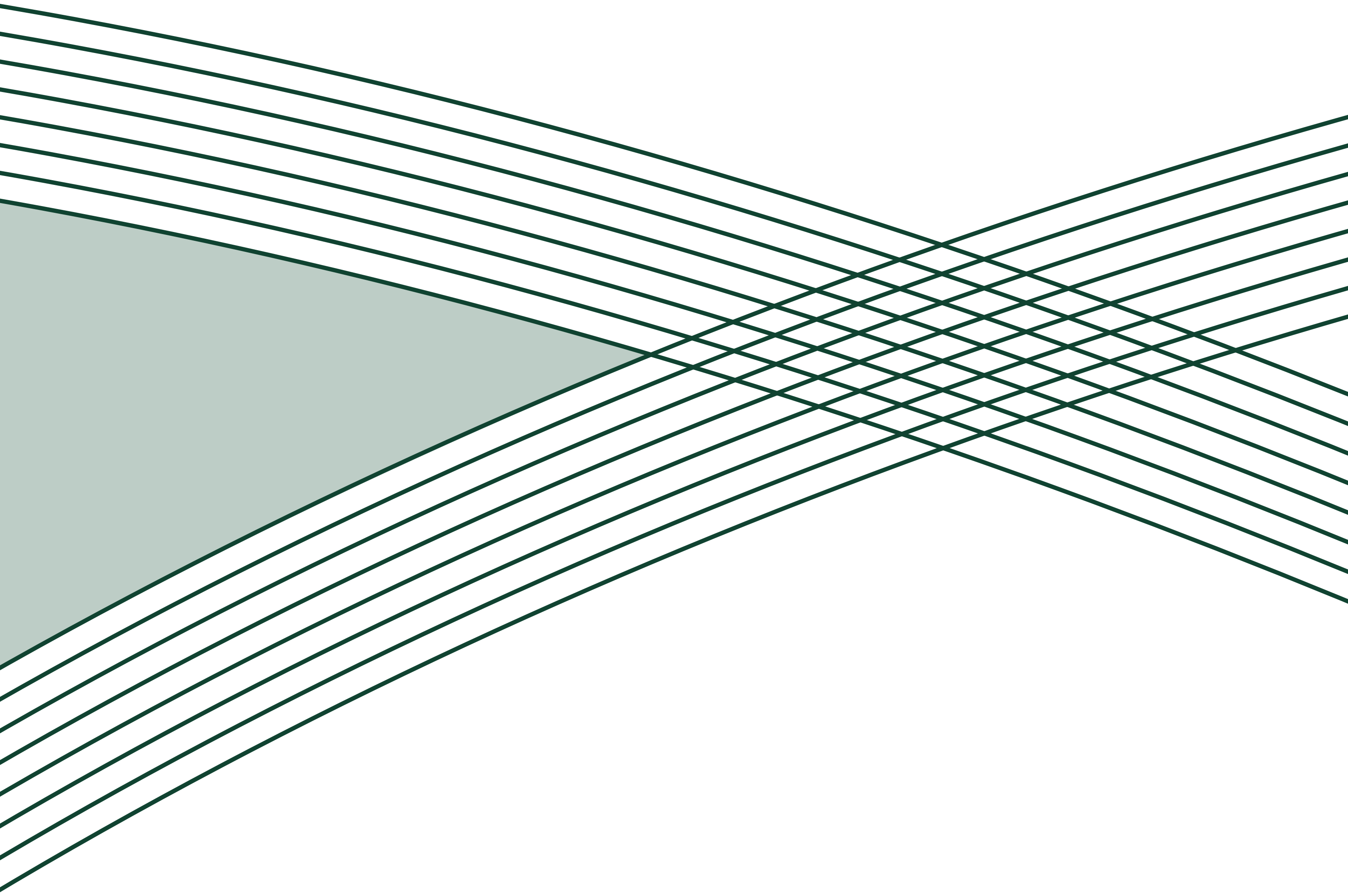


Figure 30: Relative humidity showing maximum and minimum means in the Stirling Range National Park Western Australia over five atitudinal gradiaents for the time period (a) 1-7 July 2012 (winter) and (b) 1-7 Nov 2012 (spring)



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